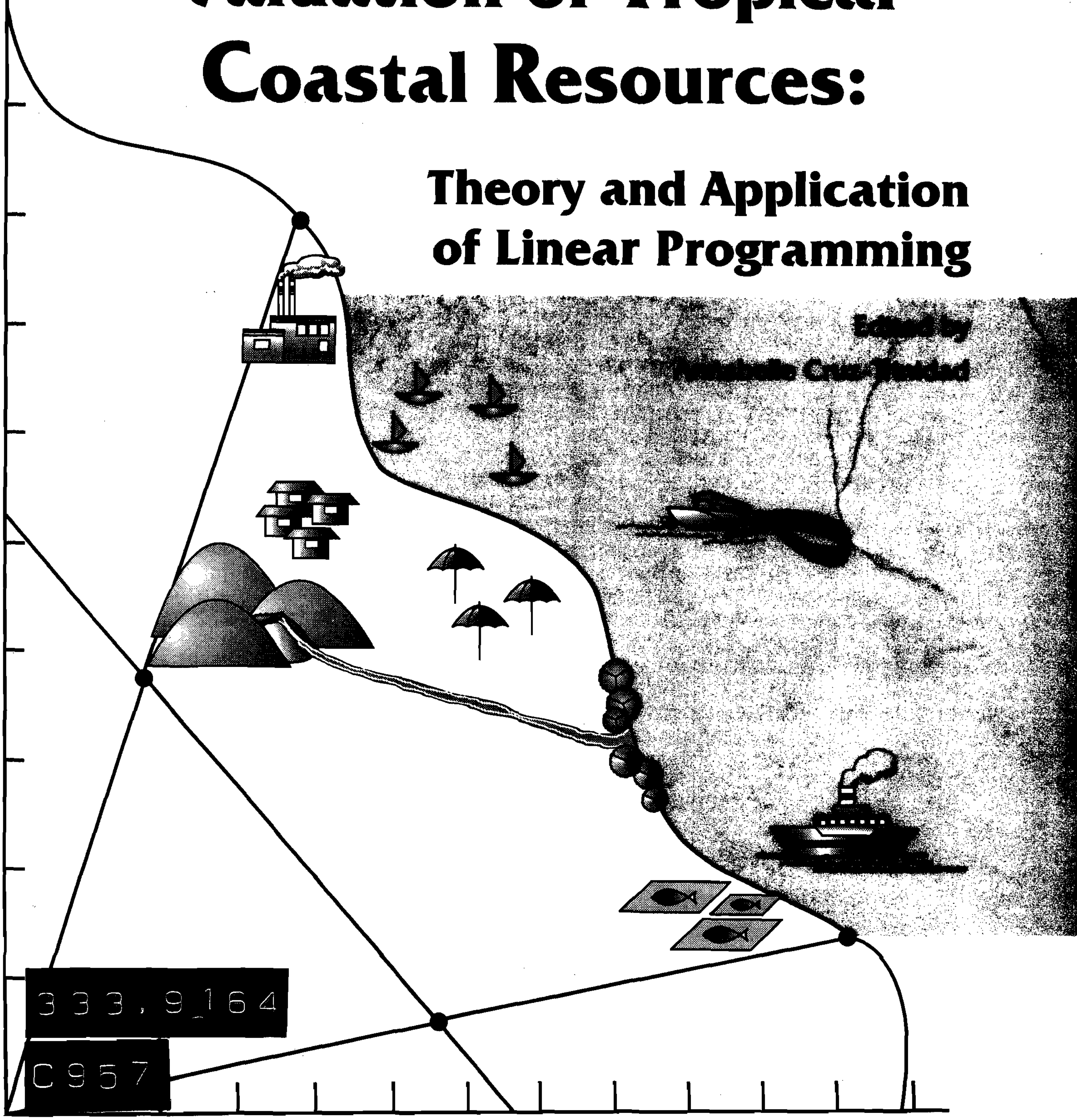
Valuation of Tropical Coastal Resources:

Theory and Application of Linear Programming



Edited by
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United Nations
Economic Commission
for Latin America and the Caribbean

ICLARM International Center for Living Aquatic Resources Management

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Annabelle Cruz-Trinidad

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The ICLARM Studies and Reviews series consist of concise documents providing thorough coverage of topics of interest to the Center, which are undertaken by staff or by external specialists on commission.

Essentially, all documents in the series are carefully peer reviewed externally and internally. A number have been rejected. Those published are thus primary literature. Between 600 and 1,000 copies of each title are disseminated - sold or provided in exchange or free of charge.

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Cover: An abstraction of the multiactivity feature of the coastal zone. Lines represent the diverse resource use constraints and the hatched (shaded) area, the optimal allocation of resources. Illustration by Chris Bunao.

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Foreword

This volume marks the culmination of ICLARM and ECLAC's collaboration which started in 1990 via the project entitled "Socioeconomic Valuation of Coastal Resources in Southwest Latin America." The worldwide trend in environmental degradation has not spared Latin America, particularly that involving large-scale mangrove conversion into shrimp ponds, and conflicting use of aquatic resources such as by fisheries and by other industries. The project aims to derive appropriate social and economic values for selected coastal resources in order to help rationalize their present use and management. The project's important achievements include a linear programming software package, OPUS; applications of linear programming models to four selected sites in Latin America and the Philippines; and a review of existing valuation methods for environmental and natural resources. The esssence of the work done by ICLARM and ECLAC is fully captured in this volume.

We would like researchers and managers to use and review our work in order to better understand the dynamics of coastal management problems and to appreciate decision tools such as OPUS. We commend all the authors including ICLARM and ECLAC staff who contributed their efforts to this book.

MERYL J. WILLIAMS
Director General
ICLARM

AXEL DOUROJEANNI
Chief, Division of Natural Resources and Energy
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Foreword

This book concludes a joint project on "Socioeconomic Valuation of Coastal Resources in Southwest Latin America" between the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, and the International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines, initiated in 1990, but whose antecedents reach much deeper. One key starting point was the doctoral thesis of the leader of that project, Dr. Max Agüero, on Chilean fisheries, which used Linear Programming (LP) as its major tool. Dr. Max Agüero joined ICLARM in March 1986 and had soon convinced his colleagues that LP could serve as framework for studies of complex biosocioeconomic systems such as the pelagic fisheries of Peru, or the floodplain fisheries of Bangladesh, studied in the context of a Ph.D. thesis that he supervised.

It was logical thus to assume that LP would also be applicable to the study of coastal areas, whose apparent complexity then seemed to defy formal analysis, allowing only conceptual description. A project to test the suitability of LP-based approaches for the analysis of intersectoral interaction and the valuation of coastal resources was thus conceived, and ECLAC identified as the best possible partner for such venture.

Dr. M. Agüero relocated from Manila to Santiago in April 1990, and immediately built a team consisting of young researchers and a programmer to develop and test suitable LP software, and to apply the LP approach to various sites in Chile and the Ecuadorian coast.

For the project to have developed its own LP software ("OPUS", see below) may appear unnecessary, as commercial packages exist - as stand alone applications, or as part of spreadsheet programs (e.g., Microsoft Excel, Quattro Pro) - which can handle such problems. However, spreadsheets with LP applications did not exist when the project started, and were not anticipated.

One particular problem which the project had to tackle was the costing of nonmarket goods and services, i.e., the "internalization" of (or: explicitly accounting for) what economists call "externalities". The contributions in this book provide some practical approaches for doing this. Still, this vexing problem is going to continue to be with us and continue to be a major cause for environmental degradation and pollution.

The ICLARM-ECLAC Coastal Valuation Project was foreseen to have two phases, Phase I for concept and software development and Phase II, for their application to various sites in Chile and elsewhere in South America. In June 1992, an external review panel led by Dr. L. Fallon-Scura concluded that the project was *"technically sound, the methods developed potentially useful, is compatible with the future ICLARM and therefore, should continue with Phase II"*. Unfortunately, ICLARM did not have the core funds required for Phase II of the project.

Ms. Abbie Cruz-Trinidad, an ICLARM researcher who had previously collaborated with Dr. Agüero, took over the task of completing and editing the publication from the numerous internal reports prepared during Phase I of the project, and thus documenting the application of OPUS to various sites in Chile and Ecuador. Moreover, she teamed up with staff from two other ICLARM research projects - one covering San Miguel Bay, the other, Lingayen Gulf, both in the Philippines, to show that the LP approach developed by the ICLARM-ECLAC team also would work in the Southeast Asian context.

We take the success of this transfer from South America to Southeast Asia as implying that the approach documented in this book can be applied to any coastline. However, we do not suggest that this approach should ever be used alone: the complexities within and among sectoral interactions occurring along the coastlines of the world cannot be described, let alone predicted by the variables - however numerous they may be - of any single model. This implies that wherever possible, a wide variety of methodological approaches should be used with the one presented in this book being one among others.

I congratulate the authors of the contributions included in this book, especially Dr. Max Agüero, for their daring to quantify and thus render available for analysis coastal interactions which others would have only talked about, and Ms. Abbie Cruz-Trinidad, for rising to the challenge of editing this volume.

Finally, I thank the Economic Commission for Latin America and the Caribbean (ECLAC) for being a gracious host to the project that led to this book, and for its help in maintaining communications between the editors and the now scattered contributors.

Daniel Pauly
Principal Science Advisor, ICLARM

Preface

This volume contains seven papers, two of which tackle the conceptual elements of Linear Programming and resources valuation; four are application papers while the last is the users' manual in support of OPUS, the LP software developed by this project. Two application papers are from Latin America: one from the Bío-Bío region in Chile and the other from the Gulf of Guayaquil, Ecuador. The other two are from the Philippines: San Miguel Bay, in Bicol province, for which ICLARM conducted multidisciplinary studies in 1980 and 1992; and Lingayen Gulf, also the site of ICLARM's coastal area management project (1986-1991) and later, Geographic Information Systems (GIS) applications. The LP tableaus used for these application papers are available in spreadsheet form and are described in Agüero et al. (this vol.)

I examine in many ways the limitations posed by LP and the importance one must must give to the data used by the model. But then, every model, no matter how elaborate, has its limitations. It is how we interpret the models and their outputs that matters. As for the usefulness of this exercise, I invite the readers to decide.

I leave for last that which I relish most—to give credit to those who made this volume possible. I thank Mr. Alexis Fabunan who painstakingly reconstructed the LP tableaus under the most constraining circumstances (a 286 computer with some 4 megabytes of RAM to handle a 780 x 560 matrix!); Mr. Alvin Catalan who helped me complete the bibliographic entries, developed the glossary of technical terms, and finalized the indices; Mr. F.S.B. Torres, Jr. for helping me with the species index and the Appendix to the paper by Araneda et al.; Dr. William Sunderlin, former ICLARM staff, now with the Center for International Forestry Research (CIFOR) who helped me reconstruct the species appendix for the forestry sector of Bío-Bío; Mr. F.C. Gayanilo, Jr. and Mr. Eli Garnace for reviewing the software and for revising the user's manual; Ms. Merly Medina for her assistance in the typing and printing of manuscripts and tables; Drs. Robert Pomeroy and Mahfuz Ahmed, for taking time out to read the concept papers and for freely providing some constructive comments; and Dr. Meryl Williams, for her support of the whole project.

This work would not have been possible without the foresight, industry and talent of Dr. Max Agüero and his team of experts from the ICLARM-ECLAC project, specifically Ms. Fabiola Bell, Ms. Angelica Arellano, Mr. Edgardo Araneda, Mr. Francisco Morales, all authors of the papers in this volume. I thank my co-authors, specifically, Ms. Zoraida Alojado and Mr. Len Garces of ICLARM and Ms. Agnes Grace Cargamento of the National Economic and Development Authority of the Philippines (NEDA-Region I) for their cooperation despite the short notice and extremely tight schedules.

I thank Dr. Daniel Pauly whose unfailing support and encouragement I began to experience in 1986 when he was then Director of the Resource Assessment and Management Program, later to become the Capture Fisheries Management Program. I thank him most especially because as a scientist from another discipline, he did not hamper my professional and intellectual interests in the 'other' sciences (i.e., economics) and had in fact encouraged me to produce work that I am very proud of today.

Annabelle Cruz-Trinidad
Research Associate, ICLARM

The Integrated Functional Coefficients Method for Coastal Resources Valuation*

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AGÜERO, M., A. CRUZ-TRINIDAD, E. GONZALEZ and F. BELL. 1996. The integrated functional coefficients method for coastal resources valuation, p. 1-8. *In* A. Cruz-Trinidad (ed.) Valuation of tropical coastal resources: theory and application of linear programming. ICLARM Stud. Rev. 25, 108 p.

Abstract

The integrated functional coefficients method is described as a linear programming algorithm that permits analysis of coastal systems with diverse and conflicting economic uses. A simple guide to the application of the technique is provided.

Introduction

The Integrated Functional Coefficients (IFC) method is a tool based on linear programming theory that was enhanced and tested by a project jointly implemented by the International Center for Living Aquatic Resources Management (ICLARM) and the Economic Commission for Latin America and the Caribbean (ECLAC) on Socioeconomic Valuation of Coastal Resources in Latin America from May 1990 to January 1993. Complementarily, linear programming software[3] was developed and applied in various sites and problems of varying complexity, including: optimal development strategies for mangroves in the Gulf of Guayaquil, Ecuador (Bell and Cruz-Trinidad, this vol.) and land use in the Lingayen Gulf area, Philippines (Cruz-Trinidad et al., this vol.); optimal fleet allocation in San Miguel Bay, Philippines (Cruz-Trinidad and Garces, this vol.); and optimal production and marketing strategies for fisheries and forestry in Bío-Bío, Chile (Araneda et al., this vol.).

The IFC method was designed to consolidate all negative (costs) and positive (revenues) flows resulting from different levels of resource exploitation activities into a single numeraire, i.e., economic value. The IFC method derived its name from its features, namely: (i) the highly integrated approach to management of resource systems and (ii) the use of functional coefficients to represent input-output efficiency.

Framework for Analyzing Coastal Resource Systems

A coastal resource system can be conceptualized as encompassing the interactions between and among the biophysical, terrestrial and marine environments and human activities, including the governing institutional and organizational arrangements (Scura et al. 1992). The coastal area is characterized by multiple resources and by multiple users and uses of resources leading to potential conflict, mismanagement, and ultimately, economic loss.

Two basic paradigms were used: i) the Total Economic Value (TEV) which is used to identify different sources of value emanating from various coastal resources, and ii) the systems approach, to analyze the whole system, its components, and interactions.

Several sources of value can be attributed to coastal resources including its use and nonuse values. A resource, such as a fish stock or charcoal, can either be directly valued as an economic good, or indirectly valued for its potential or ecological functions. The valuation of indirect goods and services is not as straightforward as those of the marketable kind but potentially applicable methods are available (see Agüero et al., this vol.). A useful exercise in valuation is the identification of interrelationships between resources and their components.

Interrelationships between a resource or its component is marked by a (+) if it is used as an input

* ICLARM Contribution No. 1217.

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[3]OPUS is linear programming software developed by the ICLARM-ECLAC Project on Socioeconomic Valuation of Coastal Resources in Latin America. The user's manual is on p. 89.

to another activity and a (-) if use of a resource impinges on the current and potential use of another (Table 1). Aquaculture and urban expansion often necessitate mangrove conversion (see Bell and Cruz-Trinidad, this vol.) and are thus marked as (-). Mangroves and, to a certain extent, seagrass beds, provide critical habitats for the juveniles of coral reef fish and crustaceans as well; these are marked (+) in the matrix. The negative impact of aquaculture, agriculture, and mineral extraction on capture fisheries and coral reef and seagrass ecosystems is via pollutants emanating from productive processes. For each resource category, there are market and nonmarket goods and services that add to the economic value. The matrix is particularly helpful in identifying indirect values or externalities imposed on certain resources.

After relevant valuation work has been made, the mode of analysis conforms to the "systems approach" which Mattessich (1984) described as having strong emphasis on input-output features and a purpose orientation. In addition, Laszlo (1972) noted that it is a *"way of thinking about phenomenon in terms of wholes, including all of the parts, components or subsystems and their interrelationships."*

The coastal zone can be viewed as an entity comprised of several interacting sources of value. The magnitude and direction of interrelationships between these sources should then be identified and, if possible, quantified, such that the effect on TEV of changes in resource endowment or linkages can be anticipated. The TEV for the coastal system is not a simple summation of the value of different sectors. Instead, the TEV accounts for dynamic functions within the system. This dynamism is embedded in the constraints posed by the use and dependency on a single resource base (natural, human and technological), the functional relationships between and among production inputs and output, and by the sequence of activities leading to an economic good. Thus, negative externalities caused by mismanagement of a particular resource would lead to the detriment of those marked (-) in the matrix and would ultimately cause a reduction in the TEV.

Perhaps the most common conflicts occur at the level of goal-setting. In the paper by Araneda et al. (this vol.) the choice as to whether fishery, forestry or tourism should be developed is of importance because the priority given to one activity implies that fewer resources are made available for other possible uses. Bell and Cruz-Trinidad (this vol.) also posed a crucial question as to the conversion *vis-à-vis* conservation of mangroves, which involves foregoing present short-term gains from shrimp aquaculture for longer-term benefits. Such is also the problem recognized by Cruz-Trinidad et al. (this vol.) in the conversion of low-yielding rice farms to shrimp and/or milkfish culture. Within the San Miguel Bay fishery (Cruz-Trinidad and

Table 1. Example of some coastal resources/activities and related influences and impacts.

	Influences and impacts[2]												
Resources/activities[1]	MG	AQ	CF	CR	SG	AG	MN	OG	SP	SM	HB	UD	CV
Mangrove/nipa swamp (MG)	XXX	-	+	+	+	-	-	-	-	-	+	-	-
Aquaculture (AQ)	-	XXX	o	o	-	-	-	-	-	-	o	-	-
Capture fishery (CF)	o	o	XXX	-	-	o	-	-	o	o	o	-	o
Coral reefs (CR)	+	+	+	XXX	+	-	-	-	-	-	+	-	+
Seagrass beds (SG)	+	-	+	+	XXX	-	-	-	-	-	+	-	-
Agriculture (AG)	-	-	-	-	-	XXX	-	-	o	o	o	-	-
Mineral extraction (MN)	-	-	-	-	-	-	XXX	o	o	o	-	+	-
Oil and gas (OG)	-	-	-	-	-	-	-	XXX	-	-	-	+	-
Salt production (SP)	-	-	o	o	o	o	o	-	XXX	o	o	-	-
Sand mining (SM)	-	-	-	-	-	o	o	o	o	XXX	-	+	-
Habitat nesting (HB)	+	-	+	+	+	-	-	-	-	-	XXX	-	+
Urban development (UD)	-	-	-	-	-	-	+	+	+	+	-	XXX	-
Coastal vegetation (CV)	+	-	o	+	+	-	-	-	-	-	+	-	XXX

[1]Adapted from Dixon (1989).
[2]Prepared by Mr. Keene Haywood, Reefbase volunteer, February-June 1995.
+ = input.
- = negative impact.
o = minimal impact, may be (+) or (-).

Garces, this vol.) conflicts arise from the choice of particular gear types.

Linear Programming

The preceding section indicates that for a particular resource system, several decisions are to be made. This section presents a range of possible tools to enable the decisionmaker to arrive at a decision and further anticipate impacts caused by changes in resource endowments or in the interrelationships between activities on the decision variable.

Features

Linear programming (LP) is an operations research method developed in the 1940s for use in military applications, and now widely used in business and agriculture. Early applications of the method assumed profit maximizing behavior, a single-period planning horizon, and no consideration for risk and uncertainty. Subsequent developments, however, proved that programming models can be more realistic and flexible. Advanced modeling techniques include multiperiod linear progamming, multi-objective modeling, nonlinear programming, game theory models and stochastic programming (Hazell and Norton 1986).

LP models address a single, linear objective function that is optimized subject to a set of rigid linear constraints (Ignizio 1985). Assumptions implicit in the productive processes, resources and activities in the linear programming model include: optimization, fixedness, finiteness, determinism, homogeneity, additivity and proportionality (Hazell and Norton 1986).

The general formation of a linear program is as follows:

Maximize

$$p_1x_1 + p_2x_2 + ... + p_nx_n \quad ...1)$$

subject to

$$a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n <= b_1 \quad ...2)$$

$$a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n <= b_2 \quad ...3)$$

$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n <= b_m \quad ...4)$$

$$x_1, x_2,..., x_n >= 0 \quad ...5)$$

Equation (1) is the objective function, here, a maximization problem. The X's are the unknowns or decision variables while the P's are the relative contribution of each variable to the value of the objective function. The a_{mn}'s represent the amount of resource b needed by activity or sector, X. The b_m's are the upper or lower limit of a resource use and in an LP tableau are usually referred to as the right-hand side (RHS) limits. Equations (2) to (4) are the constraints; Equation (5) is the nonnegativity clause. The above formulation is also called the primal problem.

The dual, which is the converse of the primal, is formulated as follows:

Minimize

$$b_1w_1 + b_2w_2 + ... + b_mw_m$$

subject to

$$a_{11}w_1 + a_{12}w_2 + ... + a_{m1}w_m >= p_1$$
$$a_{12}w_1 + a_{22}w_2 + ... + a_{m2}w_m >= p_2$$
$$.$$
$$.$$
$$.$$
$$a_{1n}w_1 + a_{2n}w_2 + ... + a_{mn}w_m >= p_n$$

$$w_1, w_2,..., w_m >= 0.$$

Note that the dual formulation is actually equivalent to the primal, i.e., the maximization problem (primal) and the inverse of the minimum (dual) are one and the same. The solution to the primal problem provides the optimizing values of the variables and the resulting value of the objective function.

The existence of the dual solution in any conventional LP formulation is one of the more important reasons for its popularity. The dual can be interpreted as shadow price or opportunity cost of a particular resource. As such, it is also a measure of the marginal increase in the objective function given an increase in the availability of the resource. Sensitivity analysis permits further analysis by varying coefficients in both the objective and input-output matrices, right-hand side limits, and the inclusion of a new goal or constraint. This was done for the San Miguel Bay study, i.e., level of fishery net revenues as affected by changes in total allowable catch rates and minimum wage rates (Cruz-Trinidad and Garces, this vol.).

Applications

Linear programming was first applied to fisheries by Rothschild and Balsiger (1971) to allocate the catch of sockeye salmon during a run in Bristol Bay. Siegel et al. (1979) used LP to maximize catches of the New England otter trawl fishery subject to total allowable catch, processing and harvesting capacity, based on an earlier work by Mueller (1976). Agüero (1987) used LP to model the Peruvian fishery and utilized six sequential activity blocks beginning from harvesting to processing, storage, transport, marketing and sales to arrive at, among other things, optimal rates of resource exploitation, plant rated capacities and prices.

Subsequent developments permit the incorporation of multiple-planning periods, risk and uncertainty into the model. McCarl and Spreen (1980) have suggested that price need not be an exogenous variable in LP formulations while Shepherd and Garrod (1980) developed a method of cautious nonlinear optimization which resolves the tendency of LP results to be "extreme, sparse and ruthless" and which "considers the initial state of the system when seeking the optimum". These improvements are incorporated via a composite objective function which consists of penalties for (i) failing to conform to one or more constraints, i.e., quota allocations and (ii) a penalty for departing from the *status quo*, i.e. historical average catch rates, and (iii) one or more objectives to be minimized. Huppert and Squires (1986) applied this technique to the Pacific coast groundfish trawl fishery and estimated maximum economic surplus and optimal fleet configuration.

Further development in the area of mathematical programming has resulted in dynamic optimization as used by Dow (1993) in the regulation of bowhead whales and Kennedy and Watkins (1986) in the southern bluefin tuna fishery. Wallace and Brekke (1986) used stochastic optimization in the Norwegian purse seiner and summer capelin fishery in the Barents Sea.

The applications of programming models to economic-environmental systems are diverse, ranging from forest management, environmental quality models, petroleum refining and electric power generation, to complex regional and national models for optimal utilization of water resources (Hufschmidt et al. 1983).

Despite the fast-paced development in mathematical programming techniques, LP applications in developing countries in both fisheries and coastal environments are few. Two have been identified in the literature, the works of Padilla (1991), using multiobjective programming to determine optimal effort in the small pelagics fishery in the Guimaras Strait, Western Visayas, Philippines, and Ahmed (1991), using price endogenous linear programming to estimate net social benefits of different types of fisheries, i.e., hilsa, prawn, catfish and carp in the floodplains of Bangladesh. The latter also involved segmentation of both objective function and constraints into harvesting, postharvest and marketing blocks. The apparent underutilization of mathematical programming and its enormous potential for use in fisheries and coastal systems in developing economies, show that the applications in this volume, and the use of OPUS, the LP software developed for this purpose, can be a significant contribution to the literature.

Potentially Applicable Techniques

Hufschmidt et al. (1983) suggested two analytical frameworks for multiactivity economic-environmental models: linear programming and input-output (I-O) models. The latter was developed by Leontief (1936) [thus, the alternate term, Leontief matrix] and emphasizes the interrelationships between production activities. Each productive activity assumes dual roles: first, as a supplier of output to other activities and final buyers and second, as a buyer of inputs including land, labor, capital and the outputs of other activities. As in standard economic systems, the final demand for goods and services determines the I-O coefficients of economic-environmental models. I-O analysis permits the decisionmaker to simulate changes in economic and environmental quality variables related to different economic development scenarios and/or changes in final demand for goods and services (Hufschmidt et al. 1983).

The following analytical techniques are extracted from a list provided by Hyman and Stiftel (1988) for Environmental Impact Assessment (EIA), which we have identified to be relevant to coastal resources as well. Sorenson (1971) devised a network or stepped matrix for which the primary focus is the environmental cost of coastal land uses. Fifty-five coastal zone uses are entered in the matrix rows. The columns represent i) causal factors, i.e., specific activities associated with particular land uses; ii) initial conditions; iii) secondary impacts; iv) ultimate environmental effects and v) management interventions. The Sorenson network has been applied to commercial, residential and transportation development in the Californian coastal zone.

Hill (1968) developed the multiple objective analysis or goals achievement matrix. This procedure involves the definition of important objectives and the subsequent assignment of weights. The crucial step is the anticipation of impacts of each objective. Hill and Alterman (1974) used multiple objective analysis to assess alternative sites for power plants. A related procedure is decision analysis (Keeney and Raffia 1976) although this technique places greater emphasis on systems modeling and evaluation under risk and uncertainty. The first step is the identification of objectives and assignment of "attributes" per objective. The next steps involve prediction of future values for each alternative plan and selection of preferences among the various alternatives. Decisionmakers base their final decision on the alternative which maximizes utility. Decision analysis was used to predict the impact of a nuclear power plant on salmonid stocks (Keeney and Robilliard 1977).

The United States Fish and Wildlife Service (1980) developed a Habitat Evaluation Procedure (HEP), which evaluates the effects of development on a single aspect of the environment — fish and wildlife habitats. The HEP enables decisionmakers to select among different project alternatives and to design mitigation and compensation measures. First, the habitat types in the area are mapped out and indicator species identified on the basis of economic or social importance, sensitivity to proposed actions, role in nutrient cycling and energy flows, and representativeness in various ecological niches. The decision rule is then based on potential changes in "habitat units" (habitat area multiplied by habitat sustainability index).

The IFC Method and Its Implementation

The integrated functional coefficients method was designed to determine the social and economic value of coastal resources within an integrated concept of the coastal ecosystem and its functions. The elements are the same as that of standard LP formulation except that the definitions are largely expansive. The objective function (Net Social Benefit Function) is structured in terms of the Total Economic Value concept (Randall 1987) allowing externalities and nonmarket goods, services and functions to be considered. Unit cost coefficients and prices are exogenous to the model and determined using statistical techniques and/or econometrics, whichever is applicable. The resulting measure of net revenue is a measure of Net Social Benefit valued at the best alternative use given the constraints imposed on the system.

Each activity is constrained by resources availability, technological efficiency, cost structures, input and output market conditions and institutional factors. The methodology is derived from the integration of several sources of value under several restraining conditions.

The elements of an IFC linear program as applied in a coastal resource system are as follows:

(i) Objective Function

Maximize Π

$$\Pi = \Sigma\left(P_{ijklmnop} \cdot X_{ijklmnop}\right) - \Sigma\left(C_{ijklmnop} \cdot X_{ijklmnop}\right)$$

where

Π = net social benefit function

$X_{ijklmnop}$ = good or service corresponding to

i = spatial location of the resource, i.e., country, region, zone, subzone;

j = economic sector, i.e., fisheries, tourism, forestry, mining, aquaculture;

k = economic activity, i.e, harvesting, processing, transporting, storage, marketing, consumption;

l = resource, i.e., fish, tree, mangrove, beach, coral reef;

m = product, i.e., in the fishery, fishmeal, oil, frozen fish; from the forestry sector, boards, chips, pulp; from tourism, recreational facilities, hotels, beach resort;

n = technology, i.e., capital intensive, labor intensive;

o = scale, i.e., large scale, medium scale, small scale; and

p = gear or equipment, i.e., in the fishery, net, boat, hook, harpoon; in the forestry sector, axe, electric chain; and in the tourism industry, car, bicycle, train.

$P_{ijklmnop}$ and $C_{ijklmnop}$ = price and cost estimates of each variable.

Further specifications to distinguish features of the resource, products or markets can be made, e.g., distinguishing frozen fish in blocks (round or fillets) or boxes of different weights or grade. Similarly, markets can be distinguished as local, domestic and foreign, etc. Because of the numerous options to disaggregate any one variable, each application paper in this volume provides a detailed explanation of the LP elements.

(ii) Functional Restrictions

$$AX_j <= b_j$$

AX_j indicates technical coefficients associated to the $X_{ijklmnpo}$

b_j indicates resource endowments, yield at different levels of use, demand for different price ranges, installed capacities, balance indicators, etc.

An additional standard restriction is the nonnegativity constraint which provides for all $X_{ijklmnop}$'s to be positive or equal to zero.

The mathematical programming problem is solved by means of the simplex algorithm (Revised Simplex Method) using OPUS, a computer software package (see Agüero et al., this vol.). The optimization process, i.e., the search for the best (optimal) value of the control variables (level of resource use/exploitation) within the feasible set of alternatives, determines the economic value of each resource in its best alternative use. The vector of shadow prices indicates how the net social benefits change as one additional unit of a resource is made available, reflecting in this way, its social value.

Use and Implementation of the IFC Method

Modeling the coastal ecosystem for valuation purposes under a mathematical programming structure requires a sound knowledge and understanding of the various resources, activities and processes taking place in the coastal area. It is essential to fully understand the various interactions to establish the limits defining each system and their linkages with each other.

The use of the IFC method involves two phases: (i) conceptual formulation and (ii) application of mathematical programming. Conceptual formulation is the more critical of the tasks and involves steps 1 to 6 in the list provided below. This phase entails understanding the human and natural dynamics of the coastal zone, determining the sources of economic value and its components, and assigning appropriate measures of value. These elements, when translated into algebraic terms, become the elements of the LP tableau. The programming application, especially with the use of available software, i.e., OPUS, becomes purely mechanical.

The following is a list of steps necessary to accomplish this task.

1. Characterize the coastal system. This is done by preparing a "profile" or description of the coastal area. The profile describes the macro-environment, both natural and human, in which the relevant economic sectors operate. Some examples of profiles are those prepared by the ASEAN/US Coastal Resources Management Project in Brunei (Chua et al. 1987), South Johore, Malaysia

(ASEAN/US CRMP 1991), Lingayen Gulf, Philippines (McManus and Chua 1990), Ban Don Bay and Phangnga Bay, Thailand (Paw et al. 1988), Segara Anakan-Cilacap, Indonesia (White et al. 1989).

2. Determine relevant sectors and activities. Economic activities should be based on the following factors: output (production in physical and monetary terms); yield (net natural growth per unit of input); employment (per category of skills required); income (per location, category of employment; local/foreign); spatial location, and impact on other sectors.
3. Identify variables that either contribute to or minimize economic value and determine thereafter, the activities or elements influencing such. For example, if the relevant sectors are aquaculture and forestry, the variables that add to economic value may include shrimps and logs, respectively. The export of shrimp would require the following activities: clearing of mangroves, stocking of ponds, harvesting, processing, transporting, and marketing, each of which is characterized by different price vectors as well as constraints.
4. Collect data required, including market and nonmarket prices, production levels, technological capacities and magnitude of externalities.
5. Establish functional relationships among the components, determining production, yield and demand functions.
6. Construct the mathematical programming tableau structure including the objective function, input-output matrix, and restriction vector (right-hand side).
7. Feed the tableau and conduct preliminary consistency tests, i.e., degeneracy, unboundness, etc.
8. Run OPUS and determine necessary improvements in data quality.
9. Analyze and validate results. Verify that results obtained in actual application are consistent with theory and the control factors pre-established for this purpose
10. Interpret final results and conduct sensitivity analysis. The final results provide estimates of economic (primal) as well as social (dual-shadow vector) values. Sensitivity analysis measures the effect of exogenous changes in prices and resources availability on the net social benefit (Value of the Objective Function) and those of the variables.

Discussion

There are no hard and fast rules in the use of IFC methods especially when applied to diverse environments such as coastal zones. The list shown above, though uncomfortably loose, provides the basic elements for the analysis and application of the technique. This is borne by the four application papers in this volume which may have varied applications but which, nevertheless, manifest all these elements.

A critical, though exogenous, aspect of this exercise is the use of appropriate price coefficients, especially when imperfect market conditions exist or when nonmarket transactions occur. The whole area of valuation and applicable techniques are discussed in Agüero and Flores (this vol.).

This volume does not attempt to break new ground in methodological development; rather, the emphasis is on using tested techniques on broader applications. Thus, the development of the conceptual issues is of greater weight than the application of the technique itself. Complementarily, we invoke Holling's (1978) caveat on the use of mathematical programming techniques: while we should not be slaves of the model, it offers a sensible start for analytical and predictive purposes.

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Valuation Concepts and Techniques with Applications to Coastal Resources*

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Abstract

Overexploitation of natural resources is linked to the use of valuation techniques that do not consider nonmarket environmental goods and services. The Total Economic Value (TEV) concept is discussed and its relevance to natural resources valuation is highlighted. Lastly, techniques for resources valuation are presented, along with an example referring to the mangroves around the Gulf of Guayaquil, Ecuador.

Introduction

Coastal ecosystems and their resources throughout the developing world are being increasingly mismanaged and exploited beyond the limits of their sustainability. Furthermore, destructive techniques for resource exploitation are proliferating in many poor coastal areas where both resources and the functional integrity of the ecosystem are being seriously threatened by illegal or uncontrolled human activities (Chua and Fallon-Scura 1992).

In recent times, research efforts and policy analysis emphasize the need to properly manage and preserve natural resources and the environment. Abundant literature from all disciplines has been produced describing, quantifying and denouncing undesirable human interventions in the ecosystem, namely, those related to pollution, waste disposal and other global environmental damage (Panayotou 1993; Pearce and Moran 1994).

Moreover, population growth and higher incomes, especially in developed nations, have increased trade opportunities for developing coastal nations with rich renewable resources. Increased technological efficiency, on the other hand, has improved the cost effectiveness of resource exploitation activities. As a consequence, developing nations are increasingly viewing the exploitation of their coastal renewable resources as a source of foreign exchange, employment and food supply. In fact, most government policies of developing countries, in one way or another, promote coastal exploitation to solve pressing social needs.

The limits to which these resources can be exploited on sustained basis, however, are not yet well known or understood, but decreasing yields in many renewable resources such as fish stocks, indicate that very probably, they are already being overexploited (Garcia and Newton 1995).

One of the causes of the abovementioned problem is the absence of well developed markets for many goods, services and functions performed by coastal resources like mangroves and coral reefs. The failure of existing methods to properly account for them results in undervaluation of total benefits and consequently, a bias towards overexploitation or conversion of resources to alternative options. Examples of this process are the increasing tendency to convert mangrove areas into shrimp ponds, the increasing degradation of the environment (pollution, sedimentation, etc.) and discharge of urban waste into the ocean without prior treatment. The overall result is rent dissipation and resource degradation (Fig. 1).

Moreover, coastal resources exploitation does not take place in isolation. The allocation of inputs to a specific process prevents its use in others, changing their relative availability to alternative activities. Also, exploitation activities generate several residuals and spill-over effects affecting the performance of others. These effects, better known as "externalities", are generally not accounted for by their generating source, but borne by society without due compensation. A divergence between social and private costs is thus created with misleading signals for an efficient resource allocation process. These signals, namely, unrealistic high profit margins and larger expected long-term yields, by default do not account for resource users' costs (value of fish in the water, clean air, etc.) nor for negative externalities imposed on society (like water pollution from fishmeal plants, siltation/sedimentation from logging, and solid wastes from tourism). When the outputs of these resource exploitation activities are exported to markets with very high price elasticities, e.g., fishmeal, considerable rents are transferred to the importing country, creating a paradoxical flow of value

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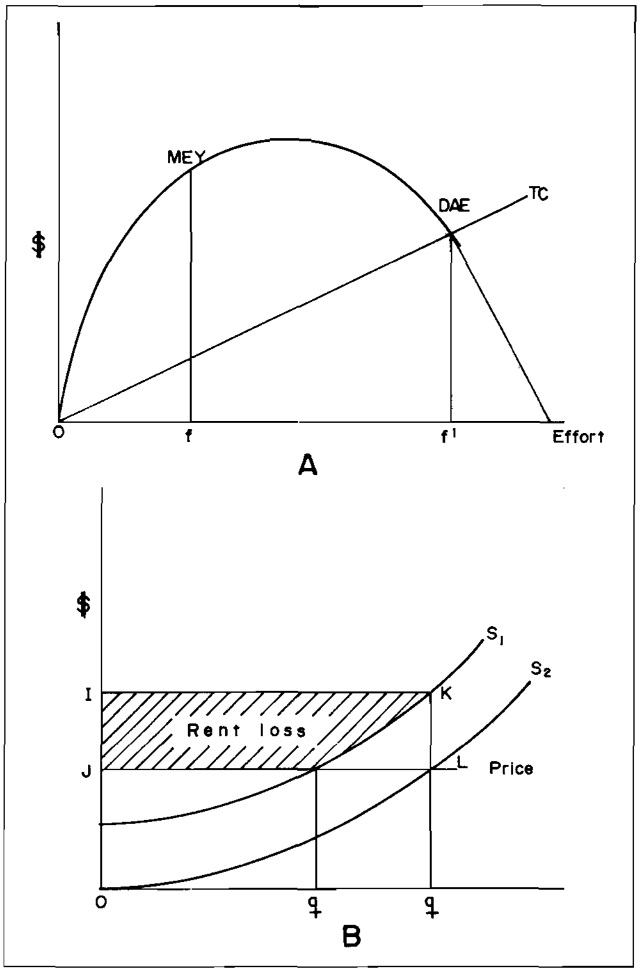

Fig. 1. Nonaccountability of externalities and other nonuse values results in exploitation beyond economically optimum levels (MEY) in A: the divergence between MEY and OAE, or the downward shift of supply curve, S1 to S2, results in rent dissipation equivalent to IJKL in B.

(a sort of subsidy) from poor to rich countries. The increasing rate of resource exploitation now taking place in many developing countries is a clear evidence of the above problem. It also shows the urgent need to incorporate new valuation techniques to improve resource management.

Valuation Concepts and Techniques

Total Economic Value

Interest in natural resources valuation stems from the realization that the economic sector is part of a wider arena that consists of multiple life-supporting ecosystems (Aylward and Barbier 1992). Valuation then becomes an interface between ecology and economics because of the use of certain commonalities from two otherwise divergent realms. First is the equivalence of what economists would refer to as "goods" to the structural component of an ecosystem, i.e., wood, fish, and water, and what economists would refer to as "services" with environmental functions such as natural protection from storms and breeding grounds for fish.

Actual valuation is the next step and can be defined as a quantitative assessment of the value of these "goods" and "services". Money is usually used as a numeraire for this purpose, since it allows aggregation and comparison of heterogenous elements through a common unit. It is then possible to compare values of fishery resources with forestry or industrial output for example. Furthermore, it allows consistency in ranking priorities for investment decisions and policy design.

Several criteria are used for this purpose, but relative scarcity and human appreciation of the resource are most relevant. For valuation purposes, coastal resources are viewed in their capacity to generate a flow of goods, services and ecological functions that can satisfy human needs of various kinds, whether directly or indirectly. In this capacity, they are valued by individuals and society according to the net benefits they provide. In other words, natural resources are considered in economic terms only in their capacity to satisfy human needs and therefore, valued as far as they enter in human preference scales. This approach is also shared in cost-benefit analysis, in which scarcity is also considered as a determining factor.

Although the concept of value, indicating worth, has been analyzed and formalized in various ways and given several interpretations over time, it is becoming well accepted now within the concept of Total Economic Value (TEV). This concept was first articulated by Weisbrod (1964) and Krutilla (1967) stating that the total value of a resource includes its use and nonuse values.

The total value of a private good is usually defined as the maximum amount of money an individual is willing to pay for it over and above the consumer surplus. For a natural resource, however, the total economic value is defined as "use value" plus "nonuse value". Use value is referred to costs and benefits of a resource for which a market exists; it can be direct (*in situ*) or indirect use. Direct use may be "consumptive" (that is, used/enjoyed by someone, thus, depriving others of its use) or nonconsumptive, meaning that others may also enjoy its benefits.

The concept of nonuse value has received special attention in recent years due to the growing concern for the environment and sustainable use of resources, as it applies to the value individuals place on resources, regardless of their present/future or consumptive/ nonconsumptive use. Several categories are included, namely, *existence value* (value of a resource for just knowing it exists or will be preserved); *option value* (willingness to pay for the option of using/consuming the resource in the future); *quasi-option* (willingness to pay to have the option of deciding in the future about its use); and *bequest/heritage and preservation value* (value to know future generations will have the opportunity to use the resource).

Hyman and Stiftel (1988) pointed out five alternative uses of option value: *risk aversion*; *quasi-option demand*; *existence value*; *vicarious use value*; and *bequest value* which altogether possess some interchangeable features.

Still another category of resource use, the *indirect use* for which the valuation depends on the "processes" that ultimately provide economic value, was proposed by Aylward and Barbier (1992). Some indirect uses of wetlands include groundwater recharge or discharge, flood and flow control, shoreline or bank stabilization, sediment retention and nutrient retention (Barbier 1989). These environmental functions must be analyzed within the broader framework of biological diversity as this implies a corresponding analysis of the linkages in the ecological chain and how changes within the system affect the environmental functions supported by it.

Measures of indirect uses are based on whether such functions support economic production or protect the conduct of economic activity. A measure of the consumer's willingness to pay (WTP) or willingness to accept (WTA) may take the form of changes in productivity, alternative/substitute costs, or actual expenditures. Valuation techniques used to estimate WTA include preventive expenditure, damage costs avoided, alternative or substitute cost and relocation costs. In both cases, an immense amount of data is required especially in developing-country situations. Moreover, some measures may prove irrelevant due to the absence of technology that would, for instance, restore the nutrient retention capabilities of mangroves.

Gregory (1987) found it useful to assess the nonmonetary benefits of extramarkets of environmental services, albeit their inclusion in TEV was not considered.

Although these preservation and nonuse values are not clearly attached to any particular component of a given resource, they tend to be associated with it as a whole. Thus, the role of a resource (like mangroves) in preserving biodiversity or the role in determining the uniqueness to culture and heritage (the condor in Chile, the bald eagle in the USA, the Pirineos in Europe, etc.) contribute to the existence, bequest and option value that individuals attach to preservation.

The TEV concept was applied by Spurgeon (1992) on coral reefs. Use values were classified as extractive or nonextractive. Among the extractive values are those of fishing, pharmaceutical, and construction and the nonextractive are tourism, education and social value. Among the techniques listed that use market or pseudo-market prices are cost-benefit analysis, change in productivity and measures of consumer surplus. Simulated markets are used in contingent valuation methods (CVM) and travel cost (TC) technique to evaluate value of tourism spots, for example. As for the indirect uses of coral reefs, like biological support, the author suggested the use of change in productivity in "with or without the reef" situations and a percentage dependence technique for which the biological support value is the value of the supported activity multiplied by an estimated percentage dependence of that activity on the reef's presence. For nonuse values, such as existence and option value, an extensive CVM survey is suggested as was implemented by Hundloe (1989) in the estimation of the vicarious value (option plus existence value) of the Great Barrier Reef which amounted to AUS $ 45 million/year.

The application of TEV in this volume has been slightly modified in the net social benefit function of the "integrated functional coefficient method" to capture the net value (positive or negative) of externalities (Fig. 2).

Aylward and Barbier (1992) pointed out some caveats in the use of the TEV especially with respect to double accounting of goods and services. This occurs when the direct use of the resource is valued in addition to the indirect functions that support these direct uses. For example, mangrove forest litter that provides food for fish and shrimp larvae is an environmental function

$$
\begin{aligned}
\text{NBSF} &= \sum (\text{TR}-\text{TC}) \\
&= \sum X_{saro} * P_{so} - \sum X_{saro} * C_{saro} \\
&\pm \sum X_{saro} * EC_{saro} + \sum X_{saro} * FB_{sr}
\end{aligned}
$$

Subject to:

Biomass abundance
Infrastructure capacity
Capital availability
Labor availability
Environmental carrying capacity

NBSF	=	net benefit social function	P	=	price
			C	=	cost of production
TR	=	total revenue	EC	=	environmental cost
TC	=	total cost	FB	=	foregone benefits
X	=	quantity of goods/ service produced			

where

Sectors (s)	Fishery	Forestry	Tourism	Environment
Activities (a)	Preparation Stocking Harvesting Processing Marketing	Preparation Planting Logging Processing Marketing	Preparation → Building → Visiting → Transporting → Marketing →	Transportation (Destruction/ enhancement) Externality (+ -)
Resource use (r)	Produce	Produce	Service	Function
Output (o)	Fresh fish Processed Fish meal Others	Wood Logs, timber Charcoal Cellulose Others	Parks, beach and camping visit Motel, hotel, restaurant Package use, etc. Others	

Fig. 2. A typical objective function characterizing a multiresource coastal zone and elaboration of coefficients.

which "can" be valued. However, if goods such as shrimps are valued likewise, some double accounting may occur. Likewise, some ambiguities arise as to the classification of option value which can be classified as a nonuse value, because it is not actually used, at present. Again, we invoke the influence of neoclassical economics on natural resources valuation, i.e., that individual satisfaction is paramount.

Valuation Techniques

Many techniques for valuation of nonmarket goods and services are based on the hedonic price theory of consumer choice. Goods are not valued in and of themselves but rather as a composite of different attributes. Thus, the valuation of each of these attributes can be computed backwards if the market value of the product is known or if the market value of related goods and services is known. The derived demand curve can thus be constructed by comparing each attribute with comparisons of actual expenditures or survey preferences for closely related goods that differ marginally in the quantity or quality of their attribute.

Classification of valuation techniques as discussed here will be based on three market categories: *conventional, implicit* or *artificial* although other authors have developed additional levels of classification. For example, Munasinghe and Lutz (1993) also used actual *versus* potential behavior while Dixon et al. (1988) used the categories: generally applicable, potentially applicable, survey-based and nonwillingness to pay-based methods.

Valuation techniques based on conventional markets are based on market prices. These techniques are particularly useful when environmental impacts have direct effects on goods and services which are priced. Under perfect competition, market prices indicate the real value to both consumers and suppliers. However, when market conditions are imperfect (i.e., monopoly, collusion), or do not exist (i.e., environmental goods and services), or exist but fail (i.e., public goods and externalities), market prices may not be an appropriate measure. A proposed alternative is the use of shadow pricing which can be used in impact assessment of environmental services (Hyman and Stiftel 1988) and when compensating for distortions in the costs of capital, foreign exchange, land and labor.

All techniques, whether they be survey based or otherwise, attempt to capture the willingness to pay (WTP) [in some cases, willingness to accept (WTA) <compensation>] criteria discussed above as the ultimate measure of utility. A societal demand curve is then constructed by horizontally summing up the individual demand curves as discussed below. Randall (1987) suggests that a cross-corroboration technique is desirable in nonmarket valuation.

A taxonomy of valuation techniques based on market category is presented in Table 1.

Table 1. Techniques currently used for natural resources valuation according to market category.

Conventional	Implicit	Constructed
Change of productivity	Travel cost	Artificial market
Loss of earnings	Wage differences	n.a.
Defensive expenditures	Property values	n.a.
Replacement cost	n.a.	Contingent
Shadow project	n.a.	valuation

CONVENTIONAL MARKETS

When environmental functions result in measurable changes in the production or productive capacity of a certain good or service, conventional market techniques can be used, i.e., the WTP is taken to be equal to the market price. In cases where noncompetitive markets exist, the shadow price or opportunity cost is taken in lieu of current price.

Change in productivity estimates changes in production arising from a particular intervention or natural resource state. This approach is by far the most common method used in coastal resources (Bell 1989; Hodgson and Dixon 1992; Ruitenbeek 1992; Sawyer 1992). A case was made by Hodgson and Dixon (1988) in their estimates of the effects of sedimentation on coral diversity and ultimately on fish production in Palawan, Philippines. The *loss of earnings* technique estimates foregone earnings arising when a number of people are affected by changes in environmental quality, e.g., declining catch rates for small-scale fishers due to trawling. *Defensive expenditures* are applied to mitigate environmental impacts, e.g., wastewater treatment facilities. In this case, the value of water pollution is taken to be the equivalent of preventing it by way of technological costs. *Replacement cost* is the cost of substituting particular features of a resource to approximate its natural characteristic. For example, Folke and Karberger (1991) estimated replacement costs for loss of wetland productivity while Araneda et al. (this vol.) used the value of freshwater needed to dilute polluted bay waters to acceptable levels.

IMPLICIT MARKETS

Valuation techniques falling under this category are based on the premise that some market goods can be related to particular environmental attributes that are not priced. Thus, *property values* and *wage differences*, both hedonic methods, are approximations of the overall environmental quality. Property values, for example, are dependent on the environmental quality of a particular housing site, e.g., a polluted site causes a drop in assessment rate; for the same reason, this same polluted site would have to offer higher wages to attract labor. Bell (1989) used the land value approach in the valuation of Florida fisheries. The *travel cost* method is commonly used for determining the value of a recreational site. Travel expenses, fees paid on site, and the opportunity cost of travel time are taken to represent "entrance fees". This information will allow the researcher to construct a demand schedule based on the number of potential vacationists as a function of travel cost; thus, consumer surplus can be estimated. The travel cost method was applied by Costanza et al. (1989) in the valuation of wetlands and by Hundloe (1989) in the Great Barrier Reef.

CONSTRUCTED MARKETS

Also called "hypothetical valuation" (Hyman and Stiftel 1988), the basic premise is to create a "market" for a specific environmental attribute by simulating demand and supply conditions. Some survey-based techniques suggested by Hyman and Stiftel (1988) include: direct questioning, bidding games, use estimation games and trade-off analysis. In the first two techniques, the respondent is made to assess either the WTP or WTA of a stated quantity or quality of a particular environmental good. In bidding games, however, the determination of the value is more of an iterative process with the researcher posing an initial bid with subsequent increments. The WTP or WTA is then the maximum (minimum) value to the user.

The validity of these techniques can be evaluated by comparison with results of elaborate market research surveys for consumer products. Several studies show that respondents did not actually behave as they had reflected in the market surveys and that several consumer products miserably failed (Spindler 1975; Schuman and Johnson 1976). It is thus expected that surveys of environmental goods, which are less tangible than consumer products, would result in inaccuracy. The use of such techniques in LDC countries where education and incomes are low are likewise cautioned by Hufschmidt and Hyman (1982).

Contingent valuation (CV) is so called because "contingent" conditions are simulated and the respondents' behavior subject to these conditions is measured. In contingent valuation, estimates of consumer's surplus are based on the direct questioning of participants. Most questions are designed to elicit information on the monetary value that an individual places on participation in a given activity - sportfishing for instance (Glass and Muth 1987). Bishop et al. (1987) applied CV techniques to estimate the preservation value of striped shiners; *Notropis chrysocephalus*, an endangered cyprinid in Lake Michigan. Whitehead (1993) used CV to estimate preservation values of coastal marine wildlife in North Carolina.

CV methods have come under attack as inappropriate for measuring nonuse values. While being reliable for measuring use values, i.e., respondents had actual experience and can thus identify values to them, values resulting from CV methods were unbelievably huge. First applications of CV to nonuse values showed that the method might not be reliable when measuring unfamiliar commodities. This problem was realized by Lazo et al. (1992) and by Pearce et al. (1989) and had prompted the group to devise survey questionnaires that provided "perfect information" and "complete psychological context of the economic decision" (Fischhoff and Furby 1988). Concern regarding the validity of CV methods was earlier summarized by Scott (1965) as *"ask a hypothetical question and you get a hypothetical answer"*. Nevertheless, CV remains popular and studies fail to indicate evidence of substantial bias.

Nonmonetary Measures

Gregory (1987) focused on nonmonetary measures to value nonmarket attributes of environmental resources but did not discuss whether these measures, when monetized, could be integrated into one or another of the components of TEV. These include measures of *social well-being*, *psychophysical measures*, *attitude measures* and *multiattribute measures*. The first measure can be simply stated by asking the respondents if a scenario would affect their happiness. Some indicators can be developed such as equity, people empowerment, participation of women and the availability of social services.

In psychophysical evaluations, a particular aspect of the physical environment is used as a stimulus to potential resource users. The stimulus-response relationship then can be modeled statistically, by means of rank orders, rating scales, paired comparisons, or magnitude estimates. Psychophysical measures have been used to value some landscape features (Buhyoff and Wellman 1980) but applications in the fishery are rare.

Multiattribute models provide a rigorous means of analyzing preferences and quantifying decision outcomes between alternatives that vary in multiple dimensions. For example, Keeney (1977) employed multiattribute procedures to study fisheries management policy alternatives on a river, and Walker et al. (1983) used the technique to analyze trade-offs between management plans for different stocks of coho salmon.

A multiattribute approach has also been applied, both passively, in identifying range of stakeholder concerns (Edwards 1977) and actively, in bargaining and negotiation (Ulvila and Snyder 1980; Raffia 1982) to assess the values that stakeholder groups (people with relatively coherent views about a problem) attach to environmental impacts of risky technologies (von Winterfeldt and Edwards 1986).

For interested readers, Barton (1994) provides an indepth analysis of popular valuation techniques with annotations on supporting economic theories, a description of the method, assumptions and other limitations, and applications to coastal studies.

By way of example, a typology of different use and nonuse values for mangroves in the Gulf of Guayaquil, Ecuador, and application valuation techniques is shown in Fig. 3. These values were derived from the profile and application papers of LP

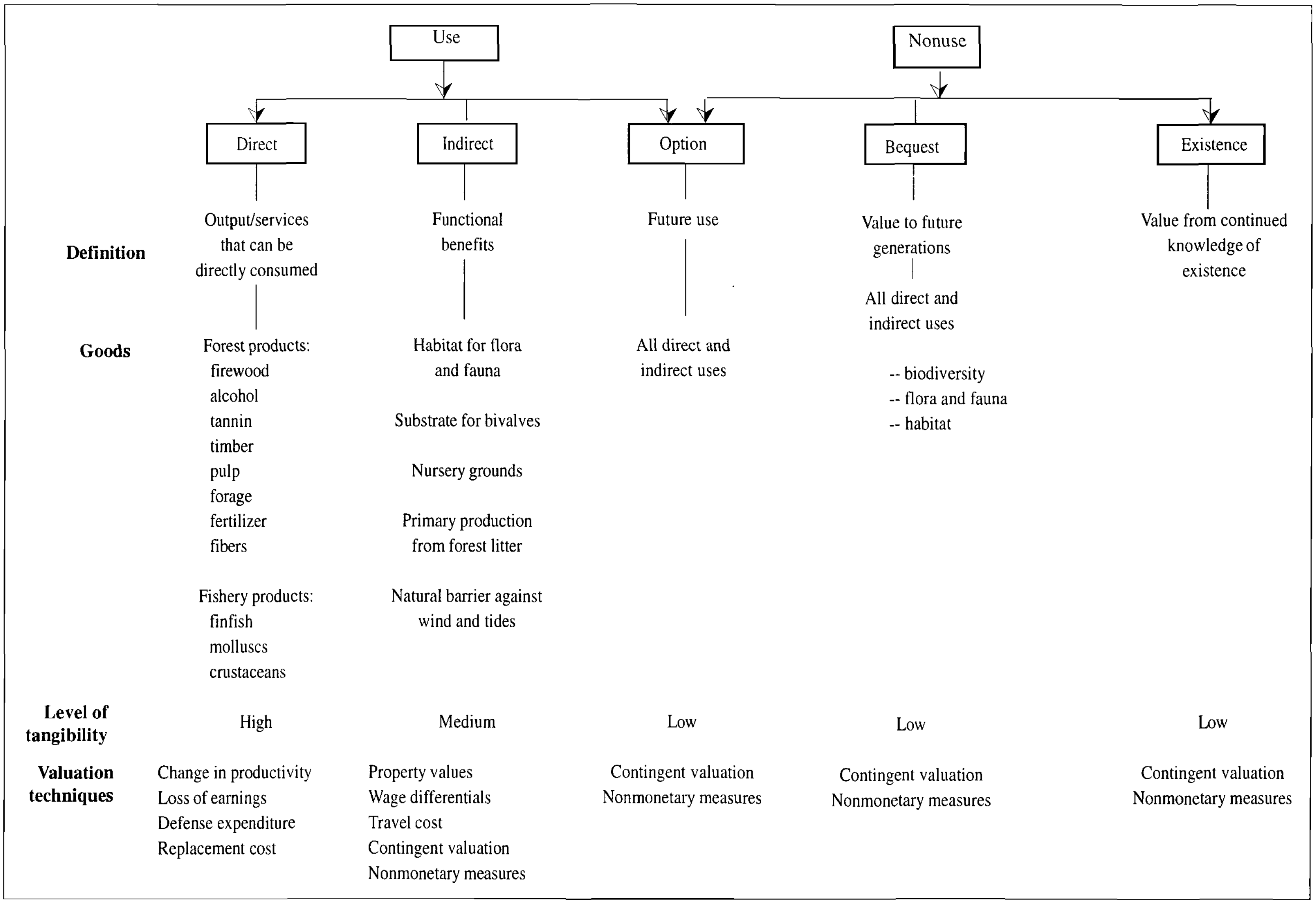

Fig. 3. Use and nonuse values of mangroves in the Gulf of Guayaquil, Ecuador; associated levels of tangibility and potentially useful valuation techniques.

on the same site. The goods and services listed are the dominant uses of mangrove resources in the area. Option, bequest and existence values are distinct but are all based on the deferment of direct and indirect uses for varying reasons (and thus values).

An argument has been made that, to a large extent, worldwide trends in resources overexploitation is an effect of flawed techniques for resources valuation. The imperfections stem from rigidities in traditional valuation techniques to account for the following features: market failures caused by externalities and public goods; nonmarket goods and services; inter- and intra-generational equity; and discounting to name a few. However, the strong linkages fostered between the fields of economics, the biological sciences, and public policy have led to the development of techniques as discussed. The work that has led to these techniques implies a new consciousness. The next step is using these measures properly, and communicating the implications of the resulting studies to policymakers.

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Options for Mangrove Management in the Gulf of Guayaquil, Ecuador*

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Abstract

The economic and ecological costs and benefits of two management strategies: (1) mangrove conversion and (2) sustainable exploitation are identified and set up as a linear programming problem. The maximization objective is to increase Total Economic Value (TEV) from these strategies satisfying constraints pertaining to land, labor, availability of penaeid shrimp fry, rated capacity of processing plants and product demand.

Aggregate benefits resulting from a combination of both strategies is US\$ $174 \cdot 10^6$ of which 60% is contributed by sustainable exploitation of mangroves (US\$ $18.4 \cdot 10^6$ from forestry and US\$ $87.6 \cdot 10^6$ from fishery); the remaining amount is accounted for by conversion to shrimp farms. These benefits correspond to the sustainable exploitation of $120 \cdot 10^6$ ha of mangroves and conversion of $5.5 \cdot 10^6$ ha.

General Description of Study Site

The Coast of Guayas

Guayas Province is one of four politico-administrative regions of Ecuador and consists of 20,900 km^2 or 34% of the national surface area. The province is bounded by the Gulf of Guayaquil and is the site of various social and economic activities (Fig. 1). Mangroves and shrimp farms are found in the coastal area with the latter comprising 30,000 ha.

An important feature of the region's oceanography is the equatorial front, normally located between 0° and 3°, and which separates the cold and nutrient rich waters of the Humboldt current and the extension of the Equatorial subcurrent from warm nutrient poor surface water. These oceanographic characteristics are seasonal in nature and dependent on the intensity and permanence of the front. The coastal areas of Ecuador likewise experience the El Niño phenomenon, an event generally occurring every 3-7 years, characterized by high water temperatures for periods ranging from 6 to 18 months, and heavy rains.

According to the Köppen classification, Guayas has three climate types which distinguish the north from the south: semi arid or steppe climate, with rainfall lower than 250 mm annually; arid, with rainfall lower than 500 mm from the months of January to April. In the zone of the Guayas River, the climate is tropical humid and savannah.

Characteristics of the Mangroves of Guayas, Ecuador

Environmental conditions in Ecuador, as in most tropical countries, are conducive to the growth and development of mangrove forests. Total mangove area in Guayas is 116,000 ha, representing 66% of total mangove area in Ecuador (CLIRSEN 1987).

Mangroves and salt flats are found in the intertidal zone; further inwards are the higher grounds, which are never flooded. The mangroves are found in areas closer to the sea and as such are frequently inundated, whereas the salt flats are periodically inundated and, in most cases, occur behind mangroves. In most cases, clayey or muddy soils are rather impermeable and easily get flooded during high tides. Areas which do not have any form of vegetation have high concentrations of salt while those in the higher areas are more conducive to agriculture (Fig. 2).

The mangrove forests of Guayas are characterized by two zones: 1) the river fringes, where *Rhizophora* spp. (red mangrove) occur and 2) the innermost to rear areas, where a mix of *Avicennia* spp. (black mangrove) and *Laguncularia* spp. occurs (Terchunian et al. 1986). The *Rhizophora* strip occurs in the zone inundated 445 to 700 times per year (Cintrón and Schaefer 1983) whereas the other zone is inundated 184 to 445 times per year. Mangrove forests may also contain zones of salt deposits *(salitrales)* and mud deposits *(lodo* or *pantone)* both of which are inundated less than 184 times per year. Due to the high salinity in this zone, the mangrove forests are collectively called *salinas* (Terchunian et al. 1986).

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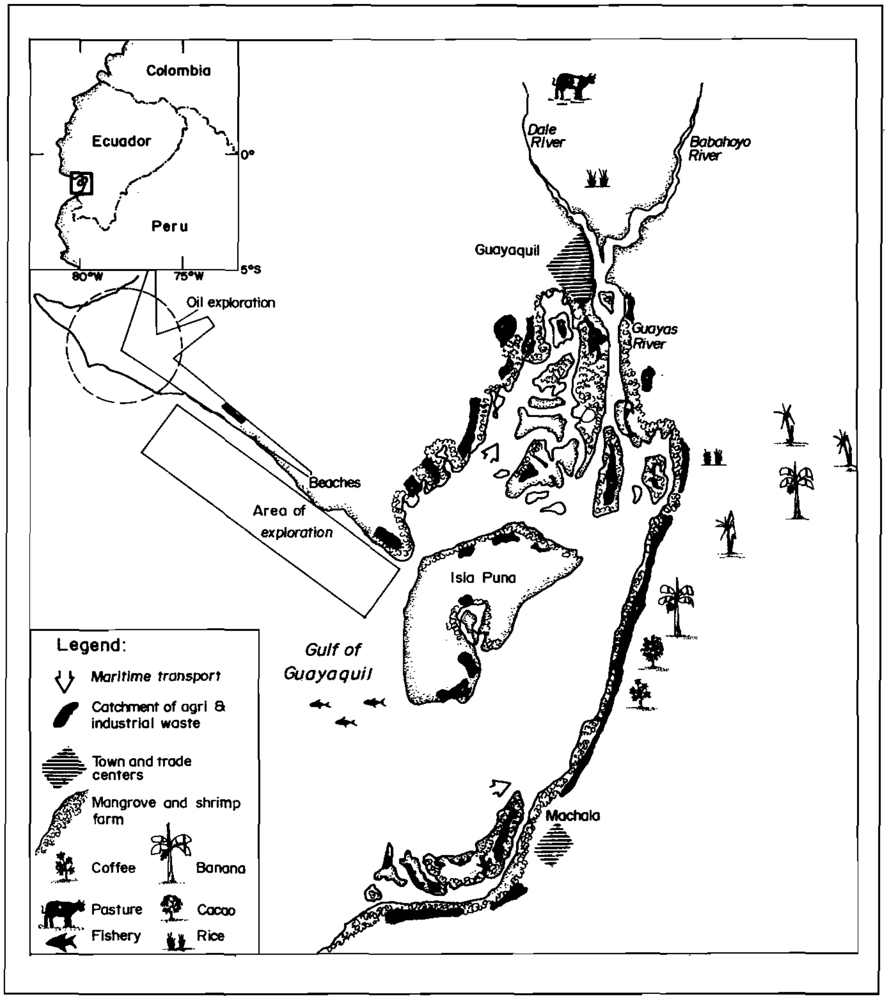

Fig. 1. The coastal zone bordering the Gulf of Guayaquil, Ecuador, as the site of multiple economic and resource-based activities.

The *Rhizophora, Avicennia* and *Laguncularia* attain heights of >15 m, 6-15 m and < 5 m, respectively. Some mangrove trees are known to reach heights of 35 m and a density of 365 trees per hectare compared to an optimum of 800 trees per hectare (FPVM 1987). In Guayas, standing density is only 185 $t{\cdot}ha^{-1}$, an indicator of overexploitation (Twilley 1989). Characteristics of mangroves are shown in Table 1. These species are utilizable as timber and other wood products.

Alternative Uses for Mangroves: Fishery, Forestry and Aquaculture

Velascó (1987) synthesizes the role of mangroves as: 1) economic and therefore exploitable and 2) ecological and therefore conservable. The economic importance of the mangrove ecosystem arises from the products and services derived from it. The ecological functions of the mangrove include the export of organic material to estuaries which serves as food for juvenile shrimps and fish and/or their prey; the root system of mangrove trees enables the retention of sediments, preventing erosion and also for shoreline protection; and lastly, providing a habitat for many aquatic species in the mud flats and roots.

Three alternative uses of the mangroves in Guayas, Ecuador, include: 1) capture fisheries, *indirect use* via the protection and nourishment provided to target species and *direct use* via the exploitation of fish and crustaceans; 2) forestry, *direct exploitation* of marketable goods; and 3) aquaculture, complete *conversion* of the physical and ecological dynamics of the ecosystem. The three uses occur simultaneously and result in a measurable quantity of economic benefits. However, mangrove conversion to shrimp aquaculture has been their main use in the last two decades because of attractive returns in the export market.

Of the three alternative uses, mangrove conversion results in the gravest damage to the environment (Paw and Chua 1991). Mangrove conversion to shrimp mariculture results in a vicious cycle because of the loss of breeding grounds for larvae which are critical inputs to the shrimp industry. Other impacts observed in Guayas include change in water quality in the coastal zone due to discharges of shrimp ponds brought about by water exchange which Twilley (1989) estimates to reach 20 million $t{\cdot}day^{-1}$.

Both aquaculture and forestry activities were observed to have adverse effects on the environment including a decline in the production of mussels, oysters and cockles. The felling of trees causes thinning of forest cover which results in direct penetration of solar rays, increasing land temperature and salinity and

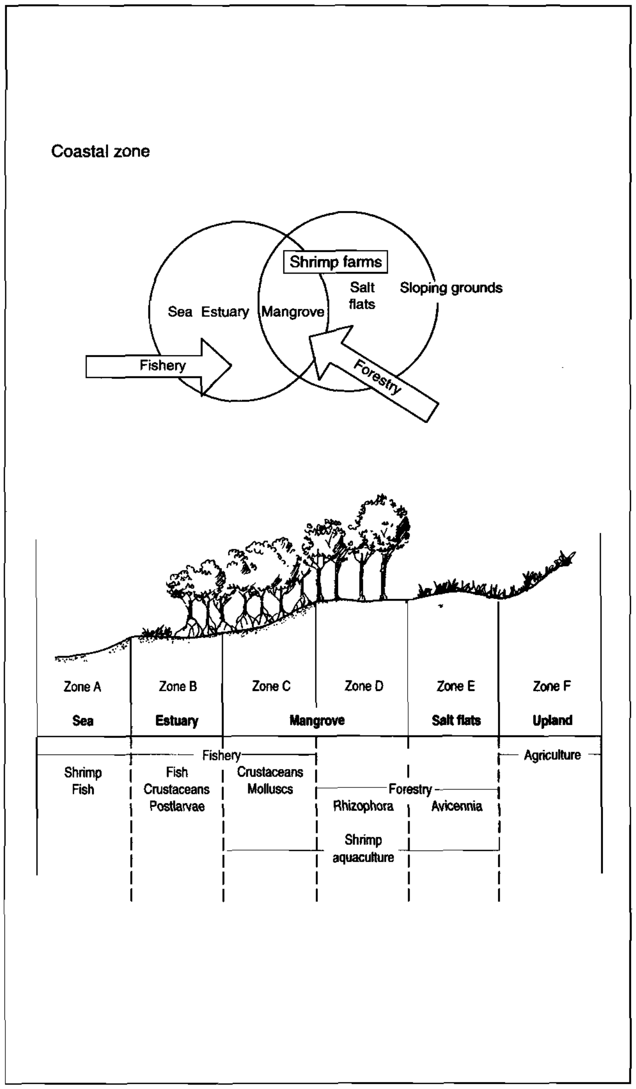

Fig. 2. Zonation, uses and products/goods derived from coastal areas in the Gulf of Guayaquil, Ecuador.

decline in oxygen levels contributing to the disappearance of species that exist in muddy substrates. It likewise causes a decrease in natural barriers that protect against surf, and with wind action causing erosion and increased salinity of interior lands.

Fishery

Commercially important species associated with mangrove include shrimp of the genus *Penaeus*: *P. vannamei, P. stylirostris, P. occidentalis* and *P. californiensis.* These species have a particular migratory cycle and appear strongly dependent on the mangroves. Other crustaceans found in mangroves include crabs (Local: *jaiba*) *(Ucides* spp., *Uca* spp., *Callinectes toxotes).* Commercially important molluscs include *Anadara tuberculosa, Anadara similis, Anadara grandis, Mytella guayanensis, Ostrea columbiensis* and *Chione subrugosa.*

Only one fish species appears to be completely dependent on mangroves, *Mugil curema* mullet *(lisa),* a detritus feeder.

THE COMMERCIAL AND ARTISANAL SECTOR

The commercially important species are exploited by both the artisanal and commercial fleet. The commercial fleet exploits the shrimp fishery which is a prominent feature in the Gulf of Guayaquil (Cun and Marín 1982). Shrimp fishing is conducted throughout the entire coast in depths of 60 m. Main gears used are pair trawlers with lengths of 10 to 25 m and 190 to 500 hp or greater.

The shrimp fishery contributed 10 to 12% of total production of shrimps in Ecuador in recent years with

Table 1. Commercially important mangrove species in Guayas, Ecuador.

	Family and species					
		Rhizophora		*Avicennia*	*Laguncularia*	*Conocarpus*
	mangle	*harrisonii*	*racemosa*	*nitida*		*erectus*
Common name(s)	*m. cholo* *m. gateado* *m. gatucho*	*m. rojo* *caballero*	*m. de pava* *m. iguaner*	*m. salado*	*m. blanco* *m. hembra* *m. bobo*	*Jeli prieto* *m. macho*
Average height, Ecuador (m)	12	51	30	30	18	13
Average height, general (m)	7-8 ; 10-12	15-35 ; 50-60	8-25			

Source: Horna (1983); Rollet (1986).

the remaining contributed by culture. Catch of fully-grown shrimp and larvae amounted to 10,800 t and $6.4 \cdot 10^9$ larvae in 1988, respectively. As for larvae, actual catch can be as high as $1.3 \cdot 10^{10}$ larvae (assuming a 50% mortality rate), and at a price of US$ 8.6 per thousand larvae, and can be valued at US$$55 \cdot 10^9$ to $110 \cdot 10^6$ per year.

The artisanal fishery uses small vessels such as rafts, canoes, boats and barges, many of which have been used since the 16th century (Lenz-Volland and Volland 1992) to catch fish, molluscs and crustaceans. The most important crustaceans are penaeid shrimps and lobsters which are sold fresh, frozen, cooked, canned or salted. Larval and juvenile shrimp are also captured for rearing in hatcheries. These are captured throughout the coastline year-round but are most abundant during the rainy months from November to April (McPadden 1985). The artisanal fleet also catches berried shrimp females using trammel nets.

Crabs are captured in marshes using manual methods, traps and baits. These are sold fresh and consumed locally and exported as well. Molluscs are manually extracted from the mud, during low tide. These are sold and consumed as fresh and unshelled and in some cases, canned or frozen. The market is domestic except in the case of *Anadara tuberculosa* which is also exported. The fish species captured by the artisanal sector are varied and consumed as fresh, cooked, salted or canned and are consumed by domestic and foreign markets.

Forestry

The exploitation of mangrove forests in Ecuador is small scale, done mostly by family groups, which have maintained the traditional exploitation systems over the years. The main modes of exploitation are partial and selective logging. Partial logging involves the felling of alternate strips of trees perpendicular to waterways every 15 years; this permits the natural regeneration of the forest. Selective logging is the felling of trees with diameter greater than 5 to 12 cm, while the smaller ones are left standing along with those which bear seeds to allow regeneration of the forest.

The principal use of wood includes felling of trees for charcoal and firewood, and the manufacture of wood products for construction. It is presumed that present exploitation systems have not changed much from traditional forms (Horna 1980).

Most mangrove products are used for construction. Red and white mangroves are valued for their pulp which is used for the manufacture of boards, panels and wood chips. The red mangrove is used for charcoal and from its bark is tannin sourced; the latter is merely a by-product and is exploited on a small scale.

PRODUCTION

Growth of mangroves is slow. The red mangrove, for example, takes about 25 to 30 years to attain maturity, while the other species take 15 to 20 years (Horna 1983).

Wood: The density of red mangrove is 0.9 to 1.2 $t \cdot m^{-3}$. To estimate yield per hectare, we consider biomass per hectare with the following percentage distribution per species:

	R. mangle	*L. racemosa*
Roots	20	–
Trunk	65	86
Branches	12	10
Leaves	3	4

Charcoal: The yield of wood charcoal is 0.5 m^3 of charcoal per m^3 of wood, at a 50% conversion rate. Thus, given a density of 680 $kg \cdot m^{-3}$ of wood carbon, this translates to 340 kg carbon per m^{-3} of wood.

Tannin: It is possible to obtain up to 90 kg of tree bark from a mature tree from which 30% can be extracted as tannin. Extraction rates of tannin from the bark and leaves are 15 to 42% and 22%, respectively.

Aquaculture

The geographical conditions of the coastal zone are conducive to the growth of the shrimp aquaculture industry which in 1988 became the second most important source of foreign exchange next to petroleum (Solorzano 1989). Presently, Ecuador accounts for 76% of shrimp production in the western hemisphere, is the second largest exporter of pond-raised shrimp in the world, and the fourth largest producer (Agüero and Gonzalez 1991). While initiated in 1968, the period of robust growth was between 1980 and 1987 from whence growth stabilized. This development has directly caused the destruction of around 30,000 ha of mangrove forest; the Manabí region suffered the most and at present has 50% of forest cover (Table 2).

Shrimp farms were initially constructed in salt flats and areas of sparse vegetation; here, costs of construction were minimal. Later, mangrove and intertidal areas and lands formerly used for agriculture were also tapped (Snedaker et al. 1988). To date, shrimp farms comprise 35 to 48% of the total area in hilly grounds, 27 to 34% in salt flats and 25 to 30% in mangroves (Meltzoff and LiPuma 1986).

In Guayas Province alone, 9,500 ha of mangroves and 31,000 ha of salt flats were converted to shrimp farms from 1969 to 1987. Overall, in Ecuador, 117,000 ha of shrimp farms have been constructed as of 1987, 63% of which is concentrated in Guayas.

Table 2. Area of mangroves, salt flats and shrimp farms in Ecuador, 1969-1987, by province.

Province	Year	Mangroves	Salt flats	Shrimp ponds
Esmeraldas	1969	32.0	-	-
	1984	30.2	-	1.6
	1987	29.3	-	2.6
Manabí	1969	12.4	845.0	-
	1984	8.0	164.0	8.4
	1987	6.6	164.0	10.0
Guayas	1969	125.5	40.1	-
	1984	119.6	17.3	52.6
	1987	116.1	9.8	74.4
El Oro	1969	33.6	9.8	-
	1984	24.4	2.5	26.5
	1987	23.4	2.5	29.7
Total	1969	203.6	51.5	-
	1984	182.2	20.0	89.1
	1987	175.5	12.4	116.8

CULTURE SYSTEMS

Shrimp farms culture the white shrimp, *Penaeus vannamei*, which is more adaptable to existing culture methods; of secondary importance is *Penaeus stylirostris* (Aquacop 1979).

Shrimp culture requires the construction of tanks or ponds with heights ranging from 0.5 to 1.2 m. The larvae are captured in estuaries by artisanal fishers and transported to stocking tanks. The larvae are either brought to grow-out farms or to hatcheries. Survival rate is low through the various stages of production (capture, transport and stocking) ranging from 1 to 5% and mortality may reach as high as 50 to 100% per stage.

Prevailing culture systems are differentiated according to the level of technology, stocking density, feeding regime, fertilization and water management (Table 3). The culture systems used in Ecuador and their characteristics include the extensive system, accounting for 35% of total pond area, practiced in El Oro Province; the semi-extensive system, accounting for 55% of total pond area, prevalent in Guayas Province; and the semi-intensive system, which operates under professional, and oftentimes, foreign management (Meltzoff and LiPuma 1986).

Shrimp mariculture begins with the capture of larvae by *semilleros* (larvae collectors) in estuaries, although recently trawlers were observed to capture gravid females for hatchery production (Meltzoff and LiPuma 1986). Larvae production has been quite erratic with peaks occurring in 1982 and 1983 being attributable to the "El Niño" phenomenon. The development cycle of shrimp mariculture is observed to be self-defeating with the construction of ponds causing widespread mangrove destruction (Terchunian et al. 1984) and the inevitable loss of breeding grounds for shrimp larvae. Thus, while shrimp pond coverage has been increasing, the availability of larvae for stocking has approached crisis levels.

COSTS

The costs associated with aquaculture include the cost of land, construction costs and operating expenses. The cost of land varies according to its location, source of water and soil quality. Highlands and mangroves are priced at US$1,000·ha^{-1} and US$6,000·ha^{-1}, respectively. Saltbeds are priced in between (Horna 1983). In Guayaquil, agricultural land convertible (to shrimp farms) costs around US$2,000·ha^{-1}.

Cost of infrastructure and equipment depends on the technology used. Construction and equipment costs may range from US$4,000 to 7,700·ha^{-1} with an economic lifetime of 5 to 10 years.

The major components of variable costs include costs of larvae, food and energy. Price of larvae depends on availability. Depending on the point of sale, source and time of year, the price of larvae in recent years fluctuated from US$1 to 13.5·thousand^{-1}.

FINAL PRODUCT AND PRODUCTION TRENDS

Upon harvest, shrimps are processed via steaming and their tails removed. Headless shrimps have final weights of about 66-67% of live weight. These are packed and frozen for transport and selling.

Table 3. Main features of shrimp culture systems in Ecuador.

Parameters	Extensive	Semi-extensive	Semi-intensive
Stocking density ($PL \cdot 10^{a} \cdot ha^{-1}$)	10-10.5	30-35	80-100
Yield ($lb \cdot ha^{-1} \cdot year^{-1}$)	300-800	975-1,300	1,900-3,250
Weight (g)	23-35	18-21.5	15-18
Supplementary feeding	none	only in final stage of life cycle	throughout cycle Feeding ratio: 1.3-2
Fertilizers	none	yes	yes
Breeding tanks	none	yes (40-45 days)	yes
Water management	seawater	pumped	aeration
Area (ha)		> 100	>1,000
% of use in Ecuador	35	55	10

Source: McPadden (1985); Espinoza (1989).

Cultured shrimp production reached 77,800 t in 1988 with a value amounting to US$322 million. Total production by both capture and culture amounts to about US$416 million/year, which is about 4.2% of GNP and 28.3% of primary production (FEDECAM 1989). The export market, notably the United States, absorbs 92% of total production while the remaining is absorbed by the domestic market.

Production has declined in recent years. In 1989 and 1990, only 64,000 and 69,000 t of shrimp, respectively, were produced by the aquaculture sector; 64% of total production is accounted for by the semi-intensive farms and the remainder is produced by extensive farms.

To date, the most critical factor that affects the viability of shrimp culture as a whole, and the hatcheries, in particular, is the availability of natural larvae for stocking in grow-out ponds and for breeding in hatcheries. In 1988, for example, the aquaculture sector utilized a total of $9 \cdot 10^9$ larvae, 72% of which was provided by the artisanal fishery. A record of operational shrimp farms in 1988 ranged from 61,000 ha to 123,000 ha, respectively. In Guayas, where there are a total of 88,000 ha, roughly 48,000 ha or 53% is operational (Meltzoff and LiPuma 1986).

Linear Programming Application to the Mangroves of Guayas, Ecuador

The Optimization Model

A model was constructed which seeks to optimize Total Economic Value (TEV) derived from the mangrove ecosystem in Guayas, Ecuador. Optimum TEV is arrived at by combining development strategies (see Fig. 3), ranging from the extreme options of conservation or conversion, or an intermediate option, i.e., partial removal of mangrove and sustained exploitation of the remainder.

Conservation does not yield any form of goods but generates benefits via services and functions (discussed in previous section). *Sustainable exploitation* involves the extraction of forestry and fishery goods in a fashion that assures future generations of the same quality of life (World Commission on Environment and Development 1987). This includes the indirect benefits associated with mangroves such as the services and ecological functions derived from them. *Conversion* involves a partial or complete alteration of the geophysical attributes of the resource. We consider only the conversion to shrimp ponds because its prevalence in our project site has elevated it to a management concern. Conversion results in a particular commodity, shrimps, and incurs costs associated with operating shrimp farms and costs attributed to loss of mangrove resource, scarcity costs and compensation costs.

The model consists of the objective function, the constraints and the technical coefficients. The mathematical formulation of these components are discussed and summarized as a representative tableau (Fig. 4).

The objective function consists of decision variables which affect the maximization objective either positively or negatively depending on the value and sign of the coefficient and on the magnitude of the decision variable. The decision variables in our objective function are influenced by two broad development options, conversion and sustainable exploitation, and their respective costs and benefits.

A general formulation is:

$$MaxZ = \sum NB_s + \sum NB_M$$

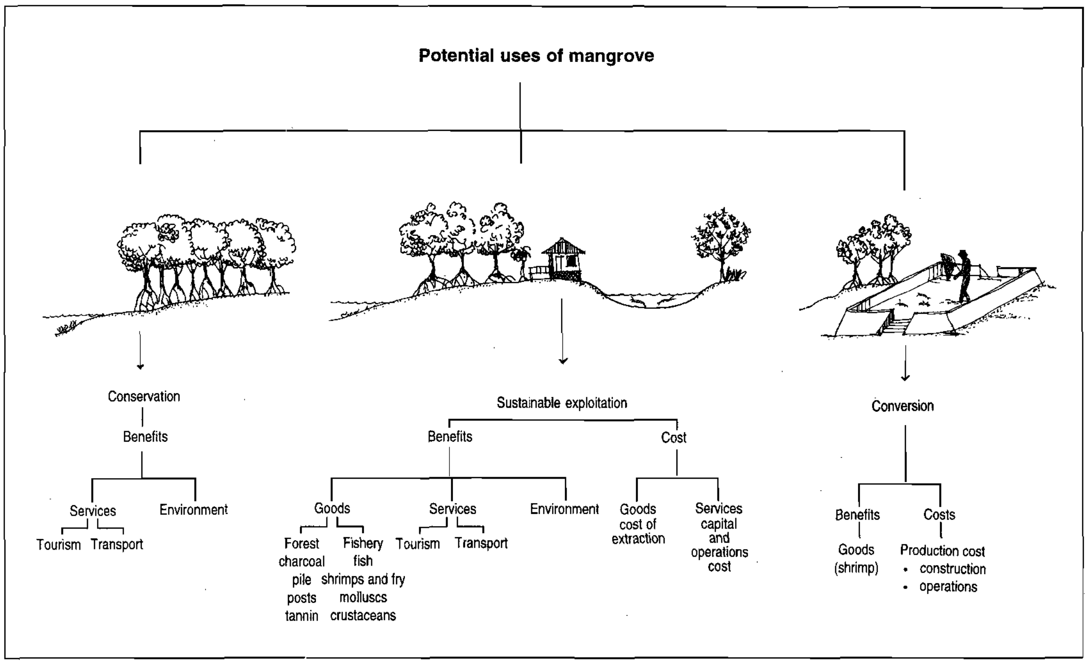

Fig. 3. Potential uses of mangroves and associated costs and benefits per category of usage.

where NB_S is the net benefit associated with shrimp culture and NB_M is the net benefit associated with sustainable development of the mangrove.

The mathematical formulation of the LP model is:

$$MaxZ = \sum_{a}\sum_{b}\sum_{c}\sum_{A_j=1}^{t}\sum_{N_k=1}^{u}\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{abcA_jN_{klmn}} * P_{abcA_jN_{klmn}}$$

$$\sum_{a}\sum_{b}\sum_{c}\sum_{i=1}^{s}\sum_{A_j=1}^{t}\sum_{N_k=1}^{u}\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{abciA_jN_{klmn}} * C_{abciA_jN_{klmn}}$$

The principal subindices define the variable according to the option of conservation or conversion to shrimp farms, the area or zone of exploitation, type of use of the resource and ecosystem based on its source of value, the productive sector, level of conversion, technology applied, resources used and final products.

The nomenclature adopted for decision variables has the form:

$X_{abciA_jN_{klmn}}$ *

$P_{abciA_jN_{klmn}}$ and $C_{abciA_jN_{klmn}}$ refer to the coefficients of the objective function and assume values pertaining to costs or prices.

The subindices represent:

1) a = land use, a = {C,M};
   C = area devoted to construction of shrimp ponds; and
   M = area devoted to conservation of mangrove, sustainable exploitation.
2) b = use of resources, b = {G, S, F, FV};
   G = resources used for the production of goods;
   S = resources used for the delivery of services;
   F = resources used for the maintenance of ecological functions; and
   FV= resources devoted for future use, existence value, and other values not previously considered.
3) c = productive sector; c = {F, P, A};
   F = forestry;
   P = fishery; and
   A = aquaculture.

Note that the subindex c, for the aquaculture sector, is not written; instead is assumed implicit in all

*The typical variables in the model start with the letter X and refer to quantities (e.g., hectarage, number of postlarvae, liters of tannin). Cases where the variable begins with a letter other than X represent situations where such variable is a component of another or a percentage of another; these variables take on a value between 0 and 1.

activities concerning shrimp farming, or where subindex a=c.

4) i = processing activity, i = {1,....s}

For the productive sector, the numbering of activities is based on the chronology: extraction, transport, processing and sales.

5) A_j = area where activity i occurs

The A_j's are the different zones of the mangrove as outlined below. The delineations are based on different ecological functions.

Zone A: open seas, with high saline concentration

Zone B: swamps and estuaries where salinity is intermediate

Zone C: coastal fringes, frequently inundated, dominant species is the red mangrove

Zone D: interior zone of the mangrove which is inundated less frequently than Zone C, dominant species are black mangrove and white mangrove

Zone E: salt flats, rarely inundated and no existing vegetation

Zone F: higher/sloping grounds, never inundated, generally used by agriculture

6) N_k = level of conversion of mangrove area, k = {1,..4} (see Table 4)

l,m = level of technology (Table 5)

l = {E,I} , m = {1,..4}, m is stocking density

E = extensive culture system

I = semi-intensive culture system

7) n = natural resource/ final product

For the forestry sector, it was assumed that *Avicennia* is the only species extracted from Area 1 and from Area 2, the red mangrove. The final products are firewood from *Avicennia* trees (F), piles from red mangrove trees (P), and tannin from red mangrove trees (T).

In the fishery, the final products include molluscs, crabs, shrimp fry, adult shrimps and fish. These products, as defined, assume no need for further processing. We assume a certain percentage loss for cleaning, for example, in the case of headless shrimps.

Constraints

Constraints include resource constraints and others related to linear programming, including balance equations, convex equations and counters. The constraints are formulated as equalities or inequalities in which the right-hand side (RHS) determines the limit. The coefficients are referred to as input-output coefficients or technical coefficients and represent the amount of each resource required by each decision variable.

The relevant resource constraints are:

1) Land

$$\sum_{b}\sum_{c}\sum_{N_k=1}^{u}\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y}\left(X_{mbc1A_jN_{klm}+XCbc1A_jN_{klm}}\right)\Leftarrow A_j$$

for all types of land area j = (1,...4)

Table 4. Assumed conversion levels for mangrove zones C, D, and C and D, in Guayas, Ecuador, in 10^3 ha.

Conversion level (k)	Zone C	Zone D	Zone C&D
1	10	10	10
2	20	20	30
3	30	30	60
4	60	65	120

Table 5. Assumed levels of stocking density and effort for forestry and aquaculture corresponding to various levels of technology.

Stocking density (m)	Aquaculture (PL·10^9·ha^{-1})		Forestry (Trees·ha^{-1}·$year^{-1}$)	
	Extensive	Semi-Intensive	Area 1	Area 2
m = 1	30	70	60	28
m = 2	40	90	80	40
m = 3	50	110	75	35

	Mangrove conversion					Sustainable exploitation					
Max TEV	Costs: Land	Costs: Construction	Costs: Operating	Costs: Harvesting	Benefits Sales	Land	Costs (Forestry): Exploitation	Costs (Forestry): Processing	Fishing Effort	Benefits Sales	RHS
Objective function coefficients	X_{CiAj}	$X_{CiAjNkL}$	C_{iNkl}	X_{CiNkl}	$X_{CiAjNkN}$	M_{iAjNk}	$X_{MiAjNkl}$	X_{MiN}	X_{MiAjN}	X_{MiN}	
Decision variables	land area	area converted to shrimp farms	area converted to shrimp farms with references to technology	quantity of shrimp harvested	quantity of shrimp sold	land area	forest area exploited	quantity of trees felled	Fishing effort per zone and per species	quantity of fishery and forestry products sold	$<=A_{ij}$ $<=L_A$ $<=L_F$ $<=L_P$ $<=P_P$ $<=P_F$ $<=P_S$ $<=Q_F$ $<=Q_P$ $<=F$ $<=K_L$ $<=K_S$
Balance equations											<=0
Convex equations											<=1
Counters											<=0

A_j	=	mangrove area from zones 1,...6	P_S	=	plant capacity, sawmill
L_A	=	labor, aquaculture sector	Q_F	=	demand, forestry products
L_F	=	labor, forestry sector	Q_F	=	demand, fishery products
L_P	=	labor, fishery sector	F	=	fishing effort
P_P	=	plant capacity, packaging	K_S	=	capital, small-scale
P_F	=	plant capacity, freezing	K_L	=	capital, large-scale

Fig. 4. The LP tableau for mangrove utilization in Guayas, Ecuador.

2) Maximum carrying capacity of forest, given existing mangrove area or level of conversion and maximum biomass based on level of effort

$$\sum_{l=1}\sum_{m=1}\left(X_{MBF_lA_jN_{klmn}} \Leftarrow R_{FA_jN_{klmn}Y*} * A_j\right)$$

$R_{FA_jN_{klmn}} * A_j$ = the maximum biomass of species n, for type of conversion N_k, given by level of technology l and effort level m

$R_{FA_jN_{klmn}}Y*$ = is the density of resource or species n, per type of mangrove zone A_j, given conversion level N_k, and level of technology l and effort level m

3) Maximum carrying capacity of the fishery, given existing mangrove area or level of conversion and maximum biomass based on applied effort in the fishery

$$\sum_{l=1}^{v}\sum_{m=1}^{w} X_{MBP_lA_jN_{klmn}Y*} <= R_{PA_jN_{klmn}} * A_j$$

$R_{PA_jN_{klmn}} * A_j$ = maximum biomass of species n, for level of conversion N_k, and level of technology l and effort m

$R_{PA_jN_{klmn}}$ = density of resource or species n, for type of land A_j, conversion level N_k, for level of technology l and effort m

4) Postlarvae

$$\sum_{A_j=1}^{t}\sum_{N_k=1}^{u}\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{CBC_lA_jN_{klmn}} <= PLM(A_j, N_k) + CPL$$

CPL = capacity of hatcheries

PLM (A_j, N_k) = availability of seeds from the wild as a function of area and level of conversion

5) Labor

$$\sum_{i=1}^{s}\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{MBC_{ijlmn}} * R_{cinY*} <= MMO_c$$

MMO_c = labor available for sector c

R_{cin} = coefficient of productivity of activity I

6) Maximum effort per productive sector, i.e, machinery, number of nets, boats available

$$\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{MBC_{ijlmn}} * R_{cinY*} <= MCE_c$$

MCE_c = maximum effort for sector c. Number of machines, nets, boats.

R_{c1lmn} = extraction rate (probability of capture), per effort applied, per level of technology applied

7) Maximum processing capacity per productive sector

$$\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{MBC_2lmn} * R_{c_2nY*} <= CP_{c_2n}$$

R_{C_2lmn} = coefficient or rate of production per type of technology m utilized

CP_{c_2n} = maximum capacity of plant, sector c for product line n.

8) Maximum capacity of cold storage per productive sector

$$\sum_{l=1}^{v}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{MBC_3lmn} * R_{c_3nY*} \leq CP_{c_3n}$$

R_{c_3lmn} = volume occupied in transport sector m, per unit of product n transported

CPc_3n = maximum capacity of warehouse, freezers in sector c for product line n

9) Capital availability for small and large investors in the aquaculture sector

$$\sum_{A_j=1}^{t}\sum_{N_k=1}^{u}\sum_{m=1}^{w}\sum_{n=1}^{y} X_{CBC_1A_jN_klmn} * R_{CA_jN_klmnY*} <= K_{C_1}$$

R_{CA_jl} = initial investment (infrastructure and other operating costs) for shrimp farms located in area A_j operating under system l

K_{c_l} = amount of credit available for investments in technology system l.

Balance Equations, Counters and Convex Sets

Balance equations were set up for successive activities in the production process. With these we are able to simulate the resource flow to final product, passing all stages and undergoing and capturing losses and wastage to the environment.

The equation can be expressed as:

$$X_{aBC_iA_jN_klmn} * R_{aBC_ilmnY*} - X_{aBC_{(i+1)}A_jN_klmn}$$

R_{aBC_ilmnY*} = percentage usage of resource between successive activities, i.e., i+1.

Counters have a similar purpose except that these are used when decision variables are broken down into several components, e.g., hectarage, and do not refer to product transformation. Convex equations are included to assure compliance with segmentation defined by piecewise linearization used in incorporating nonlinear functions.

Lastly, we also include the nonnegativity constraints with reference to our decision variables.

Values of the Constants

The constants include the coefficients of the decision variables in the objective function, the technical coefficients, and the right-hand side (RHS) elements. The first element defines the columns of the LP tableau which is a 141 x 115 matrix whereas the last two make up the rows of the tableau. The elements of the LP tableau are described in more detail in Appendix 1.

COEFFICIENTS OF THE OBJECTIVE FUNCTION

The coefficients of the objective function reflect the contribution of a particular activity to the value of the objective function (VOF). Thus, costs tend to depress VOF while revenues increase it.

The costs considered include those of land conversion (construction of shrimp tanks), shrimp fry, and extraction and processing cost for forestry and fishing. The prices refer to those of finished products which include shrimps from the aquaculture sector (whole and headless); from the forestry sector, firewood, posts and tannin; and from the fishery sector, molluscs, crabs, shrimp postlarvae, adult shrimps and fish. Prices of finished products and that of production inputs are based on current market prices.

Construction costs range from US$100 to US$10,400·ha^{-1} depending on the mangrove zone and areal coverage. Development costs are higher in salt flats and sloping grounds than in Zones A to D. For example, conversion costs in Zone A for a 10,000 ha farm costs US$500·ha^{-1} as compared to 60,000 ha in Zone E which costs US$9,150·ha^{-1}. Costs are generally higher for the same level of areal conversion in Zone E.

Construction costs of extensive farms is US$8,490·ha^{-1} while that of semi-intensive farms is US$32,460·ha^{-1} which remains constant despite different stocking regimes. An important determinant of stocking is the cost of postlarvae (PL) and related operational costs associated with feeding and air and water management. These costs range from US$8.6·thousand^{-1} PL (extensive, 10,000 ha) to US$16.9·thousand^{-1} PL (extensive, 125,000 ha). Harvesting cost is US$600·t^{-1} and is uniform for all types of operations and areal coverage.

Sustainable exploitation of the mangrove forest involves costs of extraction and processing. Extraction costs for *Avicennia* in Zone D with area of 10,000 ha ranges from US$300·ha^{-1} to 700·ha^{-1} while for red mangrove in Zone C, same areal coverage, ranges from US$225·ha^{-1} to 525·ha^{-1}.

In the fishery, collection of clams and crabs occurs in Zone C; that of shrimp fry in Zone B; and for adult shrimps and fish, in Zone A, or open seas. Collection costs for these products as well as market prices of mangrove-derived commodities are shown in Table 6.

TECHNICAL COEFFICIENTS AND RHS VALUES

In the case of a resource constraint, the technical coefficients represent the contribution of a particular resource, i.e., labor, to a particular decision variable included in the maximand.

Right hand side values define the limits of the restrictions enumerated above or, in the case of resource constraints, the supply or availability of the resource.

Results and Discussion

Solutions to the Primal Problem

The solutions to the primal problem are provided in Table 7. These include the optimal value of the objective function and the values of the decision variables.

Table 6. Average costs and market prices of products derived from the mangrove of Guayas, Ecuador.

Commodities		Exploitation/ processing costs[1]	Market price
Aquaculture		US$·t^{-1}	
	whole	n.a.	7,500
	headless	n.a.	6,700
Fishery		US$·t^{-1}	
	clams	1,000	2,000
	crabs	1,000	4,000
	postlarvae	10,000	8,600
	shrimps	5,000	6,700
	fish	5,000	2,500
Forestry		US$·m^{-3}	
	firewood	5	50
	posts	3	10
	tannin	5	150

[1]For foresty products.
Source: FPVM (1987); FEDECAM (1989).

Total net benefits that would accrue to simultaneous conversion and exploitation of Guayas mangroves amount to US$174·10^{6}·year^{-1}. Of the total, US$106·10^{6} is accounted for by sustainable exploitation of the mangrove: US$18·10^{6} from the forestry sector, US$88·10^{6} from the fishery, and US$68·10^{6} from the aquaculture sector, in which US$2.5·10^{6} represents the costs of transforming the mangrove.

The above estimates are based on the sustainable exploitation of 119.5·10^{3} ha of mangroves distributed in Zones C (46%) and D (54%) and the conversion of 5.5·10^{3} ha preferably sited in Zone C because of the lower costs (construction and opportunity costs) incurred. Optimal area of shrimp farm is 49·10^{3} ha with areal distribution as follows: mangroves, 11%; salt flats, 64%; and the remaining 25%, sloping grounds. The distribution of shrimp farms according to mode of operation is 37·10^{3} ha for extensive farms, 84% of which are located in salt flats, and 13·10^{3} ha for semi-intensive farms, all located in sloping grounds. Operations in mangrove areas are extensive. Though less in area, semi-intensive farms would provide approximately 45 million t of shrimps (heads-on) or 64% of total production.

Comparing the parameter estimates with actual values shows that mangrove conversion has clearly gone beyond sustainable levels, i.e., by about 200%. The estimates furthermore show the preference of siting ponds in mangroves rather than in salt flats and sloping grounds which are both underutilized.

Table 7. Parameter estimates of the primal LP problem for three alternative uses of mangroves in Guayas, Ecuador.

Parameters	Unit	Model	Actual*
Option: Aquaculture			
Extensive shrimp farms	ha·10³	5.5	-
Semi-intensive shrimp farms	"	0	-
Shrimp farms, mangrove area 1	"	5.5	-
Shrimp farms, mangrove area 2	"	0	-
Total area of shrimp farms, mangrove	"	5.5	9.4-22
Extensive shrimp farms, salt flats	"	31.2	-
Semi-intensive shrimp farms, salt flats	"	0	-
Total area of shrimp farms, salt flats	"	31.2	13-25
Semi-intensive shrimp farms, sloping ground	"	12.6	-
Total area of shrimp farms, sloping ground	"	12.6	17-36
Total extensive shrimp farms	"	36.7	-
Total semi-intensive shrimp farms	"	12.6	-
Total shrimp farms	"	49.3	48-74.4
Shrimp fry sourced from the wild	PL·10⁹	3.9	4.2
Shrimp fry sourced from labs	"	1	1.5
Total fry used	"	4.9	5.7
Production, extensive systems	t·10³	16.4	15.8
Production, semi-intensive systems	"	28.9	28.2
Total shrimp production (heads-on)	"	45.3	44.1
Sales of shrimp, heads-on	"	11	-
Sales of shrimp, headless	"	19.4	-
Total costs	US$ 10⁶·year⁻¹	144.4	-
Gross income	"	212	212
Net income	"	67.7	-
Option: sustainable exploitation			
Mangrove area in Zone 1	ha·10³	54.5	-
Mangrove area in Zone 2	"	65	-
Total mangrove area	"	119.5	116.1
Sector: forestry			
Avicennia felled	cu.m 10³	488.6	-
Rhizophora felled	"	510.5	-
Sale of firewood	"	390.9	-
Sale of posts	"	367.6	-
Sale of tannin	l.10⁹	35.7	-
Total costs	US$ 10³·year⁻¹	10.2	-
Gross income	"	28.6	-
Net income	"	18.4	-
Sector: fishery			
Sale of molluscs	t·10³	1.5	1.0-2.4
Sale of crabs	bundles 10³	2.7	600
Sale of fry	PL·10³	5.6	4.3-8.6
Sale of shrimps, heads-on	t·10³	4.4	7.2
Sale of fish	"	3.4	-
Total costs	US$ 10⁶·year⁻¹	11	-
Gross income	"	99.4	110**
Net income	"	87.6	-
Net benefits, service and function	"	0	-
Total cost of conservation	"	22	-
Net income of conservation	"	128	-
Net benefit	"	106	-
Total net benefit	"	173.7	-

*Based on 66% of total figures for Ecuador given that Guayas accounts for same % mangrove.
**Only for capture PL.

Solutions to the Dual Problem

The dual formulation of the linear programming problem resulted in the same level of net benefits, i.e., value of the objective function (VOF). Its mathematical interpretation as the rate of change in the VOF given a corresponding change in resource availability has immense economic implications: the dual values provide measures of opportunity costs for intermediate goods and services such as labor while in the case of final goods, dual values represent the consumer's willingness to pay (Table 8).

In the case of land, the dual value is the value of foregone production if the land were used alternatively. Thus, the VOF is estimated to increase by US$344 and US$294 for every hectare converted into shrimp ponds in Zones C and D, respectively. The ecological functions performed in Zone C resulted in a higher shadow price than Zone D. Results show that each additional hectare of shrimp farm in Zone E, salt flats, would add an average of US$677 to total net benefits notwithstanding the fact that it has already reached suboptimum levels. This is due to the fact that more than 90% of shrimp production is derived from this zone.

The dual values estimated for forestry and fishery products approximate their market prices. The higher shadow prices assigned to fishery products, especially that of shrimp fry, emphasizes the role of the mangrove in the sustenance of coastal marine resources. Another possible justification is that forestry products can be sourced from nonmangrove forests including dipterocarp and hardwood forests; thus, the lower shadow price.

Fry obtained from the wild have a positive shadow price but that obtained from the hatcheries have a zero shadow price indicating that the resource is nonscarce, i.e., the demand is less than the installed capacity.

Results further indicate that packaging and freezing capacity of the aquaculture sector as well as sawmilling capacity in forestry are in excess of demand, i.e., shadow price is zero. Likewise, there is a surplus of available labor in aquaculture, forestry and the artisanal fishery relative to the exploitable resource. Thus, increasing labor supply will not result in any change in the optimal benefits provided by mangrove conversion and/or sustainable exploitation.

Sensitivity Analysis

A sensitivity analysis was conducted to determine the effect of altering vital parameters on the net benefit (Table 9). The base scenario represents the primal problem while the additional seven scenarios considered are based on the following:

1) relaxation of the restriction pertaining to the location of fish farms, particularly, to assess the feasibility of locating in other mangrove zones;

Table 8. Parameter estimates of the dual LP problem for the mangroves of Guayas, Ecuador.

Parameter	Dual value	Unit
Mangrove area, Zone 3	344	US$·ha^{-1}·year^{-1}
Mangrove area, Zone 4	294	"
Shrimps farms, Zone 5	675	"
Avicennia	35	US$·m^{-3}
Rhizophora	15	"
Firewood	50	"
Posts	6	"
Tannin	100	"
Molluscs	2,000	US$·t^{-1}
Crab	4,000	"
Shrimp fry	9,800	"
Shrimps	6,700	"
Fish	2,500	"
Fry sourced from wild	1.72	US$·10^{-3}
Fry destined for hatcheries	0	"
Capital, extensive system	2	US$·10^{6}·year^{-1}
Capital, intensive system	450	"

2) changes in the supply of natural fry as a function of El Niño occurrences;

3) availability of capital for investment in the aquaculture sector. An increase in investment can be interpreted as a technological breakthrough or infusion of foreign investment.

In Scenarios 1 and 2, the area converted to shrimp farms in Zone C was assumed to increase with the additional area being released from Zone F (higher grounds) and from the area originally intended for sustainable management. In both cases, total net benefit is lower than the base situation. In the case of aquaculture, the decline in net income is greater in Scenario 2 due to the additional assumption of a drop in the supply of natural fry. Net income from the forestry sector dropped because of a decrease in exploitable area for red mangroves, and thus, firewood sales, whereas sales of shrimp larvae and of adult shrimp caused the slide in the fishery sector.

In Scenario 3, the increase in naturally supplied fry compensates for the total loss of hatchery fry, resulting in a net income higher than the base situation. Net income from the fishery is likewise improved mainly through higher sales of shrimp larvae. However, an increase in natural fry was not shown to impact on the supply of adult shrimp and that of finfish, in general.

Scenarios 4 and 5 have a strong conservationist bias but nevertheless resulted in net incomes higher than the base situation. Scenarios 4 and 5 assume changes in the siting of shrimp ponds in Zones E and F and with no

Table 9. Sensitivity analysis of primal problem parameter for five scenarios and effects on total net benefits.

	Scenarios					
	Base	1	2	3	4	5
Aquaculture sector						
Zone E conversion (ha·10^3)	5.5	10	7.6	5.5	0	0
Zone F conversion (ha·10^3)	0	0	0	0	0	0
Shrimp farms in salt flats (ha·10^3)	31.2	31.2	31.2	31.2	27.3	31.2
Shrimp farms in hilly grounds (ha·10^3)	12.6	7.5	7.5	12.6	0	6.5
Natural fry (PL·10^9)	3.9	3.9	2.7	4.9	3.8	6.1
Hatchery fry (PL·10^9)	1	1	2	0	2	2
Shrimp production head-on (·10^3)	45.3	45	44	45.3	62.6	86.6
Net income (US$$10^6$·year^{-1})	67.7	62.9	59.9	69.5	103.9	141.4
Sustainable exploitation						
Forestry sector						
Zone 3 conservation (ha·10^3)	54.5	50	52.4	54.5	60	60
Zone 4 conservation (ha·10^3)	65	65	65	65	65	65
Sales of firewood (m^3·10^3)	390.9	358.4	375.5	390.9	430.1	430.1
Sales of posts (m^3·10^3)	367.6	367.6	367.6	367.6	367.6	367.6
Sales of tannin (m^3·10^3)	35.7	35.7	35.7	35.7	35.7	35.7
Net income (US$$10^6$·year^{-1})	18.4	17.3	17.9	18.4	19.7	19.7
Fishery sector						
Sales of molluscs (t·10^3)	1.5	1.5	4.5	1.5	1.5	1.5
Sales of crabs (t·10^3)	2.7	2.7	2.7	2.7	2.7	2.7
Sales of larvae (t·10^3)	5.6	5.6	3.9	8.8	5.6	8.8
Sales of shrimp, head-off (t·10^3)	4.4	4.3	4.3	4.4	4.5	4.5
Sales of fish (t·10^3)	3.4	3.4	3.4	3.4	3.5	3.4
Net income (US$$10^6$·year^{-1})	87.6	87.2	75.1	111.7	88.7	112.2
Net benefit (services, function) (US$$10^6$·year^{-1})	0	0	0	0	0	0
Net benefit mangrove (US$$10^6$·year^{-1})	106	104.4	93	130.1	107.9	132
Total net benefit (US$$10^6$·year^{-1})	173.7	167.3	152.9	199.5	211.7	273.4

conversion in Zones C and D which are mangrove areas. Scenario 4 resulted in a 22% increase in total net benefit, the increase being accounted for by increased production of the aquaculture sector. Scenario 5 resulted in a 57% increase in total net benefit because of the additional assumption of peak production of natural fry. Both scenarios also resulted in an increase in net income from the fishery sector, from sales of larvae and shrimps, albeit to a greater extent for Scenario 5. This confirms the important ecological functions of mangroves and their complex linkages with the entire cycle of shrimp growth and maturation, which also affects production both from trawl fisheries and aquaculture (McPadden 1985; Pauly and Ingles 1988).

Conclusion

In Ecuador, the phenomenal growth of shrimp mariculture has been observed by Meltzoff and LiPuma (1986) to be consistent with the nation's social character and financial environment. The authors point out a tendency for business to value short-term gains to the detriment of the environment which is being viewed as being *"subservient to immediate individual economic objectives"*. Possession of shrimp farms is, furthermore, considered to be a status symbol, in the same way as possessing a *hacienda*. The financial sector complements this with its preference for short-term businesses (fast payback period) with low start-up as well as operating costs (i.e., shrimp ponds).

Preference for short-term gains, especially in relation to conservation, can be perceived as rational given the lack of information, uncertainty and risk involved in long-term investments (including investing in the environment). Furthermore, such behavior is not a distinguishing characteristic of shrimp farmers in Ecuador. When choices between development and conservation have to be made, expressing the resulting options in numbers, preferably in currency terms, permits the decisionmaker to assess short-term gains *vis-à-vis* ecological integrity which minimizes risk, uncertainty and absence of information.

LP is one of several available techniques that enables quantification of total benefits arising from simultaneous use of resources. The LP exercise is useful in three ways: 1) in developing the LP tableau, the resource system, its different components and their interlinkages, is structured and quantified; 2) through the primal and dual solution, benchmarks for decisionmakers are provided; and 3) through sensitivity analysis, alternative environmental and economic scenarios are simulated. In this exercise, we proved the compatibility between economics and ecology by showing that conservationist approaches to mangrove management would result in greater net benefits. More importantly, we have shown how the short-term gains of mangrove conversion to shrimp ponds can be wiped out by severe declines in larval production, its most critical input. This has been done given the interlinkages between ecological parameters specified in the objective function.

Our approach is a form of 'adaptive management' (Holling 1978), which emphasizes variability in time and space boundaries as well as uncertainties. Thus, what others perceive to be rational appears to be a case of misinformed decisionmaking. We have shown through this exercise how it is possible to depict an array of options that span long-term as well as short-term planning horizons and thus, make rational decisions on the basis of perfect information.

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Optimization of Economic Benefits from Fishery and Forestry in Bío-Bío, Chile*

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Abstract

The net economic value of fishery and forestry in Bío-Bío, Chile was estimated with the environment as a third sector accounting for positive and negative externalities.

The main produce of the pelagic fishery is jack mackerel *(Trachurus murphyi)* and is caught mostly by small boats and barges while hake *(Merluccius gayi)* is targetted by purse seines. An average of 95% of fishery production is converted into fishmeal 50% of which is sold to foreign markets. From the forestry sector, the pine *(Pinus radiata)* is transformed into logs for sawmilling and pulp.

Optimum net economic value is estimated at US$1.37 billion·year^{-1} 87% of which is accounted for by the forestry sector. Exports of wood chips from eucalyptus trees as well as logs and other wood products from pine contribute the bulk of earnings of this sector. The fishery sector contributed US$171 million mainly through the exports of fishmeal. However, water pollution caused by fishmeal plants diminished total economic value by at least US$20 million·year^{-1}.

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Description of Study Site

Physical Attributes

LOCATION AND TOPOGRAPHY

Bío-Bío is one of Chile's thirteen political and administrative districts. This region covers a total area of 36,820 km^2 and consists of 49 municipalities including Ñuble, Bío-Bío, Arauco, Talcahuano and Concepcion, the capital. Also included are the islands of Quiriquina, Mocha and Santa Maria (Fig. 1).

The major topographical features of the region include:

1) Andean mountain range: heights reach over 2,000 m, dotted with numerous volcanoes and the snow-capped Mt. Chillán (3,122 m), Antuco (2,985 m) and Callaqui (3,080 m);

2) mountains situated between the intermediate depression and the Andean mountain range;

3) an intermediate depression in the northern part of the region, approximately 100 km latitude from Chillán and rolling plains south of the Bío-Bío River;

4) a coastal range north of the region which weakens to a series of ridges with intermediate catchment areas; to the south of the Bío-Bío River, the coastal range sharply increases to a height of 1,000 m and acquires a wall-like feature, the Nahuelbuta Range;

5) rocky coast to the north of the Bío-Bío River with minor coastal plains; in contrast, south of the river is the smooth Arauco-Cañete plain with an average width of 25 km;

6) continental shelf: contiguous and parallel to the coast extending 70 km towards the Tumbes peninsula and from Concepcion, decreasing to 40 km towards Arauco; and

7) continental slope: the zone arising from the continental trench up to the continental shelf.

The coastal zone includes the 49 municipalities in Fig. 1, the coastal cordilleras, the littoral plains, the Bío-Bío estuarine system and the coastal system of the Arauco Gulf and the Bay of San Vicente. The Bío-Bío estuary is a brackish interphase between the river system and the Arauco Gulf. Parallel to the Bío-Bío estuarine system is the Bay of San Vicente/Arauco Gulf system, characterized by the influx of equatorial waters during spring and summer.

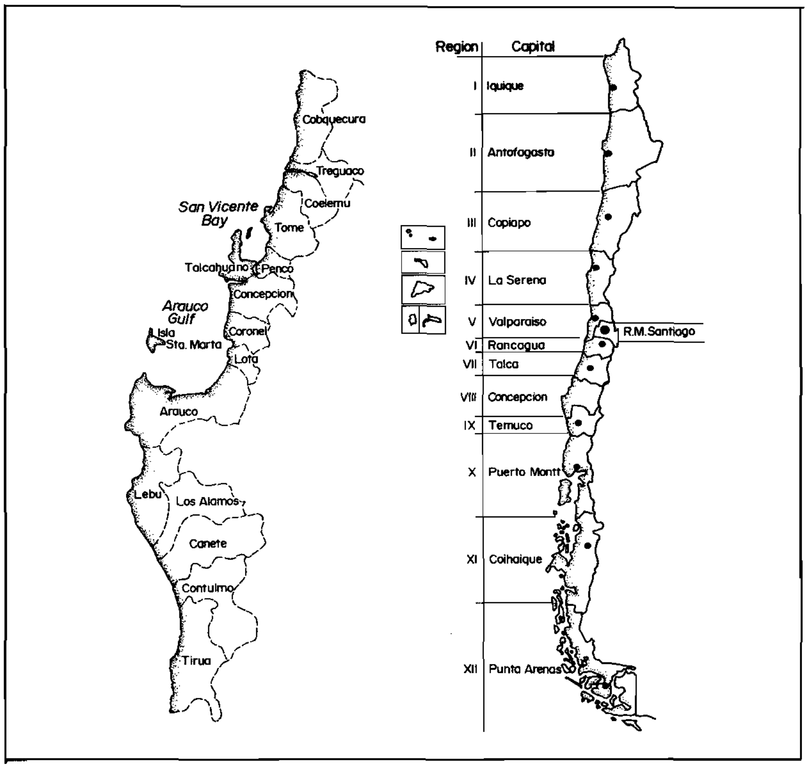

Fig. 1. The Chilean coastline and location of Region VIII, Bío-Bío (left), and the coastal municipalities bordering Arauco Gulf and Bay of San Vicente (right).

HYDROGRAPHY

The region's hydrographic network is shaped by both the Andean range and river systems. The Andean rivers, namely, the Bío-Bío, Ñuble, and Laja, originate from the internal areas of the Andean mountain range, i.e, from the melting of snow which results in a larger volume during the end of spring. The nonAndean rivers, the Chillán, Diguillín, Cholguán, Itata, Duqueco and Mulchén, originate from the western sectors of the mountain range; water supply comes from both rain and snow. Thus, the flow of water is as high in summer as in spring.

The Bío-Bío River is one of the largest in Chile draining an area of 24,000 km^2 at a flow rate of 900 m^3·second^{-1}. Its principal tributaries are the Vergara, Laja, Malleco, Rahue, Ranquil, Queco, Duqueco and Bureo rivers. The Itata River drains an area of 11,500 km^2 with a flow rate of 140 m^3·second^{-1}. Its major tributaries are the Ñuble, Cato, Chillán, Palpal, Diguillín and Larqui rivers.

CLIMATE AND OCEANIC CURRENTS

Regional climate ranges from wintry rains to prolonged dry seasons, the latter ranging from seven to eight months. The coastal cordillera acts as a climatic barrier affecting temperature and distribution of rainfall. Offshore, the Humboldt Current (Fig. 2) transports cold and low salinity waters laden with nutrients from the subantarctic region. Also, water is upwelled from the deepest zones replacing warmer and nutrient-deficient shallow waters. Nutrient enrichment processes contribute to a high primary (phytoplankton) production and thus, to large stocks of fish.

Social and Economic Attributes

POPULATION CHARACTERISTICS

Region VIII is the second most populated region of the country with estimates for 1990 at 1.7 million, about 13% of Chile's total population. Densely populated cities include Concepcion (48%), Ñuble (25%) and Bío-Bío (19%). Population density is 45 persons·km^{-2} at the regional level with variation between towns, i.e., Concepcion (231 persons·km^{-2}) and Bío-Bío (20 persons·km^{-2}). Regional population growth is 1.1%, less than the national average of 1.6%. Almost 80% of the region's population live in urban areas.

INCOME AND EMPLOYMENT

The regional contribution to GDP was 9% to 10% in the last decade. Manufacturing accounted for an average of 33% of regional GDP (1985-89), while the forestry sector ranked second, at 13%.

The labor force in Region VIII reached 600,000 persons in 1990 or 12.8% of the national labor force. Of the total, 568,000 people were fully employed. Among the productive sectors, agriculture, fisheries and forestry contributed 23%; services, 23%; industry, 17.8%; and commerce, 16%. The growth in employment in the region, which is 5.8% is greater than the national average of 4.7%.

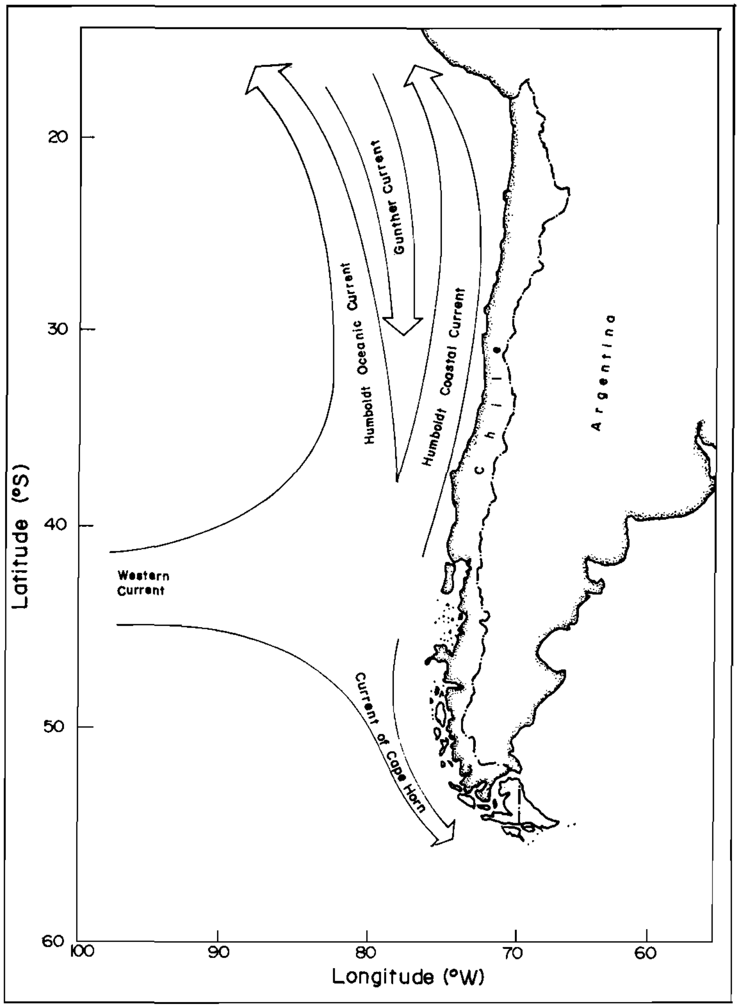

Fig. 2. Oceanic currents influencing Chile's coast.

The fishery sector employs over 25,000 persons with the artisanal sector accounting for about 15,000 fishers. Of major significance is the industrial fishery, which employs 10,000 persons, 60% of whom are employed at fishmeal plants. The region contributes 50% of employment in the forestry sector with the following breakdown: 57%, plantation and silviculture; 39%, industrial forestry; and 62%, forestry services.

INFRASTRUCTURE

The transport system of Region VIII consists of road networks, railways, ports and airports. The regional road network is constructed along the longitude of the Central Depression with connections to the coast, particularly in the city of Concepcion, and the Andean range. The main highway is the Carretera Panamericana which runs from north to south and cuts through the cities of Chillán and Los Angeles. The coastal road network covers a length of 313 km and cuts through the cities of Quirihue and Tirúa. Road networks branch out from the main highway, connecting the towns of Bulnes and Chaimávida, and Cabrero and Chaimávida.

The railway system covers 795 km, 200 km of which belong to the central railways and the remaining, the minor lines. Most of the railway traffic is directed towards Concepcion. In 1990, 3 million t of cargo were transported via the railway system with 60% being accounted for by wood and wood products. The other commodities include salt and sugar, imported wheat, fertilizers, cement and petrochemicals.

The major ports in the province are likewise concentrated in Concepcion. Among the more important ones are Puerto de San Vicente, which handles about 1.04 million t·year^{-1} of wood products; Lirquen, which is a private port; and Muelle CAP which has a combined capacity of 2.5 million t·year^{-1}. The latter's northern sector caters to bulk cargo handling while the southern sector is presently plagued with idle capacity because of the weak steel market.

The region has three important airports: Carriel Sur in Concepcion; Mara Dolores in Los Angeles; and Bernardo O'Higgins in Chillán. There are also 20 small airfields scattered in the coast and in the cordilleras.

SOCIAL ISSUES

Region VIII experiences more acute social problems than the other regions of Chile. According to CEPAL (1990), 46% of the regional population earn incomes insufficient to meet basic needs, 18% are indigents, and 25% are below poverty levels. The largest proportion of the poor population is found in urban areas. About 47% of the population live in poverty in the cities but indigence is relatively greater in the rural areas. This is manifested in low income levels while indigence, in addition to the former, is characterized by a dearth in infrastructure and basic services.

Natural Resources Endowment, Usage and Impacts in the Coastal Zone

Three decades prior to 1975, economic growth of the region was oriented towards import substitution. The emphasis was on the production of basic metals, chemicals and food. In the 1980s, there was a shift towards the exploitation of natural resources such as fish stocks and forests. This steered economic development towards the export market, particularly that of wood products and fishmeal. The trend in natural resource dependency, particularly in the coastal zone, is depicted in Fig. 3. Note that the economic activities use coastal and marine resources as raw materials for further processing or for waste deposition from the interior areas where human settlements and other economic activities abound.

The environs of the Bay of San Vicente provide excellent examples of multipurpose resources. The Bay is the site of a major port area, catering to both the industrial fishing industry as well as to commercial and passenger cargo, fishmeal plants, iron and steel plants and chemical plants. Tourist beaches are found in Lenga, Ramuntcho and Recoto while small fishing communities are in the coastal towns of San Vicente and Lenga. The other economic activities in the area include: artisanal and industrial fishing, industrial wood plants (Cia. Chilena de Astillas in Schwager and ASTEX in Colcura), mines (Cia. Carbonifera in Schwager and ENACAR in Puerto Lota), beaches in Playa Blanca, Colcura, Chivilingo and Laraquete, and sawmills and thermoelectric plants in Puerto Coronel.

Artisanal fishing communities and tourist beaches are scattered over the Arauco coastline in the towns of Arauco, Llico, Tubul and Punta Lavapie. The town of Arauco is the site of forest plantations and related industries, i.e., Forestal Arauco, Forestal Carampangue and Celulosa Arauco y Constitucion.

Fisheries

Fishery resource distribution in Chile is heterogenous due to the wide range of environmental conditions that determine productivity. The waters of Region VIII, especially in the Gulf of Arauco, support the highest catches; the total landings of marine resources reached 3.2 million t in 1991 representing 53% of the national landings.

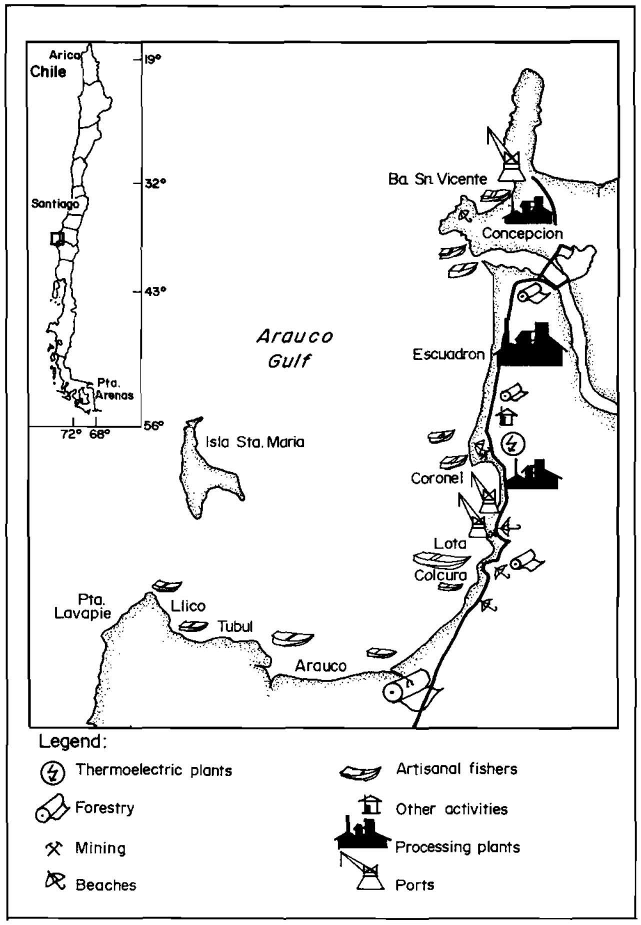

Fig. 3. The coastal area of Region VIII, Bío-Bío, Chile and the various resource-dependent economic activities situated here.

The marine species of commercial importance number about 125 (IFOP 1988), 64 of which are captured in Region VIII and which include fish (34), molluscs (12), crustaceans (9), algae (7) and echinoderms (1) (see Annex 1 for a complete list). The bulk of regional landings consists of fish species which include *Trachurus murphyii* (Chilean jack mackerel; local name, *jurel*), *Sardinops sagax* (South American pilchard; local name, *sardina española*), and *Engraulis ringens* (Peruvian anchovy; local name, *anchoveta*).

Fig. 4 depicts the historical trend in the total landings of important pelagic species in the Talcahuano area. Note the sharp increase in jack mackerel landings beginning in the 1970s against the drop in sardines and anchoveta. Presently, the fisheries deemed fully exploited include jack mackerel among the pelagics, and hake and lobsters among the demersals.

On average, 95% of the total fish catch are processed into fishmeal while the rest is processed into canned and frozen fish; molluscs are mostly canned while crustaceans are marketed in frozen form (Table 1).

TYPES OF FISHERIES

Four types of fisheries operate in the region: 1) the pelagic fishery for which the major species include the jack mackerel, the South American pilchard, and *Clupea bentincki* Araucanian herring (local name, *sardina común*); these stocks are mainly exploited by the purse seine fleet; 2) the demersal fishery which includes the following species: *Merluccius gayi* hake *(merluza común), Genypterus maculatus* black cusk-eel *(congrio negro)* and *Dissostichus eleginoides* Patagonian toothfish *(bacalao de profundidad)*; these stocks are mainly exploited by the trawler fleet; 3) the crustaceans which are likewise exploited by the trawler fleet with major species including the lobsters, *Pleuroncodes monodon* red squat lobster *(langostino colorado)* and *Cervimunida johni* yellow lobster *(langostino amarillo)* and shrimps, *Heterocarpus reedi* Chilean nylon shrimp *(Camarón nailon)*; and 4) the benthic fishery which is an artisanal one and which exploits the molluscs *Gari solida (culengue), Ensis macha* (*huepo*) and *Tagelus dombeii* (*navajuela*).

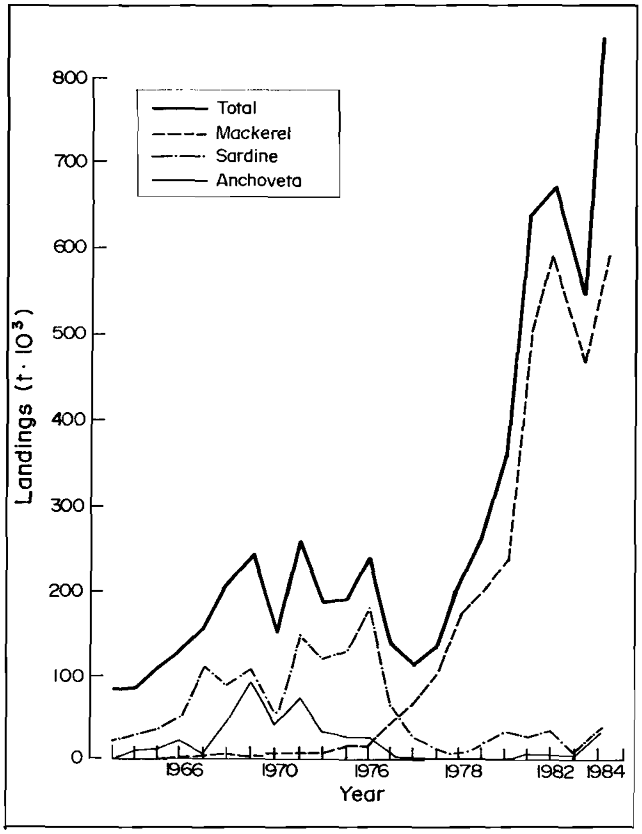

Fig. 4. Landings of major pelagic species in the Talcahuano area, 1963-1984.

Table 1. Utilization of catch in Region VIII, Chile, 1991, in tonnes.

	Type of resource			
Product type	Fish	Molluscs	Crustaceans	Others
Fresh	1,027	19	-	-
Frozen	57,694	830	1,112	534
Salted/dried	3,582	-	-	65
Smoked	34	-	-	-
Canned	119,791	3,439	-	-
Fish meal	3,010,812	-	-	-
Dehydrated	-	-	-	413
Total	3,192,940	4,288	1,112	1,012

Fig. 5 shows the location and distribution of three important pelagic species: the Peruvian anchovy; Spanish sardines; and jack mackerel. The distribution of mackerel extends from the Galápagos Islands in Ecuador to the Straits of Magallanes (IFOP 1988). It extends lengthwise to around 1500 miles in the Chilean coast and corresponds to a total area of 1 million square miles (IFOP 1988). The depth distribution is to 300 m in the south, but closer to the shore, where the upwelling is more pronounced, the depth is between 20 and 60 m. The distribution of the common sardine is from Coquimbo up to Isla Mocha and possibly extending to Chiloé to a depth of 50 m.

The fishery in Region VIII can be classified into artisanal and industrial subsectors. Artisanal fishing is defined by the General Law of Fishery and Aquaculture as conducted within 5 miles from the coastline while the industrial fishery goes beyond this limit, extending to the territorial seas and the EEZ. The industrial fishery also includes the harvesting of fish and/or the processing of such into finished products.

Region VIII contributes, on the average, half of the catches of the artisanal and industrial sectors (Table 2). Anchoveta and jack mackerel are the most important species caught by the artisanal and industrial fishery, respectively. The high volume of fish landings in the artisanal sector, roughly 64% of national fish catch levels, and the proliferation of fishing communities along the coast, prove the enormous social and economic impact of fisheries in the region. During the explosive growth period of 1980-90, average landings

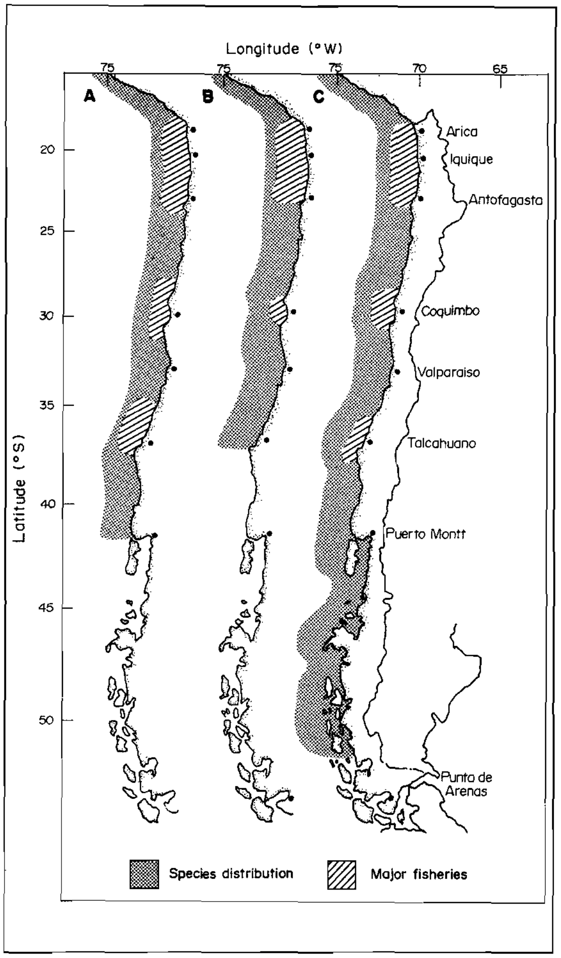

Fig. 5. Distribution of anchoveta (A), sardines (B) and jack mackerel (C) along the Chilean coast, and location of the main fisheries.

Table 2. National and regional landings of the artisanal and industrial fishery (in tonnes) by major species, and production of the industrial fishery, by product type, 1989.

Species	Artisanal		Industrial	
	National	Regional	National	Regional
Fish				
Peruvian anchovy	183,315	152,840	1,504,039	84,226
Araucanian herring	53,171	46,899	106,479	106,454
Chilean jack mackerel	16,879	10,235	2,372,982	1,751,486
Hake	10,909	3,276	-	-
Patagonian grenadier	2,744	2,676	207,209	207,157
South American pilchard	-	-	1,564,674	28,437
Others	86,838	12,371	99,950	33,544
Molluscs				
Snails	1,298	629	-	-
Cockle	1,557	466	-	-
Clam	33,367	373	-	-
Mussels	8,763	284	-	-
Others	65,489	573	-	-
Crustaceans				
Shrimps	-	-	5,575	1,196
Crab	3,288	453	-	-
Conch	1,193	328	-	-
Prawns	-	-	573	573
Algae	178,480	24,036	-	-
Other species	28,887	1,110	4,541	1,769
Product type				
Fishmeal	-	-	1,377,796	515,066
Oil	-	-	260,078	117,147
Canned	-	-	53,970	25,949
Frozen	-	-	57,236	12,472
Total	676,178	256,501	7,615,102	2,883,707

of the artisanal sector increased from 33 t to 151 t but this is nevertheless a minor percentage relative to the growth in the industrial sector.

Artisanal. Artisanal fishing communities are distributed along the coast of the Bay of San Vicente but most especially along the Gulf of Arauco due to the diversity of marine resources landed here. The major fishing towns are Concepcion, San Vicente and Coliumo, Gulf of Arauco, Santa Maria Island and between Lebu and Isla Mocha (Fig. 6). Boats usually fish within 5 km from the coastline reaching a maximum of 100 km depending on the kind of boat and on the species targetted.

The artisanal fleet is comprised of two types of fishing vessels: boats and barges. Boats are generally made of wood with a length of 10 m or less and without crew cabins. The mode of propulsion may either be inboard motor, outboard motor or oar. Crew size is usually 2 to 4 people. The gears often used include gill nets, trammel nets, longlines, compressed air diving and traps.

Barges are longer than 10 m, and generally have crew cabins and wheelhouses, with an inboard motor and a crew of 4 to 10 people. Barges use mechanized equipment such as sonar and radar. The gears usually used are longlines, gill nets and trammel nets. The fish targetted by artisanal vessels are shown in Table 3. Barges account for 89% of the catches of large pelagics and offshore demersals while the smaller boats (both mechanized and nonmechanized) target coastal demersals such as hake and grouper. A characterization of the artisanal capture fishery according to target

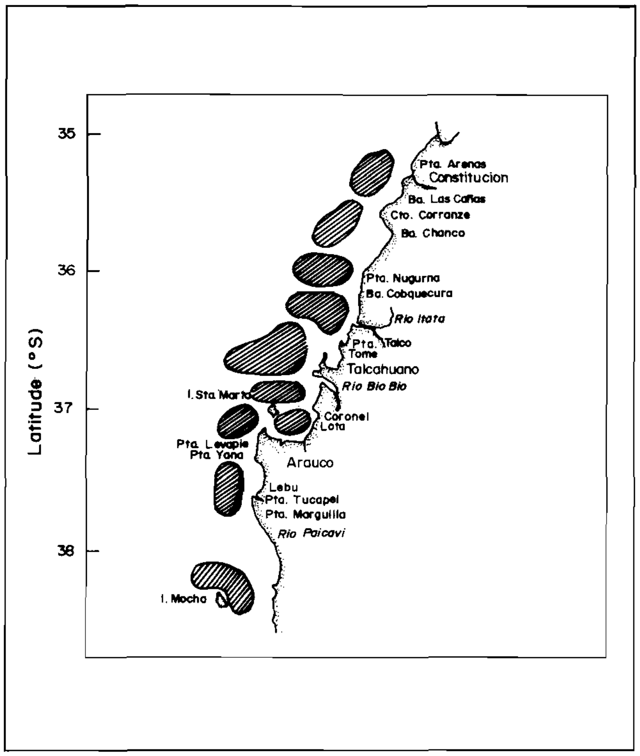

Fig. 6. Location of the artisanal fishing communities in the Bay of San Vicente and Gulf of Arauco area, Chile.

Table 3. Type and number of artisanal fishing crafts and target species in the Bay of San Vicente, Concepcion, Chile.

Target species	Barge	Motor boat	Sail boat
Large pelagics and offshore demersals (albacore, deepsea cod, golden eel)	39	-	-
Small pelagics (Spanish sardine, common sardine, anchovy, Chilean jack mackerel)	3	-	-
Medium pelagics (grunt, chub mackerel, bonito, eel, bream)	2	5	1
Benthic invertebrates (squids, snails, mussels, crabs)	-	17	8
Coastal demersals (hake, grouper)	-	43	19
Other coastal resources (algae, redfish, silversides)	-	4	7

species, vessel, engine, equipment and gear as well as average fishing distance is presented in Table 4.

Artisanal vessels (boats and barges) operate along the entire coastline of the Gulf of Arauco (Table 5). The communities of San Vicente and Lo Rojas have the largest number of vessels, with barges and sail-powered boats accounting for the largest share. Medium-size vessels (boats with inboard and outboard motors) are more prevalent in the communities of Tubul and Laraquete.

Fish landed at the ports of San Vicente and Lota are consumed fresh by the adjacent communities while those landed at the port of Coronel are used as inputs for fishmeal factories in the area. A small percentage of the fishery catch is processed, i.e., smoked, dried/salted or salted.

Industrial. The industrial fishery consists of two major components: capture fishery and processing. The capture fishery is conducted in various fishing grounds depending on the fleet and on the target species. On the average, the trawler fleet reaches a distance of 20 to 25 km from the coast while the purse seine fleet operates from Isla Mocha up to San Antonio and further up to a distance of 130 km.

Target species include the hake, black cusk-eel and Patagonian toothfish. Jack mackerel landings of the industrial sector account for 94 to 96% of the total volume of landings at the national level with the region contributing 38% to the total.

The industrial fishery uses fishing vessels of weight greater than 50 GT and includes purse seiners and trawlers. Gears used and operational regimes vary according to targetted resources (Table 6).

Industrial processing consists of the reduction of fish into meal and/or oil, canned and frozen fish. In 1989, the country produced 1.8 million t of fish products, 77% of which was fishmeal. Region VIII accounts for an average of 38% of total fishmeal production (Table 2). Major species processed as fishmeal include Chilean jack mackerel, sardines and anchovies. These species are also canned in addition to molluscs.

Most of the fishmeal factories are found in the landing centers of the industrial fleet including the ports of Talcahuano (27), San Vicente (6), Coronel (8) and Tomé (1), where most of the fishmeal factories are found (Table 7). Table 8 shows pertinent characteristics of fish processing activities in the region.

Forestry

Due to favorable environmental conditions, Region VIII is basically a forestal region with over 41% of its

Table 4. Characteristics of the artisanal capture fishery by type of species and utilization of capital and technology.

	Species	Fishing vessel Type	Useful Length (meters)	Engine HP life (years)	Useful life (years)	Equipment Type	Useful life (years)		Fishing gear Type	Useful life (years)	Fishing distance (miles)
1.	Anchoveta, sardine	Barge with inboard engine: wooden hull	12-18	20	≤120	15	Echosounder, winch	5	Encircling net	5	5-6
2.	Deepsea cod	Barge with inboard engine: wooden hull	12-18	20	140-200	15	Echosounder	5	"Espinel"	5	25-30
3.	Swordfish	Barge with inboard engine: wooden hull	12-18	20	200-250	15	Echosounder, sonar	5	Albacore net	5	40-70
4.	Merluza	Barge with inboard engine	7-12	15-30	50-80	10	Little equipment		"Espinel"	5	2-7
5.	Shellfish	Sailboat	≤7	8-10	25-40	5	-	-	-	1	
6.	Algae	Boats with outboard motors	≤7	10-15	25-40	5	Compressor, diving equipment	10/5	-	≤1	

Table 5. Vessels used by the artisanal fishing fleet, per locality, 1990.

Locality	Barges	Boats Inboard motor	Outboard motor	Sail	Total
San Vicente	86	14	47	59	206
Lenga		26	49	75	
Boca Sur				16	16
Maule			14	14	
Lo Rojas	53[1]	48	3	77	181
Pueblo H.			1	17	18
El Morro	1		2	10	13
La Conchilla			1	4	5
El Blanco			7	18	25
Lota	25	20	4	49	98
Colcura				15	15
Laraquete			25	25	50
Arauco			9	11	20
Tubul[2]			26	49	75
Llico	1	2	19	8	30
Punta Lavapie	4	10	70	34	118

[1]Twenty-one vessels land in Lo Rojas; the remaining vessels, in Coronel.
[2]Also includes Las Peñas.

Table 6. Characteristics of the industrial capture fishery, by target species.

Resources	Fishing vessel: Hold capacity (m^3)	Length (m)	Useful life (years)	Engine (hp)	Gear type	Operation: Days	Hours·day^{-1}	Product type
1. Mackerel, with hake, Spanish sardines, anchoveta, common sardine	≤350	30-40	30	≤1,200	Purse seine	2-5	16	Fishmeal; canned; frozen
	600	41-60	30	≤1,800	Purse seine	2-5	16	Fresh
	≤1,200	61-70	30	≤2,800	Purse seine	2-5	16	
2. Hake, with black and gold conger, breams, elephant fishes	150	20-30	30	375	Trawler	2-4	12	Frozen
	350	30-40	30	1,200	Trawler	2-5	16	Fresh
3. Shrimp	100	20-30	30	375	Trawler	2-3	-	Frozen

Table 7. Number and location of fish processing plants in Region VIII, Concepcion, Chile, per product line.

Location	Fishmeal	Frozen	Canned	Dried/salted	Smoked
Tomé	1	1	1	-	-
Talcahuano	8	14	16	3	1
San Vicente	6	2	2	1	-
Coronel	5	3	2	-	-
Total	20	20	11	4	1

Table 8. Important characteristics of industrial fish processing.

Product	Production rate (t·hour^{-1})	Reduction rate (%)	Equipment	Market (%)
1. Fishmeal and oil (Type A)	50	20 4.5	Boilers, press, mill drier	Domestic (20) Export (80)
2. Fishmeal (B and C) Oil (Type B)	100	23 6	Boilers, press, mill drier	Domestic (20) Export (80)
3. Fishmeal (C) Oil (C)	100	23 6	Boilers, press	Domestic (10) Export (90)
4. Canned (jars)	6,000	30	Boiler Pressure cooker	Domestic (25) Export (75)
5. Frozen	5	30	Freezing chamber	Export (100)

Notes: Types of fishmeal and oil vary according to quality with Type A having the lowest quality, etc.

area comprising native (400,000 ha) and plantation forests (600,000 ha). Table 9 shows the contribution of primary and plantation forests to total forest area and the areal coverage of Region VIII. A listing of native forest species in Chile and that of Region VIII is provided in Annex 2.

The expansion of forest plantations have been tremendous between 1965 and 1986 (Figs. 7 and 8) with the increase in area along the coastline. The forestry sector posted a robust economic growth in the last decade with contribution to GDP averaging 3% and to exports, 9.4%.

Forest resources are used for two purposes: 1) the export of logs and 2) the use of these primary materials as inputs for further processing. Wood processing, on the other hand, is classified into two ways: 1) processes which do not alter the basic structure of the raw material, i.e., logs, chips, lumber, boards; and 2) those that undergo chemical processes, i.e., cellulose and its derivatives.

The forestry sector employs approximately 83,000 workers, 50% of which come from Region VIII. Of the total regional employment, 48% is involved in silviculture and harvesting activities, 43% in industrial forestry and the rest in related forestry services.

Table 9. Forestry resources of Chile and Region VIII, area covered and production.

Resource	National		Region VIII		Regional contribution to total (%)
	Area (ha)	Volume ($m^3 \cdot 10^6$)	Area (ha)	Volume ($m^3 \cdot 10^6$)	
Primary forest	7,616,500	915.1	401,700	24.1	5.3
Plantation	1,386,444	177.6	592,355		42.7
P. radiata	1,192,287	144.1	560,448	78.1	47.0
Eucalyptus	81,773		31,840		38.9
Others	112,384	33.5	67		0.1
Total	10,389,388	1,270.3	1,586,410	102.2	-

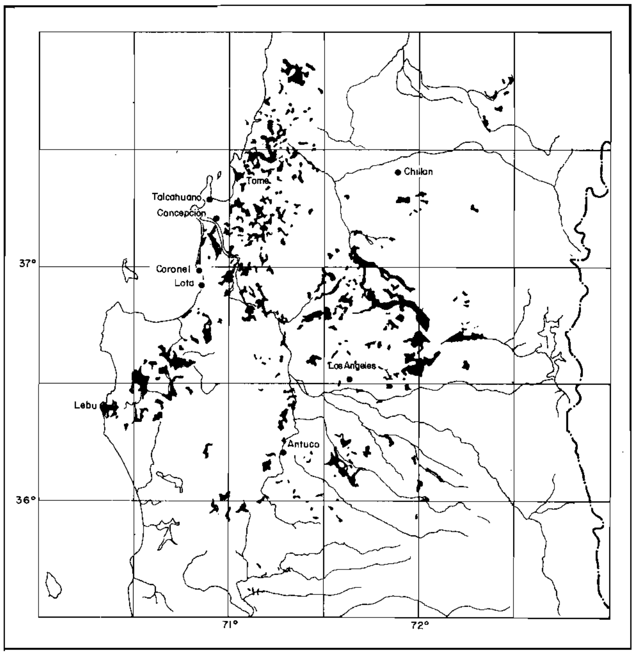

Fig. 7. Forest plantation in Bío-Bío region, Chile, 1965.

FOREST RESOURCES: NATIVE AND PLANTATION SPECIES

Two types of plantation species are cultivated in the region: the pine *Pinus radiata (pino radiata)* and eucalyptus *Eucalyptus globulus, E. camaldulensis* and *E. viminalis*. The pine is of major importance in terms of area planted and volume exploited. It represents 85% of total forest plantation in Chile and 90% in Region VIII.

All eucalyptus plantations in Chile use the species *E. globulus* while the other two species are used in marginal areas as windbreakers. Regional coverage of eucalyptus is about 64,000 ha, 4.5% of the plantation area in Chile.

Among the native forest species in Region VIII, the more significant ones in terms of area planted and volume are those of the genus *Nothofagus*, i.e., *Nothofagus obliqua, N. dombeyi* and *N. alpina*. Characteristics of important forest species are provided in Table 10.

PRODUCTION DYNAMICS

Forestry activities include all work relating to the use of forest resources. Two phases are considered in this paper: 1) the initial phase including subactivities such as nursery, plantations (forestation and reforestation), silviculture, and harvesting; and 2) the processing phase or what is referred to here as industrial forestry.

Forest nurseries or forest reserves are land areas alloted to the growing of plant seedlings, which, once adequate growth has been attained, are transported to designated places of planting. There were 120 nurseries identified in 1989 contributing 50.6% to national seedling production with shares of pine and eucalyptus reaching 47.9% and 60%, respectively.

Two main processes are of interest in the harvesting stage: felling and hauling. Felling involves the processes of rotating, cutting, chopping, thinning and trimming. The most common tools are the motor-saw, arch-saw, bent-saw and ax. Hauling is the process of transporting felled trees to a storage area such as a lake or to a

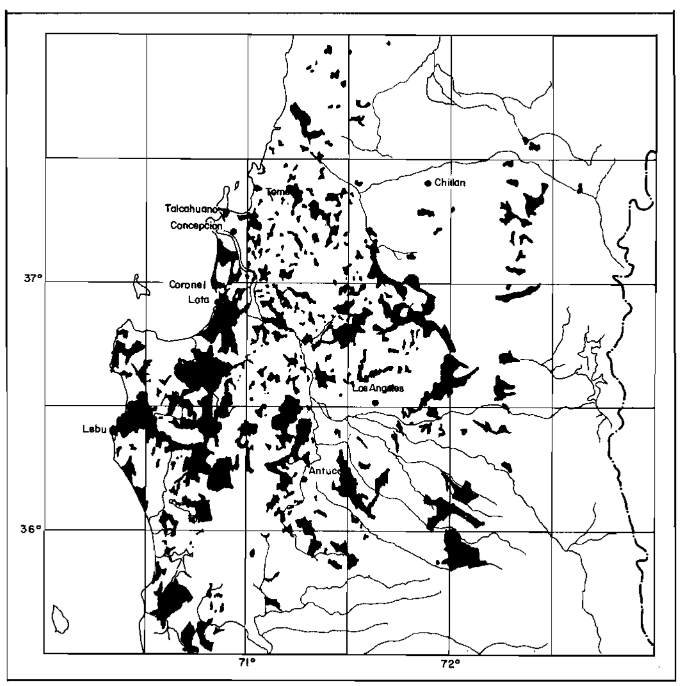

Fig. 8. Forest plantation in Bío-Bío region, Chile, 1986.

Table 10. Characteristics of important forest species in Region VIII, Chile.

English common name	Scientific name	Spanish common name	Maximum height/width	Origin	Occurrence in Chile
Plantation species					
Pine	*Pinus radiata*	*Pino*	40 m / 90 cm	California	All regions
Eucalyptus	*Eucalyptus globulus*	*Eucalypto*	40 m / 1 m	Australia	Coastal areas and central plains
Native species					
Rauli beech	*Nothofagus alpina*	*Rauli*	40 m / 2 m	Endemic	Regions VII to X
Coigue	*Nothofagus dombeyi*	*Coihue*	40 m / 2.5 m	Endemic	Regions VI to XI; very common; found around lakes and rivers

processing line. The simplest form of hauling is done using oxen while the mechanized forms include forest tractors and logging turrets.

The regional contribution of the industrial forestry sector is the most important in the country with cellulose and paper production contributing 77% to national production; lumber, 55%; and fiberboard, 100%.

Industrial forestry can be divided into two categories: 1) that which manufactures wood without altering its structure (chips, pulpwood, logs, sawable wood, serrated wood, etc.); and 2) that which applies chemical processes in the wood for the extraction of cellulose and its derivatives. Regional production for both categories is shown in Table 11 and general descriptions follow.

Sawmilling. The pine *Pinus radiata* is the main species used in sawmilling. The sawmilling industry in Chile is highly heterogenous in terms of scale of operations, technology, products and yield. Sawmills can be classified as either mechanized, nonmechanized, and/or temporary. Mechanized sawmills attain an average production of 50,000 $m^3 \cdot year^{-3}$ and utilize sophisticated technology. Temporary sawmills use old machineries which are manually operated; average annual production is 10,000 m^3. In the intermediate are the traditional nonmechanized sawmills with average production ranging from 10,000 to 50,000 $m^3 \cdot year^{-1}$.

The yield of sawmills depend on a host of factors such as: the state of mechanization, i.e., (type of saws, chipping machines, etc.); the system of felling; and the state of raw material. Sawdust is a by-product of sawed timber and commands the lowest price in the market; thus, the efficiency of sawmilling is gauged by the production of sawdust which should be kept at a minimum.

Table 11. Production of forestry sector in Region VIII.

Product	1989 ($m^3 \cdot 10^3$)
Category 1	
Wood pulp	2,465.3
Logs	2,172.3
Wood chips	3,766.6
Lumber	1,230.2
Sawdust	1,040.9
Others	771.5
Category 2	
Cellulose	435.9
Newsprint	155.9
Others	80.1

Boards and plywood industry. The particleboard industry is formed by four factories, two of which are located in Region VIII. Both belong to the Wood and Synthethic Enterprises S.A. (MASISA). These are: Wood and Panel Plant S.A. (MAPAL), in Concepcion, and the MASISA plant in Chiguayante. MAPAL is known to be a very efficient producer, even on the national level, with an average input of 2.45 m^3/board ton. MASISA Chiguayante ranks next with average input of 3.03 m^3/board ton.

Only one fiberboard factory exists in the whole country: Pressed Woods CHOLGUAN S.A., which is located in the Yungay commune. The products of CHOLGUAN factory fall under the distinctly hard fiberboard classification, with a density of 1 $t \cdot m^{-3}$.

Table 12. Names and important characteristics of wood chip centers in Region VIII, Bío-Bío, Chile.

Establishment	Technology	Annual production (m^3)	Species	Market
Asseradero San Lorenzo	Drum	10,000-50,000	Pine	Export
Aserradero Copihue	Disc	10,000-50,000	Pine	Export
Astillas Exportaciones	Disc	> 100,000	Pine, eucalyptus native species	Export
Astillas J.C.E. Ltda.	Blade	10,000-50,000	Native species	-
Bosques Arauco S.A.	Disc	10,000-50,000	Pine	Domestic
Cia. Astillas Concepcion	Disc	> 100,000	Eucalyptus and native species	Export
Cia. Chilena Astillas	Disc	> 100,000	Eucalyptus and native species	Export
Forestal Coronel S.A.	Disc	50,000-100,000	Native species	Export
Gonzalez Huepe Maria E.	Blade	< 10,000	Eucalyptus and native species	Export

Table 13. Paper and cellulose plants in Region VIII, Bío-Bío, Chile and selected characteristics.

Firm	Species used	Annual production (t)	Market orientation	Final product
Celulosa Arauco y Constitución				
Planta Arauco I	*Pino radiata*	150,000-200,000	Export	Kraft cellulose
Planta Arauco II	*Pino radiata*	> 300,000	Export	Kraft cellulose
Celulosa del Pacifico				
Planta Mininco	*Pino radiata*	> 300,000	Export	Kraft cellulose
Companía Manufacturer de Papeles y Cartones				
Planta Laja	*Pino radiata* *Eucalipto*	> 300,000	Export	Kraft cellulose, printing paper, packing paper
Forestal e Industrial Sta. Fe S.A.				
Planta Nacimiento	*Eucalipto*	200,000-250,000	Domestic and export	Kraft cellulose, white paper
Industrias Forestales				
Planta Nacimiento	*Pino radiata*	100,000-150,000	Export	Mechanical pulp, newsprint
Papeles Bío-Bío S.A.				
Planta San Pedro	*Pino radiata*	100,000-150,000	Domestic and export	

The veneer and nonveneer industry is composed of six enterprises, of which one is found in Region VIII, the Agricultural and Forestal Society COLCURA in Lota. The veneer industry utilizes, except for the eucalyptus species *Eucalyptus globulus*, only indigenous species. The installed capacity of the COLCURA plant is 450,000 $m^3 \cdot year^{-1}$ of veneer.

Wood chips. Nine firms produce wood chips in the region. All factories use stationary equipment but different technologies, level of production, species used and market (Table 12).

Cellulose and paper. The industry consists of six enterprises which operate seven plants in the region. Table 13 lists these enterprises, their annual production, species used and final product.

Tourist Resources

Region VIII offers a diverse range of tourist attractions: urban centers, rivers, snow-capped mountains, hot springs, industrial parks, beaches and ports, and sites of historical and cultural importance. The benefits produced by the tourism sector include foreign exchange generation, savings (via "invisible export" of native products) and employment generation, all of which contribute significantly to regional and national development. The tourism industry, however, contributes minimally to regional income and employment, the latter averaging no more than 0.5%. This potential is threatened by pollution from industry, mainly from fishmeal plants and cellulose and paper factories.

The tourist attractions can be classified geographically as:

1) Andean zone

The principal resources include hot springs, volcanoes, snow slopes and fishing but there is no large-scale development except those with foreign tourist appeal. The main tourist attractions are the ski center and hot springs of Chillán. The ski center is complete with skiing equipment, a hotel, as well as five open-air and naturally heated pools. Of secondary importance is the Antuco tourist complex which is situated at the foot of the Antuco volcano which is inside the Laja Lake National Park. Site facilities include cablecars, restaurants, bars and ski equipment.

2) Coastal range

The most prominent attractions are the beaches to the north of Penco and to the south of the Bay of San Vicente. Among the beaches identified, less than half can be reached by public transport while most beaches do not have facilities such as hotels and restaurants (Table 14). Also of major importance is the Concepcion metropolis which is considered a historical, cultural, folkloric and gastronomic center and boasts of major infrastructure including hotels and transportation facilities.

3) Araucanian route

The most important tourist attraction in the region based on the number of visitors are its beaches, notably the Playa Blanca, and the beaches at Chivilingo and Laraquete. Tourism services such as hotels, inns and camping sites, are most prevalent in Concepcion and Ñuble. Tourism activities peak during spring (January and February) and winter (July and August). Domestic tourists come mainly from the Santiago area whereas foreign tourists come from the United States, Germany and several Asian countries.

Externalities

The environmental problems of the region are reflective of the diverse economic activities and natural resource use in the area (Tables 15 and 16). The Bay of San Vicente is the site of petrochemical plants, fishmeal plants, cement plants, iron and steel mills,

Table 14. Location and characteristics of beaches in the coastal zone of Region VIII.

Beach	Town	Transport	Facilities	Activities
Lenga	Talcahuano	Private	None	Recreation/swimming
Ramuntcho and Recoto	Talcahuano	Private	None	Recreation/fishing
Desembocadura	Talcahuano	Private	None	Recreation/fishing
Las Escaleras	Talcahuano	Private	None	Recreation/fishing
Escuadron	Coronel	Private	None	Recreation/fishing
Playa Blanca	Coronel	Public	Restaurants	Recreation/swimming
Colcura	Lota	Public	None	Recreation/swimming
Chivilingo	Lota	Public	None	Recreation/swimming/fishing
Laraquete	Arauco	Public	Hotels and restaurants	Recreation/swimming/fishing
Arauco	Arauco	Public	Hotels	Recreation/swimming/fishing
Llico	Arauco	Private	None	Recreation/swimming/fishing
Tubul	Arauco	Private	None	Recreation/swimming/fishing
Punta Lavapie	Arauco	Private	None	Recreation/fishing

Table 15. Principal contaminants originating from liquid effluents in Concepcion Bay.

Pollutant source	Production system	Product	Treatment	Principal contaminants
Tomé	Slaughterhouse	Cut meat	None	Water with blood, grease, excrements
	Textile industry	Spun cotton	None	Solids (fibers), maltose, glucose, solvents, caustic soda, colorings, auxiliary chemical substances.
	Fishing industry	Flour, oil and frozen fish	Glue water concentration	Organic matter (Glue water, oils, blood water)
Penco	Porcelain factory	Porcelain, sanitary wares	-	Clays, colorings, anilines
El Morro	Fishing industry	Flour, frozen oil and canned fish and shellfish.	Glue and blood water concentration	Organic matter
Isla Rocuant	Fishing industry	Flour, canned fish in oil	None	Organic matter
Lirquen	Glass industry	Glasses and crystals	-	Fine sand, china clay
Talcahuano	Dockyards	-	-	Heat, Calcium hydroxide, Sodium hydroxide, Sodium carbonate, Sulphuric acid, Hydrocarbons.
	Mercantile ships, petroleum retailers fishers and launches.	-	-	Spilled petroleum, oils, food residues.
San Pedro	Paper factory	-	-	Organic matter (fibers, bark), talc, china clay, aluminum sulfate, fungicides.
Laja	Paper factory	-	-	Cellulose fibers (organic matter), Sodium lignite, Chlorine lignine, Mercury.
Chiguallante	Textile factory	-	-	Sodium sulfide, hypochlorite sulfite, sulfuric acid, formic acid, starch, glucose, wax, pectins, alcohols, fixatives, acetic acid, detergents, soaps, organic tints.
	Brewery	Beer	-	Liquid presser and aquarelle tint, yeast, starch, alcohol, chromium salts.

Table 16. Principal contaminants originating from liquid effluents dumped into the Bay of San Vicente.

Pollutant source	Production system	Product	Treatment	Principal contaminants
Talcahuano	Iron and steel mill	Iron ingots, laminated steel	Sedimentation and neutralization	Iron sheet, ammonia, phenols, ferrous salts, cyanid oils; lubricants.
	Petrochemical	Polychloride vinyl (Pvc), chloride vinyl Dychlorotene hydrochloric acid polyethylene	Sedimentation Neutralization	Hydrochloric acid, chloride, salts, oils, lubricants, hydrocarbon chlorates
	Petrochemical	Chlorine, caustic soda and other by-products	Sedimentation Neutralization	Chlorine compounds, mercury
San Vicente	Fishing industry	Flour, canned fish in oil	Glue water concentration	Organic matter
	Wood chips	Chips	-	Chips
	Wire factory	Wire	-	Small iron sheets, sulphuric acid, hydrochloric acid, soap
	Cement factory	Cement	-	Heat, sediments
	Mercantile ships Petroleum retailers and launches	-	-	Spilled petroleum, oils, food residues
San Vicente and Talcahuano	Sewage and waste disposal	-	-	Detergents, soaps, coliforms, excrements, grease oils, food residues, urea

merchant vessels and oil tankers; it also serves as a repository of the public waste system in the towns of Talcahuano and San Vicente. In the Bay of Concepcion, are abattoirs and textile mills in Tomé, fishmeal plants in Tompé, El Morro and Isla Rocuant, sawmills in Talcahuano, and a paper factory in Laja.

The environmental problems of the region are attributable to two important economic sectors, namely: fishery and forestry.

Industrial effluents from reduction plants constitute the main source of contamination in the region in the form of liquid discharges, specifically in the Bays of San Vicente and Concepcion, gaseous emissions and particulate matters. Fig. 9 shows the processing structure of a typical reduction plant and the resulting effluents per stage in the production cycle.

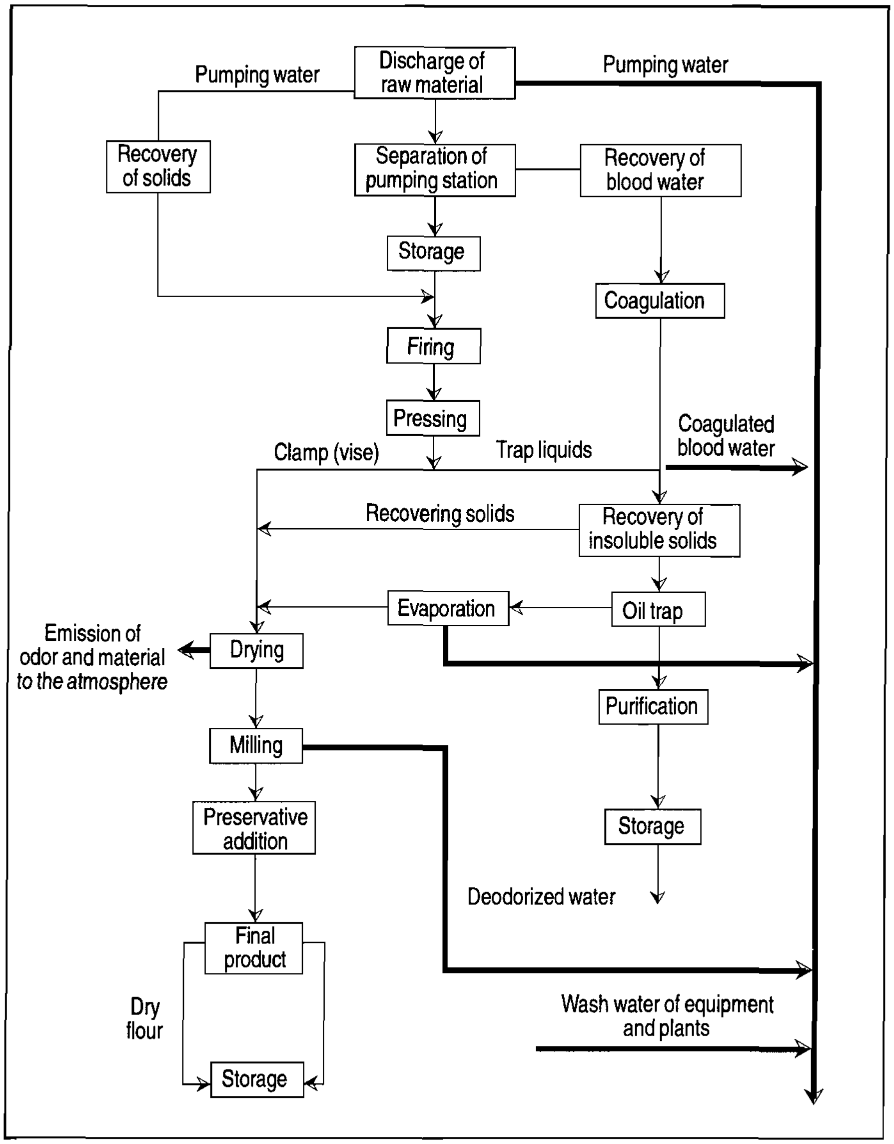

Fig. 9. Typical operation of a fish reduction plant and resulting effluents.

The environmental impacts of the artisanal fishery emanate from inadequate solid and waste disposal systems. This has proven harmful to the marine environment and has caused attendant health risks in all of the coastal fishing communities (Table 17). Another environmental concern is the collection of firewood for cooking which causes not just the deterioration of mangrove and upland forests but also erosion and seawater seepage.

The industrial forestry sector, mainly through cellulose and paper plants, is the source of liquid effluents and gaseous emissions. These are dumped in high concentrations in the Bío-Bío River or directly into the Arauco Gulf from the seven plants operating in the region. The principal contaminants are lignin, chlorine, mercury and different kinds of salts derived from the whitening of cellulose (COREMA 1992). The most noxious is mercury which causes harmful effects on the nervous system and even death when absorbed in high dosage.

Another environmental irritant associated with forestal exploitation and the sawmilling industry is the discharge of sawdust or chips into waterways or directly to the sea resulting in the suffocation of marine flora and fauna. This is prevalent in Dichato and in the Ports of San Vicente and Lirquen where sawmills abound. Erosion is another serious problem due to bad management and inappropriate use of the soil.

Model Formulation and Implementation

The varied and conflicting uses of coastal resources and resulting environmental externalities set the framework for the development of the linear model.

Table 17. Environmental impact of the artisanal fishery in communities located in the coastal zone of the Bío-Bío region, Chile.

Community	A1	A2	A3	A4	B1	C1	C2	D	E	F
Lenga			X	X		X		X		X
Boca Sur			X	X	X	X		X		
Maule			X	X		X		X		
Lo Rojas		X	X	X				X		
Pueblo Hundido		X	X	X	X			X		
El Morro		X	X	X				X		
La Conchilla		X	X	X				X		
El Blanco		X	X	X				X		
Lota		X	X	X				X		
Colcura		X	X	X		X		X		
Laraquete		X	X	X		X		X		
Arauco			X	X		X		X		
Las Peñas	X	X	X	X	X	X	X	X		
Tubul	X	X	X	X	X	X		X	X	X
Llico	X	X	X	X	X	X		X		
Punta Lavapie		X	X	X	X	X	X	X		

A : deficiency of domestic waste disposal systems and sources of potable water.
A1 : contamination of ground aquifers.
A2 : visual and foul odor.
A3 : contamination of marine environment.
A4 : health risks.
B : deficiency of solid waste collection systems.
B1 : contamination by nonbiodegradable waste matter.
C : use of firewood for cooking.
C1 : deterioration of flora and fauna.
C2 : erosion.
C3 : seawater seepage.
D : presence of domestic animals.
D1 : animal excreta.
E : use of mechanized fishing crafts.
E1 : water contamination from hydrocarbons.
F : algae cultivation.
F1 : contamination caused by use of nonbiodegradable elements.

The basic structure consists of three elements: the objective function, the constraints, and the coefficients of the matrix.

The *objective function* is the maximization of net benefits accruing from forestry and fishery. The tourism sector was not considered in model formulation because of its insignificant contribution to total revenues. The *constraints* may theoretically include biological limits such as biomass for fishery and maximum allowable cut for forestry or technological limits as in plant processing capacity. However, our model does not deal with real resource constraints but rather with balance and convexity equations which makes the interpretation of matrix coefficients quite different. This is discussed in greater detail in the relevant section.

Lastly, the *matrix coefficients* are input-output ratios, i.e., the amount of resource i that is needed by process x. The valuation of environmental externalities and its incorporation in model-building is discussed separately.

We first elaborate the nomenclature to provide clarity in the design and to aid us in the identification of the variables used.

Nomenclature

Objective function variables can either be cost or revenue variables with the respective specifications:

Cost: X_{estgra}

Revenue: X_{emp}

Cost variables are further characterized as either a financial cost, X_{estgra}^{f}, or as an environmental cost. The cost variable ranges are as follows:

A = activities or stages of production required to reach the final product stage (Fig. 10 and section below);

R = resources;

G = gear or method used, which may be specific to the type of resource being exploited;

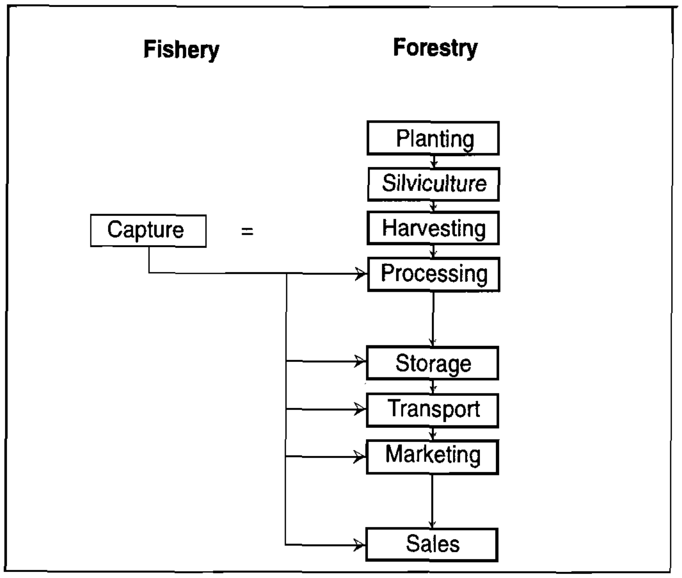

Fig. 10. Activity stages for fishery and forestry. Note that capture fishery is equivalent to harvesting in the forestry sector; otherwise all other activities are the same.

T = technology, here defined as being capital intensive or labor intensive;
S = scale of operation, here defined as large scale or small scale; and
E = economic sectors, here defined as fishery and forestry.

The revenue variable ranges are:
P = final product;
M = markets, including 1) domestic, major markets; 2) domestic, minor markets; 3) international markets; and
E = economic sectors as previously defined.

Elaboration of Variables

The activities in the fishery and forestry sector resemble those of a manufacturing concern, i.e., initial stage is actual production while final stage is marketing. In fisheries, the initial stage is capture or harvesting. This is likewise the case for forestry but only for the native species which are not planted. In the case of plantation species considered here, i.e., the pine *Pinus radiata* and eucalyptus, the initial stages begin with planting and silviculture. Henceforth, the resources take on a similar path. An elaboration of these stages according to scale of operation, gear or method used, resources, and final products is presented in Tables 18,19 and 20.

THE OBJECTIVE FUNCTION

The objective function consists of elements that either add (revenue) or diminish (cost) the benefits derived from various economic sectors of the coastal zone. Environmental externalities are also considered as cost items in the objective function.

The general form of the objective function is:

$$NB = (R_i - C_i) \qquad \text{...1)}$$

where

R_i = total revenue associated with economic activities ranging from i to E; and
C_i = costs associated with economic activities previously defined.

The computational form is given as:

$$C_i = \sum^{E}\sum^{S}\sum^{T}\sum^{G}\sum^{R}\sum^{A}[(C_{estgra}{}^{f} * Q_{estgra}{}^{f}) - (C_{estgra}{}^{x} * Q_{estgra}{}^{x}) \qquad \text{...2)}$$

where

$C_{estgra}{}^{f}$ = associated financial cost per activity;
$Q_{estgra}{}^{f}$ = quantity of the product/good for a given activity level;
$C_{estgra}{}^{x}$ = value placed on environmental externalities; and
$Q_{estgra}{}^{x}$ = quantity assigned to a particular environmental externality.

$$R_1 = \sum^{P}\sum^{M}\sum^{E}{}_{emp}{}^{i} * Q_{emp}{}^{i} \qquad \text{...3)}$$

where

$P_{emp}{}^{i}$ = price of product P at market M utilizing resource E; and
$Q_{emp}{}^{i}$ = quantity of product P produced, destined for market M, utilizing resource E.

The computational form shows that while all levels of costs are considered per activity, only the final

Table 18. Assumed sequence of production activities in the fishery sector, characterization and resources used.

Activity	Scale	Technology	Gear	Resources
Capture	Small	Labor intensive	Handline	Crabs Common hake Mackerel
			"Espinel"	Common hake
		Capital intensive	Encircling net	Mackerel Spanish sardine Anchoveta
			"Espinel"	Cod
			Albacore net	Albacore
	Large	Capital intensive	Encircling net	Anchoveta Common sardine Mackerel Spanish sardine "Merluza de cola"
			Trawler	"Merluza comun" Black crab Shrimp
Processing	Small	Labor intensive	Slaughter	Anchoveta
			Salting	Mackerel Common hake
			Smoking	Mackerel Common hake
			Table and knife	Mackerel Common hake Black crab
		Capital intensive	Canning lines	Mackerel Spanish sardine Sardine
			Freezing lines	Cod Albacore Common hake Black crab
			Fishmeal plants	Mackerel Spanish sardine Sardine Anchoveta
	Large	Capital intensive	Canning lines	Mackerel Spanish sardine Sardine
			Freezing lines	Cod Albacore Common hake Black crab Shrimp
			Fishmeal plants	"Merluza de cola" Mackerel Spanish sardine Sardine Anchoveta
Storage	Small	Labor intensive	Bulk	Shellfish
			Sacks/crates	Crab Common hake
		Capital intensive	Fish tank	Shellfish
			Cold storage	Cod Albacore Common hake Black crab
	Large	Capital intensive	Cold storage	Cod Albacore Common hake Black crab Shrimp

continued

Table18. continued

Activity	Scale	Technology	Gear	Resources
			Warehouse	Mackerel Sardine Spanish sardine
			Container Warehouse	"Merluza de cola" Mackerel Sardine Spanish sardine
			Fishmeal Sacks/warehouse	Anchoveta "Merluza de cola" Mackerel Sardine Spanish sardine Anchoveta
			Bottles	Fish oil
Transport	Small	Labor intensive	Human hauling	Black crab Mackerel Common hake
			Animals	Black crab Mackerel Common hake
		Capital intensive	Truck/van	Mackerel Anchoveta Sardine
			Barges	Black crab Mackerel Common hake Albacore
	Large	Capital intensive	Refrigerated trucks	Black crab Mackerel Common hake Albacore Shrimp
			Trucks	Mackerel Shellfish Anchoveta Sardine
			Tankers	Bulk oil
			Ship	Fishmeal sacks Bulk meal Cans Frozen items

Table 19. Assumed sequence of production activities in the forestry sector, characterization, resources used and final products.

Activity	Scale	Technology level	Gear	Final products (Resource used)
Planting	Small	Labor intensive	Seeding by hand	
		Capital intensive	Plough Animal cart	
	Large	Capital intensive	Tractor	
Silviculture	Small	Labor intensive	Ax/hatchet Hacksaw	
		Capital intensive	n.a.	
	Large	Capital intensive	Mechanical saw	
Harvesting	Small	Labor intensive	Lumber jacks Animal carts	
		Capital intensive	Lumber jacks Tractors Mechanical saw	
	Large	Capital intensive	Lumber jacks/mechanical saws Tractors	
Processing	Small	Labor intensive	Oven Hatchet	Charcoal/(PR, EG) Firewood/(PR, EG)
		Capital intensive	n.a.	n.a.
	Large	Labor intensive	Makeshift sawmills	Lumber/(PR, EG, EN) Wood products/(PR, EG, EN)
		Capital intensive	Chipmakers	Chips/(PR, EG)
			Pulp and paper industry	Chemical pulp/(PR, EG) Mechanical pulp/(PR, EG) Paper and carton/(PR, EG)
			Woodboard industry	Particleboard/(PR) Fiberboard/(PR) Plywood/(PR, EG, EN) Panel/veneer/(EN)
			Mechanized sawmills	Lumber/(PR, EG, EN) Wood products/(PR, EG, EN)
Storage	Small	Labor intensive	Sacks Bulk storage	Charcoal
		Capital intensive	Warehouse Timberyard	Lumber Wood products
	Large	Capital intensive	Shed, storehouse	Paper and carton Particleboards Fiberboard Plywood
			Stacking yard	Chips
			Tanks	Chemical pulp Mechanical pulp
Transport	Small	Labor intensive	Animal and human Haulage	Charcoal and firewood
		Capital intensive	Light trucks	Lumber and wood products
	Large	Capital intensive	Tanks	Chemical pulp Mechanical pulp
			Trucks	Lumber Wood products Chips
			Train	Logs for export Lumber Wood products
			Ships	Chips Chemical pulp Mechanical pulp Lumber Wood products Logs

PR : *Pinus radiata.*
EG : *Eucalyptus globulus.*
EN : Endemic species.

Table 20. Upper limits of catch levels ($t \cdot 10^3$), based on Schaefer yield functions segmented into 6 groups, Y_i (i = 1,2....6).

Species	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
Eels	1.3	1.9	2.4	2.7	2.9	3.0
Hake	12.0	22.0	30.0	34.0	36.0	37.0
Jack mackerel	550.0	1,000.0	1,430.0	1,720.0	1,850.0	1,900.0
Molluscs	2.0	2.5	3.2	3.6	3.9	4.0
Spanish sardine	20.0	25.0	32.0	36.0	39.0	40.0
Anchovy	50.0	75.0	95.0	108.0	115.0	117.0
Patagonian toothfish	22.0	0.35	0.45	0.53	0.58	0.60
Swordfish	0.8	1.30	1.90	2.4	2.7	2.9
Patagonian grenadier	72.0	84.0	94.0	100.0	104.0	106.0
Shrimp	0.04	0.065	0.095	0.12	0.13	0.135
Algae	5.5	9.50	13.0	15.0	16.0	16.5
Common sardine	130.0	180.0	220.0	250.0	270.0	280.0

product stage, i.e., that which reaches final and intermediate consumer, is incorporated as revenue.

COEFFICIENTS OF THE OBJECTIVE FUNCTION

The coefficients of the objective function are prices of inputs and outputs. Table 21 shows the yield levels associated with each of the six segments of the Schaefer curve; harvesting costs are presented in Table 22. The increasing cost function can be explained by Fig. 11 which depicts linearly decreasing yield per effort as effort increases. Cost per unit of effort was assumed constant and thus becomes an increasing function of output (Agüero 1987).

Table 23 shows the processing costs per product line and the species that undergo such processing. Costs were assumed to be constant over a range of different species. Processing of fresh and dried fish products incur the least cost while canning incurs the greatest cost. Among the species, jack mackerel and the sardine species are subjected to most types of processing; algae is only processed into its dried form and bacalao, albacore, and eels as fresh and frozen.

Storage, transport and marketing costs are presented in Table 24. Transport of fresh and frozen fish is more expensive due to its high perishability. Storage costs for fresh and frozen and well as dried fish are relatively cheaper due to the simpler technology required, i.e., crates and ice chests.

Average weighted price of processed fish products and market destination varies according to species used (Table 25). The price of fishmeal and oil is not dependent on the fish species; contrarily, frozen fish is highly sensitive with shrimps, bacalao and albacore commanding the highest prices. Hake and jack mackerel, which are more abundant, command lower prices.

Average cost of planting pine varies proportionally with stocking density (Table 26). The ranges given for silviculture and harvesting correspond to different pruning and harvesting rates. Processing, storage and transport costs for pine as well as domestic and market prices are shown in Table 27. Note the high margins between export and domestic price for all but one product, wood chips.

No plantation activities were assumed for eucalyptus. However, pruning and harvesting costs were also shown to vary with level of exploitation, i.e., US\$33.33-156$\cdot$ha^{-1}. Other costs as well as prices are provided in Table 28. Logs, pulp and wood chips are marketed entirely in foreign markets while plywood, veneer and firewood are sold entirely in the local markets.

THE CONSTRAINTS

The type of constraints used in this exercise in addition to the nonnegativity constraints are:

1) Convexity

$$-\sum_{i}^{n}(b^{i+1} * 1) + b^{i} = 0 \qquad ...4)$$

where

b^i = resource biomass in section i; and
n = number of sections considered (six, in this application).

2) Balance

$$pr * b^i - Qrp = 0 \qquad ...5)$$

Table 21. Assumed harvesting costs (in US$·t⁻¹) for various fish species and yield levels.

Resources	Harvesting costs					
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
Eels	413	603	762	857	921	953
Hake	150	275	374	424	449	462
Jack mackerel	4,014	7,299	10,437	12,554	13,503	13,868
Molluscs	334	418	534	601	651	668
Spanish sardine	148	185	237	267	289	297
Anchovy	604	906	1,148	1,305	1,390	1,414
Patagonian toothfish	231	375	549	396	780	837
Swordfish	61	98	126	148	162	168
Patagonian grenadier	536	626	700	745	775	790
Shrimp	55	90	132	166	180	187
Algae	1,086	1,754	2,338	2,672	2,839	2,923
Common sardine	1,593	2,206	2,697	3,064	3,310	3,432

Note: Harvesting costs correspond to each yield segment (Table 20).

Table 22. Assumed processing costs (in US$·t⁻¹) by product.

Product	Processing cost	Eels	Hake	Jack mackerel	Mollusc	Spanish sardine	Common sardine	Anchovy	Toothfish	Swordfish	Grenadier	Shrimp	Algae
Fresh	55.55	X			X	X			X	X			
Frozen	416.62	X	X	X	X	X	X		X	X	X	X	
Meal A	97.61			X		X	X	X			X		
Meal B	97.61			X		X	X	X			X		
Dried	40												X
Canned	686.92			X	X	X	X	X					

Table 23. Assumed storage, transport and marketing costs (in US$·t⁻¹) per type of processed fish product.

Product	Costs		
	Storage	Transport	Marketing
Fresh	1.5	43	20
Frozen	1.5	43	22
Fishmeal A	12.0	30	26
Fishmeal B	12.0	30	20
Dried	1.5	30	10
Canned	6.0	30	25

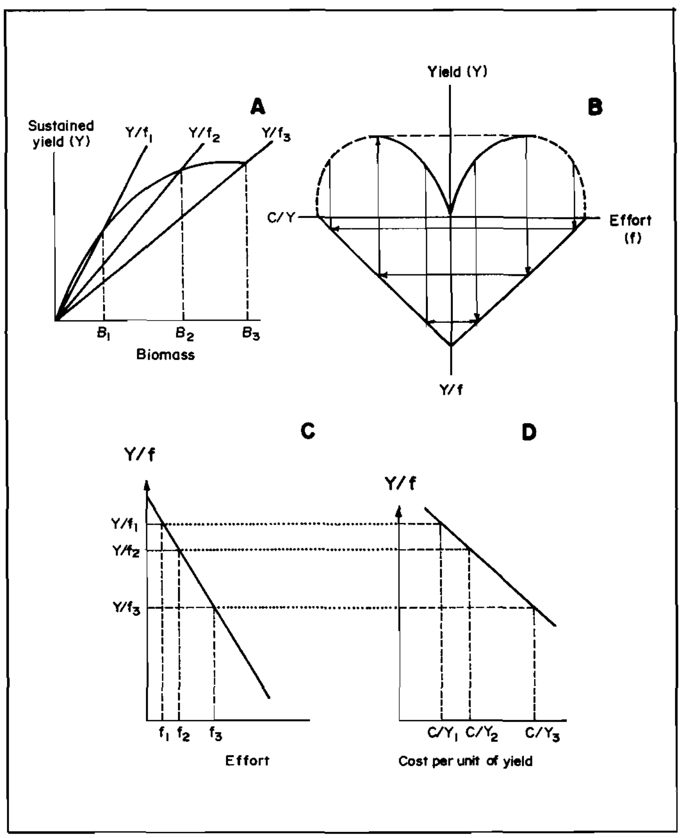

Fig. 11. Fundamental relationships between biological characteristics of fish resources and technology of capture and various cost factors. A) Relationships between yield and the underlying fish biomass (note that $B_1 > B_2 > B_3$). B) Relationships between yield, effort and the quotients cost per unit of yield and yield per unit of effort. C) Relationships between yield per effort, effort and cost per unit of yield.

Table 24. Average weighted price (export and domestic) (in US$·t^{-1}) of processed fish products.

Species	Price							
	Fresh	Frozen	Meal A	Meal B	Oil A	Oil B	Dried	Canned
Eel	5,500	2,143						
Hake		1,779						
Jack mackerel		1,435	400	450				867
Mollusc	5,000	4,500						8,000
Spanish sardine	5,000	682	400	450	138	150		
Anchovy			400	450	138	150		1,000
Toothfish	5,000	6,150						
Swordfish	7,567	6,939						
Grenadier			400	450	138	150		
Shrimp		8,596						
Algae							532	
Common sardine		591	400	450	138	150		1,000
Market distribution								
Domestic	0	5	45	62				
Export	100%	95	55	38				

Table 25. Plantation, culture and harvesting cost (in US$·ha^{-1}) of pine at various stocking densities.

Pine	Stocking density 1 769 s·ha^{-1}	Stocking density 2 1,845 s·ha^{-1}	Stocking density 3 2,190 s·ha^{-1}	Stocking density 4 3,280 s·ha^{-1}
Plantation	440	460	462	480
Silviculture	6.7-21.8	6.2-21.9	6.2-17.5	5.5-17.5
Harvest	36.6-115.8	34.4-109	31.3-99.5	31.2-97.8

Table 26. Processing, transport and storage costs (in US$·m^3) for wood products derived from pine and corresponding market prices.

Product type	Processing	Transport (pine)	Storage	Price	
				International	Domestic
Logs	6.0	1.1	3.0	40	25
Lumber	5.7	1.2	2.5	51	28
Wood products	5.5	2.0	2.5	125	63
Chips	3.1	1.7	2.0	166	183

Table 27. Processing, transport and storage costs (in US$·m³) for wood products derived from eucalyptus and corresponding market prices.

Product type	Processing	Transport (pine)	Storage	Price International	Price Domestic
Logs	5.1	3	1.1	48	n.a.
Pulp	4.5	2.7	1.7	418	n.a.
Chips	3.1	2.5	1.5	60	n.a.
Plywood	4	3.2	1.2	n.a.	265
Veneer	5.5	2.5	2	n.a.	296
Firewood	1	1.5	0	n.a.	0

Table 28. Estimates of net benefit per sector from LP exercise.

	Economic sector	Net benefit (US$.$10^3$·year^{-1})
Fishery		171,358
	Mackerel	120,177
	Common hake	21,551
	Others	29,630
Forestry		1,186,410
	Pine	105,552
	Eucalyptus	1,080,858
Total		1,357,768
Environment		(20,000)
Total		1,137,768

The equation indicates the conversion rate (pr) representative of a particular production process, say frozen fish or fishmeal in the case of fish processing, at which the biomass is converted into a finished product (Qrp).

3) Balance

$$Rrp * Qrp - Qra = 0 \qquad \text{...6)}$$

The output of activity A_a becomes the input for the next activity A_{a+1}, i.e., no wastage is involved.

4) Convexity of demand

$$(1/Qra^i) * Qra <= 1 \qquad \text{...7)}$$

or

$$coef\ (Qra^i) * Qra <= 1 \qquad \text{...8)}$$

This equation indicates that each activity can be taken as a segment of the total demand curve, thus, the restriction <= 1.

5) Land availability

$$A_p + A_a <= \text{Total Area} \qquad \text{...9)}$$

The only real resource constraint used in the model is the availability of land for forest plantation. The area planted to pine and eucalyptus must be less than or equal to total plantation area.

THE MATRIX COEFFICIENTS

Coefficients pertain to the yield per segment, as in forestry, or catchability, as in the fishery. In most cases, coefficients are exogenously determined percentages such as the disaggregation of harvests by scale of operation, type of gear, product type and market destination. In like manner, coefficients represent disaggregation of finished wood and fish products into its different forms.

The matrix coefficients, constants of the objective function and constraint elements are incorporated into a final LP tableau that is a 782 x 530 matrix (Appendix 1).

Environmental Externalities

Among the numerous environmental effects resulting from activities in the fishery and forestry sector, only water contamination as a consequence of the fish processing activities was quantified here. An index of water pollution is the decrease of oxygen levels as measured by dissolved oxygen (DO) levels. Oxygen is removed from the water as the organic matter in it decays. According to IFOP (1988), liquid effluents of fishmeal plants reach BDO7 levels equal to 0.57 kg·t^{-1} of fish processed. In order to maintain an acceptable standard (BDO7 10 mg·l^{-1}, as in Spain), it is necessary to dilute the affected area by 57,000 l for every tonne of fish processed.

To implement this, a constant in the objective function was added, i.e., imputing the cost of freshwater, here assumed to be US\$ 1·t^{-1}. The constraint row merely summed up total fish processed and is similar in form to the balance equations enumerated above.

Results and Discussion

Results

The solution to the linear programming problem is the estimate of total net benefit generated by fishery and forestry. In the process, the solution identifies the optimum values of the variables which vary from one sector to another. In the fishery, the variable is the amount of fish "handled" at each activity level while in the forestry sector, the quantity of wood and/or wood products. The algorithm used in linear programming essentially estimates dual values as well as right-hand side and objective function coefficient ranges, but due to the absence of real resource constraints the dual values as well as the right-hand side ranges are not analyzed.

Total net benefit amounts to US\$1.36 billion·year^{-1}, 87% of which is accounted for by forestry; the fishery contributes US\$171 million (Table 29). The Chilean jack mackerel, which is sold at international and national markets as frozen, fishmeal and oil, contributed 70% of sectoral revenue while hake, marketed only as frozen, ranked second (Table 30). The optimum annual harvesting levels for jack mackerel and hake are 1.9 million t and 37,000 t, respectively. These levels are contingent on several factors including final market demand, transport, processing and storage capacity, as well as current levels of effort in the industrial capture fishery.

The large-scale sector contributes a major portion of catch for hake, jack mackerel, Spanish sardine, anchoveta and Patagonian grenadier whereas the small-scale sector dominates the capture of eels, molluscs, bacalao, albacore and algae.

In the forestry sector, the optimum areas planted to pine and eucalyptus are 50,000 and 30,000 ha, respectively. All areas planted to pine are based on a stocking density of 3,280 seedlings·ha^{-1}. No planting is involved in the case of eucalyptus.

Total quantity of timber is based on the amount harvested and/or thinned, as part of silvicultural practices. Logs constitute a major use of pines and the optimum level of export was estimated at 1,384 m^3 (Table 31). In addition to wood products and wood chips, eucalyptus is also used for veneer and firewood. Wood chips constitute the major export and is valued at an average price of US\$60·t^{-1}. No pulpwood is extracted from both species.

The optimum net benefits are diminished by a total of US\$20 million considering the environmental externalities attributed to pollutants from fishmeal plants. This represents the cost of pumping in freshwater to improve the DO levels. The estimate of optimum net benefits should be lower due to a larger number of externalities which could not be quantified.

While real resource constraints were missing and that many variables were exogenously determined, the emphasis of this application is the linkage between different activities within each sector to arrive at an optimum quantity. Thus, the optimum quantity harvested is not based on biomass constraints or effort constraints alone but also by demand conditions for the final product.

The relevance of coastal zone management and the "systems approach" espoused in Agüero et al. (this vol.) is highlighted by the interconnectedness of economic activities in the fishery and forestry. A succinct example is the determination of optimal catch levels in the capture fishery which was shown to be an indirect function of final market demand and constrained by prevailing capacities in the transport, storage and processing sectors. Without such framework, optimal catch levels would be based, for example, on either MSY or MEY, which are purely biological parameters. Even the latter, which at best considers appropriate measures of opportunity costs of the factors of production, thereby incorporating macroeconomic factors, is relatively myopic and still quite limited to the capture fishery sector.

This framework has the potential of estimating the impact of factors outside the capture fishery sector on itself, e.g., changes in storage fees or in increased demand for substitute products. Unfortunately, this particular application, though not of linear programming in general, did not deal with real resource constraints. A useful sensitivity analysis would have emerged if hypothetical cases of increased or decreased resource endowments could be measured against potential economic benefits and on the values of the variables.

Table 29. Optimum levels of production (in $t \cdot 10^3 \, year^{-1}$) resulting from LP exercise, by product type, activity and major species.

Activity	Crabs	Hake	Jack mackerel	Molluscs	Spanish sardine	Anchovy	Toothfish	Swordfish	Grenadier	Shrimp	Algae
Capture	3.00	37.00	1,898.96	4.00	40.00	115.04	2.90	0.60	103.98	0.14	16.00
Large scale	0.90	35.52	1,898.96		39.60	78.20		0.00	102.94	0.14	0.00
Small scale	2.10	1.48		4.00	0.40	36.90	2.90	0.60	1.04		16.00
Processing											
Fresh											
Before processing	0.01			0.40	0.03		0.01	0.04			
After processing	0.01			0.36	0.02		0.01	0.04			
Frozen											
Before processing	2.99	37.00	13.48	1.10	2.12		2.89	0.56	0.42	0.14	
After processing	1.59	17.76	5.53	0.22	1.42		1.53	0.36	0.13	0.14	
Fishmeal and oil											
Before processing		1,773.43		37.85	114.62			103.56			
Fishmeal A		620.70		13.25	40.12			36.25			
Fishmeal B		1,152.12		24.60	74.51			67.32			
After processing											
Fishmeal A		136.55		3.05	8.83			7.25			
Fish Oil A		27.93		0.60	1.81			1.63			
Fishmeal B		253.60		5.66	16.39			13.46			
Fish Oil B		69.16		1.48	4.47			4.04			
Dried											
Before processing											16.00
After processing										15.20	
Canned											
Before processing			108.62	2.89		0.03					
After processing		42.36	0.58		0.01						
Storage											
Fresh	0.01			0.36	0.02			0.04			
Frozen	1.59	17.76	5.53	0.22	1.42			0.36	0.13	0.03	
Fishmeal A		136.55		3.05	8.83			7.25			
Fishmeal B		253.60		5.66	16.39			13.46			
Dried										15.20	
Canned fish		42.36	0.58		0.01						
Transport											
Fresh	0.01				0.02			0.04			
Frozen	1.59	17.76	5.53		1.42			0.36	0.13	0.03	
Fishmeal A		136.55		3.05	8.83			7.25			
Fishmeal B		253.60		5.66	16.39			13.46			
Dried										15.20	
Canned fish		42.36			0.01						
Marketing											
Fresh	0.01			0.36	0.02			0.04			
Frozen	1.59	17.76	5.53		1.42			0.36	0.13	0.03	
Fishmeal A		136.55		3.05	8.83			7.25			
Fishmeal B		253.60		5.66	16.39			13.46			
Dried										15.20	
Canned fish		42.36			0.01						

continued

Table 29. continued

Activity	Crabs	Hake	Jack mackerel	Molluscs	Spanish sardine	Anchovy	Toothfish	Swordfish	Grenadier	Shrimp	Algae
Sales											
Fresh											
International	0.01			0.36	0.02		0.01	0.04			
Domestic											
Frozen		5.28									
International	1.51	16.87	5.22	0.21	1.35		1.46	0.34	0.13	0.03	
Domestic	0.08	0.89	0.06	0.01	0.07		0.08	0.02	0.01	0.00	
Fishmeal A		136.55									
International		75.10		1.68	4.85			3.99			
Domestic		61.45		0.02	3.97			3.26			
Fishmeal B		253.60									
International		96.37		1.35	6.23			5.12			
Domestic		157.23		2.15	10.16			8.35			
Fish oil A											
International		27.93		0.60	1.81			1.63			
Domestic											
Fish oil B											
International		69.16		1.48	4.47			4.04			
Domestic											
Dried											
International										0.46	
Domestic										14.74	
Canned											
International			0.43		0.01						
Domestic			0.14		0.00						
Net benefit (US$·$10^3$)	1,600.8	21,550.81	120,176.84	5,065.87	2,286.37	5,207.66	7,459.51	2,299.04	4,658.38	21.39	1,030.73

Table 30. Optimum estimates (in $m^3 \cdot 10^3$) of LP exercise for forestry sector, by product type, activity and species.

Activity levels	Pine	Eucalyptus	Activity levels	Pine	Eucalyptus
Plantation and silviculture			Transport		
			Logs	2,308.13	n.a.
Quantity thinned	800.00	1,546.39	Lumber	907.98	n.a.
Quantity of timber extracted	800.00	17,647.06	Wood products	1,548.92	1,036.45
Harvesting			Wood chips	1,218.72	10,433.56
Quantity harvested	9,090.90	17,647.06	Veneer	n.a.	1,036.45
Quantity of timber extracted	9,090.90	17,647.06	Firewood	n.a.	191.93
Total quantity of timber	9,890.90	19,193.45	*Sales*		
Processing			Logs		
Raw material inputs			International	1,384.80	
Logs	3,659.63	n.a.	Domestic	923.20	
Lumber	1,681.45	n.a.	Lumber		
Wood products	2,868.36	1,919.30	International	635.59	
Wood chips	1,681.45	14,395.00	Domestic	272.40	
Veneer	n.a.	1,919.30	Wood products		
Firewood	n.a.	959.67	International	1,239.13	0.00
Output			Domestic	309.78	1,036.45
Logs	2,308.13	n.a.	Wood chips		
Lumber	907.98	n.a.	International	1,218.71	10,433.56
Wood products	1,548.92	1,036.45	Domestic		0.00
Wood chips	1,218.72	10,433.56	Veneer		
Veneer	n.a.	1,036.45	International		0
Firewood	n.a.	191.93	Domestic		1,036.45
Storage			Firewood		
Logs	2,308.13	n.a.	International		0
Lumber	907.98	n.a.	Domestic		191.93
Wood products	1,548.92	1,036.45			
Wood chips	1,218.72	10,433.56			
Veneer	n.a.	1,036.45			
Firewood	n.a.	191.93	Net revenue (US$)	105,552.47	1,080,858.35

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Annex 1. Hydrobiological resources of Chile exploited at the national and regional (Bío-Bío) level (*).

	Local name	Scientific name	Presence of species in Bío-Bío, Chile
Fish			
1.	*Acha*	*Kyhosus analogus*	
2.	*Agujilla*	*Scomberesox saurus*	
3.	*Albacora*	*Xiphias gladius*	*
4.	*Anchoveta*	*Engraulis ringens*	*
5.	*Anguila*	*Ophictus* spp.	
6.	*Apañado*	*Hemilutjanus macrophthalmos*	
7.	*Atún aleta amarilla*	*Thunnus albacares*	
8.	*Atún aleta larga*	*Thunnus alalunga*	
9.	*Atún de ojo grande*	*Thunnus obesus*	
10.	*Ayanque*	*Cynoscion analis*	
11.	*Azulejo*	*Prionace glauca*	
12.	*Bacalao de profundidad*	*Dissostichus eleginoides*	*
13.	*Bacalao o mero*	*Polyprion* spp.	
14.	*Blanquillo*	*Prolatilus jugularis*	*
15.	*Bonito*	*Sarda chiliensis*	
16.	*Breca*	*Acantholatris gayi*	
17.	*Brótula*	*Salilota australis*	
18.	*Caballa*	*Scomber japonicus*	*
19.	*Cabinza*	*Isacia conceptionis*	*
20.	*Cabrilla*	*Sebastes oculatus*	*
21.	*Cabrilla común*	*Paralabrax humeralis*	*
22.	*Cachurreta*	*Katsuwonus pelamis*	
23.	*Cazón*	*Galeorhinus ziopterus*	
24.	*Chancharro*	*Helicolenus lengerichi*	*
25.	*Cojinoba del norte*	*Seriolella violacea*	*
26.	*Cojinoba moteada*	*Seriolella porosa*	
27.	*Cojinoba del Sur*	*Seriolella caerulea*	*
28.	*Congrio colorado*	*Genypterus chilensis*	*
29.	*Congrio dorado*	*Genypterus blacodes*	*
30.	*Congrio negro*	*Genypterus maculatus*	*
31.	*Corvina*	*Cilus montti*	*
32.	*Dorado*	*Coryphaena hippurus*	
33.	*Jurel*	*Trachurus murphyi*	*
34.	*Lenguado de ojos chicos*	*Paralichthys microps*	*
35.	*Lenguado de ojos grandes*	*Hippoglossina macrops*	*
36.	*Lisa*	*Mugil* spp.	*
37.	*Machuelo*	*Ethmidium maculatum*	*
38.	*Marrajo*	*Isurus glaucus*	*
39.	*Merluza del sur*	*Merluccius australis*	
40.	*Merluza de cola*	*Macruronus magellanicus*	*
41.	*Merluza de tres aletas*	*Micromesistius australis*	
42.	*Merluza común*	*Merluccius gayi*	*
43.	*Mulata*	*Graus nigra*	
44.	*Nanue*	*Girellops nebulosus*	
45.	*Palometa*	*Parona signata*	
46.	*Pampanito*	*Stromateus stellatus*	*
47.	*Pejegallo*	*Callorhinchus callorhinchus*	*
48.	*Pejeperro*	*Pimelometopon maculatus*	
49.	*Pejerrata*	*Coelorhynchus* spp.	*
50.	*Pejerrey de mar*	*Odonteshes* spp.	*
51.	*Pejesapo*	*Sicyases sanguineus*	
52.	*Pejezorro*	*Alopias vulpinus*	
53.	*Peto*	*Acanthocybium solandri*	
54.	*Raya*	*Raja* spp.	*
55.	*Reineta*	*Lepidotus australis*	*
56.	*Róbalo*	*Eleginops maclovinus*	
57.	*Rollizo*	*Mugiloides chilensis*	*
58.	*Roncacho*	*Sciaena* spp.	
59.	*Salmón del Pacifico*	*Oncorhynchus* spp.	
60.	*Salmón del Atlántico*	*Salmo salar*	

*Indicates presence of species.

continued...

Annex 1. continued

	Local name	Scientific name	Presence of species in Bío-Bío, Chile
61.	*Sardina*	*Sardinops sagax*	*
62.	*Sardina común*	*Clupea bentincki*	*
63.	*Sargo*	*Anisotremus scapularis*	
64.	*Sierra*	*Thyrsites atun*	*
65.	*Tollo*	*Mustelus mentu*	*
66.	*Tomoyo*	*Labrisomus philipii*	
67.	*Trucha arco iris*	*Salmo gairdneri*	*
68.	*Trucha café*	*Salmo trutta*	
69.	*Trucha de arroyo*	*Salvelinus fontinalis*	
70.	*Vidriola*	*Seriola mazatlana*	
Molluscs			
1.	*Almeja (taca)*	*Venus antiqua*	*
2.	*Almeja*	*Protothaca thaca*	*
3.	*Calamar*	*Loligo gahi*	*
4.	*Caracol locate*	*Thais chocolata*	
5.	*Caracol trumulco*	*Chorus giganteus*	*
6.	*Caracol tegula*	*Tegula atra*	*
7.	*Chocha*	*Calyptraea trochiformes*	
8.	*Cholga*	*Aulacomya ater*	*
9.	*Chorito*	*Mytilus chilensis*	*
10.	*Choro zapato*	*Choromytilus chorus*	*
11.	*Culengue*	*Gari solida*	
12.	*Jibia*	*Dosidicus tunicata*	
13.	*Lapas*	*Fissurella* spp.	*
14.	*Loco*	*Concholepas concholepas*	*
15.	*Macha*	*Mesodesma donacium*	*
16.	*Navaja de mar*	*Solen gaudichaudi*	*
17.	*Navaja de mar*	*Ensis macha*	
18.	*Navajuela*	*Tagelus dombeii*	
19.	*Ostión del norte*	*Chlamys purpurata*	
20.	*Ostión del sur*	*Chlamys patagonica*	
21.	*Ostra*	*Ostrea chilensis*	
22.	*Ostra del Pacifico*	*Crassostrea gigas*	
23.	*Piquihue*	*Odontocymbiola magellanica*	
24.	*Pulpo*	*Octopus vulgaris*	
Crustaceans			
1.	*Camarón de roca*	*Rhynchocinetes typus*	*
2.	*Camarón nailon*	*Heterocarpus reedi*	*
3.	*Centolla*	*Lithodes antarticus*	
4.	*Centollón*	*Paralomis granulosa*	
5.	*Gamba*	*Haliporoides diomedeae*	*
6.	*Jaiba*	*Cancer edwardsii*	
7.	*Jaiba limón*	*Cancer porteri*	*
8.	*Jaiba mora*	*Homalaspis plana*	*
9.	*Jaiba peluda*	*Cancer setosus*	*
10.	*Jaiba reina*	*Cancer coronatus*	*
11.	*Krill*	*Euphausia superba*	
12.	*Langosta de Juan Fernández*	*Jasus frontalis*	
13.	*Langosta de Isla de Pascua*	*Panulirus pascuensis*	
14.	*Langostino amarillo*	*Cervimunida johni*	
15.	*Langostino colorado*	*Pleuroncodes monodon*	*
16.	*Langostino de los canales*	*Munida subrugosa*	
17.	*Picoroco*	*Megabalanus psittacus*	*
Algae			
1.	*Chasca*	*Gelidium rex*	*
2.	*Chasca gruesa*	*Gymnogongrus furcellatus*	
3.	*Chascón*	*Lessonia nigrescens*	*

continued...

Annex 1. continued

	Local name	Scientific name	Presence of species in Bío-Bío, Chile
4.	*Chicorea de mar*	*Mastocarpus papillatus*	*
5.	*Cochayuyo*	*Durvilaea antarctica*	*
6.	*Huiro*	*Macrocystis pyrifera*	
7.	*Lechuha de mar*	*Ulva lactuca*	
8.	*Liquen gomoso*	*Chondrus canaliculatus*	*
9.	*Luche*	*Phorphyra columbina*	
10.	*Luga-luga*	*Iridaea ciliata*	*
11.	*Pelillo*	*Glacilaria* spp.	*
12.	*Anhfeltia*	*Anhfeltia plicata*	
Echinoderms			
	Erizo	*Loxechinus albus*	
Hemichordate			
	Piure	*Pyura chilensis*	*

Annex 2. Principal native forest species of Chile and Region VIII (*).

	Local name	Scientific name	Presence of species in Bío-Bío, Chile
1.	*Araucaria*	*Araucaria araucana*	*
2.	*Ciprés de Cordillera*	*Austrocedrus chilensis*	*
3.	*Alerce*	*Fitzroya cupressoides*	
4.	*Ciprés de Guaitecas*	*Pilgerodendron uriferum*	
5.	*Manio de Hojas Largas*	*Podocarpus salignus*	*
6.	*Manio de Hojas Punzantes*	*Podocarpus nubigemns*	
7.	*Lleuque*	*Podocarpus andinus*	*
8.	*Manio de Hojas Cortas*	*Saxegothaea conspicua*	
9.	*Espino*	*Acacia caven*	
10.	*Palma Chilena*	*Jubaea chilensis*	
11.	*Algarrobo*	*Prosopis chilensis*	
12.	*Tamarugo*	*Prosopis tamarugo*	
13.	*Pimiento*	*Schinus molle*	
14.	*Pelu*	*Sophora microphylla*	*
15.	*Tineo*	*Weinmannia trichosperma*	*
16.	*Avellano*	*Gevuina avellana*	*
17.	*Trevo*	*Dasyphyllum diacanthoides*	*
18.	*Naranjillo*	*Villarezia mucronata*	*
19.	*Olivillo*	*Aextoxicom punctatum*	*
20.	*Lingue*	*Perseá lingue*	*
21.	*Litre*	*Lithraea caustica*	*
22.	*Canelo*	*Drimys winteri*	*
23.	*Notro*	*Embothrium coccineum*	*
24.	*Quillay*	*Quillaja saponaria*	*
25.	*Maitén*	*Maytenus boaria*	*
26.	*Sauce Chileno*	*Salix chilensis*	

*indicate presence of species.

continued...

Annex 2. continued

	Local name	Scientific name	Presence of species in Bío-Bío, Chile
27.	*Coigue de Chiloé*	*Nothofagus nitida*	
28.	*Coigue*	*Nothofagus dombeyi*	*
29.	*Coigue de Magallanes*	*Nothofagus betuloides*	
30.	*Roble*	*Nothofagus obliqua*	*
31.	*Ñirre*	*Nothofagus antarctica*	*
32.	*Rauli*	*Nothofagus alpina*	*
33.	*Ruil*	*Nothofagus alessandri*	
34.	*Bollán*	*Kageneckia oblonga*	
35.	*Molle*	*Schinus latifolius*	*
36.	*Radal*	*Lomatia hirsuta*	*
37.	*Lenga*	*Nothofagus pumilio*	*
38.	*Hualo*	*Nothofagus glauca*	*
39.	*Boldo*	*Peumus boldus*	*
40.	*Peumo*	*Cryptocarya alba*	*
41.	*Belloto del Sur*	*Beilschmiedia berteorana*	*
42.	*Belloto del Norte*	*Beilschmiedia miersii*	
43.	*Qeule*	*Gamortega keule*	*
44.	*Arrayán*	*Luma apiculata*	*
45.	*Pitra*	*Myrceugenia exsucca*	*
46.	*Luma*	*Amomyrtus luma*	*
47.	*Meli*	*Amomyrtus meli*	
48.	*Patagua*	*Crinodendron patagua*	*
49.	*Laurel*	*Laurelia sempervirens*	*
50.	*Tepa*	*Laurelia philippiana*	*
51.	*Tiaca*	*Caldcluvia paniculata*	*
52.	*Ulmo*	*Eucryphia cordifolia*	*

Options for Land Use Management in Lingayen Gulf, Philippines*

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CRUZ-TRINIDAD, A., Z. ALOJADO and A.G.C. CARGAMENTO. 1996. Options for land use management in Lingayen Gulf, Philippines, p. 64-77. *In* A. Cruz-Trinidad (ed.) Valuation of tropical coastal resources: theory and application of linear programming. ICLARM Stud. Rev. 25, 108 p.

Abstract

In view of the fast-changing pace of land use in the Lingayen Gulf area, Philippines, this study estimates optimal land use combinations, particularly with respect to aquaculture. A direct cost and revenue approach would result in total net revenues of P7.4 billion or US$0.29 billion and total conversion of remaining mangrove areas to milkfish ponds. However, the Total Economic Value (TEV) approach resulted in a net revenue of P35 billion with the following land use scenarios: i) no mangrove conversion; ii) conversion of salinized ricelands to milkfish ponds; and iii) conversion of grasslands to shrimp ponds. The results emphasize the importance of valuation as this greatly influences the results of linear programming solutions.

Introduction

Lingayen Gulf was the Philippine pilot site of the ASEAN-USAID Coastal Resources Management Project which was executed by the International Center for Living Aquatic Resources Management (ICLARM) from 1986 to 1992. The study produced several technical reports including the Lingayen Gulf Profile (McManus and Chua 1990) and the Lingayen Gulf Coastal Area Management Plan (NEDA Region I 1992). The area was subsequently studied using an approach based on Geographic Information Systems (GIS) with the major objective of a zonation scheme for both land use and water space utilization (Paw et al. 1994). This latter project was comprised of several research components which independently determined suitable areas for human settlements (Cargamento and Rillon 1994), tourism (Cargamento et al. 1994), mangrove reforestation (Alojado et al. 1994) and brackishwater development (Paw et al. 1994).

Paw et al. (1994) determined suitability for brackishwater pond siting using several physical criteria including soil type, elevation, physiography, access to road networks, and access to water and land use. This study prioritized marginal lands (grasslands, swamps), coconut plantations, and unproductive agricultural lands as well as degraded mangroves as having the greatest potential for conversion.

As a complement to the study by Paw et al. (1994), this study focuses on net economic returns of particular land use options to determine the feasibility of converting to aquaculture (both shrimp and milkfish) or to retain the use of land. Four land types are considered: 1) productive ricelands, 2) salinized ricelands, 3) grasslands, and 4) mangroves. The framework used is a constrained maximization approach where optimal land use results in the greatest level of net revenue for society. Net revenues are valued using a direct cost and revenues approach, future value approach and foregone earnings approach. The last two were used to account for indirect and nonuse values in accordance with the Total Economic Value (TEV) concept.

Lingayen Gulf Profile

Resource-based Activities and Issues: Fisheries, Aquaculture and Tourism

Lingayen Gulf, located in northwestern Luzon, Philippines, has a surface area of 2,100 km^2 and is bounded by the provinces of La Union and Pangasinan. Seventeen municipalities border the Gulf; ten are from Pangasinan, namely: Alaminos, Anda, Bani, Bolinao, Sual, Labrador, Lingayen, Binmaley, San Fabian and Dagupan, while seven are from La Union, namely: Agoo, Aringay, Bauang, Caba, Rosario, San Fernando and Sto. Tomas (Fig. 1).

Previous studies have delineated the Gulf into three sectors (Mines 1986). Sector I includes the municipalities of Sual towards the northernmost tip of Bolinao, characterized by hard-bottom coralline substrates. Most brackishwater ponds and trawling activities are

*ICLARM Contribution No. 1220.

localized in Sector II, characterized by soft and muddy substrates and in Sector III, with sandy substrates.

The population of Pangasinan and La Union provinces was estimated at 1.15 million in 1989 by the Philippine National Census and Statistics Office with an average of 40% living near the coast. Density is highest in Sector II at the municipal and village levels. Estimated population growth rate is 3.2% at the municipal level but is estimated to reach 12% in the coastal villages (McManus and Rivera 1990).

Ferrer et al. (1988) note that the Gulf provides more than half of the employment in the area either through direct fishing or its ancillary activities. Fishing and related activities account for 83% of total employment in Sector III but only 46% in Sector I where farming is a more important occupation.

FISHERIES

The fisheries of Lingayen Gulf consists of the commercial and municipal sector. The commercial sector is represented by at least thirty-eight trawlers which increased twofold by the 1990s owing to the trawling ban in Manila Bay. The increase in numbers may well include danish seines (*hulbot hulbot)* which are actually refitted trawlers. Average catch of the commercial sector amounted to 38,000 t·year^{-1} from

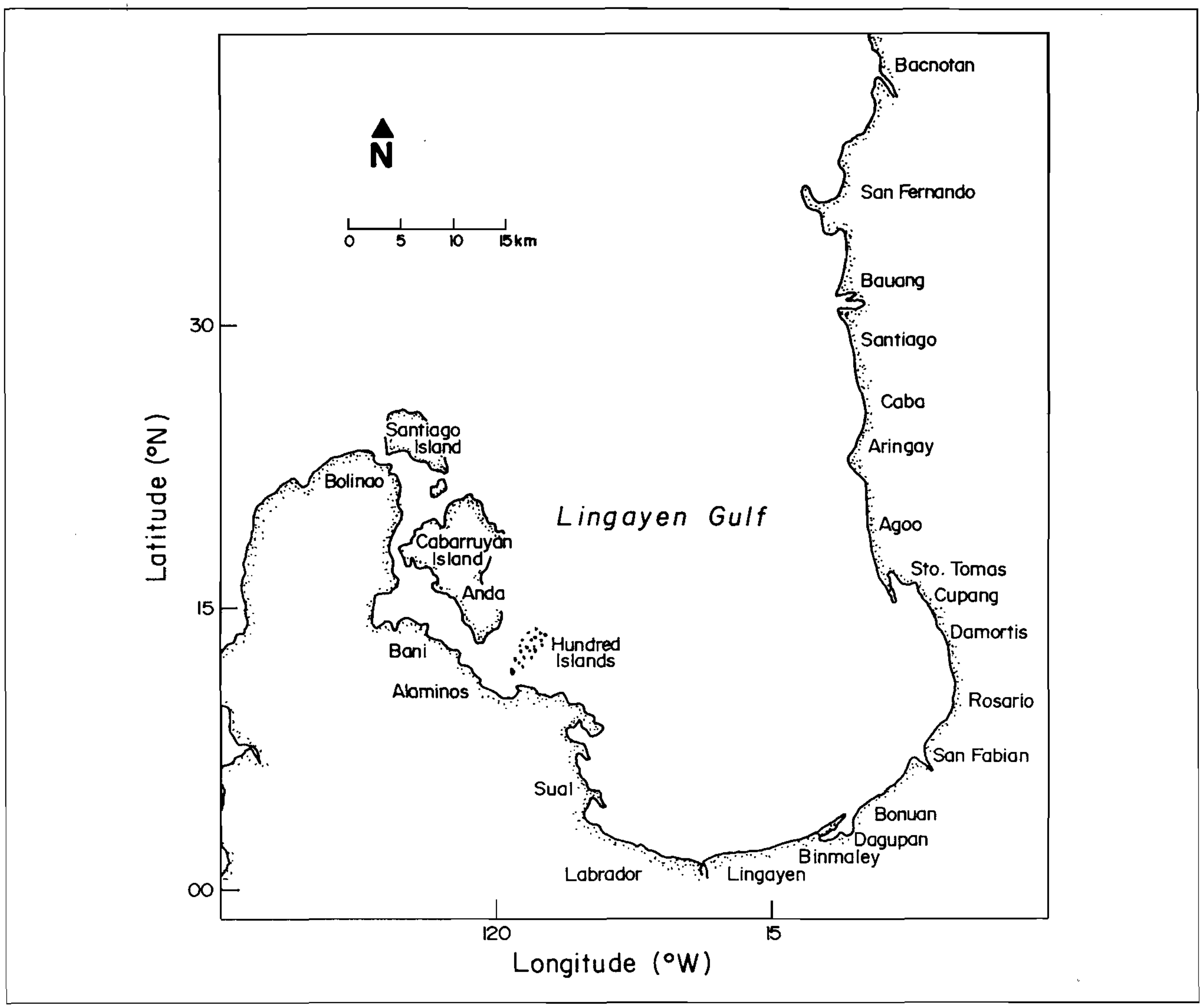
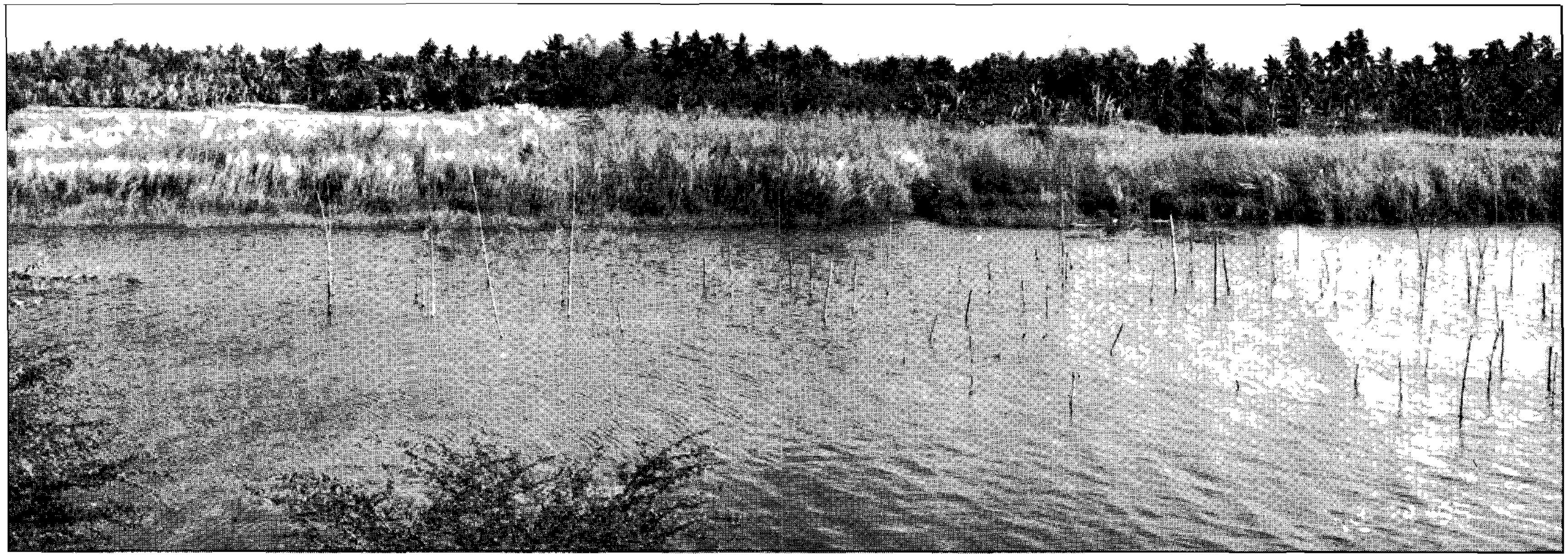
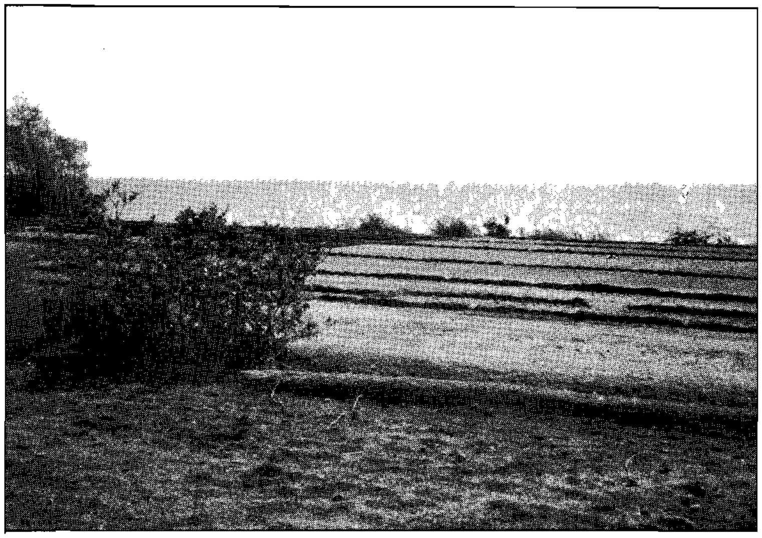


Fig. 1 . Lingayen Gulf coastal area.

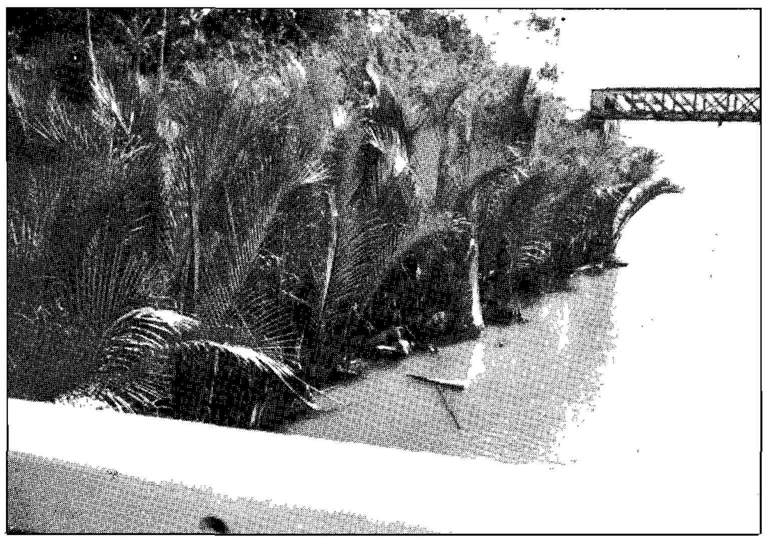


Estuarine grasslands in Dagupan City, Pangasinan with potential for aquaculture conversion. Photo by A. Cruz-Trinidad.

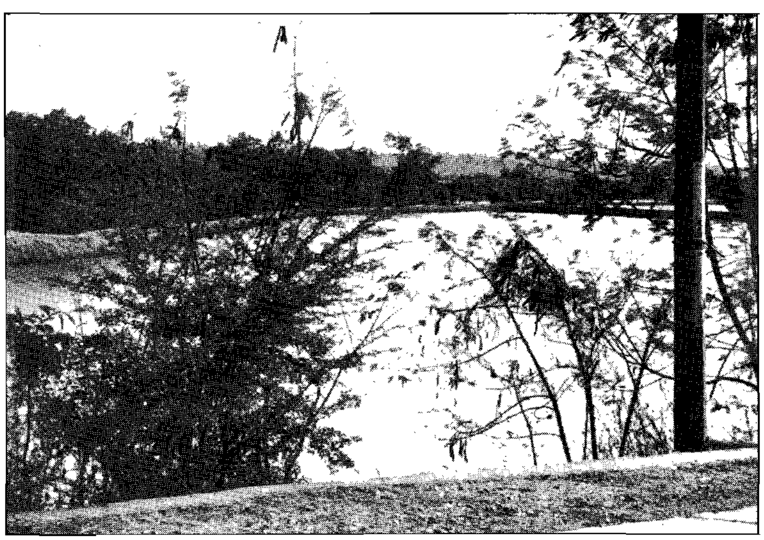


Coastal ricelands with potential for aquaculture conversion.

Photos by A. Cruz-Trinidad



Mangrove area in Lingayen Gulf dominated by Nipa species *(Nipa fruticans)*.



Aqua-silviculture practice: fishpond areas where paddies are planted with mangrove species.

1989 to 1993 whereas the municipal sector landed an average of 21,000 t·year^{-1} during the same period. The municipal sector has 28 different types of gears (Silvestre and Palma 1990), the most important of which are gill nets and explosives. The sectoral contributions to gross revenues are P631 million* and P130 million for the municipal and commercial sectors, respectively.

Several studies point to the overexploitation of the Lingayen Gulf fisheries. Fox (1986) used fisher density, Silvestre (1986) analyzed biologically optimum mesh sizes and species composition, while Signey (1987) and Cruz and Silvestre (1988) compared profitability parameters of various types of fishing gears. Furthermore, intense competition between municipal and commercial fishers is prevalent due to the intrusion of trawlers into municipal inshore waters. The situation is aggravated by the increase in number of municipal fishers who feel forced to deploy destructive fishing techniques such as blast fishing (Pauly 1990).

AQUACULTURE

The importance of aquaculture, especially the brackishwater culture of milkfish *Chanos chanos,* and much later, shrimp, cannot be overemphasized. The region is the country's third largest producer of milkfish and tiger shrimps (in volume and value terms) next to Western Visayas and Central Luzon. From 1990 to 1993, an annual average of 17,000 t of milkfish was produced yielding P585 million·year^{-1}. Shrimp production, while yielding an average of 2,100 t during the same period, resulted in annual average receipts of P343 million (Table 1).

There are 16,000 hectares of fishponds in Pangasinan and La Union provinces, 13,000 ha of which are privately owned (Table 2). Fishpond density is highest in the municipalities of Dagupan, Binmaley and Lingayen with an average pond size of 1.9 ha. Fishponds are managed extensively with an average production not exceeding 1,000 kg·ha^{-1}year^{-1} (Paw et al. 1994). Monoculture of milkfish predominates, but some farmers especially in the Binmaley area have experimented with polyculture of milkfish-siganid, shrimp-milkfish, and shrimp-siganid-milkfish. Oyster farms with an average area of 100 m^2 are concentrated in the Dagupan-Binmaley area. Hanging culture or *bitin* is the most common method. Cage culture of groupers, snappers and siganids is a nascent but highly promising industry. Groupers, in particular, fetch attractive prices in the domestic markets, more so in the export market, especially when sold live (Agüero and Cruz 1991).

Table 1. Production of milkfish and shrimp from brackishwater ponds in the Ilocos Region: volume and value of production, 1990-93.

	1990	1991	1992	1993
Volume (t)				
Milkfish	17,804	23,561	17,017	11,195
Shrimp	4,189	4,556	875	1,619
Value (in thousand pesos)[1]				
Milkfish	363,208	662,076	719,820	593,990
Shrimp	518,442	534,186	119,611	199,600

[1]US$1 = P25.4, July 1992-June 1993

Table 2. Number and total area of privately-owned brackishwater fishponds in the coastal municipalities of Pangasinan Province, 1984.

Municipality	No. of fishponds	Total area (ha)
San Fabian	324	279
Mangaldan	71	157
Dagupan	2,693	3,830
Binmaley	3,721	3,728
Lingayen	2,337	1,729
Labrador	138	153
Sual	61	112
Alaminos	305	1,200
Bani	205	1,328
Anda	137	881
Bolinao	50	55
Total	10,042	13,452

Water pollution from domestic and industrial waste affects growth and survival of cultured species. Serious contamination of the Dagupan-Binmaley River with domestic wastes resulting in high coliform counts affect the oyster farms in the area. Industrial pollution from the Bayawas River and mine tailings from the Benguet uplands is detrimental to the fishponds. Another issue faced by the industry is the low productivity of milkfish ponds which has vast implications on land use alternatives.

TOURISM

The Lingayen Gulf area is endowed with long stretches of sandy beaches running from Bauang to Agoo in La Union, natural scenic areas such as the Hundred Islands in Alaminos, and a rich culture and

*US$1 = P25.4 (July 1992 to June 1993).

history. A complete list of tourist sites, together with resorts and facilities, is provided by Cargamento et al. (1994).

Tourism development is highly dependent on environmental quality, so the issues that confront fisheries and aquaculture also affect this sector, albeit not directly. Water pollution and siltation are problems that directly affect tourism. Siting of ponds and cages are also potential deterrents to tourism activities. Overfishing and its attendant evils, e.g. coral mining and blastfishing, indirectly affect tourism because it renders the resource aesthetically unappealing, not to mention the dangers posed by illegal fishing methods.

Changing Land Use Patterns

The Medium Term Regional Development Plan of Region I emphasizes the significance of the provinces of Pangasinan and La Union as primary growth hubs (Cargamento and Rillon 1994). Under the Northwestern Luzon Growth Quadrangle Program, this area will be the site for three of the industrial centers to be developed in addition to its traditional activities in fishing, aquaculture and tourism. These development trends are expected to exert further pressure on coastal resources mainly due to an increase in population and in-migration. The following section describes the fast pace of land use change and maps out development trends.

Existing land use of the 17 coastal municipalities is shown in Table 3. Ricelands and grasslands occupy a significant area in the region. Mangroves, though presently occupying only 227 ha, have been dominant in the Gulf area and are prime areas for fishpond sites, especially in the eastern and central portions. Irrigated ricelands occupy 46% of the total land area and are mostly situated in Alaminos and Bani. The area of salinized ricelands was estimated based on a distance of 1.5 km from the shore or 15,612 ha. Grasslands dominate the landscapes of Sual, Bani and Labrador while the remaining mangroves are localized in Bolinao and Lingayen.

Land use conversion patterns are derived from 1986 and 1990 maps produced by the Bureau of Soils and Water Management (BSWM) (Tables 4 and 5). Of the 1,163 ha of mangroves, 73% have been retained as such while 243 ha have been converted to ricefields. While the BSWM maps showed no mangrove conversion to fishponds during the period, the abovementioned GIS study noted the conversion of at least 21 ha in Bolinao (Alojado et al. 1994; Paw et al. 1994).

Irrigated ricefields have been converted into grasslands, fishponds, mangroves and built-up areas. Conversion of irrigated ricelands to aquaculture is significant in the municipalities of Bani and Lingayen (Table 5). Out of the total fishpond hectarage, only 58% have been maintained as such, with 30% of the area being converted to ricelands and a smaller percentage to coconut

Table 3. Change in land use from 1986 to present (area in hectares).

Municipalities	Grassland	Mangrove/ nipa	Ricefield, irrigated	Fishponds	Beach sand	Riverwash	Freshwater swamp	Salt beds	Total
Alaminos	5,259	0	9,283	734	0	0	0	0	15,276
Anda	620	0	3,756	502	0	0	0	124	5,002
Bani	6,151	0	8,531	2,202	0	0	0	0	16,884
Bolinao	1,502	183	2,868	123	0	0	0	0	4,676
Sual	9,012	0	4,132	69	0	0	0	0	13,213
Labrador	5,488	0	1,391	305	0	0	0	0	7,184
Lingayen	0	285	2,867	1,855	357	13	157	0	5,534
Binmaley	0	0	1,769	2,822	12	0	0	0	4,603
San Fabian	3,169	0	2,516	55	11	578	0	0	6,329
Dagupan	0	0	1,141	2,541	19	0	0	0	3,701
Agoo	464	0	1,724	27	10	0	0	0	2,225
Aringay	2,335	0	1,831	608	42	21	0	0	4,837
Bauang	2,250	0	1,854	131	99	245	0	0	4,579
Caba	2,227	0	1,023	0	60	19	0	0	3,329
Rosario	2,945	0	3,055	0	0	0	0	0	6,000
San Fernando	3,253	0	1,988	254	0	0	0	0	5,495
Sto. Tomas	1,547	0	2,311	375	48	0	0	0	4,281
Total	46,222	468*	52,040	12,603	658	876	157	124	113,148

*Total mangrove/nipa area as updated by areal photo is 227 ha.

Table 4. Change in land use in Lingayen Gulf from 1986 to 1990, from existing to potential land use.

Legends	Primary forest	Secondary forest	Grassland	Mangrove/ nipa	Paddyrice irrigated	Shrubs	Coconut	Built-up	Coffee	Cassava	Sugarcane	Corn	Fishpond
Forest	2,445	33,372	9,297		302	1,337							
Grassland	559	15,010	140,644		21,620	16,059	437	1,159		287	1,219	57	293
Mangrove/ nipa				848	249	54		12			1,552		
Paddyrice irrigated		465	18,444	1,698	183,043	9,244	3,082	14,660	166	1,113	384	946	3,073
Shrubs		10,521	17,117	48	8,149	57,252	944	747		15	152	131	453
Coconut			233	78	5,118	2,404	6,311	863			527		205
Built-up			1,021	111	17,379	460	808	12,509	16	75		93	713
Fruits					33			24	45				
Cassava			753		61					503			
Sugarcane					1,289		533	899			1,834		15
Corn			32		277	182		94					
Fishpond			266	40	3,842	149	566	883			73		7,923
Saltbed			9		124	64	7						134
Beachsand			18		1,398	85	369	423					338
Ipil-ipil						45							
Riverwash		1,586	2,352		5,378	708	149	1,368	1	9	569	509	94
Grapes					22	91							
Mango			18		43	30	10						
Maguey					15	87					36		
Swamp			103	10	841		21	70		445	46		1,217
Total	3,004	60,954	190,307	2,833	249,183	88,251	13,237	33,711	228	2,447	6,392	1,736	14,458

Legends	Bamboo	Upland rice	Salt-bed	Beach-sand	Ipil-ipil	River wash	Rice terrace	Grapes	Mango	Maguey	Swamps	Kaingin	Vegetable low terrace	Airport	Total
Forest						118	33							46,904	
Grassland		155	246		13	651	100		152	10			100		198,771
Mangrove/ nipa															1,163
Paddyrice irrigated	13	296	236	48		3,328	324	19	194	3	1,370		79		243,396
Shrubs	49	246	61	31	75	245	151		93	338		22	266	10	97,348
Coconut				34	43						33	24			15,498
Built-up	10			18		233		34			10		43	15	34,075
Fruits															102
Cassava															1,317
Sugarcane						75			9						4,654
Corn		24							19				48		676
Fishpond	10			13											13,765
Saltbed			230												568
Beachsand				771									105		3,507
Ipil-ipil															45
Riverwash				33		7,949			42				523		21,270
Grapes								39							152
Mango											49				150
Maguey															138
Swamp											61				2,814
Total	82	721	773	948	131	12,599	608	92	509	351	1,523	46	1,164	25	686,313

Table 5. Change in land use in Lingayen Gulf area from 1986 to 1990, by municipality.

Change	Alaminos	Anda	Bani	Bolinao	Sual	Labrador	Lingayen	Binmaley	San Fabian	Dagupan	Agoo	Aringay	Bauang	San Fernando	Sto. Tomas	Total
1	131.50	372.00			213.70											717.20
2			891.80	20.90												20.90
3	377.90	383.90	98.60	68.70	10.50	210.60	611.00	470.60	7.50	331.60	7.50	86.60		52.30	127.00	3,637.50
4	101.60	256.90		135.90									50.80			643.80
5		85.10	28.40	38.80			9.00			115.00			23.90			271.80
6	68.70	1.50	1,807.50			23.90	92.60	64.20	7.50	207.60				88.10		582.50
7	434.70	131.50	130.00	1.50		70.20	1,384.80	2,216.80	23.90	2,207.90	14.90	431.70		113.50	216.60	9,055.50
8																130.00
9							68.70	230.00	16.40	135.90	4.50		52.30		31.40	539.20
10												89.60	4.50			94.10
11							248.00	448.10								696.10
12		9.00														9.00
13									7.50							7.50
14									3.00							3.00
15				13.40												13.40
Total	1,114.40	1,239.90	2,956.30	279.20	224.20	304.70	2,414.10	3,429.70	65.80	2,998.00	26.90	607.90	131.50	253.90	375.00	16,421.50

and built-up areas. Grasslands have been converted to rice paddies, especially in the municipalities of Anda and Sual, and into shrublands and secondary forests. Table 5 also indicates that suitable areas for aquaculture conversion are minimal: some 7.5 ha of riceland, 3 ha of grassland in San Fabian and 13.4 ha of shrubland in Bolinao.

Substantial mangrove and nipa swamps including ricelands were converted to aquaculture farms with mangrove conversion having begun during the 1950s (Dannhaeuser 1986; Paw and Palma 1991). Present aggregate area of brackishwater ponds is 14,589 ha with about 1,566 ha located in La Union, the rest being distributed among the municipalities of Binmaley, Dagupan, Bani, and Lingayen in Pangasinan. Paw et al. (1994) showed the conversion rate of different land use types to brackishwater ponds from 1986 to 1990 to total 6,534 ha or an average of 1,300 ha·year^{-1}.

Costs and Benefits of Altering Land Use

Monetary

Table 6 lists four types of land use types and corresponding parameters reflecting alternative uses, i.e., milkfish ponds, shrimp ponds and maintenance of existing use. "Maintenance" use includes both productive and nonproductive use of land.

Table 6. Cost and revenue parameters of different land use types in Lingayen Gulf area.

Existing land use and parameters	Alternative use: Milkfish ponds	Shrimp ponds	No conversion
Productive ricelands			
Conversion cost (P·ha^{-1})	100,000	100,000	
Operating cost (P·ha^{-1}·year^{-1})	100,000	100,000	10,000
Production (kg·year^{-1})	5,000	4,000	9,200
Average net revenue[1]	265,000	420,000	55,200
Salinized ricelands			
Conversion cost (P·ha^{-1})	100,000	100,000	
Operating cost (P·ha^{-1}·year^{-1})	100,000	100,000	12,000
Production (kg·year^{-1})	7,500	5,000	7,000
Average net revenue	452,500	490,000	42,000
Grasslands			
Conversion cost (P·ha^{-1})	200,000	200,000	
Operating cost (P·ha^{-1}·year^{-1})	100,000	100,000	75,000
Production (kg·year^{-1})	5,000	4,000	0
Average net revenue	255,000	360,000	-75,000[2]
Mangroves			
Conversion cost (P·ha^{-1})	500,000	500,000	
Operating cost (P·ha^{-1}·year^{-1})	100,000	100,000	0
Production (kg·year^{-1})	10,000	6,000	8,695
Average net revenue	600,000	570,000	8,695[3]

[1]Based on farmgate price of P120·kg^{-1} for shrimps, P75·kg^{-1} for milkfish and P6·kg^{-1} for rice.
[2]Based on assessed value and represents foregone earnings.
[3]Based on mangrove valuation in Pagbilao, Quezon.

Productive and salinized ricelands can be converted to ponds at a development cost of P100,000·ha^{-1}. Conversion costs of grasslands is P200,000 ha^{-1}, twice the cost of ricelands due to the absence of paddy structures. Mangrove conversion cost is estimated at P500,000·ha^{-1} (A. Cargamento, pers. comm.) and includes the construction of dikes and the clearing of forests. Operating costs for all types of ponds irrespective of initial land type is held constant at P100,000·ha^{-1} (Primavera 1993).

Average milkfish production is assumed to be higher than the current average to reflect the thrust towards semi-intensive pond operation. Minimum production level for milkfish is 5,000 kg·ha^{-1}·year^{-1} for productive ricelands and grasslands but is assumed to be higher, i.e., 7,500 kg·ha^{-1}·year^{-1} for salinized ricelands as an effect of saltwater intrusion. The production level for shrimp is based on estimates used by Primavera (1993) for semi-intensive farms. As in the case of milkfish, production levels for shrimps from salinized farms are increased to 5,000 kg·ha^{-1}·year^{-1}. Production levels for both shrimps and milkfish are considerably increased in the case of conversion from mangroves due to its favorable physical and ecological attributes.

Ricelands yield net revenues if maintained as such. Production for a two cropping period is 9,200 kg·year^{-1} (C.R. de la Cruz, pers. comm.) and operating cost is P10,000·year^{-1}. Operating cost includes cost of seeds, fertilizers, and labor and is assumed similar for salinized ricelands. Average production for the latter, however, was assumed to be 7,000 kg·year^{-1} due to the effect of saltwater intrusion.

Grasslands would yield no revenue if maintained in their existing form because no directly marketable goods and services arise from their use. Society would, in fact, incur a cost equivalent to their current assessed value.

The value of mangroves was based on PIDS (1994), which did valuation work for two mangrove ecosystems, i.e., Pagbilao Bay in Quezon Province and Ulugan Bay in Palawan. The value used for Lingayen Gulf was based on the former because of similar areas, i.e., 350 ha for Pagbilao and 227 ha for Lingayen as opposed to 1,800 ha for Ulugan Bay, as well as status of exploitation. The value was based on summation of direct (fish, invertebrates and juveniles) and indirect goods (litterfall).

The conversion option results in average net revenue based on a 10-year cash flow where conversion costs are reflected only for the first year. Thus, net revenue resulting from mangrove conversion are the highest among all alternatives despite high conversion costs. Net revenue resulting from the conversion of grasslands is the lowest. The *status quo* results in net revenue for productive and salinized ricelands, albeit lower for the latter. Net revenue accruing to mangroves is minimal but positive because no costs are incurred, while grasslands result in a net loss because no marketable goods and services result from its nonuse.

A straightforward comparison of the net revenue resulting from three land use options shows that, based on economic efficiency objectives and in the absence of fixed (e.g., land availability) as well as exogenous limits (conversion limits), all mangroves would be converted to ponds and none of the existing land types would be retained. The LP exercise allows us to determine the optimal land use mix without compromising these limits.

Environmental

Use of the TEV approach necessitates the identification of use and nonuse values of land types as presented in Table 7. Ricelands and grasslands found in the Lingayen Gulf area have two direct uses: agriculture and human settlements. Moreover, ricelands and grasslands play an important role of providing vegetative cover thus preventing soil erosion and decreasing the amount of sediments reaching the Gulf. Granting that the Lingayen Gulf area is flood prone, ricelands and grasslands also have a role in flood prevention.

Mangrove is a very critical resource found in the coastal area. Aside from the directly marketable goods and services such as forest resources (charcoal, firewood, tannin), wildlife, fisheries, forage and water supply, mangroves have important ecological functions. Zamora (1989) points out that once a mangrove area is converted into a fishpond, it no longer functions as a natural system and ceases to contribute to the productivity of the nearby nearshore ecosystem. Furthermore, mangrove conversion results in the loss of all standing biomass as well as the total disruption of soil, preventing natural regeneration.

Adverse effects of mangrove conversion include decreases in catches of mature and juvenile fish and shrimp (Martosubroto and Naamin 1977; Camacho and Bagarinao 1986). The loss of nursery grounds and eventual scarcity of shrimp fry also affect aquaculture operations as documented in Bell and Cruz-Trinidad (this vol.).

Linear Programming Application

Objective Function

The objective function is the maximization of net revenue arising from the use of four types of land for three possible options. Net revenue per option is dependent on two components: 1) area of land devoted for a particular purpose; and 2) net revenue resulting from the production of marketable products including rice, shrimps, ponds. Component 2 is computed based on prices and estimated production levels.

The solution to the objective function includes optimal land use mix and the resulting level of total

Table 7. Use and nonuse values of land types in coastal areas of Lingayen Gulf, Philippines.

Land type	Direct use	Indirect use	Nonuse
Ricelands	Agriculture Human settlements	Nutrient retention	
Grasslands	Agriculture Human settlements	Sediment retention Wildlife habitat	
Mangroves	Forest resources Wildlife Fisheries Forage Agriculture Water supply	Groundwater recharge/discharge Flood and flow control Shoreline/bank stabilization Sediment retention Nutrient retention Biological diversity	External support Recreation/tourism Water transport Uniqueness to culture/heritage

profits. The representation of the objective function is as follows:

Max ¶

where ¶ is profit and is equal to

$$¶ = NR_{ij} * H_{ij}; \quad ...1)$$

Nr_{ij} = the net revenue resulting from land type i and option j; and

H_{ij} = the area devoted to land type i and potential and use j.

The subscripts i and j refer to existing land type and potential land use, respectively:

i = 1,...4
1 = productive ricefield;
2 = salinized riceland;
3 = grasslands; and
4 = mangroves.
j = 1,...3
1 = no change;
2 = milkfish ponds; and
3 = shrimp ponds.

$$Nr_{ij} = TR_{ij} - CC_{ij} - OC_{ij} \quad ...2)$$

where

Tr_{ij} = Total revenue, product of price, P_k and quantity of production, Q_k;

Cc_{ij} = Conversion cost of land type i into option j;

Oc_{ij} = Operating cost of land type i used for option j;

where

k = 1,...3
1 = rice;
2 = milkfish; and
3 = shrimp

Constraints

1) Land use constraints

H_{1j} <= 36,428 ...3)
H_{2j} <= 15,612 ...4)
H_{3j} <= 46,222 ...5)
H_{4j} <= 227 ...6)

The above constraints are the existing area of the four types of land use, which is theoretically the maximum allowable level of conversion.

2) Conversion constraints

H_{i2} <= 10,000 ...7)
H_{i3} <= 10,000 ...8)

An additional constraint imposed on the system is the maximum conversion rate to pond aquaculture. The limit imposed is 10,000 ha each for milkfish and shrimp ponds and is binding for a period of 10 years. This translates to an annual conversion rate of 1,000 ha which was observed to be the average conversion rate for the region (Paw et al. 1994).

3) Nonnegativity constraints

H_{ij} >= 0

Results

Optimal Land Conversion Rates

Using a direct cost and revenues approach, the areal distribution for different land types across three land use options is summarized in Table 8. Productive ricelands are maintained but all salinized ricelands are converted to ponds. Milkfish ponds account for 63% of the total area of salinized ricelands while the remaining amount is devoted to shrimp ponds. Due to the limits imposed on area of shrimp and milkfish ponds, only 4,161 ha of grasslands resulted from optimal conversion rates, while the remaining area would be retained despite the low returns. This scenario supports the total conversion of the remaining 227 ha of mangroves to milkfish ponds. Potential benefits resulting from this land use mix amount to P7.4 billion·year^{-1} which is about 50% of the estimated Gross Value Added in agriculture and forestry of P15.3 billion in current prices (NSCB 1995).

The optimal distribution changes when the TEV approach is used. This approach involves the estimation of Future Value (FV)* and the incorporation of foregone benefits. The latter is estimated by subtracting from potential net revenues the corresponding amount foregone by maintaining the land in its existing form.

*An analog of the Present Value (PV) criterion, the use of FV emphasizes the importance of future rather than present benefits.

Table 8. Optimal land use allocation (ha) using a direct costs and revenues approach (Case 1) and a Total Economic Value (TEV) approach (Case 2).

Case 1	Alternatives		
	Milkfish ponds	Shrimp ponds	Existing use
Productive ricelands	0	0	36,428
Salinized ricelands	9,773	5,839	0
Grasslands	0	4,161	42,061
Mangroves	227	0	0
Net benefits	-	$7.4 \cdot 10^9$	-
Case 2			
Productive ricelands	0	0	36,428
Salinized ricelands	10,000	0	5,612
Grasslands	0	10,000	36,222
Mangroves	0	0	227
Net benefits	-	$35 \cdot 10^9$	-

For example, the conversion of productive ricelands to milkfish ponds would necessarily eliminate possibilities of using said land for rice production. Potential net revenue is then minimized by the amount of revenue foregone by maintaining land in its existing form (Table 9). This procedure is based on the assumption that land conversion results in adverse and oftentimes irreversible environmental impacts. On the other hand, land that is maintained in its existing form has implicit potentials for conversion. The resulting net revenue is thus estimated as the existing revenue plus average potential revenue arising from conversion. This procedure has an inherent conservationist bias since it has a minimization effect on the conversion option and an enhancement effect on the nonconversion option.

Future Values (FV) were estimated for mangroves because of indirect as well as nonuse values which were not adequately assessed. Furthermore, it is assumed that the value of critical ecosystems increase exponentially in relation to the remaining area mainly because of their bequest value. Future value of mangroves was estimated to reach P6.1 million·year^{-1}

Table 9. Estimation of net revenue based on a Total Economic Value (TEV) approach, in pesos.

Land type	Milkfish	Shrimp	Existing use
Productive ricelands	219,800	324,800	317,500
Salinized ricelands	422,500	460,000	471,250
Grasslands	255,000	360,000	307,500
Mangroves	600,000	570,000	6,120,394

based on a 10-year planning scenario and a discount rate of 3%. The optimal land use mix resulting from said approach is as follows: 1) productive ricelands are maintained as such while more than 60% of salinized ricelands are better off being converted to milkfish ponds; 2) of the total grasslands area, 10,000 ha are proposed for conversion to shrimp ponds; and 3) no mangroves are to be converted to ponds. This optimal land use mix results in a net benefit of P35 billion.

Sensitivity Analysis

This exercise determines the effect of changing the constraints and that of the coefficients in the objective function on the estimate of net revenue and optimal land use distribution, assuming a direct cost and revenue approach (Case 1). Changes in the constraints assumed a downscaling of the limits to pond conversion, i.e., from 10,000 ha·year^{-1} to 5,000 ha·year^{-1} for a period of 10 years. The result is a corresponding decrease in total revenue by more than half and a shift in the allocation of land. The 5,000 ha conversion limit for milkfish ponds was allocated among salinized ricelands, 4,773 ha and mangroves, 227 ha. Shrimp ponds were wholly allocated to salinized ricelands. Productive ricelands and grasslands were maintained in their existing form, the former because of revenue resulting from rice production. Grasslands were retained because of the relatively low returns after conversion (Table 10).

Changes in objective function coefficients would be brought about by changes in one or more of the components, e.g., production levels, price, or costs. Assumed increases in production levels of milkfish would result in an increase in total revenues to P9.8 billion. Milkfish pond conversion was totally allocated to grasslands with the remaining area being retained. The allocation for shrimp ponds was distributed among salinized ricelands, 9,773 ha and mangroves, 227 ha. Productive ricelands are retained.

Conclusion

The LP was used to determine optimal land use based on two conflicting scenarios. The first uses a direct cost and revenue approach and results in an optimal mix which maximizes net revenue but has an inherent bias towards short-term gains. Thus, Case 1 results in a total conversion of mangroves. The second

Table 10. Sensitivity analysis of optimal land allocation applied to two cases and resulting benefits: Case 1, pond conversion cut by half; Case 2, increase in milkfish production[1] (land use in ha, total benefit in pesos).

Land type	Local distribution		
	Milkfish	Shrimp	Existing use
Case 1			
Productive riceland	0	0	36,428
Salinized riceland	4,773	5,000	5,839
Grassland	0	0	46,222
Mangroves	227	0	0
Total benefit	-	$3.1 \cdot 10^9$	-
Case 2			
Productive riceland	0	0	36,428
Salinized riceland	0	9,773	5,839
Grassland	10,000	0	36,222
Mangrove	0	227	0
Total benefit	-	$9.8 \cdot 10^9$	-

[1]Productive riceland, salinized riceland and grassland to 10,000 kg·ha^{-1}; mangroves to 15,000 kg·ha^{-1}.
US$1=P25.40 (July 1992 to June 1993)

case is an adaptation of the TEV approach and incorporates all possible sources of value. Case 2 emphasizes the future earnings of a particular land use and accounts for all foregone earnings as well. The distribution of land use based on Case 2 shows a bias towards maintaining land in its present state, especially for land with large foregone earnings as in the case of productive ricelands, or as in the case of mangroves, large indirect and nonuse values. The resulting net revenue is higher in Case 2 despite the fact that large earnings from shrimp and milkfish culture are foregone in the short-run.

The exercise results in recommendations that are only as good as the values used. The value assigned to a particular resource is dependent first on the knowledge and appreciation of its natural function and next on the valuation procedure used. The critical role of valuation is emphasized in Aguero et al. (this vol.) as being the essential inputs of the Linear Program (LP). More theoretical and applied work in natural resources valuation is obviously required in order to establish guidelines for applicability, especially pertaining to issues of double-counting and appropriate use of discount rates. Furthermore, a more effective interface between the biological sciences and resource economics should be fostered to determine the linkages of ecological functions to marketable goods and services.

The procedure used, however, has proven to be useful in policy setting in this fast-growth region where excessive pressures on coastal land use may compromise sustainability objectives.

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Optimal Fleet Configuration in San Miguel Bay, Philippines: A Simple Linear Programming Approach*

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Abstract

Three alternative scenarios were used to estimate fishery net revenues in San Miguel Bay, Philippines, using a constrained maximization approach. The constraints included total allowable catch, catch distribution and crew wages. The scenario which closely approximated the existing effort levels in the fishery resulted in net revenues amounting to P6.3·10^6·$year^{-1}$ or US\$248·10^3·$year^{-1}$. A scenario which accommodated an increased number of fish corrals but diminished "baby" trawlers by almost 30%, resulted in a net revenue increase to P19.4·10^6·$year^{-1}$. The latter scenario's bias towards small-scale gears resulted in the highest level of net revenues, thus maintaining a congruence between efficiency and equity objectives. Wages, which were observed to be greater than prevailing opportunity costs, were deemed unsustainable if catch constraints were to be met.

Introduction

San Miguel Bay (Fig. 1), located in the Bicol region in the Pacific coast of the Philippines, is a shallow, estuarine body of water with an area of about 1,115 km^2. The bay is bounded by seven coastal municipalities, Mercedes and Basud, in Camarines Norte, and Sipocot, Cabusao, Calabanga, Tinambac and Siruma, in Camarines Sur province. The National Statistics Office (NSO 1990a, NSO 1990b) estimates population in the 74 coastal villages to have reached 93,000 in 1990. Agriculture, fishery and forestry are the major sources of income.

Since the first investigation of the San Miguel Bay fisheries in the late 1930s (Umali 1937), a series of works followed (e.g., Warfel and Manacop 1950; Legasto et al. 1975; Simpson 1978) which were wholly or partly on the Bay's fisheries. Detailed assessment conducted by the Institute of Fisheries Development and Research (IFDR) of the University of the Philippines, College of Fisheries and the International Center for Living Aquatic Resources Management (ICLARM) in the area in 1979-81 summarized these works (Bailey 1982a, 1982b; Pauly and Mines 1982; Smith and Mines 1982; Smith et al. 1983), presented a diagnosis of the status of the fisheries, which were characterized by overexploitation and distributional inequity, and provided appropriate management options. The area was revisited by ICLARM in 1992-93 via a Resource and Ecological Assessment (REA) study under the auspices of the Philippine Department of Agriculture's (DA) Fisheries Sector Program (FSP). Data were collected in the San Miguel Bay area during July 1992 - June 1993 based on three data generation activities: 1) inventory of fishing gears, from January to June 1993; 2) monitoring of commercial and municipal fisheries, from July 1992 to June 1993; and 3) monitoring of fishing operations from July 1992 to June 1993 (Silvestre et al. 1995).

Thus far, the REA study is the most comprehensive, dealing with physical and biological oceanography, fisheries stock assessment and threatened ecosystems. The socioeconomic components included cost and returns of different types of gears, fishing dynamics,

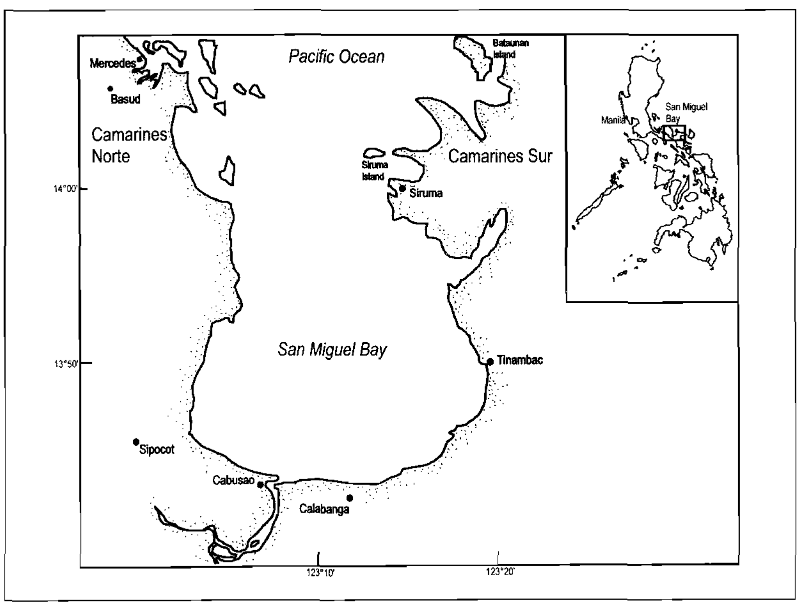

Fig. 1. San Miguel Bay, Philippines.

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market performance, livelihood options and institutional arrangements.

This paper estimates fishery net revenues from data collected by the DA-FSP San Miguel Bay project, using a constrained maximization approach. Fishery net revenue is the aggregate revenue earned by individual fishing units and is thus affected by fleet structure. Several strategies can be adapted to maximize net revenues: for example, concentrate on a choice group of highly efficient vessels; or fully exploit the resource to increase catch levels. The first proposal is invalidated by equity considerations while the latter is not sustainable. A possibility examined here is the maximization of net revenues that incorporates constraints such as allowable catches, equity implications and minimum wages.

The San Miguel Bay Fishery

San Miguel Bay is characterized by a multigear and multispecies fishery. About 5,300 fishers reside in the seven coastal municipalities bordering the bay (Sunderlin 1995a, 1995b) and employ over 50 distinct types of fishing methods/gear and over 4,700 units of various types of fishing gear. The major gears considered in this paper contributed roughly 75% of the total catch in 1993 and are listed together with the number of boats per class in Table 1. They are classified as trawlers, gill nets, push nets and stationary gears including fish corrals, lift nets, and filter nets.

Gears Operating in San Miguel Bay

TRAWLERS

San Miguel Bay is one of the most important trawling grounds in the Philippines. It is relatively shallow, with 89% less than 7 fathoms, and 95% of its bottom is composed of sand, mud and sandy-muddy substrate. The fishing fleet is dominated by trawlers and their "derivatives" the latter including mini and baby trawlers, both classified, by tonnage less than 3 gross tons (GT), as municipal gears.

Small or 'baby' trawlers use boats that are 1.6-3.0 GT with 68-160 hp diesel engines. Crew size is five to six fishers. Each trip lasts 2-3 days. Mini trawlers *(itik-itik or kuto-kuto)* use *bancas* with outriggers and are powered by 10-16 hp gasoline engines. Crew size is two to three fishers and fishing lasts from 5:00 a.m. to 3:00 p.m. Mini trawls are used in shallow waters of 4-10 m depth and target sergestid shrimps.

There were 35 large trawlers and 38 medium trawlers registered in the area but only one large trawler was observed to operate intermittently during the sampling period. There are 260 mini trawlers and 50 baby trawlers presently operating; these were all included in the sample.

Table 1. Comparison of fishing effort and catch per gear type in San Miguel Bay from 1980-81 to 1992-93.

Gear type	1980-81				1992-93			
	No. of units	Trips per year	Catch (t)	(%)	No. of units	Trips per year	Catch (t)	(%)
Trawlers								
Large	30	103[a]	2,385[b]	12.5[b]	35	125[a]	25	0.14
Medium	17				38		308	1.7
Small	72		9,291[c]	48.6[c]	50		3,905	22
Mini	188	191			260	202	1,901	10.7
Other gears								
Gill nets	1,345	156	4,854	25	2,670	171	7,550	42
Lift net	171	53	624	3	60	115	1,021	6
Filter net	60	225	295	1.5	260	240	967	5
Scissor net	834	150	476	2.5	245	168	823	5

[a]All others
[b]Large and medium
[c]Small or (baby) and mini

GILL NETS

The study identified 24 types of gill nets totalling to 2,670 units. Gill nets are named according to mode of operation (e.g., drift gill net, bottom set gill net) or target species (e.g., shrimp gill net, *lait;* crab gill net, *pangasag)* but the most common is the ordinary gill net, *panke*. Characteristics of gill nets in Table 1 actually refer to an index based on *panke* units.

PUSH NETS

Silvestre et al. (1995) described push nets or scissor nets (*hud-hud)* as consisting of collapsible, triangularly-framed netting material mounted over two criss-crossed bamboo poles. Operations usually involve a single fisher pushing the gear along the bottom within wading depth but they have been recently observed to be mounted in front of *bancas* powered by 10-16 hp gasoline engines.

STATIONARY GEARS

Stationary gears include fish corrals, lift nets and filter nets. The descriptions provided below are based on Silvestre et al. (1995).

Fish corrals, *sagkad,* are semi-permanent gears used for guiding and trapping fish. The gear consists of a guiding barrier, two to three playground areas, and a bunt or catching area. The bunt is usually set in the evening; harvesting using scoop nets occurs the following morning. Operations involve two to three fishers who are transported by a nonmotorized banca. Target species are pelagics but usually include small demersals and shrimps.

Lift nets, *bukatot,* are square-shaped nets attached by pull ropes to four bases made of bamboo or coconut trunks planted on the seabed. Lift nets are operated in waters of about 10-20 m depth usually near the mouth of the Bay and were observed in the towns of Mercedes, Siruma and Basud. They are only used during the dark phases of the moon and have kerosene lamps to attract fishes. Operations involve about four to five fishers who raise the net via the pullropes. Target fishes are slipmouths and clupeids.

Filter nets, *biakus,* are conical bags of netting set against the tidal currents near the mouth of rivers. The net is usually lowered at dusk and retrieved 4 hours later; the process is repeated for harvest the following morning. Target species include sergestid and penaeid shrimps and anchovies.

Catch and Species Composition

Total landings were estimated to be about 17,750 t from July 1992 to June 1993 (Silvestre et al. 1995). About 35% were landed by trawls, 42% by gill nets and the remaining 23% by the other gears.

A total of 175 species distributed among 110 genera and 70 families were observed to occur in the catch (Cinco et al. 1995). Croakers (Sciaenidae), slipmouths (Leiognathidae), penaeid shrimps (Penaeidae), sergestid shrimps (Sergestidae), crabs (Portunidae) and anchovies (Engraulidae) dominate the landings, collectively accounting for 58.5% of the total landings during the period. A detailed breakdown of species composition per gear type is provided in Silvestre et al. (1995).

Status of Exploitation

A comparison of key physical indicators by major gear types between the 1980-81 and 1992-93 studies is presented in Table 1. Except for the small/baby trawlers, all gears increased in numbers. Moreover, there is also a marked increase in the frequency of trips per gear type.

In addition to increased fishing effort are other parameters that point to a worsening of the status of exploitation in the Bay including: excessive fishing pressure, changes in species composition, and changing economic performance.

EXCESSIVE FISHING PRESSURE

Excessive fishing pressure continues to be an overriding issue confronting the fisheries of San Miguel Bay despite the reallocation of effort (Silvestre et al. 1995). A comparison of relative indices of total catch, aggregate trawl horsepower, number of fishers and trawlable biomass shows that trawlable biomass has declined by about 80% from its 1940 levels (Fig. 2). The decline in catch rates is most abrupt for trawlers, i.e., 11,700 t in 1980 to about 6,100 t in 1992-93, in view of the strict enforcement of the 7 km, 7 fathom ban, the decline in number of small trawl units, and reduced catch rates of mini trawls.

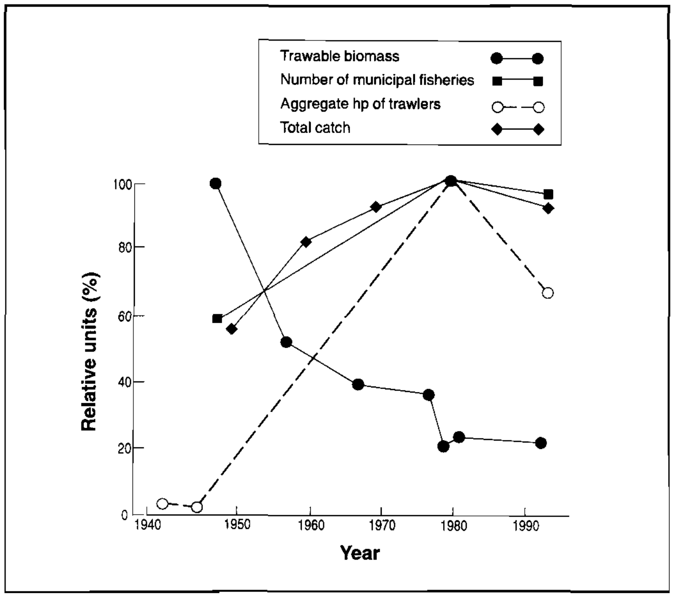

Fig. 2. Relative indices of trawlable biomass, total catch, number of fishers and aggregate horsepower of trawlers in San Miguel Bay from the 1940s to the early 1990s.

Cinco et al. (1995) also noted that mean exploitation ratio for the more abundant species is 0.65. These observations are indicators of overfishing and are supported by conventional fisheries theory and likewise reflects that a stock is overfished when biomass is reduced below 30 to 50% of virgin stock levels or if the exploitation ratio is way above the "optimum" values ranging from 0.3 to 0.5 (Silvestre et al. 1995).

CHANGE IN SPECIES COMPOSITION

Table 2 gives a summary of trends in species composition changes reflective of growth, recruitment and ecosystem overfishing (Cinco et al. 1995). This trend is also manifested in species composition changes by gear type. In 1980-81, croakers *(abo* and *pagotpot)* constituted 82% of the catch of gillnets; this figure was down to 20% in 1992-93 with other species such as shrimp, manta rays, and hairtails occurring. Liftnets still catch anchovies *(dilis)* but none of the minor catches such as herrings, crevalles and squids are known to presently occur in the catch; instead, there has been replacement by other species including croakers, slipmouths and sergestid shrimps.

CHANGE IN ECONOMIC PERFORMANCE

The impacts of these variables on economic parameters are shown in Table 3a. Monthly catch value for all but one gear, push nets, has declined severely. Baby trawls were the largest casualties with monthly catch value depreciating by almost 90% from 1980-81 levels.

Declines in the rate of return on investment (ROI) were experienced by fish corrals and mini and baby trawlers although remaining positive. In contrast, filter nets, push nets and gill nets experienced robust growth. Changes in ROIs can be partially attributed to changes in capital requirements (Padilla et al. 1995). The 1980-81 study showed that it was more expensive to engage in gill net fishing than other artisanal fishing methods such as fish corrals and lift nets (Supanga 1982; Supanga and Smith 1982; Tulay and Smith 1982; Yater 1982). At that time, investment cost for mini trawlers was only half of that required by gill nets. By 1993, capital

Table 2. Changes in relative abundance of various families/groups in the catch during surveys in San Miguel Bay in the late 1940s, early 1980s and early 1990s (Cinco et al. 1995).

Family/group	Observed change in relative abundance	Probable cause
Sharks and rays	Massive decrease	Recruitment overfishing
Cephalopods	Relative increase	Reduced predation
Penaeid shrimps	Relative increase	Reduced predation
Pristidae	Disappearance	Recruitment overfishing
"Trash" fish		
a) low-value species (e.g., Gobiidae)	Relative increase	Species replacement reduced predation
b) juveniles of high-value species	Relative increase	Growth overfishing
Leiognathidae	Massive decrease	No straightforward explanation
Tetraodontidae Apogonidae	Relative increase	Species replacement
Sphyraenidae Drepanidae Synodontidae	Relative decrease	Recruitment overfishing
Engraulidae Trichiuridae Carangidae Scombridae	Relative increase	Technological improvement (higher trawl opening and speed)

Table 3a. Comparison of key economic indicators between 1980-81and 1992-93 San Miguel Bay studies.

	Monthly catch value (Peso)		ROIs		Derived wage rates* Peso·day^{-1}		Pure profit for all units (thousand P)	
Gear type		1981		1993	1981	1993	1981	1993
Fixed gears								
Fish corral	10,622	190.8	8,257	101.1	36.1	80.7	1,295	5,700
Filter net	2,669	35.2	2,301	190.2	53.0	60.7	308	1,793
Lift net	15,947	(1.8)	7,391	(1.7)	23.3	31.0	(3,074)	(648)
Trawlers								
Mini	15,236	83.6	8,357	78.4	92.0	93.4	6,115	4,397
Small/baby	25,908	63.6	8,781	12.9	114.7	54.7	8,635	(30)
Large		-		0.2	-	66.2	-	-
Other gears								
Gill nets	12,524	25.6	5,974	46.6	47.7	61.8	899	1,934
Push nets	148	14.8	247	145.8	-	-	(108)	764

*Unskilled crew.
Source: Padilla et al. (1995).

cost requirements had tilted in favor of gill nets with initial outlay amounting to 51%, 60% and 70% that of lift nets, fish corrals and mini trawls, respectively.

Wage rates were derived by Padilla et al. (1995) based on total payments to labor (cash and in-kind). Only master fishers of trawlers and the unskilled crew of fish corrals and mini trawlers were observed to earn wages that are higher than the agricultural (nonplantation) rate. However, all fishers earned wages that were above the region's opportunity wage rate of P35·day^{-1} (US$1=P25.4 July 1992-June 1993). Table 3b shows that wage rates increased between 1980-81 and 1992-93 for fixed gears and gillnets but declined by almost 50% for baby trawls.

Pure profit, the economic benefit from fishing, net of the opportunity costs of the factors of production, was taken to represent economic rent. Fish corrals, filter nets and gill nets experienced a large improvement in pure profits while mini trawlers suffered a 28% decline. Baby trawlers, which had the largest level of pure profits in 1980-81 reflected losses in 1993.

Despite indications of overexploitation, total pure profit for the San Miguel Bay fishery for 1992-93 was positive and greater than 1980-81 levels. This can be explained by the evolution of the fleet into its present configuration thereby minimizing losses. Another hypothesis is the worsening quality of life

Table 3b. Comparison of key economic indicators between 1980-81and 1992-93 San Miguel Bay studies.

Gear type	Catch rate per year[1] (t)	Catch value per year[2] (Peso)	Costs per year[2] (Peso)	Wtd price (Peso·kg^{-1})[2]	Labor requirements per trip[2]	Labor per year (person-trip)
Fish corral	1.8	34,180	7,774	20.6	1.6	170
Filter net	3.7	28,920	9,635	9.6	1.2	288
Lift net	17.02	40,864	31,555	11.6	4.6	529
Mini trawl	7.3	74,670	53,539	14.6	1.5	303
Baby trawl	78.1	88,940	77,122	31.2	1.8	239
Large trawl	24.7	171,368	110,143	14.9	9	72
Gill net	2.8	50,322	39,334	31.2	2	328
Push net	3.4	9,914	2,598	39.6	1.4	235

[1]Silvestre et al. (1995).
[2]Padilla et al. (1995).
US$1=P25.4 (July 1992-June 1993).

in the region which drives down the alternative uses and returns to labor and capital.

Linear Programming Application

Linear programming was used to estimate potential benefits accruing to the San Miguel Bay fishery under varying constraints. The elements of the linear program are as follows: 1) an objective function, the maximization of net revenues; 2) constraints, including total allowable catch, minimum and/or maximum number of units per gear type; and 3) the input-output coefficients, including catch rates per gear type. The variables optimized by the linear program in the primal formulation, i.e., the primal solution, are the number of units per gear type. The dual solution, being the converse of the primal, has as its variables the constraints used in the primal solution. The dual solution provides a measure of the opportunity cost of the particular resource (Agüero et al., this vol.) and as such indicates changes in net revenue if a certain constraint is relaxed.

Objective Function

Maximize profit, Π, such that:

$$\Pi = \quad TR - TC$$

$$\Pi = \sum_{i=1}^{8} [\{(R_i - OC_i) * X_i\} - \{LC_i * W_i\}] \qquad \text{...1)}$$

where the coefficients include:

TR = total revenue;

TC = total costs;

R_i = catch value of fish per gear type;

OC_i = material and fixed expenses per gear type; and

LC_i = labor costs per gear type

and the variables are:

X_i = number of boats per gear class; and

W_i = wage rate.

The coefficients of the objective function are catch value per year and operating costs. Catch value is estimated by multiplying catch rate per year (Silvestre et al. 1995) by average weighted prices per gear type (Padilla et al. 1995). All cost items were derived from the work of Padilla et al. (1995). The eight types of gears considered include three fixed gears, i.e., fish corral, filter net and lift net; three types of trawlers, i.e., mini, baby (small) and large; and gill nets and push nets.

Constraints

a) Total allowable catch

$$\Sigma\, CV_i * X_i <= 14{,}000 \qquad \text{...2)}$$

where CV_i = volume of catch per gear type.

Given the level of overexploitation, total annual catch for all gear types must be less than or equal to 1993 levels.

b) Distribution of catch

$$\Sigma\, CV_i * X_i <= 5{,}880 \qquad \text{...3)}$$

$$\Sigma\, CV_i * X_i <= 4{,}900 \qquad \text{...4)}$$

$$\Sigma\, CV_i * X_i <= 3{,}220 \qquad \text{...5)}$$

The present distribution of total catch should be maintained with gill nets, stationary gears and trawlers contributing 42%, 35% and 23%, respectively. This is to ensure that in the search of maximum revenues, equity objectives are not compromised.

c) Effort limits

$$X_i <= X_E \qquad \text{...6)}$$

In consonance with effort reduction in the trawl fleet, the number of units for all types of trawlers should be less than or equal to existing levels; the other types of gears were allowed to expand.

d) Minimum wage rates

$$W_i >= 35 \qquad \text{...7)}$$

Wage rates must be at least equal to the prevailing opportunity cost of labor in the region.

e) Non-negativity constraints

$$X_i >= 0 \qquad \text{...8)}$$

$$W_j >= 0 \qquad \text{...9)}$$

Input-Output Coefficients

Volume of catch per gear type, CV_i, is provided in constraint (a), the summation of which should be less than or equal to total allowable catch. The same coefficient is used to satisfy constraint (b), the distribution of catch. Otherwise, the other coefficients would take on a value of 1 or 0 depending on whether they are affected by particular constraints.

Results

The primal values correspond to the optimal number of gears and wage levels (Table 4). The dual value of wages represents the opportunity cost of labor; that of gears represent the increase (decrease) in the value of the objective function if constraints on the number of units were relaxed, i.e., specific gears were increased by one unit.

Scenario A is a current representation of the San Miguel Bay fishery with the following constraints: total allowable catch of 14,000 t·year^{-1}, a catch distribution ratio as specified in constraint b), and minimum wage rates of P35·day^{-1}. Scenario B examines the effect of a different fleet configuration on net revenues, i.e, current level of effort for the trawler fleet is maintained while gill nets and other stationary gears are allowed to expand. Scenario B likewise considers constraints (a) and (b). Scenario C is similar to Scenario B except that catch distribution ratio is modified as follows: 50%, gill nets, 30%, stationary gears, and 20%, trawlers. Scenario D is a situation wherein wage rates were pegged at the levels derived by Padilla et al. (1995) which were, in most cases, higher than the opportunity costs of P35·day^{-1}.

Scenario A yielded net revenues of P6.3 million with lift nets, gill nets and push nets, sustaining losses. Optimal number of units matches existing levels except for baby trawls which were reduced by 24%. Dual values show that fishery net revenues would diminish by P9,206, P492 and P909, for every lift net, gill net and push net added to the existing fleet, respectively. In the same manner, fishery revenues would increase if the number of profitable gears were expanded, for example, each large trawl has the potential of increasing net revenue by P57,613.

The constraints introduced by Scenarios B and C via limitations on "perceived" destructive gears such as trawlers and on catch distribution resulted in higher levels of net revenue (Table 4). The number of baby trawls diminished by 24% for Scenario B and 88% for Scenario C whereas optimal number of fish corrals increased by 82% and 520%, respectively. The optimal number of other stationary gears however remained unchanged. Scenario C resulted in the highest level of benefits, P19.4 million, despite having the lowest number of baby trawlers (88% less than existing levels) and the highest number of fish corrals. Lift nets had the highest opportunity costs despite having a minimal fleet size, i.e., 60 units. This is because of its huge labor requirement per year and the relatively large costs incurred relative to catch value (Table 3b). Scenario D resulted in a net loss of P14 million and the total eradication of mini and baby trawlers; otherwise, the number of all other gear types are maintained at its present levels.

The primal value of wages is P35·day^{-1} for all scenarios. Because wage is a cost factor in the estimation of net revenue, the dual values are negative with the magnitude depending on the labor requirements per gear type and the wage rate. For example, increasing wages by one peso would result in a P74 reduction in net revenue for large trawlers; on the other hand, gill nets would suffer a greater decline amounting to P509,712.

Conclusion

The LP simulation proved to be a useful management tool in its predictive and analytic capacity. This exercise helped predict changes in fishery net

Table 4. Optimal number of units per gear type and optimal wage levels (primal) compared with opportunity costs (dual) of linear programming variables used to model San Miguel Bay fisheries.

		Scenario A		Scenario B		Scenario C		Scenario D	
Gear	Current levels	Optimal number of units per gear type/ optimal wage rates	Oppor-tunity costs	Optimal number of units per gear type/ optimal wage rates	Oppor-tunity costs	Optimal number of units per gear type/ optimal wage rates	Oppor-tunity costs	Optimal number of units per gear type/ optimal wage rates	Oppor-tunity costs
Number of units									
Fish corral	123	123	20,456	224	0	767	0	123	20,456
Filter nets	260	260	9,205	260	(32,843)	260	(32,843)	260	9,205
Lift nets	60	60	(9,206)	60	(202,629)	60	(202,629)	60	(9,206)
Mini trawls	260	260	10,203	260	10,203	260	10,203	0	10,203
Baby trawls	50	38	0	38	0	11	0	0	0
Large trawls	1	1	57,613	1	57,613	1	57,613	1	57,613
Gill nets	1,554	1,554	(492)	1,554	(492)	1,554	(492)	1,554	(492)
Push nets	245	245	(909)	245	(39,548)	245	(39,548)	245	(909)
Wage rates (Peso)									
Fish corral	80.7	35	0	35	(38,137)	35	(130,692)	80.7	(20,910)
Filter nets	60.7	35	0	35	(74,880)	35	(74,880)	60.7	(74,880)
Lift nets	31.0	35	0	35	(31,740)	35	(31,740)	31.0	(31,740)
Mini trawls	93.4	35	0	35	(78,780)	35	(78,780)	93.4	(78,780)
Baby trawls	54.7	35	(31,740)	35	(9,111)	35	(2,685)	54.7	(9,111)
Large trawls	66.2	35	0	35	(72)	35	(72)	66.2	(72)
Gill nets	61.8	35	(509,712)	35	(509,712)	35	(509,712)	61.8	(509,712)
Push nets	-	35	(57,575)	35	(57,575)	35	(57,575)	-	-
Net revenues (Peso)		P6.3 million		P8.4 million		P19.4 million		(P14 million)	

'US$1 = P25.4, July 1992-June 1993.

revenues given alternative fleet configuration and wage structures. Scenario A is the closest approximation to the existing situation in San Miguel Bay minus the constraints. The exercise shows that had these constraints been in force, the fishery would gain P6.3 million per year or 6% of operating and labor costs. It seems rational to assume that existing net revenues are larger given that no catch limits are in force; this is corroborated by the work of Padilla et al. (1995) who estimated positive pure profits amounting to P13 million.

Linear programming is another economic technique that uses economic efficiency as its sole numeraire, i.e., equity considerations are not considered. In fact, in situations where catch distribution limits were not applied, the resulting fleet structure consisted solely of large trawlers. Likewise, the institution of catch distribution limits as well as limits on the number of trawlers caused the phenomenal increase in the number of fish corrals simply because it had, relative to the other stationary gears, the largest average profit. Both configurations would increase net revenues substantially but would provide reason to eradicate the small-scale, mostly unprofitable, gears.

This situation was resolved by incorporating catch distribution ratios as constraints. In this exercise, there seems to be a congruence between economic efficiency and equity objectives given that Scenario C, which has an inherent bias towards small gears resulted in a fishery revenue that was also the highest. This observation seems to augur well for future management initiatives especially in effort reduction because this will tend to minimize potential conflicts.

Simulating alternative wage levels indicates the increasing volatility of the labor market in the region. Current wage payments coupled with catch constraints resulted in a nonfeasible solution as in Scenario D, i.e., net revenues were negative. Clearly, wages cannot be maintained by specific gear types if catch or effort limits were simultaneously enforced. Thus, resource overexploitation can be viewed as an indirect result of maintaining current wage rates because if labor were paid rates higher than prevailing opportunity costs, then due to open access, more fugitive labor is attracted to the fishery. The fishery resource would be subsidizing labor that is being used inefficiently. Thus, it is often the case that in overexploited fisheries, e.g., Lingayen Gulf (Cruz and Silvestre 1988) and Philippine small pelagics fishery (Trinidad et al. 1993), labor earns pure profit even if entrepreneurs sustain economic losses. On the other hand, if access were limited by any of the constraints incorporated in the linear program, current wage rates could not possibly be maintained.

This theoretical exercise provides a useful tool for policy setting and while the estimates may never attain point accuracy, the method certainly contributes appropriate benchmarks for decisionmaking.

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OPUS: Interactive Software for Solving Linear Programming Models Using the Simplex Algorithm*

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Abstract

This document introduces the OPUS software conceptualized and developed under the ICLARM/ECLAC Project on Socioeconomic Valuation of Coastal Resources of Southwestern Latin America from 1990 to 1992. The software is designed and developed for use with IBM PC or its compatibles. The routines in the software are structured to assist scientists working on coastal resources valuation through linear programming models.

Introduction

This section gives a general description of the program and defines the symbols and conventions followed or used in the OPUS software and this manual.

What Is OPUS?

OPUS is an interactive and user-friendly linear programming software. Its design philosophy is intended for users with little experience in microcomputers. Depending on the need of the user, OPUS offers a set of facilities for file management and for configuring the program's working environment. The other contributions in this volume should be consulted for the theory behind this approach and examples of practical applications.

OPUS' menus serve as a guide to the different procedures and functions of the program. These facilities, as an example, allow you to:

- manage and maintain the data files efficiently;
- select data entry (tableau in a matrix format);
- select the working language (English or Spanish; English is the default); and
- sort the data based on geographic areas.

The program was developed using the "Revised Simplex" algorithm, for solving large models.

OPUS Structure

OPUS has two main modules, Data Manager and Solution Algorithm. Data Manager enables management of the data and controls the execution of the model. It also generates the interface between the users and the Solution Algorithm.

The second module, Solution Algorithm, solves the model using the "Revised Simplex" algorithm.

Symbols and Conventions

The following symbols and conventions are used or followed throughout this manual:

-

This box emphasizes important messages of command or set of instructions.

- ***BOLD WORDS***

This is used to highlight terms in this manual.

Software Installation

This section lists the hardware and software required to install OPUS. It describes the contents of the diskettes including configuration parameters and installation procedure.

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System Requirements

OPUS was designed to run on the IBM PC (DOS ver. 3.0 or later) and its compatibles. The following is the minimum system configuration:

- 640 K-bytes of RAM memory;
- 1 Floppy Disk drive (only for installation);
- 1 Hard Disk drive;
- Color or Monochromatic monitor; and
- 1 Printer.

OPUS cannot run from floppy disks. It is essential to install the program in a hard disk.

Installation Procedure

An installation routine is included in the distribution disk to install properly the software to a hard disk. Installation involves a set of procedures described below.

Insert the **Disk** in a floppy drive and enter the following command:

INSTALL <destination drive:>

To complete the installation, the AUTOEXEC.BAT file will have to be edited to include the following command lines:

PATH=C: installation directory

SET OPUS=C: installation directory

Finally, you must reboot the system to record the new commands.

Installation Test

Once you have completed the installation, the following steps can be used to test that installation was successfully completed.

1st. Run OPUS from DOS prompt.

C:\OPUS01 <enter>

OPUS will display its identification screen (Fig. 1).

Press any key to exit from this logotype screen and get into the Main Menu.

2nd. Once you are inside the OPUS Main Menu, select the test file **MANGLAR**.

3rd. From the Parameters screen, press **<F4>** to activate the data entry/edit procedure (tableau).

4th. Once you are in the data tableau, run the program with **<F3>** and then see the outputs.

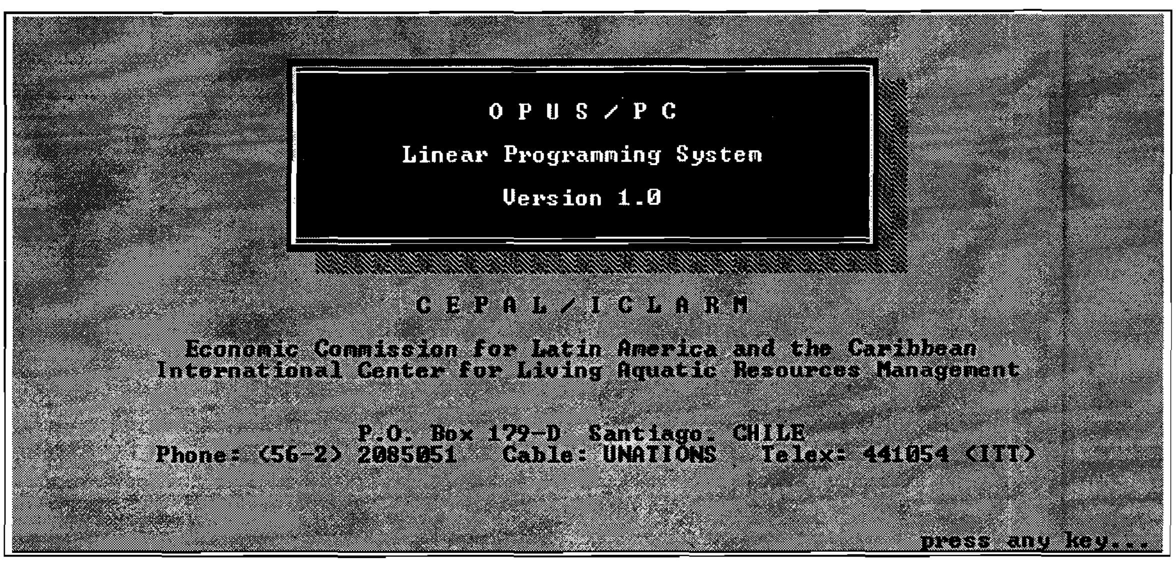

Fig. 1. OPUS introductory screen.

5th. Press **<F10>** several times to go to the preceding level screens, to complete a run of all of the routines in OPUS.

If the system does not respond correctly, proceed as follows:

1) Make sure that the AUTOEXEC.BAT file has the correct path given in the installation.
2) Make sure that you have enough memory (640K).
3) Reduce the parameter definitions in the **PATH** and **SET** commands in the **CONFIG.SYS** file.
4) Make sure that in the installation directory of OPUS, all the following files exist:

- OPUS.EXE (System manager)
- LPNEW006.EXE (SIMPLEX algorithm)
- SWAPCTRL.EXE (Swap routine)
- LSORT.EXE (Sort procedure)
- PL_MESSA.ENG (English messages)
- PL_MESSA.SPN (Spanish messages)
- PL_HELPR.ENG (Help in English)
- PL_HELPR.SPN (Help in Spanish)
- MANGLAR.* (Data files to test installation)

Using the Software

File Organization

In order to facilitate file management, it is advisable to create the directories to store data at DOS level (please refer to the DOS manual for details on how to create subdirectories). Moreover, it is recommended that you update the information contained in the working directories used by OPUS as often as possible. It is important to delete all files that are not used and backup all the standing files. If you want to delete files, you may do it automatically from the program's **Main Menu** but if you want to make backup files, use the DOS **COPY** or **BACKUP** commands.

Screens and Messages

One of the main characteristics of OPUS is the common screen format used throughout for the user interface so as not to distract and to avoid confusion in using the program.

OPUS has two kinds of messages, **help messages** and **error messages**. The former is activated by pressing **<F1>** and provides information and guidance on the use of the different commands and functions of the program (Fig. 2). The Help feature can be invoked while using the following routines: file management,

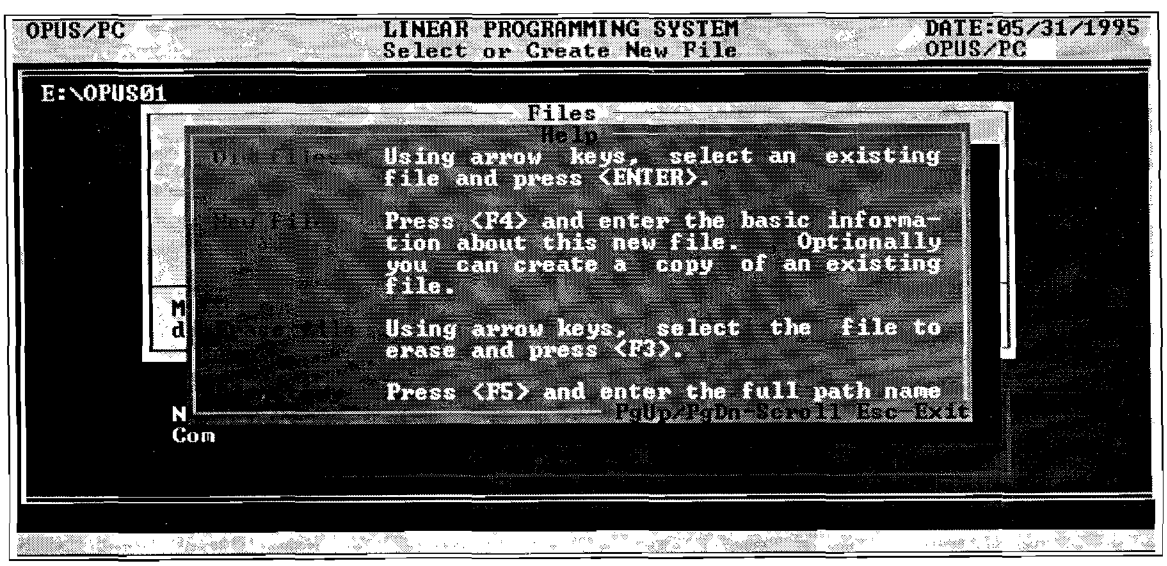

Fig. 2. Sample help window.

parametrization, data entry and editing. The error messages are automatically activated every time an invalid operation is encountered or invalid data are entered.

Both kinds of messages are shown in the same screen where it was activated or where the error appeared. The help messages are displayed in a window while the error messages appear on the 23rd line of the screen (on top of the Options Menu). To deactivate a message, press **<ESC>**.

Main Menu

The Main menu contains a set of file management functions and utilities to configure the program's working environment. In the upper portion of the window, the names of the existing data files in the selected directory are shown, while file creation/identification is done in the lower window (see Fig. 3).

File management includes creation, copying and deleting. The program configuation allows the user to select the working language (English or Spanish) and define data directories.

- To create a new data file (NewFile). Press **<F4>**, and the following data/information requirements appear:
- **New file (name):** Use a combination of up to eight alphanumeric characters based on the format conditions of the file names managed by the MS-DOS Operating System.
- **Base file (copy from):** To create a copy of an existing file, enter the name of this file then press **<F2>**.
- **Comments:** To make your file identification easier, provide some kind of comments referring to the model/application you want to make with the data.

Once you have entered everything, press **<F2>** to proceed and record the data or press **<Esc>** to Cancel. These comments are displayed in the lower part of the window.

- To select any existing data file, look for its name in the list of **Existing Files**, set the cursor on top of it using the arrow keys, and then press **<Enter>** to complete the selection and the screen for S03 - parameters is displayed (see section PARAMETERS for further information).
- To delete a data file (Erase), set the cursor on top of the name using the arrow keys and then press **<F3>**. Once you have done this, OPUS will ask you to confirm the operation.
- If you want to access your files from a particular directory (Dir), press **<F5>** and then enter the pathname of the directory (refer to DOS manual for more information about directories and pathnames).

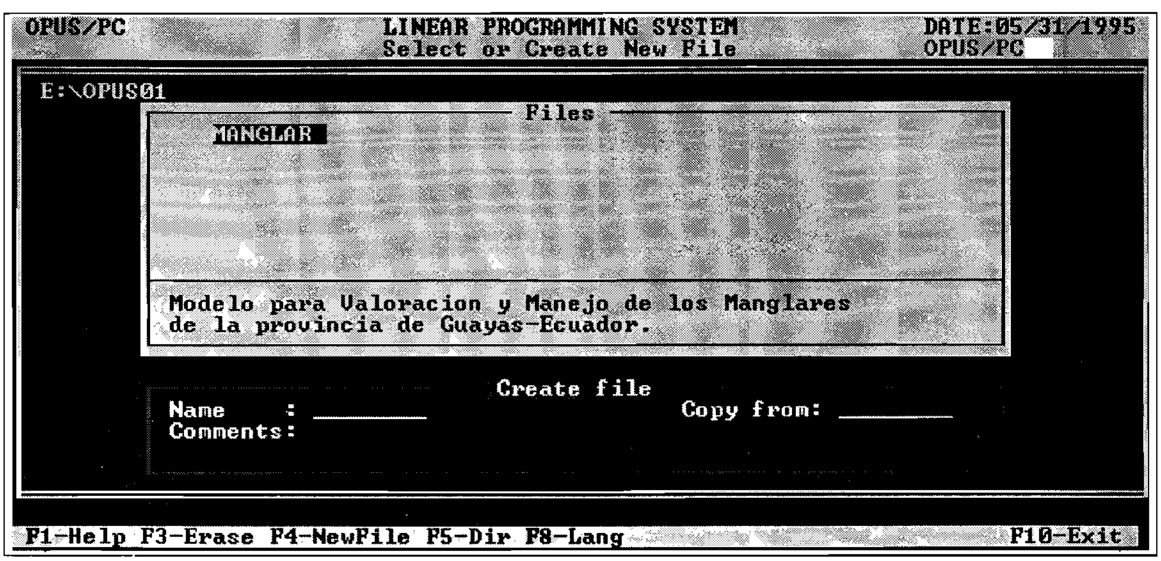

Fig. 3. File selection screen.

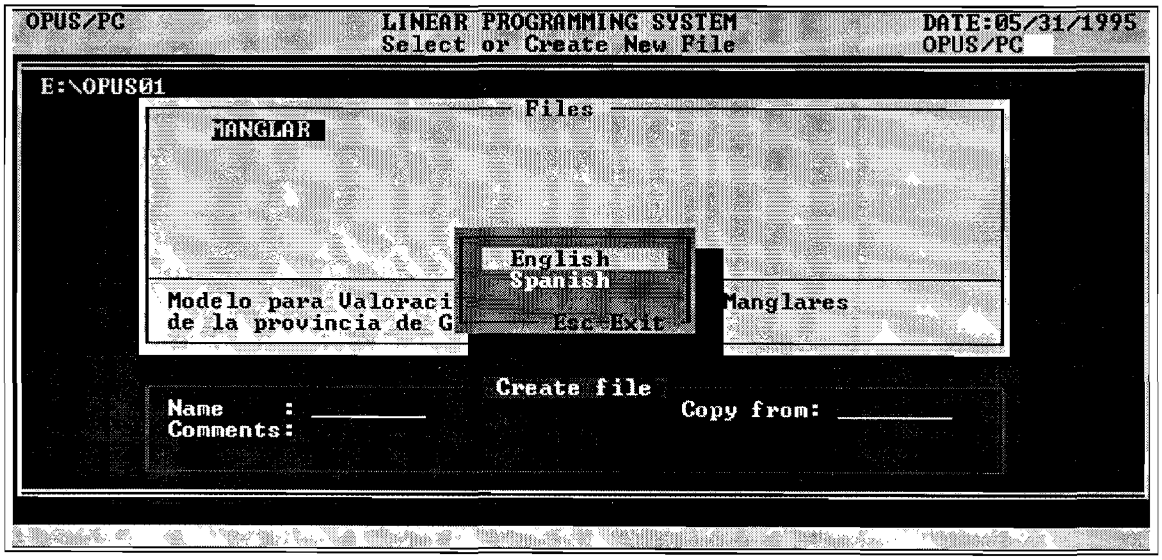

Fig. 4. Language selection screen.

- OPUS can operate in two languages, English or Spanish. To select the language interface, press **<F8>** and then choose the language using the arrow keys (see Fig. 4). Press **<Enter>** once you have selected or **<Esc>** if you want to keep the language selected before.
- To terminate OPUS and exit to DOS, press **<F10>**. To temporarily exit to the DOS environment, press **<F9>**. On a temporary exit to DOS, once you have finished working in DOS, enter **'EXIT'** from the DOS prompt to return to the OPUS environment.

Parameter Setting

This routine allows you to:

• select the kind of optimization that will be carried out with the data;

• fix the control points to run the program; and

• define data ranges for calibration.

The required data for this screen are as follows (see Fig. 5):

• To begin the maximization process, type **MAX**, otherwise type **MIN**. Press **<Enter>** to go to the next field, or move with the arrow keys.

• To select the number of restrictive equations (rows) that your model will have, press **<Enter>** to go to the next field and replace with new inputs or move with the arrow keys.

• To select the number of variables of the model, less the slack and artificial variables, press **<Enter>** to replace new inputs or move with the arrow keys.

Data Entry/Edit

The data entry/edit routine allows the configuration of the tableau in a matrix form. The screen format used for this purpose is shown in Fig. 6 and the main components are as follows:

1. Heading: On the first two lines of the screen, OPUS shows the file identification and the objective, i.e., minimize or maximize. The data that may be entered/edited here are:

• Data filename

• Kind of process (maximize or minimize)

• Number of constraints in the tableau

• Number of variables (without considering slack and artificial variables)

• Active edition sector in the tableau (objective function, constraints coefficients and the right-hand side of the constraints)

• Cursor position in the tableau

2. Data tableau: OPUS uses its own coordinate system. It utilizes the columns identified through a sequence of alphabetic characters that are located immediately under the screen heading. The constraints are enumerated at the left side of the tableau.

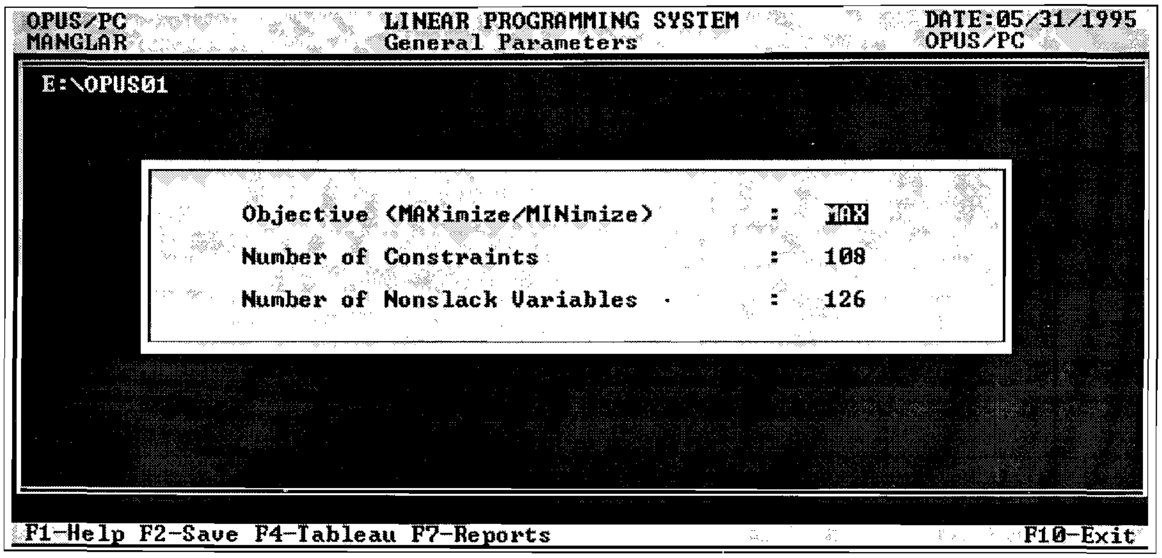

Fig. 5. Variable number entry screen.

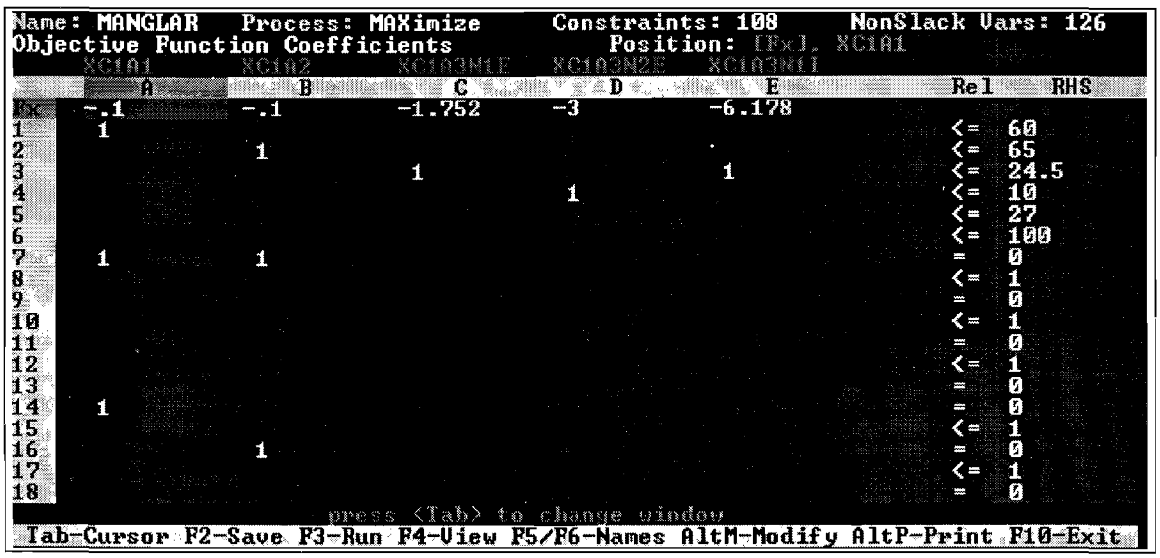

Fig. 6. Data entry screen.

• OPUS gives default names for the objective function variables (X1, X2, X3 ... etc.), however, these labels can be altered. To edit the names of these variables, press **<F5>** (see Fig. 7). A window is displayed and you can enter the new names. If you have more than eighteen variables, you can use the **<PgUp>**, **<PgDn>** keys to go forwards or backwards in the window. To exit this window, press **<Esc>**.

• OPUS gives default names for constraints (Y1, Y2, ... etc), which can be edited and changed by pressing **<F6>**. The screen used for this purpose has the same format as the one shown in Fig. 7.

The edit feature in the tableau is done by sector.

• The first sector consists of the coefficients of the objective function, which are edited on the first row of the tableau, and is denominated as row **"Fx"**.

• The second sector consists of the constraints coefficients and are edited in the matrix located immediately under the objective function.

• The third sector consists of the right-hand side (RHS) values of each constraint, together with the relation that conditions them (Rel), which are edited in the columns located at the right side of the screen.

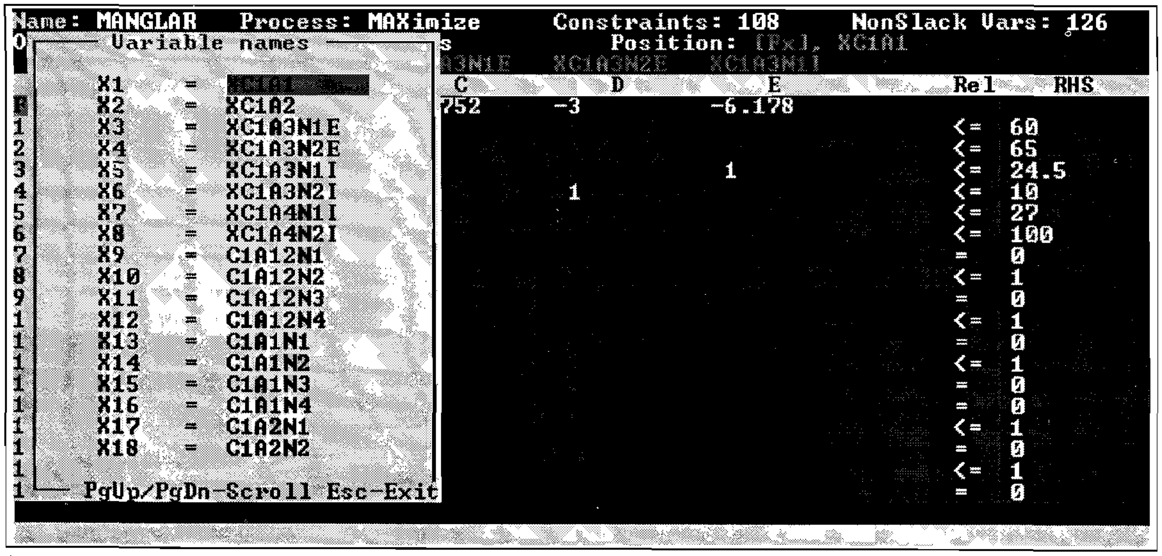

Fig. 7. Variable name entry screen.

To move within the tableau, use the **<Tab>** key and arrow keys.

3. Functions menu: The functions menu provides alternatives and facilities to execute the process.

- To save your data in the data directory, press **<F2>**. While the data are being saved, a message appears at the right corner of the screen which indicates this.
- To execute the process, press **<F3>**. Processing time depends on the size of data and speed of computer. Hence, it is advisable to first save the data (see below) before pressing **<F3>** (see Fig. 8).
- To see the results of a previous execution (View), press **<F4>**. This operation displays the outputs of a process, if any.

4. Multiplying data: To change the values of the objective function and/or the constraint's coefficients, and/or the right-hand side in a proportional way, i.e., multiplying each group by a constant, press **<Alt>+<M>** and a window will be displayed for you to enter the options (see Fig. 9). If you enter an option, the program prompts for the ranges and for the multiplicative factor. Press **<F2>** to proceed or **<Esc>** to Exit.

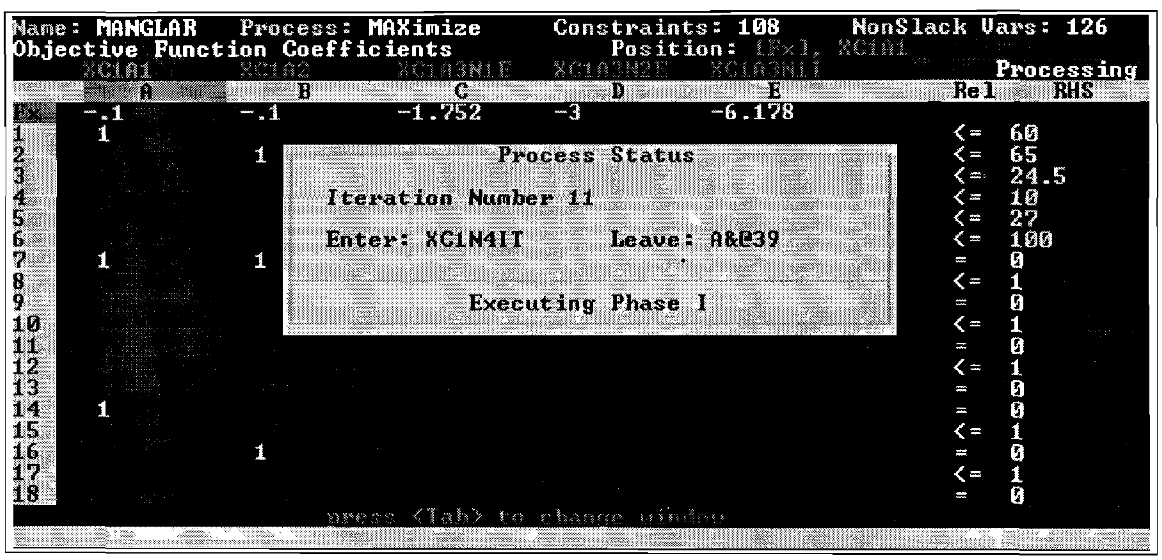

Fig. 8. Process status window.

5. Exiting: To exit the data tableau and go to the previous screen, press **<F10>**.

Printing

- Data

To print the information contained in a data tableau (Print), press **<Alt>+<P>**. This function will activate the menu that will allow you to use one of print options (see Fig. 10):

1. Print the variables and coefficients of the objective function. For that, you have to enter the range you want to print, or use the range given by default if you want to print the objective function completely.

2. Print the constraint coefficients and, optionally, print the objective function coefficients and the right side of the tableau.

To print part of the coefficients matrix, enter the coordinates of the upper left corner and the lower right corner.

3. Print only the values of the right-hand side of the tableau and its relational operators. In case the printer is not enabled, an error message is displayed.

Press **<F2>** to proceed or **<Esc>** to Exit

- Reports

Before you enter the tableau and run the process, you can select the listings with the results. To do that, press **<F7>** and a window with a different set of options is displayed.

The screen that displays the final results has the following options:

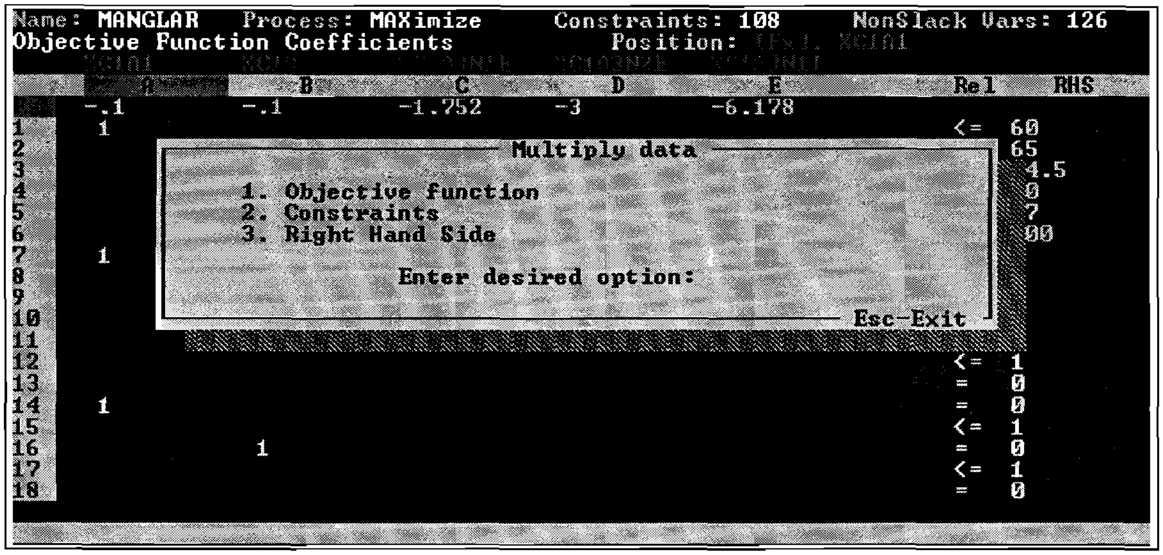

Fig. 9. Multiply data menu.

Selecting the options : To select the results of the process, the following may be followed:

1st. Set the cursor on top of the kind of result you want to obtain.

2nd. Mark this result pressing **<Space>**

3rd. Repeat steps one and two to select the results of interest.

To complete the selection procedure, press **<F2>**.

Exit results menu: To exit the results selection screen, press **<Esc>**.

Outputs

OPUS can generate a set of reports from the final results of the process. As an option, OPUS generates a report with the partial results in each iteration that you specify.

• Final results

The report with the final results that you selected is shown in a special screen which provides a set of options that, among other things, allows you to print selected results (Fig. 11).

• OPUS allows you to print results selectively. To do that, a special menu is displayed that is activated by pressing the **<F7>** key. This function allows you to select from a menu (see Fig. 13), the kinds of results you want and the variable range to print. menu.

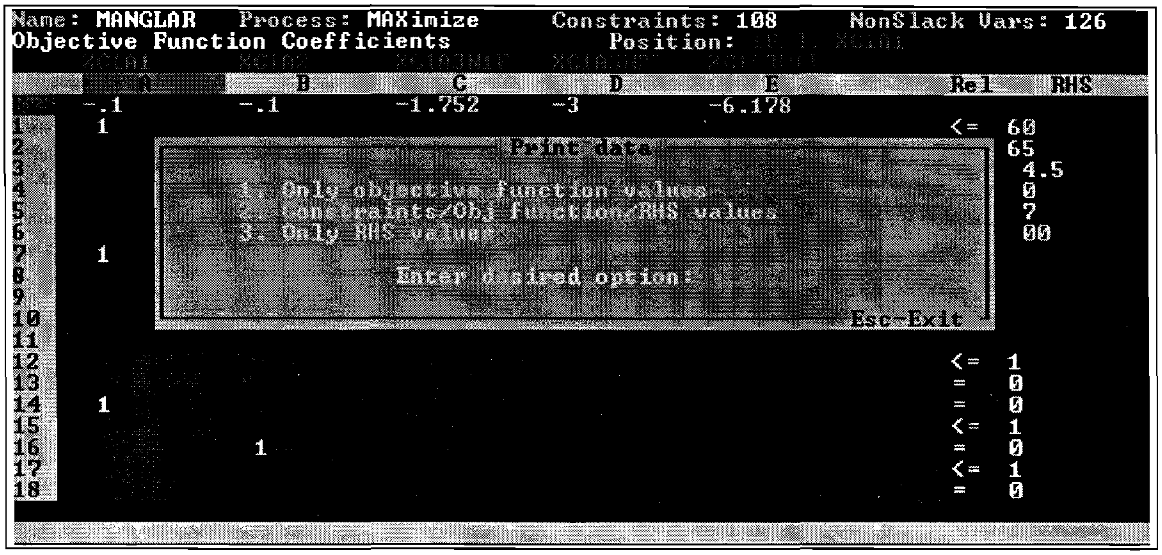

Fig. 10. Data printing menu.

• To move from one place to another in the results report (Fig. 12), use the **<PgUp>**, **<PgDn>**, and **arrow** keys.

• To activate the results printing process, press **<F8>**.

• To exit this screen and go back to the previous one, press **<F10>**, otherwise press **<Esc>**.

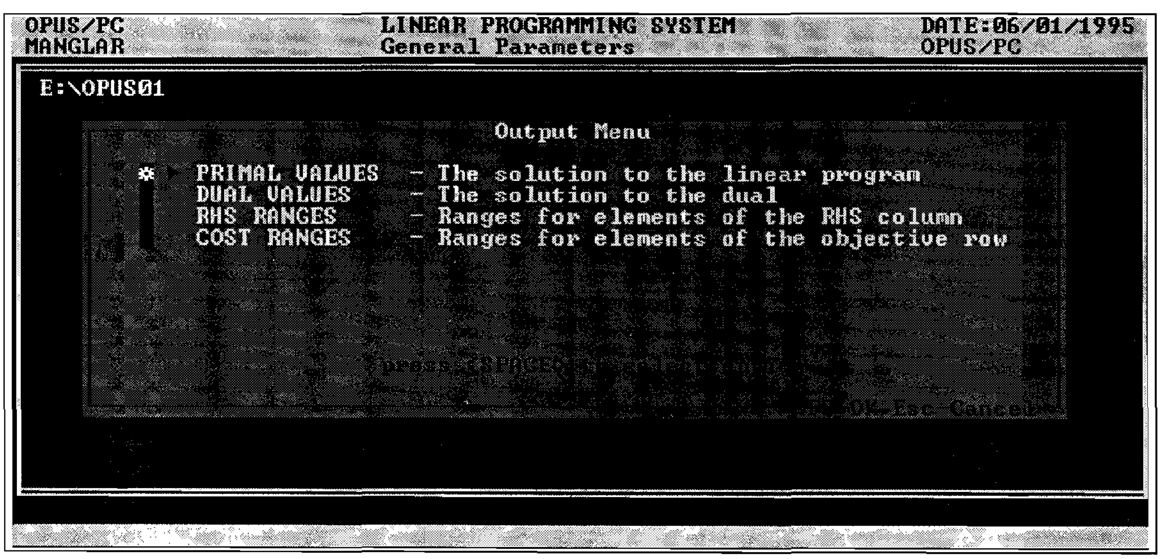

Fig. 11. Output menu.

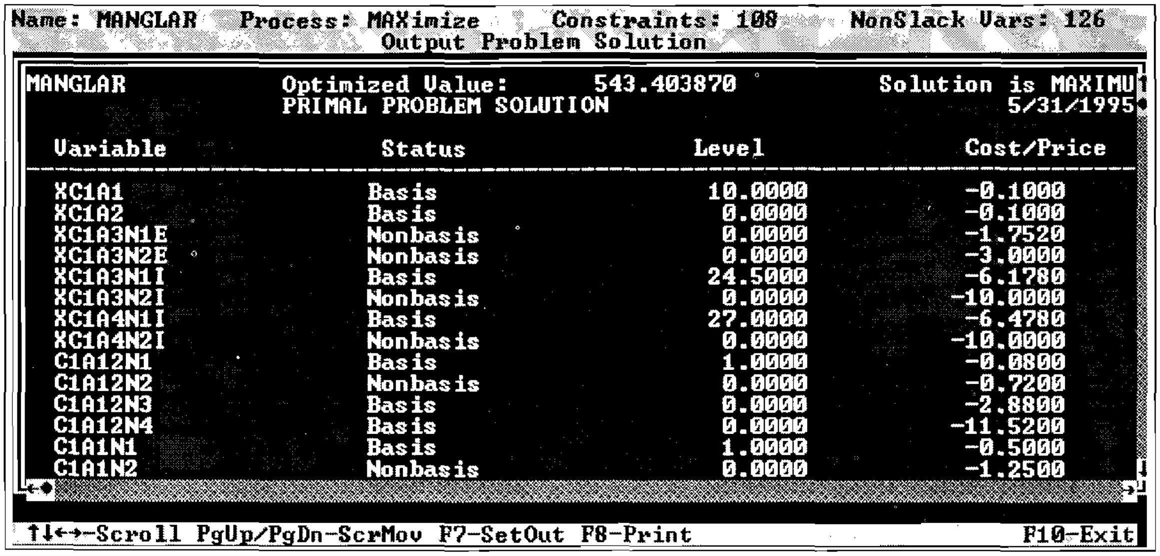

Fig. 12. Solution output screen.

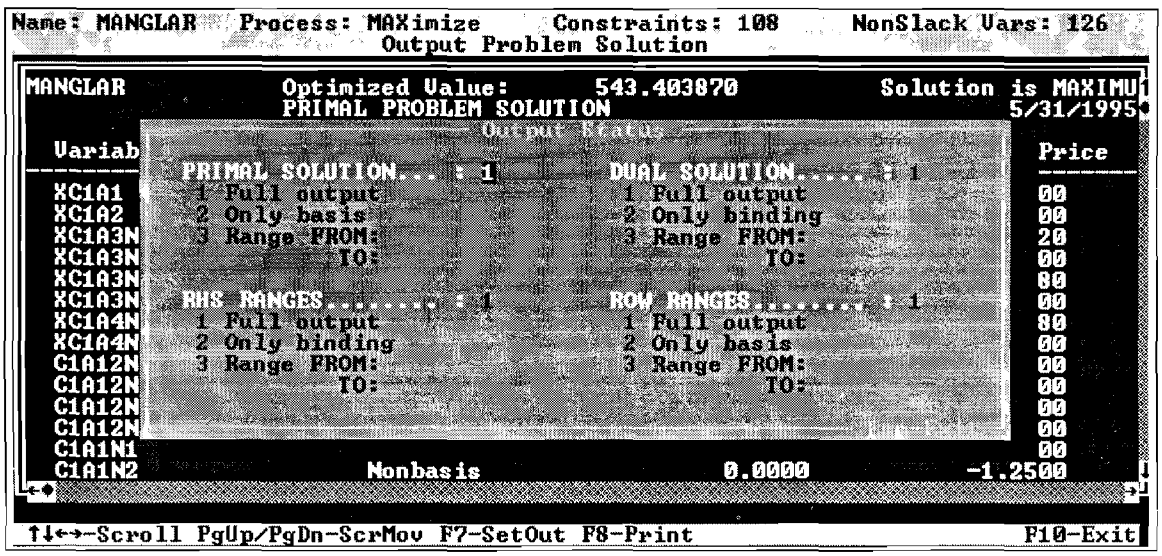

Fig. 13. Output status menu.

Acknowledgements

The assistance of ICLARM programmers, Eli Garnace and Felimon C. Gayanilo, Jr. as well as the supervision from Daniel Pauly are acknowledged gratefully.

Reference

Pauly, D. 1993. Data-rich books. BioScience 43(3): 167-168.

Appendix 1. Documentation of LP tableaus.

In the tradition of data-rich books (Pauly 1993), this appendix is written for users who may want to test, verify and update the data used in the linear programming tableaus (Araneda et al., this vol.; Bell and Cruz-Trinidad, this vol.; Cruz-Trinidad et al., this vol.; and Cruz-Trinidad and Garces, this vol.).

The files used in these application papers are available in spreadsheet format. Files Bio.wb1 and Fabio.wb1, having been validated using LP88, are available in LP format. Files Linga.wb1 and Sanmig.wb1 have been validated using the LP routine of a commercial spreadsheet package.

All files can be accessed and processed in OPUS software or any other LP program that is available.

File Name	File Size (KB)
1. Fabio.wb1	31,200
2. Bio.wb1	115,652
3. Linga.wb1	6,736
4. Sanmig.wb1	34,264

Appendix 2. Glossary of technical terms.

artificial market - a market that could be constructed for experimental purposes, to determine consumer willingness to pay for a good or service. For example, a home water purifier kit might be marketed at various price levels or access to a game reserve might be offered on the basis of different admission fees, thereby facilitating the estimation of the value placed by individuals on water purity or on the use of recreational facility, respectively.

backup - security copy for effective recovery in the event of loss of service from some other resource.

balance equations - constraint equations used in the stepwise linearization process.

basic solution - augmented corner-point (infeasible) solution.

bequest value - value that people derive from knowing that others (perhaps their own offspring) will be able to benefit from the resource in the future (also heritage or preservation value).

coefficient - constant value for variables in the various equations and/or objective function.

collusion - agreement between firms to cooperate to avoid mutually damaging rivalry which may involve informal or tacit agreement, arising, for instance, from the pooling of information, to formal arrangement within cartel organizations where sanctions are imposed on defectors.

constrained maximization approach - the maximization of an objective function where the choice variables are subject to some constraints.

constraints - restrictions to which the objective function is subjected; usually a mathematical relationship between the choice variables of an optimization problem, in which some function of the variable (e.g., a linear function) is not equal to a constant. An example is a budget constraint on the maximization of utility.

contingent valuation - a nonmarket valuation technique which tries to obtain information on consumers' preferences by posing direct questions about willingness to pay. What is sought are personal valuations of the respondent for increases or decreases in the quantity of some good, contingent upon a hypothetical market.

data files - set of stored data, containing the inputs given by the users, grouped together under a unique file name.

defensive expenditure - one approach in eliciting willingness to pay based on direct effects valued on conventional markets. Individuals, firms, and governments undertake a variety of "defensive expenditures" in order to avoid or reduce unwanted environmental effects. Environmental damages are often difficult to assess, but information on defensive expenditures may be available or can be obtained at lesser cost than direct valuations of the environmental good in question. Such actual expenditures can then be interpreted as a minimum valuation of benefits.

dual - the minimization associated with each linear programming problem in standard form, i.e., mathematically,

$$\text{given LP1: Max } c^t x \quad \text{such that } Ax \leq b, \quad x \geq 0$$

then the LP given by

$$\text{LP2: Min } b^t y \quad \text{such that } A^t y \geq c, \quad y \geq 0$$

is called the dual of LP1 and LP1 is called the primal.

elasticity - a measure of the percentage change in one variable with respect to a percentage change in another variable. Measures of elasticity tend to be carried out for very small changes in the variable causing the response (e.g., a percentage change in quantity due to a very small change in price).

existence value - the perceived value of an environmental asset unrelated either to current or optional use; that is, simply because the resource exists.

externality - externalities are variously known as external effects, external economies and diseconomies, spillovers and neighborhood effects. Externalities exist when the production or consumption of a good or service by one economic unit has a direct effort on the welfare of producers or consumers from another unit.

future value - the value in the future of an amount to be received or paid in the current period. This is determined by multiplying the present value of income by the discount factor $1 \div (1 + i)^n$.

game theory models - models using a theory of individual rational decisions under conditions of less than full information concerning the outcomes of those decisions. The theory examines the interaction of individual decisions given certain assumptions concerning decisions made under risk, the general environment, and the cooperative or uncooperative behavior of other individuals.

indirect use value - value of an ecosystem in the provision of a number of biological life support functions that are generally public goods (e.g., coral reefs provide biological support in the form of nutrients and habitat for coral fisheries, and coastline protection functions).

input-output models - models utilizing a method of analysis in which the economy is represented by a set of linear production functions, describing the interrelationships between all sectors.

linear programming - a technique for the formalization and analysis of constrained optimization problems in which the objective function is a linear function, and is to be maximized or minimized subject to a number of linear inequality constraints.

market failure - the inability of a system of private markets to provide certain goods at the most desirable or 'optimal' levels. In general, market failures arise because of 1) nonexcludability; and/or 2) nonrival consumption of a good. Nonexcludability means that individuals who have not paid for a good cannot be prevented from enjoying its benefits. A good is nonrival if its consumption by one person does not preclude its enjoyment by anyone else.

monopoly - in the strictest sense of the term, a firm is a monopoly if it is the only supplier of a homogeneous product for which there are no substitutes and many buyers.

multiperiod linear programming - activities are repeated in a number of periods and constraints are progressively modified over time so that the optimal solution within periods varies.

nonlinear programming - in contrast to linear programming, this involves an optimization framework that can handle nonlinear objective functions as well as nonlinear inequality constraints.

nonuse value - value attributed to a resource for its use by future generations (bequest value), its future direct and indirect use by present generations (option and quasi-option value), and its present utility because of the knowledge of its existence (existence value).

objective function - a function relating the objective (the variable to be optimized) to the choice variable in an optimization problem.

option value - the value of a resource based on how much individuals are willing to pay today for the option of preserving the asset for future (personal) direct and indirect use.

perfect competition - a market structure is perfectly competitive if the following conditions hold: 1) a large number of buyers and sellers; 2) homogenous products; 3) availability of perfect information; and 4) free entry.

pivot element - coefficient located in the intersection of the entering basic variable and the leaving basic variable.

primal - (see dual).

property value - also referred to as a "hedonic price" technique, the property value method is based on the general land value approach. The objective is to determine the implicit prices of certain characteristics of properties. In the environmental area, for instance, the aim of the method is to place a value on the benefits of environmental quality improvements, or to estimate the costs of a deterioration (for example, the effects of air pollution in certain areas).

pure profit - a residual sum left over when we have subtracted from the revenue generated by some activity all of the opportunity costs of production, the normal profit required to keep the producer in business.

reduced cost/return - feasible range given to the cost/return variables in the optimization process.

replacement cost - under this approach, the costs that would have to be incurred in order to replace a damaged asset are estimated. The estimate is not a measure of benefit of avoiding the damage in the first place, since the damage costs may be higher or lower than the replacement cost. However, it is an appropriate technique if there is some compelling reason as to why the damage should be restored, or certainty that this will occur.

right-hand side (RHS) - constant value located at the right-hand side of the equation (constraint).

sensitivity analysis - involves changing the parameters of a decision problem and studying how this affects the outcome. It is particularly associated with cost-benefit analysis, where the most common form is the use of alternative discount rates. The purpose of the analysis is to identify the important assumptions upon which the analysis is based - those to which the outcome is sensitive.

shadow price - an imputed valuation of a commodity or service which has no market price. Shadow prices are used in cost-benefit analysis and in the application of mathematical programming to a planned economy. They represent the opportunity cost of producing or consuming a commodity which is generally not traded in the economy. Even in a market economy certain outputs such as health, education, and environmental quality do not attract a market price. A set of shadow prices representing consumers' marginal rates of substitution or producers' marginal rates of transformation between such commodities may be calculated reflecting the marginal costs of production or the marginal value of their use as inputs. To the extent that market prices do not reflect opportunity costs, cost-benefit analysis may substitute shadow prices.

shadow price vector - represents the (maximum) change in value that the objective function can take if an additional unit of a constraining factor is available.

simplex algorithm - a simplex is a sort of n-dimensional analog of a triangle, with corners that represent extreme points, and the simplex method provides a systematic procedure whereby we can move from one extreme point of the feasible region to another, till the optimal one is reached.

slack variables - variables that are introduced to convert the functional inequality constraints into equivalent equality constraints.

swap - computational techniques that involve transferring data to another storage media while it is not being used to maximize RAM memory.

tableau - a tabular form to record the essential information in a linear programming problem, namely, the coefficients of the variables, the constants on the right-hand side of the equations, and the basic variables for each equation.

Total Economic Value (TEV) - sum of total use value and nonuse values of the environment when viewed as an asset.

travel cost - the travel cost method measures the benefits produced by recreation sites (parks, lakes, forests, wilderness). A related method can also be used to value "travel time" in projects dealing with fuelwood and water collection.

use value - associated with both direct extractive uses (e.g., of fish, coral) and nonextractive direct uses (e.g., recreation) of the environment as an asset.

virtual disk - a store management system in which a user is able to use the storage resources of a computer without regard to constraints imposed by a limited main store, and the requirements of other applications which may be using the system.

wage difference - this method is based on the theory that in a competitive market the demand for labor equals the value of the marginal product and that the supply of labor varies with working and living conditions in an area. A higher wage is therefore necessary to attract workers to locate in polluted areas or to undertake more risky occupations. Again, as in the case of property value, the wage differential can only be used if the labor market is very competitive.

willingness to pay (WTP) - a measure of consumer's surplus, it is the amount a consumer is willing to pay over and above current consumption of a particular good or service.

working directory - directory configured by the user to save swap files, communication files between the data manager module and the solution algorithm module, and output files. The default working directory, if the user does not configure one, is the data directory.

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