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Economic Analyses of Man's Utilization of Environmental Resources in Aquatic Environments and National Park Regions

人間による環境資源利用の経済分析
―水環境と国立公園地域を対象にして―

Edited by Yoshifusa Kitabatake
北畠能房（編）

Systems Analysis and Planning Division
総合解析部

環境庁　国立公害研究所
THE NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES

PREFACE

The Systems Analysis and Planning Division in the National Institute for Environmental Studies performs research concerning a wide range of environmental problems in a comprehensive manner. Most of the researches conducted in the Division are inherently interdisciplinary. Thus their satisfactory execution will often require intra-divisional, inter-divisional, and sometimes inter-institutional research collaboration.

This report on economic analyses of man's utilization of environmental resources in aquatic environments and National Park regions presents one such a bundle of collaboratory research works. Though the binding theme of selected works in the report is related to the economic analyses of environmental resources management, the economics, especially microeconomics, contained in the report is a broad ranging one which brings into the analysis environmental, social and institutional factors in order to clarify the economic aspects of both environmental pollution and nature conservation. In organizing the report, the editor first constructs a kind of systems analysis framework for classifying and thinking about environmental resource management. He then clarify the relation of each chapter to the framework, where each chapter deals with an economic analysis of a *specific problem* related to environmental resource management.

In short, the report presents empirical and theoretical works related to current Japanese environmental conservation problems in aquatic environment and National Park regions, which have been developed in past ten years of the Division's existence. While undoubtedly there are a number of points at which the report could have been extended, it is hoped that this report is also of some use for those who are interested in the economic aspects of environmental conservation.

Masaaki NAITO
Dr. Eng.
Director of the Systems
Analysis and Planning Division

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Part I Case of Aquatic Environments

Part II Case of National Park Regions

Abstract

This report represents a collection of selected works undertaken in the special research project concerning eutrophication of Lake Kasumigaura and in several basic research studies of Systems Analysis and Planning Division. It addresses economic analyses of man's utilization of environmental resources in aquatic environments and National Park regions. In particular it seeks to shed light on three main issues confronting the environmental resources management: the determination of management goal, the determination of the preferable system of management measures, based on the understanding of man's utilization processes of environmental resources, and the formation of the appropriate social arrangements for managing the environment.

The report consists of two parts. Part I of the report deals with the case of aquatic environments such as lake and river, where many of the environmental resources are common property and the spatial extent of man's utilization is mainly limited to a region such as a watershed. Part II deals with the case of natural environment in National Park regions, where property rights of the lands are explicitly defined and the spatial extent varies from local to nation at large.

In each part, empirical and theoretical works related to three issues of management goal, system of management measures, and institutional arrangements are presented.

LIST OF AUTHORS

Yoshifusa Kitabatake
Shuzo Nishioka
Osami Nakasugi
Masaaki Naito
Systems Analysis and Planning Division, the National Institute for Environmental Studies.
Tadakuni Miyazaki
Environmental Information Division, the National Institute for Environmental Studies.
Yuzuru Matsuoka
Visiting Fellow of the National Institute for Environmental Studies,
Present Address: Faculty of Sanitary Engineering, Kyoto University.

Chapter 1

Editor's Introduction

As economic development and a growing population increase the demand on environmental resources mostly in extra market manner, it becomes increasingly important to tackle three main issues concerning the environmental resources managements: 1) how do we determine the management goal such as the specified level of environmental quality with degree of certainty? 2) what is the preferable system of management measures for achieving the management goal? 3) what are the adequate institutional or organizational arrangements for managing environmental resources? Though these three issues were originally presented by Kneese and Bower (1968) for the case of water quality management, they are also applicable to the management of environmental resources in general, where the "environmental resources" are defined to be the resources supplied by the environment.

As Pearce (1976) has noted, the environment, from man's point of view, supplies 1) natural resources which are used to create economic goods, 2) "natural goods" or public-consumption goods such as beautiful scenery, and 3) a "sink" into which wastes generated by man's activities can be discarded. Limited supply of environmental resources and the possible interrelationships among three types of resources supplied by the environment generate the situation in which competing demands for the utilization of environmental resources exist. This may explain the importance of the three main issues introduced above.

The objective of this research report is twofold: One is to help shed light on three issues through several case studies of actual situations. In doing so, we pay special attention on clarifying man's utilization processes of environmental resources. The other is to clarify the theoretical backgrounds of and to practice the representative methods in the field of environmental economics. Examples of methodological arguments include how pollution charges are calculated, how to estimate a pollution damage function, how to analyze the use of the environment in a dynamic context, and how to calculate consumer surplus of nature preservation. In order to satisfy the above two objectives, most of the following chapters consist of a theoretical part and an empirical part.

Fig. 1 is a schematic diagram indicating the relationships among the following chapters, where four types of the environment are classified in terms of two characteristics of the environment: establishment of property rights and spatial extent of man's utilization of environmental resources. Part 1 of the report deals with the case of aquatic environments such as lake and river, where many of the environmental resources are common property and the spatial extent is mostly limited to a region such as a watershed. Part 2 deals with the case of natural environment in National Park regions, where property rights of the lands are explicitly defined and the spatial extent varies from local to nation at large. Though type (1) and (4) are not discussed in the report, type (1) may correspond to a type of the environment such as agricultural lands or forests managed by the respective landowners, and type (4) to the case of global environment such as ocean.

The reason we choose these two types of the environment is related to a survey article written by Fisher and Peterson (1976). In their article, they first characterized the traditional view of the environment as a source of extractive resource, and then interpreted the new view as having two distinct focuses on the environment; i) a use of the assimilative capacity of the environment (pollution problem), and ii) alternate uses of natural environments. The first focus is "similar to sustainable yield exploitation of renewable resource - both are reversible, except in cases of extreme abuse, and both involve flows rather than stocks" (Fisher & Peterson, 1976, p. 2). The second focus is concerned with the conflict between the use of extractive resources and the use of in situ resources of a natural environment, and is closely related to the valuation of the opportunity costs of development activities with high degree of irreversibility, or to the valuation of the benefit from preservation of in situ resources. The type of the environment discussed in Part I of the report is related to the first focus, and that in Part II to the second focus. Two characteristics of the environment in Fig. 1 are chosen based on the distinguishing features of these two types of the environment discussed in the report, and are somehow related to the two characteristics of "public good" stated by Buchanan (1968, p. 174-177), the degree of indivisibility of good or service in question and the size of the interacting group (the range or limit over which the indivisibility charateristics hold).

In each part, empirical and theoretical works related to the three issues of management goal, system of management measures, and institutional arrangements are presented. Part I contains 5 chapters. Chapter 2 through 4 are mainly concerned with the "preferable" system of management measures for achieving a given management goal. Chapter 2 reports a theoretical model for the analysis of wastewater management in a region and its application to the watershed of Takahamairi inlet, a part of Lake Kasumigaura. The chapter also discusses an economic incentive technique, "effluent charges" for implementing a given water quality standard, on the basis of economic efficiency and equity considerations. Though the model presented in chapter 2 does not directly discuss the problem of management goal, the model helps choose management goal with respect to level and distribution of water quality to be attained. Chapter 3 extends the work reported in chapter 2. In chapter 2 the population distribution as well as the location of treatment plants are predetermined in the model. Chapter 3 addresses the problem of how the heterogeneity in population distribution and river characteristics, as well as the management goal such as the trade-off ratio between water quality and least cost expenditure, affects the optimal number and location of sewage treatment plants, where the empirical part deals with the case of Tama River. Chapter 4 deals with the problem of devising an economically preferable water quality monitoring system in terms of the costs of monitoring and wastewater treatment and the degree of certainty with which the specified level of water quality is obtained.

Chapters 5 and 6 are specifically concerned with the economic analyses of man's utilization of environmental resources in Lake Kasumigaura. Chapter 5 presents a methodology to evaluate production damages from deteriorating water quality, which is applied to the case of aquaculture. Chapter 6 analyzes the interaction between fishermen's behavioral characteristics represented by short-run profits or long-run profits maximization and ecological characteristics such as the predator-prey relationships of the fishery resources. Though these two chapters do not directly deal with the question of management goal, the discussions in these chapters imply that appropriate level of environmental qualities differs among the users of environmental resources.

Part II is concerned with the socio-economic aspects of the management of National Park regions. Chapter 7 introduces the Japanese National Park system as the area designation system, and analyzes the socio-economic characteristics of National Park regions.

Chapters 8 and 9 deal with the economic analyses of man's utilization of environmental resources. Chapter 8 is concerned with preservation use of the natural environment and analyzes a representative case of a new movement in nature conservation that is inspired by the National Trust in UK. Chapter 9 analyzes a representative dispute case of nature conservation vs development and clarifies the characteristics of the current management measures for National Park. Though this introduction is written based on the framework of systems analysis, in chapter 10 Editor summarises what we learn from each chapter from the perspective of economics.

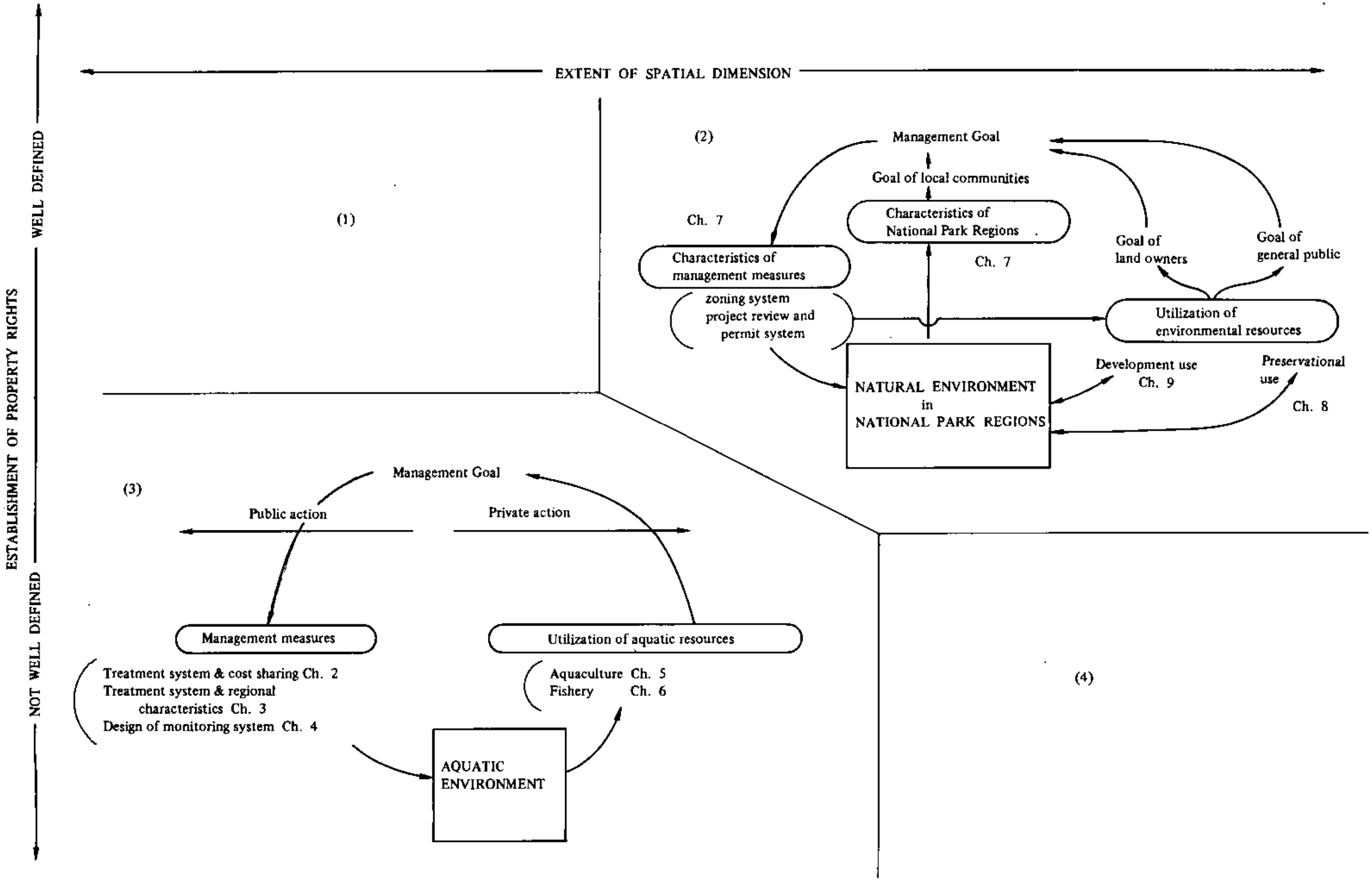

Fig. 1 Plan of the Report

Chapter 2 through 9 are written by respective authors based on the following works, where " * " in front of the author name represents an oral presentation, and chapter 3 and 5 reproduced in this report with some modification of the published articles on behalf of kind permission of publishers of J. Environ. Econ. Manage., and Environ. Plann. A.

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Chapter 2

An Illustrative Model of Regional Water Quality Management

Y. Kitabatake, T. Miyazaki and O. Nakasugi

ABSTRACT

An illustrative model of regional water quality management is developed and applied to the case of Takahamairi inlet in Lake Kasumigaura. The model consists of a nonlinear programming model for the efficient wastewater treatment system for given amounts of discharged wastes, an environmental model simulating the relationships between discharged waste loads and water qualities, and an equitable cost distribution medel. Our contribution is to calculate pollution charge data for a relatively large wastewater treatment model and to employ this charge data in a cost distribution model. Specifically, the nonlinear programming model is transformed into a dynamic programming model for numerical simulation. The dynamic programming model and the Kuhn-Tucker conditions for the original nonliner programming model generate the pollution charge data. The equitable cost distribution model considers both pollution charge data and wastewater dischargers' ability to pay.

1 INTRODUCTION

The traditional approach to regional environmental quality management (Davis, 1968) is to provide the least cost solution for any given set of conditions such as regional environmental quality standards, with a recognition of the range of residuals management alternatives. This traditional approach is characterized by its aim of attaining the regional economic efficiency in the field of pollution and the means to implement the efficient plan is usaually chosen among 1) direct controls such as limitation on pollutant emissions, 2) indirect controls such as pollution charge and subsidies (Kamien *et al.*, 1966; Hass, 1970), and zonal price and standards system (Tietenberg, 1974), depending on an institutional framework of regional environmental quality management.

Current approaches have more emphasis on 1) the problem of distribution such as who pays for achieving the desired environmental quality standards (Spofford *et al.*, 1976) and 2) the relationship between different institutional frameworks and the problem of efficiency and distribution (Russel *et al.*, 1974) with reference to the concept of waste reduction efficiency.

This chapter employs both the traditional approach and current approaches. Especially we deal with the problem of devising an efficient wastewater treatment system and an equitable cost distribution scheme. Section 2 presents the theoretical framework of regional environmental quality management which consists of three sets of submodels; 1) environmental models, 2) efficiency model, and 3) equity model. Section 3 develops the efficiency model and the equity model. Section 4 presents an illustrative regional water quality management model which considers all of three submodels, and which is applied to the watershed drained to Takahamairi inlet in Lake Kasumigaura in Japan.

2 THE THEORETICAL FRAMEWORK

Consider a region which has been partitioned into zones with environmental standards. In practice, the partitions would be different for different environmental media such as a watershed and an airshed. We, though, assume in this paper that it is possible to have a unique partition of the region. We further assume that there exists a central agency which has the sole power of setting environmental standards for each zone and of formulating appropriate rules to attain these standerds.

Fig. 1 shows schematically an overall model framework of the regional environmental quality management. Given the environmental standards for each zone in terms of air, water, soil qualities, environmental models simulate the relationships between the emissions of various components, each component representing a type of pollutant, within the region and the quality of the receiving environmental media in each zone. These models, based on some rigid assumptions, enable us to derive the so-called "transfer functions" (Kneese, 1975) which pass the information to the efficiency model, concerning the total emissions in each zone in the region.

Primal part of the efficiency model is concerned with an optimum design of generation, modification, and the transport of pollutants in production and consumption activities in the region. The short or medium term optimality is here defined as the minimization of related pollution control costs subject to constraints such as the size of population and of economic activities. This optimality criterion represents an economic goal of allocative efficiency, provided that no substitution and income effecs caused by a pollution control program are allowed and that the benefits, such as avoidance of damages, of the program are somehow neglected.

The equity model is concerned with an equitable distribution of the total costs to the emitters of various pollutants in the region. The model is constrained by the three types of exogenously given data. The efficiency model supplies two among the three types. That is, the total costs

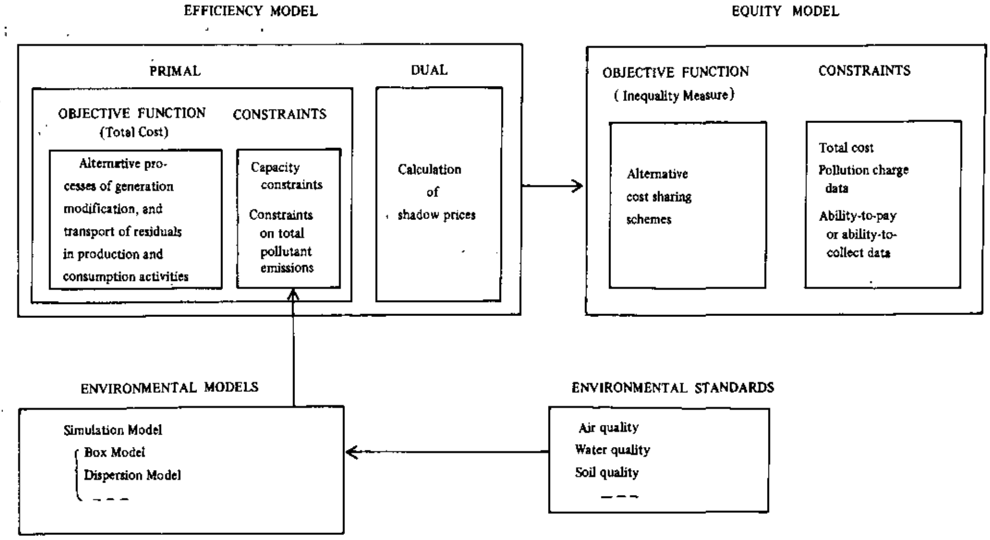

Fig. 1 Schematic diagram of the regional environemental quality management model

needed to achieve the given environmental standards are supplied by the primal part, and the dual part supplies the values of the dual variables (shadow prices) related to the constraints. Third type of the exogenously given data is either on an ability to pay or on the central agency's ability to collect from each emitter or group of emitters. The theoretical implication of shadow prices in the equity model deserves an explanation. Let us write the total costs derived in the primal part of the efficiency model as $C = f(z_1 \ldots z_n)$, where the variables correspond to the constraining factors such as the capacity constraints and the constraints on the total emissions. Then, if a shadow price for a constraining factor, which is equal to the marginal cost of the factor, is assumed to be the opportunity cost of the factor, the shadow price becomes the so-called "pollution charge" (Baumol & Oates, 1975) which is a major policy device in attaining the given envirionmental standards via the use of price mechanism.

In spite of the theoretical elegance, the difficulties of the pollution charge approach lie in 1) its inability to attain a point of global efficiency in the presence of nonconvexties in the production set (Baumol & Oates, 1975) and in 2) its failure to serve as a means of cost sharing scheme. The second difficulty is related to the history of the famous "adding up problem" (Robinson, 1934). That is, the total cost, C, is not equal to the sum of pollution charges in which each constraining factor is paid its shadow price (marginal cost), unless C is a homogeneous function of the first degree. Since it is recognized that "significant economies can be obtained through the combination of waste water flows in common sewers with subsequent treatment at a single waste treatment facility" (Whitlatch & Revelle, 1976), the first and second difficulties seem apparent in the study of regional environmental quality management, though we in this chapter disregard the consideration of environmental damage functions.

We thus use the pollution charge data as the exogenously given variables in the equity model. Then it is shown that any inequality measure satisfying the principle of transfers (Dalton, 1920) derive, under the previous three sets of exogenously given variables, an equitable cost sharing scheme which is exactly compensatory to the total cost needed to attain the given environmental standards. The inequality measures satisfying the principle of transfers include such measures as the variance, Theil's entropy measure, and the Gini coefficient, and are shown to be equivalent to the social welfare functions which are strictly S-concave (Dasgupta *et al.*, 1973). The differnce between the equitable cost and the pollution charge for each emitter is considered a subsidy if its value is negative and an extra charge if positive. In sum, we follow in spirit Tietenberg's zonal price and standards system, but our pricing data are modified by equity considerations.

3 THE MODEL

3. 1 Economic efficiency model

We first formulate a theoretical model for efficient allocation of scarce resources to production and pollution control activities. Given the market prices of saleable outputs and of production factor, regional economic efficiency in production and pollution control is achieved by maximizing the aggregated regional profit subject to a set of constraints. The regional profit is defined as the total revenue minus the total cost of production. The objective function is, therefore, written as follows:

Maximize

$$\sum_{i=1}^{I} \sum_{l=1}^{L} \sum_{n \in N_l} p_i q_{in} - \sum_{m=1}^{M} w_m \Big(\sum_{l=1}^{L} \sum_{n \in N_l} \big(V_{nlm} + \sum_{s=1}^{S+1} V_{nsm}\big) + \sum_{l=1}^{L} \sum_{s=1}^{S+1} V_{Jslm}\Big) - \sum_{p=1}^{P} w_p \sum_{l=1}^{L} \sum_{n \in N_l} V_{np}$$

where p_i represents the price of saleable output i ($i = 1 \cdots I$), q_{in} the production of output i of firm

n ($n \in N_l$) in zone l ($l = 1 \cdots L$), w_m the price of ordinary input m ($m = 1 \cdots M$), V_{n1m} the amount of ordinary input m used in the treatment processes of firm n, V_{nsm} the amount of ordinary input m used in the treatment processes of firm n, V_{Jslm} the amount of ordinary input m used in the *collective treatment process J in zone l, w_p the price of joint input p ($p = 1 \cdots P$)*, and V_{np} the amount of joint input expended by firm n. The collective treatment facilties are assumed to be constructed by the central agency for each zone if necessary. The symbol s ($s = 2 \cdots S+1$) corresponds to the type of pollutants.

The previous objective function is to be maximized subject to certain constraints. The first constraint set specifies the structure of production sectors, based on the model of generalized joint production (Whitcomb, 1972), and is written for the n-th firm as follows:

$$F_{n1}(q_n^i,\ \overline{X}_n^s,\ V_{n1}^m,\ V_n^p) = 0$$

$$F_{ns}(X_{ns},\ W_{ns},\ V_{ns}^m,\ \overline{X}_{ns},\ V_{ns}) = 0 \qquad \text{for } s = 2 \cdots S+1$$

where

$$X_{ns} \leqq \overline{X}_{ns} \qquad \text{for } s = 2 \cdots S+1 \tag{1}$$

and where $F_{n1}(\ )$ is the production function of firm $n \in N_l$ and $F_{ns}(\ )$ is the corresponding treatment function of firm n for the s-th pollutant. The arguments have the following meaning:

$q_n^i = (q_{n1} \cdots q_{nI})$; a vector of saleble outputs of firm n

$\overline{X}_n^s = (\overline{X}_{n2} \cdots \overline{X}_{nS+1})$; a vector *of pollutants generated through the production process of* firm n

$V_{n1}^m = (V_{n11} \cdots V_{n1M})$; a vector of ordinary inputs used in the production process of firm n

$V_n^p = (V_{n1} \cdots V_{np})$; a vector of joint inputs used by firm n

X_{ns} ; an amount of pollutant emitted from s-th treatment process of firm n

$V_{ns}^m = (V_{ns1} \cdots V_{nsM})$; a vector of ordinary inputs used in the s-th treatment process of firm n

In order to explain the remaining arguments, W_{ns} and V_{ns}, the meaning of joint inputs must be clarified. A joint input is here defined as that input appearing in both the production function and the treatment functions of each firm. One example is water which is used in producing outputs as well as an input to the treatment processes of waterborne residuals. Another example is fuel or its *equivalent* gas volume used in both the production process and the treatment process of gaseous residual. Our definition of "joint input" is slightly different from Whitcomb's one in which a joint input is to appear in all equations of firm's production set. We require that a joint input is to appear not necessarily in all equations, but in more than two equations of firm's production set. Thus V_{ns}, an element of V_n^p, is the joint input used both in producing saleable outputs and in the s-th treatment process of firm n. Any pollutant s emitted from firm n's treatment process s is, therefore, characterized by (X_{ns}, V_{ns}). W_{ns} is a part of the joint input V_{ns}, which is passed to the central agency for further treatment of the s-th pollutant type, where the remaining part, $V_{ns} - W_{ns}$, is directly discharged in the environmental media in zone l in which firm n is located. The socond constraint set arises from the previous definition of W_{ns} and is written as follows:

$$W_{ns} \leqq V_{ns} \qquad \text{for } s = 2 \cdots S+1 \quad \text{and} \quad n \in N_l (l = 1 \cdots L) \tag{2}$$

The third constraint set specifies the treatment process at collective facilities provided by the central agency:

$$F_{Js}(x_{Js}^l,\ W_{Js}^l,\ \overline{X}_{Js},\ W_{Js},\ V_{Js}^{lm}) = 0 \qquad \textit{for } s = 2 \cdots S+1$$

$$\overline{X}_{Jsl} = \bar{k}_s W_{Jsl} \geqq \sum_{n \in N_l} (X_{ns} W_{ns}/V_{ns}) + \overline{X}_{Hsl} \quad \text{for } s = 2 \cdots S+1 \quad \text{and} \quad l = 1 \cdots L \tag{3}$$

where

$X^l_{Js} = (X_{Js1} \cdots X_{JsL})$; the vector of the s-th pollutant emitted from the collective treatment facility in each zone l

W_{Js} ; the total amount of the s-th joint input collected by the central agency

$W^l_{Js} = (W_{Js1} \cdots W_{JsL})$; the vector of the s-th joint input treated at the collective facility in each zone

$\overline{X}_{Jsl}$; the upper limit on the total mass of the s-th pollutant collected by the central agency in zone l, given the total amount of joint input, W_{Jsl}

$V^{lm}_{Js} = (V_{Jslm})(l = 1 \cdots L; m = 1 \cdots M)$; a L by M martrix of ordinary inputs used in the s-th treatment process of the collective facilites in the region

$\bar{k}_s$; the concentration of the s-th pollutant in effluent flow from the collective facilities

$\overline{X}_{Hsl}$; the total mass of the s-th pollutant generated by households in zone l.

The fourth constraint set is provided by the environmental models and specifies the upper limit on the total emission of the s-th pollutant type in each zone as follows;

$$X_{Js} + \sum_{n \in N_l} X_{ns}(V_{ns} - W_{ns})/V_{ns} \leqq L_{sl} \tag{4}$$

where L_{sl} represents the upper limit on the s-th pollutant emission ($s = 2 \cdots S+1$) in zone l ($l = 1 \cdots L$).

The fifth constraint set is related to the mass balance equation for each joint input which carries the specific pollutant type:

$$\sum_{l=1}^{L} \sum_{n \in N_l} W_{ns} + \sum_{l=1}^{L} W_{Hsl} = \sum_{l=1}^{L} W_{Jsl} \tag{5}$$

where W_{Hsl} corresponds to the amount of the s-th joint input ($s = 2 \cdots S+1$) generated by households in zone l ($l = 1 \cdots L$).

We now assume that the production function as well as a vector of saleable outputs for each firm is exogenously given to our partial equilibrium, optmization model. In other words, the range of management alternatives available to the central agency is assumed not to include such options as shutdown or scaledown of waste-generating production activity, internal process change, and recovery and recycle of residuals, but to be limited to end-of-pipe treatment of the wastes and public investment in collective treatment facilities. Fig. 2 describes the structure of regional treatment system considered in this paper.

The assumption just stated enables us to 1) disregard the production functions in the first constraint set and 2) to exclude several variables from our optimization problem due to their constancies. Furthermore, it is sometimes easier to obtain data on the cost functions than to obtain data on the treatment functions. One may rewrite the previous objective function in terms of cost functions, with reference to the treatment functions in the first and third constranint sets:

Minimize

$$\sum_{s=2}^{S+1} \sum_{l=1}^{L} \sum_{n \in N_l} C_{ns}(X_{ns}, W_{ns}, \overline{X}_{ns}, V_{ns}) + \sum_{s=2}^{S+1} C_{Js}(X^l_{Js}, W^l_{Js}, \overline{X}_{Js}, W_{Js}) \tag{6}$$

where $C_{ns}(\ )$ is the treatment cost function for the s-th pollutant type for firm n in zone l , in which the vector of generated pollutants, $(\overline{X}_{n2} \cdots \overline{X}_{nS+1})$ and the vector of joint inputs, $(V_{n2} \cdots V_{nS+1})$, are both exogenously given data. $C_{Js}(\ )$ represents the treatment cost function for the collective

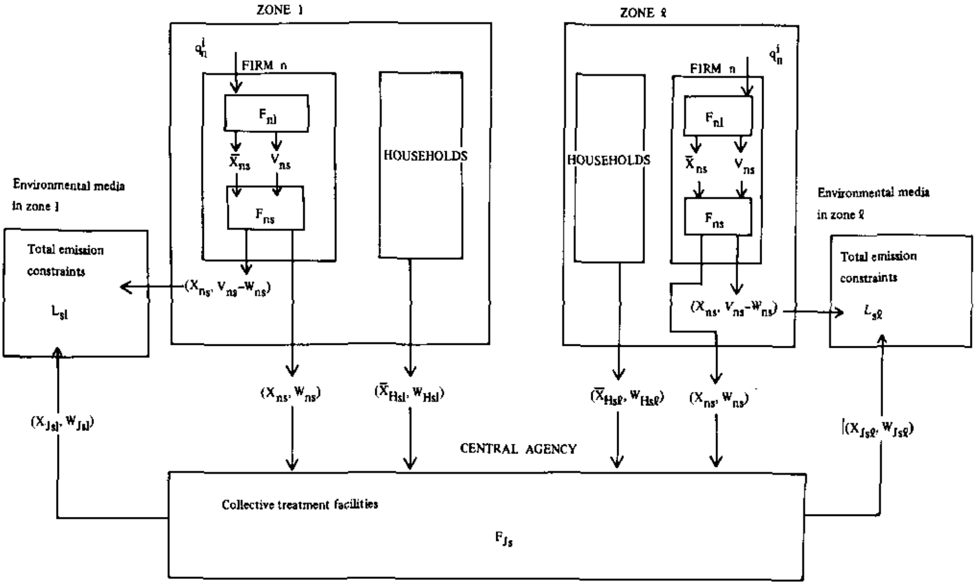

Fig. 2 The structure of regional treatment system

treatment of the s-th pollutant. In sum, the primal part of the efficiency model is to minimize (6), the sum of private treatment costs and collective treatment costs, subject to (1), (2), (3), (4), (5), and non-negative conditions for the endogenous variables of the model.

The dual part of the efficiency model is based on the following Lagrangian function:

$$\begin{aligned} L = {} & \sum_{l=1}^{L} \sum_{n\in N_l} \sum_{s=2}^{S+1} C_{ns}(X_{ns},\ W_{ns}) + \sum_{s=2}^{S+1} C_{Js}(X_{Js}^{l},\ W_{Js}^{l},\ \overline{X}_{Js},\ W_{Js}) \\ & + \sum_{s=2}^{S+1} \sum_{l=1}^{L} \alpha_{sl}(X_{jsl} + \sum_{n\in N_l} X_{ns}(V_{ns} - W_{ns})/V_{ns} - L_{sl}) \\ & + \sum_{s=2}^{S+1} \sum_{l=1}^{L} \sum_{n\in N_l} \gamma_{ns}(W_{ns} - V_{ns}) + \sum_{s=2}^{S+1} \beta_s(\sum_{l=1}^{L} \sum_{n\in N_l} W_{ns} + \sum_{l=1}^{L} W_{Hsl} - \sum_{l=1}^{L} W_{Jsl}) \\ & + \sum_{s=2}^{S+1} \sum_{l=1}^{L} \sum_{n\in N_l} \delta_{ns}(X_{ns} - \overline{X}_{ns}) + \sum_{l=1}^{L} \sum_{s=2}^{S+1} \theta_{sl}(-\overline{X}_{Jsl} + \sum_{n\in N_l} X_{ns}W_{ns}/V_{ns} + \overline{X}_{Hsl}) \end{aligned} \tag{7}$$

We then obtain as Kuhn-Tucker conditions (Luenberger, 1973);

$$\left.\begin{aligned} \partial L/\partial W_{ns} = {} & \partial C_{ns}/\partial W_{ns} - \alpha_{sl}(X_{ns}/V_{ns}) + \gamma_{ns} + \beta_s + \theta_{sl}(X_{ns}/V_{ns}) \geqq 0 \\ & W_{ns}\,\partial L/\partial W_{ns} = 0 \\ & \gamma_{ns}(W_{ns} - V_{ns}) = 0 \\ & \gamma_{ns} \geqq 0 \end{aligned}\right\} \tag{8}$$

$$\left.\begin{aligned} \partial L/\partial X_{ns} = {} & \partial C_{ns}/\partial X_{ns} + L_{sl}(V_{ns} - W_{ns})/V_{ns} + \delta_{ns} + \theta_{sl}W_{ns}/V_{ns} \geqq 0 \\ & X_{ns}\,\partial L/\partial X_{ns} = 0 \\ & \delta_{ns}(X_{ns} - \overline{X}_{ns}) = 0 \\ & \delta_{ns} \geqq 0 \end{aligned}\right\} \tag{9}$$

$$\left.\begin{aligned}\partial L/\partial W_{Js} &= \partial C_{Js}/\partial W_{Js} - \beta_s = 0\\ W_{Jsl}\partial L/\partial W_{Jsl} &= 0\end{aligned}\right\} \qquad (10)$$

$$\left.\begin{aligned}\partial L/\partial X_{Js} &= \partial C_{Js}/\partial \overline{X}_{Js} - \theta_{sl} = 0\\ \overline{X}_{Jsl}\partial L/\partial \overline{X}_{Jsl} &= 0\end{aligned}\right\} \qquad (11)$$

where we disregard those conditions which are not necessarily needed for calculation and interpretation of shadow prices. The first Lagrange multiplier set, α_{sl}, is the shadow pirce of the s-th pollutant constraint in zone l, the marginal social cost of an increase in the stringency of the s-th pollutant emission constraint in zone l. The second Lagrange multiplier set, β_s, is the shadow price of the flow constraint on the s-th joint input flowing into the collective facilities, and, as equation (10) shows, is independent of where the joint input is treated. β_s, thus, represents the marginal social cost of an increase in the s-th joint input collected by the central agency. The third Lagrange multiplier, θ_{sl}, is the shadow price for zone l of the constraint on the collective facilities' ability to treat the pollutant type s for a given amount of the s-th joint input.

In order to interpret the fourth Lagrange multiplier set, γ_{ns}, we obtain the following relationship for each $n \in N_l$ from the equation set (8):

$$\gamma_{ns} = \alpha_{sl}X_{ns}/V_{ns} - (\partial C_{ns}/\partial W_{ns} + \beta_s + \theta_{sl}X_{ns}/V_{ns}) \geqq 0 \quad \text{if } W_{ns} = V_{ns} \qquad (12)$$

The first term on the right-hand side(RHS) of (12) is the marginal benefit of not cousuming s-th pollutant constraint in zone l. The second term in parenthesis represents, as a whole, the marginal cost of passing to the collective facilities the s-th pollutant emitted by firm n and characterized by(X_{nsl}, W_{nsl}). The left-hand side(LHS) of (12), γ_{ns}, is interpreted as the marginal opportunity cost of the n-th firm's capacity constraint on the s-th joint input. Similarly, we have the following relation from the equation set (9):

$$\delta_{ns} = -\partial C_{ns}/\partial X_{ns} - (\alpha_{sl}(V_{ns} - W_{ns})/V_{ns} + \theta_{sl}W_{ns}/V_{ns}) \geqq 0 \quad \text{if } X_{ns} = \overline{X}_{ns} \qquad (13)$$

The first term on the RHS of (13) is the marginal benefit due to an increase in the maximum amount of the s-th pollutant emission by the n-th firm. The second term in the parenthesis is the sum of 1) the marginal cost of consuming the total emission constraint of pollutant type s in zone l and 2) the marginal cost of touching on the collective facilities' ability to treat the s-th pollutant type. The LHS of (13), then, represents the marginal opportunity cost of the n-th firm's constraint on the total emission of pollutant type s.

Table 1 shows the pricing scheme or the setting of pollution charge in attainig the given environmental standards in each zone via the use of shadow price data, provided that 1) the sufficiency conditons for minimization are satisfied and 2) the central agency operates the collective facilities in a way specified by Kuhn-Tucker conditions. The pricing scheme specified in Table 1 enables the private sector's decentralized cost minization efforts to meet Kuhn-Tucher conditions which represent the necessary conditions for the socially optimal configuration of pollution control activities. The private sector here, however, does not include the household sectior whose pollution loads are exogenenously given data to the central agency. As is mentioned in Section 2, there is no assurrance that the money sum collected through the pricing scheme is equal to the total cost needed to execute the efficient configuration of pollution control activities.

3. 2 Equitable cost distribution model

The proposed equitable cost distribution model is specified below, where for notational convenience we disregard the suffix representing the location of each emitter:

Choose the values of y_1 through y_m so as to minimize

Table 1 Setting of pollution charge for the alternative cases of individual and collective treatment[1]

individual treatment Collective treatment	treatment at source $X_{ns} < \bar{X}_{ns}$		no treatment at source $X_{ns} = \bar{X}_{ns}$	
FIRM				
no collective treatment $(W_{ns}=0)$	pay A		pay A+E	
partially treated at collective facility $(0<W_{ns}<V_{ns})$	pay A+C	if (3) is not *binding*	pay A+C+E	if (3) is not *binding*
	pay A+B+C	if (3) is binding	pay A+B+C+E	if (3) is binding
wholly treated at collective facility $(W_{ns}=V_{ns})$	pay D+C	if (3) is not binding	pay D+C+E	if (3) is not binding
	pay D+C+B	if (3) is binding	pay D+C+B+E	if (3) is binding
HOUSEHOLDS			pay F	if (3) is not binding
			pay F+G	if (3) is binding

1) Each symbol is written as follows,

$A=\sum_S \alpha_{sl} X_{ns_l} \left(\frac{V_{ns}-W_{ns}}{V_{ns}}, \right)$ $C=\sum_S \beta_s W_{ns}$, $E=\sum_S \delta_{ns} X_{ns}$, $G=\sum_S \theta_s X_{Hsl}$,

$B=\sum_S \theta_s X_{ns} W_{ns} / V_{ns}$, $D=\sum_S \gamma_{ns} W_{ns}$, $F=\sum_S \beta_s W_{Hsl}$,

$$f(y_1 \cdots y_M; P_1 \cdots P_M) \tag{14}$$

subject to the constraints

$$0< y_m \leqq C_m/C \quad \text{for } m = 1 \cdots M \tag{15}$$

$$\sum_{m=1}^{M} y_m = 1 \tag{16}$$

where

C ; the total cost derived in the primal part of the efficiency model

C_m; the ability to pay for or the central agency's ability to collect from the m-th emitter (group of emitters), which are exogenously given data

y_m; the ratio of the cost shared by the m-th emitter (group of emitters) to the total cost

P_m; the ratio of the pollution charge imposed on the m-th emitter (group of emitters) to the total pollution charge. These ratios are given by the dual part of the efficiency model.

We now prove the following Proposition.

Proposition 1:

The following procedural steps represent the optimum solution for the proposed equitable cost distribution model, provided that 1) we use as objective functions the inequality measures satisfying the principle of transfers, and 2) the sum of the ability to pay (ability to collect) data is greater than the total cost, where the principle of transfers is taken to mean, in our context, that if we make a strictly positive transfer of distributed cost from an emitter (group of emitters) with a value of y_m/p_m, say D, to any emitter with a value less than D, this ought to lead to a strictly positive reduction in the index of inequality;

Step 1: Calculate for each emitter (group of emitters) m the shared cost $y_m C$ for the case in which $y_m/p_m = 1$ holds

Step 2: Call the set of those emitters (group of emitters) as I group in which the distributed cost $y_i C$ is less than the ability-to-pay data, C_i

Step 3: Call the set of those emitters (group of emitters) as $\bar{I}$ group in which the distributed cost, $y_l C$, is greater than or equal to the ability-to-pay data, C_l

Step 4: For each emitter (group of emitters) l in $\bar{I}$ group calculate y_l/p_l where y_l is given by C_l/C, and order them in the increasing values of y_l/p_l. Then the following relation is obtained

$$y_{l1}/p_{l1} \leqq y_{l2}/p_{l2} \leqq \cdots \leqq y_{lm}/p_{lm} \quad \text{for } l_1 \cdots l_m \in \bar{I}$$

Step 5: For each emitter (group of emitters) i in I group, calculate the distributed cost, $y_i C$, in such a way that the following equality is satisfied

$$y_i/p_i = (1 - \sum_{l \in \bar{I}} y_l)/(1 - \sum_{l \in \bar{I}} p_l) \text{ for } i \in I$$

Step 6: In case that $y_i \geqq C_i/C$ is obtained for any emitter (group of emitters) i in I group, put the emitter i into $\bar{I}$ group and return to step 4.

Proof:

The proof is greatly simplified by using the familiar Lorenz curve, whereby the percentages of the pollution charge, which are arranged in the increasing order of y_m/p_m, are represented on the horizontal axis and the percentages of cost shared by the bottom x % of the pollution charge is shown on the vertical axis. Fig. 3 shows two Lorenz curves. Line of absolute equality represnts the situation in which every emitter shares the cost proportional to his share of pollution charge. It is easily seen, in the presence of constraint on the ability to pay, that any Lorenz curve corresponding to a feasible solution of the equitable cost distribution model must lie below the

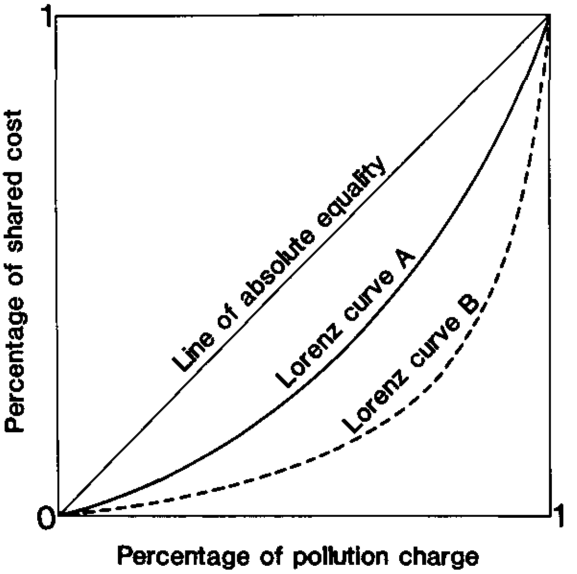

Fig. 3 Lorenz curves

diagonal. Let us treat Lorenz curve A as the curve of repressenting the optimum solution specified in Proposition. Then we can say that any other Lorenz curve corresponding to any other feasible solution lies strictly outside the Lorenz curve A, where "strictly outside" is taken to mean that the Lorenz curve of B lies nowhere inside that of A and at some place (at least) it lies strictly outside the latter. Furthermore, it has been proved that Lorenz curve A can be reached from any Lorenz curve outside that of A by the successive transfer of distributed cost from an emitter with a value of y_m/p_m, say D, to any emitter with a value less than D (Rothschild & Stiglitz, 1973). The proof flollows directly from the principle of transfers under which our inequality measures always, by definition, give the minimum value to the Lorenz curve A. Q. E. D.

4 AN ILLUSTRATIVE MODEL

4. 1 Description of the study area

The area under cosideration is the watershed drained to Takahamairi inlet in Lake Kasumigaura(see Fig. 4). Water quality level of Takakamairi inlet was about 3.14 ppm in terms of annural average of monthly COD concentration in 1968. This was deteriorated into 7.71 ppm in 1976. On the other hand, Lake Kasumigaura, which contains Takahamairi inlet, was designated the water quality standard of class A which requires to achieve the COD concentration of 3 ppm in comparison to the current state of 7−8ppm.

The watershed in question contains two cities and eight municipal towns. The COD load generated in this area is in the following: industry sources generate 60%, household 9%, stockbreeding sector 27%, and agricultural lands 4%, respectively of the total loads generated. Industry souces are mainly composed of two industrial complexes in Ishioka city and in the village of Tamari, and four large-scale food companies in Ishioka city and in the town of Minori. These four food companies share 70% of the total COD load generated by the industry sector. With regard to household sector, City of Ishioka counts 40% of the total population included in the study area. Furthermore, the region is nationally noted for its hog raising. This fact is reflected in a large COD load share of stockbreeding sector, relative to other regions.

A pilot area is chosen from the Takahamairi watershed for the analysis in Section 4. 3 of the efficient treatment system concerning industry and household wastewater. Thus the waste load generated by industries and households in the pilot area becomes controllable load for the following analysis. These data are estimated on the basis of data available from Japan Environment Agency and the Ministry of Construction, Japan(1974). On the other hand, the following waste loads constitute uncontrollable loads: 1) COD loads discharged by all industries and households in the whole watershed area excluding the pilot area, which is estimated based on the assumption that the COD concentration of all effluents is 40 ppm; 2) the COD loads discharged by the stockbreeding sector and the natural loads from fields in the whole watershed area, which are slso estimated with data available form Japan Environment Agency and the Ministry of Construction, Japan. These uncontrollable loads are passed on to section 4. 2 as the influent loads to Takahamairi inlet.

4.2 Environment model

Takahamairi inlet of Lake Kasumigaura is divided, for its mathematical representaion, into 5 sections with the areas shown in Fig. 5, each of which is essentially homogeneous in water quality. Within a section, all parameters are considered uniform, although the parameters can be varied from section to section. Fig. 6 shows that the hydraulic sections which comprise the model are idealized as 5 compartments. For each of these compartments, a mass-balance equation is

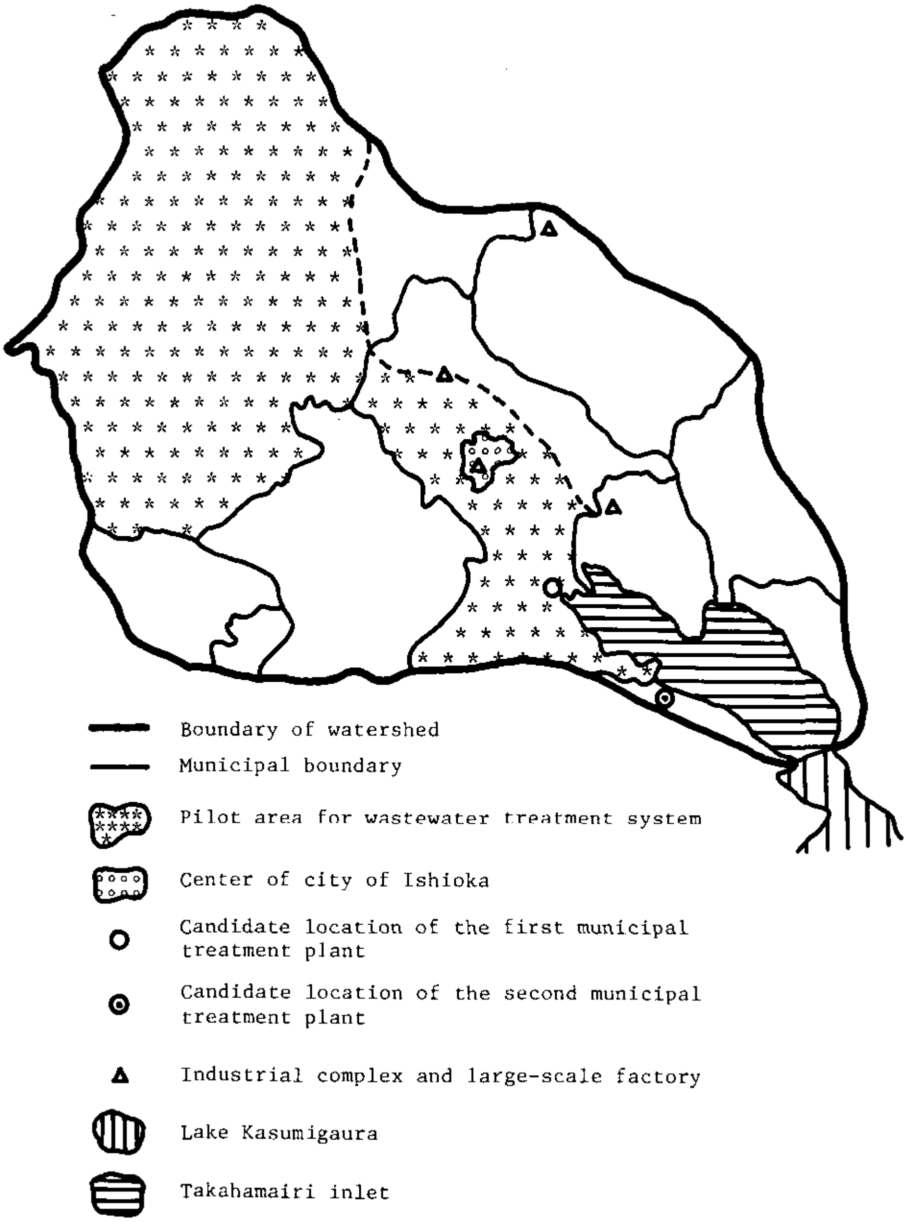

Fig. 4 Takahamairi watershed

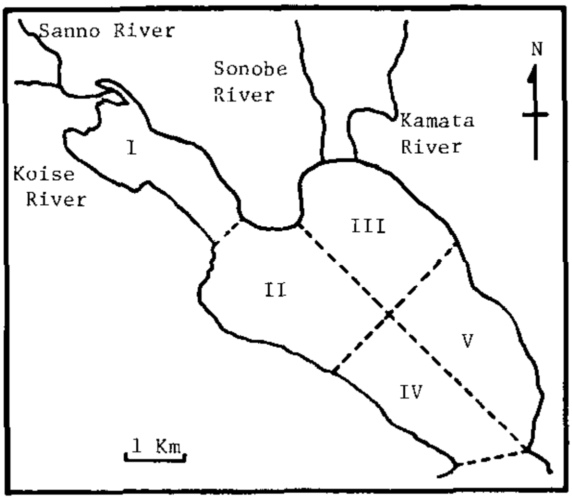

Fig. 5 Division of Takahamairi inlet

writen for COD, and this resulted in the 5 linear differential equations based on the physical, hydrological, and biochemical characteristics of the section. The equations are as follows:

$$\left.\begin{aligned}
V_1dC_1/dt &= \bar{L}_1+\bar{L}'_1-Q_{12}C_1+R_1V_1\\
V_2dC_2/dt &= \bar{L}_2+\bar{L}'_2-(Q_{23}+Q_{24})C_2+Q_{12}C_1+Q_{32}C_3+Q_{42}C_4+R_2V_2\\
V_3dC_3/dt &= \bar{L}_3+\bar{L}'_3-(Q_{32}+Q_{35})C_3+Q_{23}C_2+Q_{53}C_3+R_3V_3\\
V_4dC_4/dt &= \bar{L}_4+\bar{L}'_4-(Q_{42}+Q_{45}+Q_{46})C_4+Q_{24}C_2+Q_{54}C_5+R_4V_4\\
V_5dC_5/dt &= \bar{L}_5+\bar{L}'_5-(Q_{53}+Q_{54})C_5+Q_{35}C_3+Q_{45}C_4+R_5V_5
\end{aligned}\right\} \tag{17}$$

where

$R_i = -k_{1i}C_i+k_{2i}P_i \quad (i = 1\cdots 5)$
k_{1i} = decay coefficient in the i-th water section (l/d)
k_{2i} = dissolution coefficient from total phosphorous (l/d)
P_i = total phosphorus concentration of the i-th water section (ppm)
V_i = volume of the i-th water section (m^3)
$\bar{L}_i$ = controllable effluent load to the i-th water section (ton/d)
$\bar{L}'_i$ = uncontrollable effluent load to the i-th water section (ton/d)
Q_{ij} = advective flows from the i-th water section to the j-th water section ($j = 2\cdots 6,\ i = 1\cdots 5$)($m^3$/d)
C_i = COD concentration of the i-th water section (ppm)

A sutable boundary condition for each section is given by:

$$C_i = C_{0i} \qquad \text{at } t = 0, \qquad \text{for } i = 1\cdots 5 \tag{18}$$

The equations (17) simply state that the time rate of change of the substance C is equal to the difference between the sum of the amount of total input and dissolution, and the amount discharged and lost by its decay in a water section. The system coefficients are extremely important since they imply a great deal about the inlet's properties and behaviours such as the

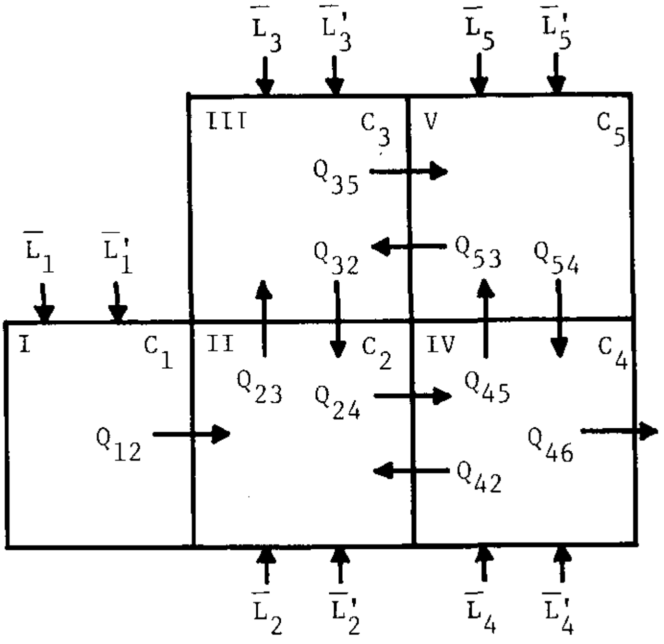

Fig. 6 Idealized hydraulic elements

decay rate, sedimentation, absorption, multiplication, and dissolution of substance. Some of these coefficients are fundamental in nature and can be derived based on the literatures (Chen & Orlob, 1975; Thomann, 1972; Ibaraki Prefectural Government, 1972). Others are still quite empirical and must be estimated.

It should be noted that the decay coefficients k_{1i} in the equations represent the total decay rate of the sedimentation, absorption, biological uptake and multiplication of COD, and are derived from the experimental data (The Ministry of Construction, Japan, 1973). On the other hand, the dissolution coefficients R_i are empirically estimated by a paramater fitting technique utilizing the least square method (Naito *et al.*, 1969).

This model also requires weather information concerning air temperature, rainfalls, evaporation rates, and wind speed which are regularly reported by Japan Meteorological Agency (The Japan Meteorological Agency, 1972). The hydrological data of inlet are taken from water resouces data published by the Ministry of Construction, Japan (1974). The advective flows Q_{ij} between sections, however, are calculated from the rate of rainfall, evaporation, and surface flow which is assumed to be approximately 2-4% of mean wind speed.

Fig. 7 shows the results of the water quality simulation throughout 5 years for the values of parameters and constants listed in Table 2.

A set of water quality profiles in terms of COD is illustrated in Fig. 8, provided that $\bar{L}_1$ and $\bar{L}_2$ are ranging from 0 to 200 and 0 to 200 kilograms per day, respectively.

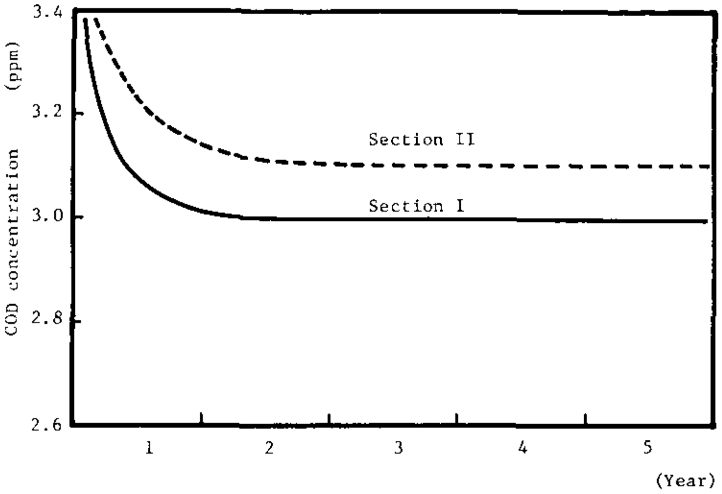

Fig. 7 5 year forecast of COD concentration

Table 2 Values of parameters and constants

Water section number	V $10^6 m^3$	$\bar{L}$ t/d	$\bar{L}'$ t/d	P ppm	k_1 1/d	k_2 1/d
I	5.489	0.1	2.381	0.08	0.05	0.00
II	15.23	0.1	0.072	0.08	0.02	0.64
III	12.87	—	1.904	0.08	0.03	0.64
IV	13.53	—	0.013	0.06	0.03	0.50
V	15.24	—	0.035	0.06	0.03	0.50

4.3 Efficiency and equity model

Based on a target water quality level which specifies the values of $\bar{L}_1$ and $\bar{L}_2$, this section considers the problem of determining the levels of wastewater treatment accomplished at each of a number of treatment facilities which are to be constructed, and that of distributing the needed total cost.

4.3.1 Waste treatment alternatives

Table 3 categorizes the total of 468 industry sources in the pilot area into nine groups with regards to the quantity of an individual wastewater and a level of the COD concentration prior to treatment. Household sources in the area are treated one group as a whole.

Treatment facilities are assumed to be constructed (if necessary) at each of the 468 individual industry sources. The whole or a part of the effluent from each private treatment plant is either 1) discharged into nearby rivers flowing into the bottom reach of Takahamairi inlet, or 2) be collected in a municipal sewer to be treated at municipal plants. The main sewer, which ranges 10 km in distance, also collects the whole amount of households wastewater generated in the area. Municipal plants are assumed to be constructed (if necessary) at locations described in Fig. 4. The COD concentration of households wastewater mixed with industry effluents is assumed not to exceed some critical level. This level is set at 500 ppm in the following analysis.

Next, it is assumed that each individual industry sources in the same group employs the

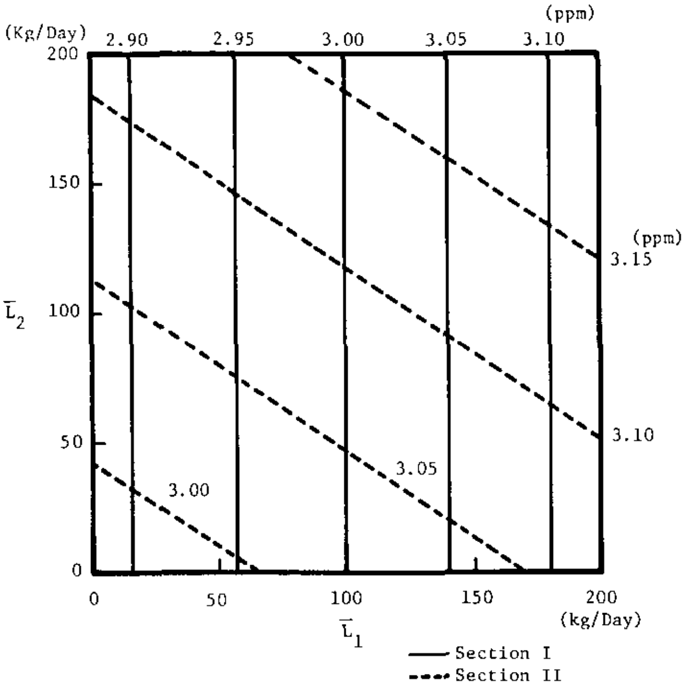

Fig. 8 Water quality response to effluent load

Table 3 Grouping of industry sources

		Quantity (t/d)		
		10	50	500
COD concentration prior to treatment (ppm)	1500	3	1	1
	350	71	4	4
	20	354	27	2

same treatment technology. Alternative treatment types is terms of the effluent COD concentration, available to each source group, are listed in Table 4 with other data relevant to the following analysis. For example, the first group may reduce its COD concentration from 1500 ppm to any level chosen among 1500 ppm, 350 ppm, 80 ppm, 10 ppm, and 4 ppm. On the other hand, municipal treatment plants choose one among three treatment types, 20 ppm, 10 ppm, and 4 ppm. Table 5 describes the combination of unit treatment processes corresponding to each type treatment, where the variables used in the table implies the following: BB is dilution (4 times), AA preliminary treatment, A1 conventional primary sedimentation, C1 conventional activated sludge, C6 high rate activated sludge, F2 two-stage tertiary lime treatment, D filtration, E activated carbon, and I ion exchange.

Table 4 Input data to the efficiency model

Zone	Source group number	Amount of generated COD concn. (ppm) $\bar{x}_{nl}$	Alternative treatment type in terms of emitted COD concn. (ppm)						Total amount of joint input (t/d) V_{nl}	Number of group number P(n)
1	1	1500	1500	350	80		10	4	30	3
	2	350		350	80		10	4	710	71
	3	1500	1500	350	80		10	4	50	1
	4	350		350	80		10	4	200	4
	5	350		350	80		10	4	2000	4
	6	1500	1500	350	80		10	4	500	1
	7	20				20	10	4	3540	354
	8	20				20	10	4	1350	27
	9	20				20	10	4	1000	2
	10 (Households)	100			80		10	4	17510	

Tabel 5 Combination of unit treatment processses

		Type of treatment in terms of effluent COD (ppm)			
		350	80	10	4
Influent COD concentration	1500	BB	B+AA+A1+C1	BB+AA+A1+C1+F2+D+E	BB+AA+A1+C1+F2+D+E
(ppm)	350−100		AA+A1+C1	AA+A1+C1+F2	AA+A1+C1+F2+D+E
	20				AA+A1+E+E

4.3.2 Model formulation

Our model deals with the case of one pollutant ($s = 1$), nine source groups ($n = 9$), two zones ($l = 2$), and one household group in zone 1. Thus the efficiency model for regional wastewater treatment system is formulated as follows;

Minimize

$$f(W_{n1}, x_{n1}, W_{J11}, X_{J11}, W_{J12}, X_{J12}) \tag{19}$$

subject to

$$\sum_{n=1}^{9} x_{n1}(V_{n1} - W_{n1})/1000 + X_{J11} \leqq \bar{L}_1 \tag{20}$$

$$X_{J12} \leqq \bar{L}_2 \tag{21}$$

$$W_{n1} \leqq V_{n1} \quad \text{for } n = 1 \cdots 9 \tag{22}$$

$$\underline{x}_{n1} \leqq x_{n1} \leqq \hat{x}_{n1} \quad \text{for } n = 1 \cdots 9 \tag{23}$$

$$X_{J11} \leqq \bar{L}_1 \tag{24}$$

$$W_{J11} + W_{J12} - \sum_{n=1}^{9} W_{n1} - W_{H11} = 0 \tag{25}$$

$$W_{n1} \geqq 0 \quad \text{for } n = 1 \cdots 9 \tag{26}$$

$$W_{J11}, X_{J11}, W_{J12}, X_{J12} \geqq 0 \tag{27}$$

where

$$f(W_{n1},\ x_{n1},\ W_{J11},\ X_{J11},\ W_{J12},\ X_{J12}) = \sum_{n=1}^{9} \{TC_n(x_{n1},\ V_{n1}) + PC_n(W_{n1})\}$$

$$+ f_{J11}(W_{J11}, X_{J11}) + f_{J12}(W_{J12}, X_{J12}) + g(W_{J11}, W_{J12}) \qquad (28)$$

Interpretation of variables are as follows:

W_{J11} = the amount of wastewater flow treated at the first municipal plant in zone 1
W_{J12} = the amount of wastewater flow treated at the second municipal plant in zone 2
X_{J11} = the amounts of COD load discharged from the first municipal plant
X_{J12} = the amounts of COD load discharged from the second municipal plant
V_{n1} = the total of the wastewater flows generated by the n-th source group
x_{n1} = the treatment level, in terms of the concentration of COD load, chosen by the n-th source group
$\bar{x}_{n1}$ = the upper limit of the treatment level chosen by the n-th source group
$\underline{x}_{n1}$ = the lower limit of the treatment level chosen by the n-th source group
$TC_n(\ )$ = the anualized treatment cost function for the n-th source group
$PC_n(\ )$ = the anualized piping cost function for the transport of wastewater from the n-th source group to the main sewer
$f_{J11}(\ )$ = the anualized treatment cost function for the first municipal plant
$f_{J12}(\ )$ = the anualized treatment cost function for the second municipal plant
$g(\ )$ = the anualized piping cost function for the transport of wastewater through the main sewer to the municipal treatment plants

Anualized piping cost function assumes the following form (The Ministry of Construction, Japan, 1974):

$$[i(1+i)^m/((1+i)^m-1)](10.69h+0.3261)\exp[(1.0145-0.0092\mathrm{h})2\sqrt{q/(\pi Z)}]$$

where

i = discount factor assumed 0.07
m = depreciation periods assumed 30 years
h = burying depth assumed 2 m for collecting sewers and 4 m for the main sewers
Z = flow velocity through sewer assumed 2 m/s
q = flow rate (t/d)
d = distance of sewers assumed 0.5 km for each collecting sewer, 10 km for the main sewer to the first municipal plant, and 10 km for the main sewer connecting the first and the second municipal plant.

As to the anualized treatment cost function, we refer to the study done at the U. S. Environment Protection Agency (Van Note *et al.*, 1975), which specifies the anual treatment cost for each unit treatment process. The cost equations for our treatment types are based on this study, where the parameter values such as land price and wholesale price index assumed the 1973 values. Fig. 9 illustrates, in terms of unit cost, one of the cost functions used in the numerical computations of the model.

The constrained minimization problem of (19) through (27) is transformed into the following Lagrangian function

$$L = f(W_{n1},\ x_{n1},\ W_{J11},\ X_{J11},\ W_{J12},\ X_{J12})$$

$$+ \alpha_{11}(\sum_n x_{n1}(V_{n1}-W_{n1})/1000 + X_{J11} - \bar{L}_1) + \alpha_{12}(X_{J12} - \bar{L}_2)$$

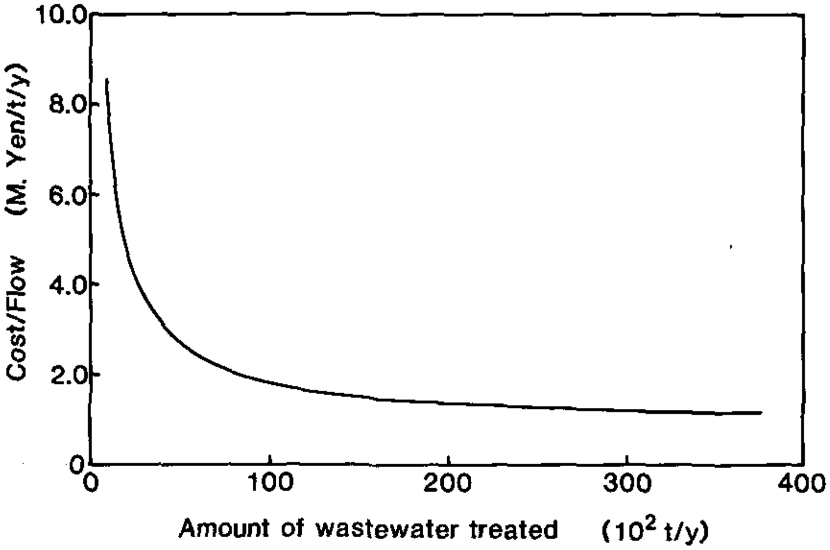

Fig. 9 Unit cost for a plant reducing COD contents from 350 ppm to 4 ppm

$$+\sum_{n}\gamma_{n1}(W_{n1}-V_{n1})+\sum_{n}\delta_{n1}(x_{n1}-\bar{x}_{n1})+\sum_{n}\theta_{n}(-x_{n1}+\underline{x}_{n1})$$

$$+\delta_{J11}(X_{J11}-\bar{L}_1)+\beta(W_{J11}+W_{J12}-\sum_{n}W_{n1}-W_{H11})+\sum_{n}\mu_{n}(-W_{n1}) \qquad (29)$$

Where the symbols are similar to those in equation (7). The Kuhn-Tucker conditions are written, in this case, as follows:

$$\left.\begin{aligned} \partial L/\partial W_{n1} &= \partial f/\partial W_{n1}+\alpha_{11}(-\bar{x}_{n1}/1000)+\gamma_{n1}-\beta-\mu_{n} \geqq 0 \\ W_{n1}\,\partial L/\partial W_{n1} &= 0 \\ \mu_{n}(-W_{n1}) &= 0 \quad \text{for} \quad n=1\cdots 9 \end{aligned}\right\} \qquad (30)$$

$$\left.\begin{aligned} \partial L/\partial W_{J11} &= \partial f/\partial W_{J11}+\beta \geqq 0 \\ W_{J11}\,\partial L/\partial W_{J11} &= 0 \end{aligned}\right\} \qquad (31)$$

$$\left.\begin{aligned} \partial L/\partial W_{J12} &= \partial f/\partial W_{J12}+\beta \geqq 0 \\ W_{J12}\,\partial L/\partial W_{J12} &= 0 \end{aligned}\right\} \qquad (32)$$

$$\left.\begin{aligned} \partial L/\partial x_{n1} &= \partial f/\partial x_{n1}+\alpha_{11}(V_{n1}-W_{n1})/1000+\delta_{n1}-\theta_{n} \geqq 0 \\ x_{n1}\,\partial L/\partial x_{n1} &= 0 \\ \delta_{n1}(x_{n1}-\bar{x}_{n1}) &= 0 \\ \theta_{n}(-x_{n1}+\underline{x}_{n1}) &= 0 \quad \text{for} \quad n=1\cdots 9 \end{aligned}\right\} \qquad (33)$$

$$\left.\begin{aligned} \partial L/\partial X_{J11} &= \partial f/\partial X_{J11}+\alpha_{11}+\delta_{J11} \geqq 0 \\ X_{J11}\,\partial L/\partial X_{J11} &= 0 \\ \delta_{J11}(X_{J11}-\bar{L}_1) &= 0 \end{aligned}\right\}, \qquad (34)$$

$$\left.\begin{aligned} \partial L/\partial X_{j12} &= \partial f/\partial X_{j12} + \alpha_{12} \geqq 0 \\ X_{j12}\,\partial L/\partial X_{j12} &= 0 \\ \alpha_{12}(X_{j12} - \bar{L}_2) &= 0 \end{aligned}\right\} \qquad (35)$$

4. 3. 3 Computation results

Numerical computations are carried out recursively with the use of dynamic programming technique applied to a nonsequential multistage problem with a converging branch (Nemhauser, 1966), for a given pair of ($\bar{L}_1$, $\bar{L}_2$), the maximum permissible COD load for zone 1 and for zone 2. Appendix 1 to this chapter explains the computation procedure. Fig. 10 shows the set of isocost curves, where the hirizontal axis corresponds to the total COD costraint in zone 1, and the vertical axis to that in zone 2. Fig. 10 is calculated based on a rather rough spacing on the state variables, and, consequently, represents a rough approximation to the true solution. In our efficency model, the total cost function of (28) is dominated by the wastewater treatment cost function which is characterized by the scale economy as shown in Fig. 9. Thus the isocost curve does not become convex to the origin. Combining Fig. 8 and Fig. 10, we obtain a couple of trade-off curves in Fig. 11 which shows the substitution relationships between water quality of water section 1 (zone 1) and that of water section 2 (zone 2) for a given amount of total cost.

An example of the efficient treatment system along with the corresponding shadow prices is shown in Table 6 which corresponds to the given pair of water qualities, 2.97 ppm for water section 1 and 3.05 ppm for water section 2. As to the shadow prices not specified in Table 6, we disregard δ_{n1} and θ_n for $n = 1$ through 9, for our cost function is discontinuous with respect to x_{n1}. We then obtain in Table 7 the pollution charge data for the efficient treatment system described in Table 6, which are to be imposed on source groups and which are derived from the pricing scheme of Table 1. The solution in Table 6 to the efficiency model is obtained by searching, in terms of the coarse grid approach, the globally optimum point, and finetuning the

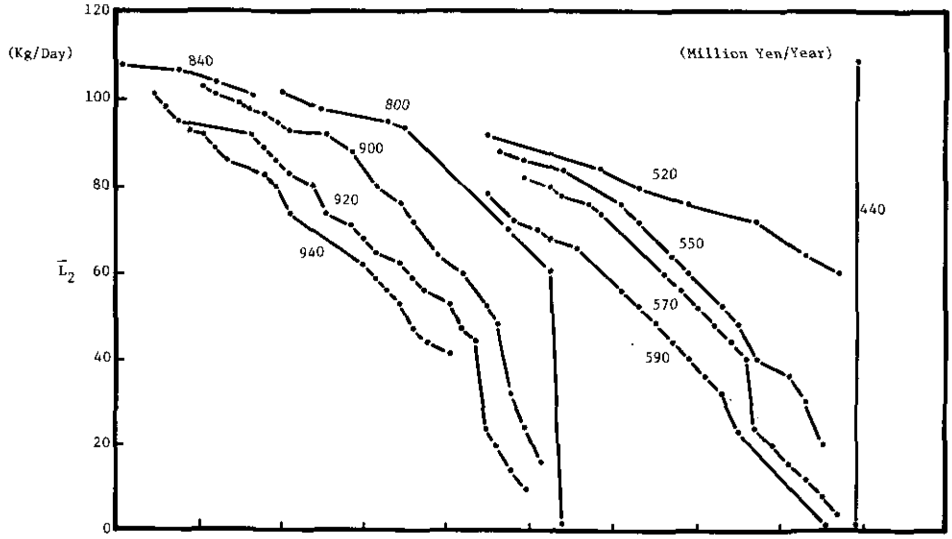

Fig. 10 Isocost curves

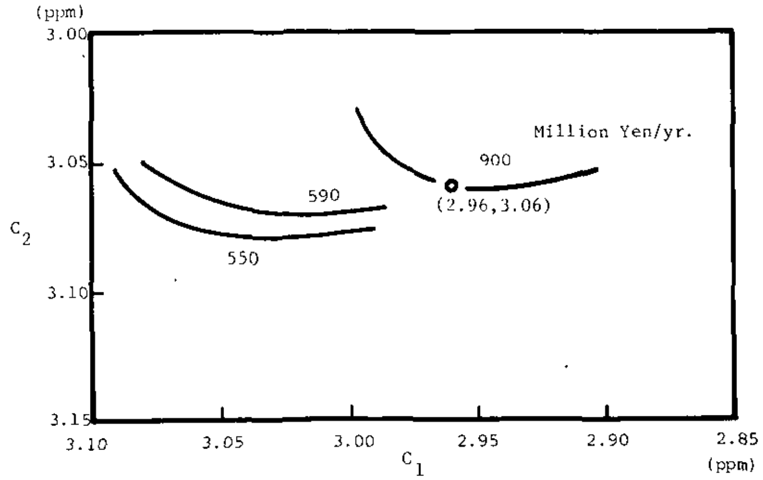

Fig. 11 Water quality trade-off curves

Tabel 6 The efficient treatment system and the corresponding shadow prices for given amounts of $\bar{L}_1$ and $\bar{L}_2$

a) Individual treatment

	treatment level		shadow price
n	x^*_{n1}	W^*_{n1}	γ_{n1}
1	1500 ppm	30(t/d)	0.7436485 (Mil. yen/t)
2	350	710	0.1658276
3	1500	50	0.7438344
4	350	200	0.1660135
5	350	2000	0.1661164
6	1500	500	0.7439373
7	20	3186	0
8	20	0	0
9	20	1000	0.000307

b) Collective (Municipal) treatment

treatment level	shadow price
$x^*_{J11} = 4$ ppm	
$x^*_{J12} = 4$ ppm	
$W^*_{J11} = 11416$ t/d	
$W^*_{J12} = 13770$ t/d	$\beta = 0.0096918$ Mil. yen/t

c) Effluent constraints and shadow prices

$\bar{L}_1 = 79.74$ kg/d	$\alpha_{11} = 0.502453$ Mil. yen/kg
$\bar{L}_2 = 55.08$ kg/d	$\alpha_{12} = 0.560898$ Mil. yen/kg

Table 7 Pollution charge data

Source group number (n)	Pollution charges (Million yen/y)
1	22.600
2	124.618
3	37.676
4	35.141
5	351.616
6	376.814
7	34.435
8	13.566
9	9.998
Households	169.703
Total	1176.1>898

searched solution via the Kuhn-Tucker conditions, it may be of some theoretical interest to derive and check the sufficiency condition for the solution to be a local optimum (see Appendix 2 to this chapter).

National survery data are available, despite of their incompleteness, concerning how much money has been invested by an individual firm during the time periods of 1970-1975 in wastewater treatment plants for each industry category (Japan Environment Agency, 1977). We assume arbitrarily that 3% of this stock value represents a firm's ability to pay datum. To use this ability to pay data, we have to regroup individual industry sources in Table 2 into a number of (in this case 17) industry categories. Table 8 shows the correspondence between industry categories and 9 industry source groups. As to the household sector, the ability to pay datum is estimated, based on the assumption that each household in the study area is able to pay at most 60 yen per ton of wastewater. Applying these data to Proposition 1, we obtain an equitable cost distribution scheme shown in the fifth column of Table 9.

5 CONCLUSION

The preceding discussion has presented an analysis for regional environmental quality management. As Bower(1977) well summarized, this kind of analysis requires "(1) the development of models of residuals generation and modification activities; (2) the development of models of the processes which affect, and are affected by the residuals after their discharge into the environmental media, termed "environmental models" ; (3) specification of an explicit objective function, which include ambient environmental quality indicators either in the function itself or as constraints; (4) the selection of a method of analysis; and (5) the development and applications of criteria for evaluating strategies.

As to the first requirement, we have considered only the end-of-pipe treatment for the given outputs of products and/or services, which include both treatment at source and collective treatment at given locations.

Our environmental model is a water quality (COD) model and transforms the time-constant spatial pattern of COD discharge into the lake environment into the long-run (five years) spatial pattern of lake water quality.

As to the third requirement, our objective function consists of an economic objective of minimizing the total annualized cost of residurals treatment, and the environmental constraint on

Table 8 Industry category vs. Insustry source group

Industry category	Source group								
	1	2	3	4	5	6	7	8	9
1 Food and kindred	3	63	1	3	3		4	1	
2 *Textiles and apparel*		4			1		131	1	
3 Lumber and wood Furniture and fixtures							97		
4 Pulp and paper		3		1			1		
5 Publishing and printing							9		
6 Chemicals		1				1			
7 Petroleum and coal								1	
8 Tanned Leather							6		
9 Ceramic, stone and clay							27	7	1
10 Iron and steel									1
11 Non-ferrous metal								1	
12 Fabricated metal							24	3	
13 Ordinary machinery							14	3	
14 Electrical machinery							5	2	
15 Transport equipment							2	1	
16 Precision instruments							4	2	
17 *Others*							30	4	

Table 9 The equitable cost sharing scheme

Industry category number (m)	Number of firms	Ratio of pollution charge (P_m)	Ability to pay data (C_m) (Million yen/y)	Shared cost ($y_m \cdot C$) (Million yen/y)
1 Food and kindred	78	.3927	243.91	243.91
2 Textiles and apparel	137	.0919	306.36	209.56
3 *Lumber and wood* Furniture and fixture	98	.0084	8.35	8.35
4 Pulp and paper	5	.0120	240.11	27.36
5 Publishing and printing	9	.0007	7.08	1.60
6 *Chemicals*	2	.3219	16.95	16.95
7 Petroleum and coal	1	.0004	24.59	.91
8 Tanned Leather	6	.0005	.21	.21
9 Ceramic, stone and clay	35	.0095	20.03	20.03
10 Iron and steel	1	.0043	16.77	9.81
11 Non-ferrous metal	1	.0004	5.28	.91
12 Fabricated metal	27	.0033	18.78	7.53
13 *Ordinary machinery*	17	.0024	25.08	5.47
14 Electrical machinery	7	.0013	32.31	2.96
15 Transport equipment	3	.0006	10.91	1.37
16 Precision instruments	6	.0012	10.33	2.74
17 Other	34	.0042	88.72	9.58
HOUSEHOLDS		.1443	383.5	329.05

the total allowable COD discharges into the lake environment, which is derived from the environmental model.

We used, as the method of analysis (the fourth requirement), the dynamic programming technique to calculate the minimum cost set of treatment measures to meet the specified COD discharge constraints, where we have also used the Kuhn-Tucker conditions both as a means to calculate the shadow price data and as a means to refine the dynamic programming calculations.

As to the final requirement of evaluating criteria, our criteria cosists of threeholds: the maintenance of a single water quality indicator of COD at a specified level, minimizing the direct economic costs of maintaing the water quality at the specified livel, and an equitable distribution of the needed cost in relation both to the residuals dischargers' ability to pay and to the shadow price data(their contribution to the total cost).

Therefore the analysis in this chapter neglected various problems related to multiple environmental quality indicators, damage function, optimal locations of collective treatment facilities, etc., some of which are taken up in the following chapters.

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APPENDIX 1 On the treatment cost function

We employs in chapter 1 the treatment cost functions specified in Van Note et al. (1975). In this appendix, we briefly introduce their work. They have specified a cost function for each unit process of wastewatrer treatment in terms of the following three formulae: 1) a formula for amortized capital cost; 2) a formula for fixed operation and maintenance costs; and 3) a formula for flow-variable operation and maintenance cost. In each formula, the following 7 variables can be changed as the specific conditions to the problem in question warrant: i) plant capacity (*Q; Million Gallon per Day); ii) capital recovery factor* (CRF); iii) service and interest factor which includes allowance for engineering, contingencies, and interest during construction (SIF; %); iv) labour rate (MHR; $/man-hour); v) land cost (ULC; $/acre); vi) wholesale price index of industrial commodities (EPI); vii) national average wastewater treatment plant cost index (STP), where CRF is written in terms of interest rate(i ; %) and amortization period (n ; years) as follows,

$$\mathrm{CRF} = i(1+i)^n/((1+i)^n-1) \tag{A1}$$

Then the first formula for amortized capital cost is written with the unit of cents per 1000 Gal. as

$$[(\mathrm{BCC})(\mathrm{STP}/177.5)+(\mathrm{LR})(\mathrm{ULC})]((100+\mathrm{SIF})/100)\mathrm{CRF}/3650Q \tag{A2}$$

where BCC is base capital cost($) and LR is land requirement (acres).

The second formula for fixed operation and maintenance cost is written with the unit of cents per 100 Gal. as

$$(\mathrm{BMH})(\mathrm{MHR})/3650Q \tag{A3}$$

The third formula for variable operation and maintenance costs is written with the unit of cents per 1000 Gal. as

$$(\mathrm{BMC})(\mathrm{WPI}/120)/3650Q \tag{A4}$$

where BMC is base material costs ($/yr.).

BCC, LR, BMH, and BMC are estimated for each unit process. For example, in case of conventional primary sedimentation (A1), these are written as follows.

$$\mathrm{BCC} = 139753+17341.2Q$$
$$\mathrm{LR} = 0.23+0.088Q$$
$$\mathrm{BMH} = 1852.8Q^{0.42}$$
$$BMC = 1158.4Q^{0.62}$$

In chapter 2 we have employed the following U. S. value (mostly as of February 1973),

$\mathrm{SIF} = 27\%$; $\mathrm{WPI} = 120$; $\mathrm{STP} = 177.5$;
$MHR = 5\$/\text{man-hour}$; $ULC = 2000\$/acre$,

except $n = 20$ years and $i = 7\%$, by converting dollar into yen, if necessary.

APPENDIX 2 Dynamic programming formulation of the efficiency model

The efficiency model specified in equations (19)-(28) are rewritten as follows,

$$\mathrm{Min}\sum_{n=1}^{9} P(n)f_n(q(n);\, d_n, e_n)+f_{10}(Q^H;\, Z, e_{10})+f_{11}(e_{10};\, d_{11})+f_{12}(e_{10};\, d_{12}) \tag{A1}$$

subject to

$$\sum_{n=1}^{9} d_n(1-e_n)Q(n)+d_{11}(1-e_{10})(Z+Q^H) \leqq \bar{L}_1 \tag{A2}$$

$$d_{12}e_{10}(Z+Q^H) \leqq \bar{L}_2 \tag{A3}$$

$$Z \triangleq \sum_{n=1}^{9} e_nQ(n) \leqq \sum_{n=1}^{9} Q(n) \tag{A4}$$

where

$P(n)$ = the number of plant in the n-th source group

$q(n)$ = the average amounts of wastewater generated by an individual plant in the n-th source group

$Q^H \triangleq W_{H11}$

$Q(n) \triangleq V_{n1}$

$d_n \triangleq x_{n1}$ = the treatment level chosen by the n-th source group

d_{11} = the treatment level chosen by the first municipal treatment plant

d_{12} = the treatment level chosen by the second municipal treatment plant

e_n = the amounts of wastewater disposed in the public sewer divided by $q(n)$, $0 \leqq e_n \leqq 1$.

e_{10} = the amounts of wastewater treated by the second municipal plants divided by the total amounts of wastewater collected through public sewers, $0 \leqq e_{10} \leqq 1$.

$f_n(\ )$ = the cost function for an individual plant in the n-th source group

$f_{10}(\ )$ = the cost of transporting wastewater to the municipal treatment plants by public sewers.

$f_{11}(\ )$ = the treatment cost function for the municipal plant.

$f_{12}(\ )$ = the treatment cost function for the second municipal plant.

We then state the dynamic programming version of this nonlinear programming problem in terms of the following recursion equations

$$F_N(X_N, V_M, Z_N) = \min_{d_N} \{f_N(d_N, Z_N)+F_{N-1}(X_{N-1}, V_M, Z_{N-1}) \tag{A5}$$

$$\begin{aligned} F_{N-1}(X_{N-1},\ V_M,\ Z_{N-1}) = \mathop{\mathrm{Min}}_{W_{M-1}} \{ & f_{N-1}(Z_{N-1},\ W_{M-1};\ Q^{\mathrm{H}})+F_{N-2}(X_{N-2},\ Z_{N-2}) \\ & +G_M(V_M,\ W_{M-1})\} \end{aligned} \tag{A6}$$

$$F_n(X_n, Z_n) = \min_{d_n, e_n} \{P(n)f_n(d_n, e_n;\, q(n))+F_{n-1}(X_{n-1}, Z_{n-1})\} \qquad \text{for } n = 2\cdots N-2 \tag{A7}$$

$$F_1(X_1, Z_1) = \min_{d_1, e_1} \{P(1)f_1(d_1, e_1;\, q(1))\} \tag{A8}$$

where

$$G_M = \begin{cases} f_M(d_M,\ W_{M-1}) & \text{for } W_{M-1}>0 \text{ and } d_M = V_M/W_{M-1} \\ 0 & \text{otherwise} \end{cases} \tag{A9}$$

The interpretation of each state variable is as follows,

V_M = the state variable concerning the total allowable load to the second water section, $0 \leqq V_M \leqq \bar{L}_2$.

W_M = the state variable concerning the amounts of wastewater treatment at the second municipal plant, $0 \leqq W_M \leqq Q = \sum_{n=1}^{10} Q(n)$.

X_N = the state variable concerning the total allowable load to the first water section, $0 \leqq X_N \leqq \bar{L}_1$.

Z_N = the state variable concerning the amounts of wastewater treated at the first municipal plant, $0 \leqq Z_N \leqq Q$.

X_n = the state variable concerning the disposal of effluent load by the source groups 1 through n to the first water section.

Z_n = the state variable concerning the amounts of wastewater generated by the source groups 1 through n and transported through public sewers to the municipal treatment plants.

As to the stage transformation of state variables (Z, W), we obtain

$$\begin{aligned} & W_M \leqq Q = \sum_{n=1}^{10} Q(n) \\ & W_{M-1} = W_M \end{aligned} \tag{A10}$$

$$\mathrm{Z}_N \leqq \mathrm{Q} = \sum_{n=1}^{10} (n)$$

$$\mathrm{Z}_{N-1} = \mathrm{Z}_N \tag{A11}$$

$$\mathrm{Z}_{N-2} = \mathrm{W}_{M-1}+\mathrm{Z}_{N-1}-\mathrm{Q}(10) \tag{A12}$$

$$\mathrm{Z}_{N-3} = \mathrm{Z}_{N-2}-\mathrm{e}_{N-2}\mathrm{Q}(N-2) \tag{A13}$$

. . . . .

$$\mathrm{Z}_1 = \mathrm{Z}_2-\mathrm{e}_2\mathrm{Q}(2) \tag{A14}$$

$$\mathrm{Z}_0 = \mathrm{Z}_1-\mathrm{e}_1\mathrm{Q}(1) \tag{A15}$$

where $\mathrm{Q}(10) = \mathrm{Q}^H$ and

$$\mathrm{Q}(10) \leqq \mathrm{Z}_N+\mathrm{W}_M \leqq \mathrm{Q} \tag{A16}$$

From (A10) through (A16), we obtain

$$\mathrm{Z}_{N-2} = \mathrm{Z} \tag{A17}$$

$$\mathrm{Z}_0+ \sum_{n=1}^{N-2} \mathrm{e}_n\mathrm{Q}(n) \leqq \sum_{n=1}^{N-2}\mathrm{Q}(\mathrm{n}) \tag{A18}$$

Thus, in order for (A18) to be equivalent to (A4), the following must hold

$$\mathrm{Z}_0 = 0 \tag{A19}$$

As to the stage transformation of state variables (V, X), we obtain

$$\mathrm{V}_M \leqq \bar{\mathrm{L}}_2 \tag{A20}$$

$$\mathrm{V}_M = \mathrm{d}_M\mathrm{W}_{M-1} \tag{A21}$$

$$\mathrm{X}_N \leqq \bar{\mathrm{L}}_1 \tag{A22}$$

$$\mathrm{X}_{N-1} = \mathrm{X}_N-\mathrm{d}_N\mathrm{Z}_N \tag{A23}$$

$$\mathrm{X}_{N-2} = \mathrm{X}_{N-1} \tag{A24}$$

$$\mathrm{X}_{N-3} = \mathrm{X}_{N-2}-\mathrm{d}_{N-2}(1-\mathrm{e}_{N-2})\mathrm{Q}(N-2) \tag{A25}$$

. . . . .

$$\mathrm{X}_1 = \mathrm{X}_2-\mathrm{d}_2(1-\mathrm{e}_2)\mathrm{Q}(2) \tag{A26}$$

$$\mathrm{X}_0 = \mathrm{X}_1-\mathrm{d}_1(1-\mathrm{e}_1)\mathrm{Q}(1) \tag{A27}$$

By substituting the following *relationship*

$$\begin{aligned}\mathrm{Z}_N &= (1-\mathrm{e}_{N-1})(\mathrm{Z}_{N-2}+\mathrm{Q}(10)) \\ &= (1-\mathrm{e}_{N-1})(\mathrm{Z}+\mathrm{Q}(10))\end{aligned} \tag{A28}$$

into (A23) and by utilizing (A22) through (A27), we obtain

$$\mathrm{X}_0+ \sum_{n=1}^{N-2} \mathrm{d}_n(1-\mathrm{e}_n)\mathrm{Q}(\mathrm{n})+\mathrm{d}_N(1-\mathrm{e}_{N-1})(\mathrm{Z}+\mathrm{Q}(10)) \leqq \bar{\mathrm{L}}_1 \tag{A29}$$

Thus, in order for (A29) to be equivaluent to (A2), the following relationship must hold,

$$\mathrm{X}_0 = 0 \tag{A30}$$

Similaly, from (A28), (A12), (A20) and (A21), we obtain

$$\mathrm{d}_M\mathrm{e}_{N-1}(\mathrm{Z}+(10)) \leqq \bar{\mathrm{L}}_2$$

which is equivalent to (A3).

Thus if we solve the recursion equations (A5)-(A9) subject to (A19) and (A30), we obtain the solution to the original non-linear programming problem (A1)-(A4). Fig. A1 explains graphically the recursion equations, (A5)-(A9).

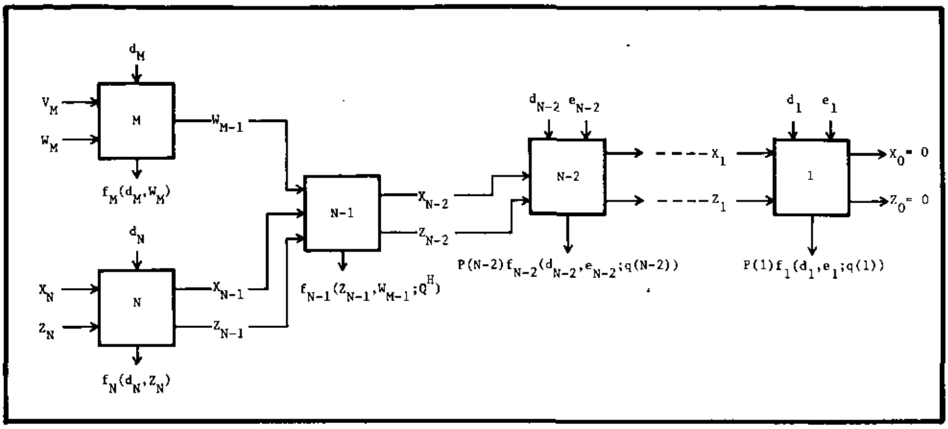

Fig. A1 The backward multistage structure characterized by converging branch system

APPENDIX 3 Derivation of the sufficiency condition

Since the solution in Table 6 is derived so as to satisfy the Kuhn-Tucker coditions (30) through (35), it satisfies the necessary conditions for a local optimality. In order to derive the sufficiency condition, we simplify the notation of variables as follows,

$X_{J11} \rightarrow X_N$
$X_{J12} \rightarrow X_M$
$W_{J11} \rightarrow W_N$
$W_{J12} \rightarrow W_M$

The sufficiency condition that the solution $S^* = (x^*_{n1}, W^*_{n1}, X^*_N, W^*_N, X^*_M, W^*_M)$ specified in Table 6 represents a strict relative minimum point of the nonlinear progrmming problem (19)-(28) is that the following Hessian Matrix

$$L(S^*) = F(S^*) + \lambda H(S^*) + \mu G(S^*) \tag{A1}$$

is positive definite on the subspace

$$M' = \{T: \nabla h(S^*)T = 0, \nabla g_j(S^*)T = 0 \quad \text{for all } j \in J\} \tag{A2}$$

where

$$J = \{j: g_j(S^*) = 0, \mu_j > 0\} \tag{A3}$$

(Luenberger, 1973, p235). In (A1), $F(S^*)$, $H(S^*)$, and $G(S^*)$ are the Hessian matrix of the total cost function (19), the equality constraint (25), and the inequality constraint ((20)-(24), (26), (27)), respectively, and λ and μ are the corresponding vectors of Lagrange multipliers. Since all of our equality and inequality constraints except (20) are linear equations, $L(S^*)$ is greatly simplified.

As to the tangent subspace M', the comparison of Table 4 and Table 6 shows that there are 20 active constraints at S^* such that

$$x^*_{n1} = \bar{x}_{n1} \text{ for } n = 1 \cdots 6, 9$$

$$x^*_{81} = 0$$

$$W^*_{n1} = V_{n1} \text{ for } n = 1 \cdots 9$$

$$W^*_N + W^*_M - \sum_{n=1}^{9} W^*_{n1} - W_{H11} = 0$$

$$\sum_{n=1}^{9} x^*_{n1}(V_{n1} - W^*_{n1})/1000 + X^*_N = \bar{L}_1$$

$$X_M^* = \bar{L}_2$$

Thus we obtain

$$M' = \{(W_N, W_M, X_N):\ -0.02W_N - 0.02W_M + X_N = 0\}$$

When we introduce the following orthonormal basis, $E = (e_1, e_2)$, in order to obtain an explicit matrix representation on M',

$$e_1 = (1 \quad 0.02 \quad 0)/\underline{1}.0004$$
$$e_2 = (1 \quad 0 \quad -1)/\sqrt{2}$$

the sufficiency condition is simplified such that the following matrix

$$E' \begin{pmatrix} \partial^2 f/\partial W_N^2 & \partial^2 f/\partial W_N X \partial_N & \partial^2 f/\partial W_N \partial W_M \\ \partial^2 f/\partial X_N \partial W_N & \partial^2 f/\partial X_N^2 & \partial^2 f/\partial X_N \partial W_M \\ \partial^2 f/\partial W_M \partial W_N & \partial^2 f/\partial W_M \partial X_N & \partial^2 f/\partial W_M^2 \end{pmatrix} E \tag{A4}$$

becomes positive definite. Thus, if the total cost function satisfies the following property

$$\partial^2 f/\partial X_N^2 > -0.345906 \tag{A5}$$

or, from (A1) in Appendix 2,

$$\partial^2 f/\partial X_N^2 = \partial^2 f_N/\partial X_N^2 > -0.345906$$

we can conclude that the sufficiency condition is satisfied. Since our treatment cost function is not a continous function of X_N, however, we cannot verify (A5) for our case.

Chapter 3

The Location of Sewage Treatment Plant on a Continuous Space: Theoretical and Empirical Analyses*

Y. Kitabatake and T. Miyazaki

ABSTRACT

A theoretical model of the sewage treatment plant location problem is presented, based on the assumptions of a homogeneous space and a homogeneous channel geometry of a river running parallel to a one-dimensional region. The analytical structure of the model is discussed. The model is then applied to the specific case of a suburban region of the Tokyo Metropolitan Region, where both the homogeneity assumptions are dropped. The numerical simulations show clearly how the heterogeneity in population distribution and river characteristics, as well as the trade-off ratio between water quality and least cost expenditure, affects the optimal plant locations.

1 INTRODUCTION

In this chapter, we deal with the problem of optimal location of collective treatment facilities. Especially, a new approach to the (collective) sewage treatment plant location problem is proposed. Generally speaking, sewage treatment plant location problems have been analyzed either without or with consideration for the water quality of the receiving body of water. In the first case, the optimal trade-off between the number of treatment plants and the extent of sewerage systems was analyzed with the dynamic programming formulation of Converse (1972), the nonlinear programing formulation of Joeres *et al.* (1974), and the network flow analysis method of Jarvis *et al.* (1978). In the second case, the optimal number, location, and level of treatment for sewage treatment plants was analyzed using dynamic programing, linear programing, and heuristic location techniques by Whitlatch & ReVelle (1976). In all cited works, a region is defined as a cluster of locations generating wastewater and the wastewater treatment system either as a multistage optimization problem or as a network flow problem.

In reference to location problems, regional scientists and urban economists have traditionally been concerned with agricultural location (von Thünen, 1842; Lösch, 1954), industrial location (Moses, 1958), and residential location (Alonso, 1964; Muth, 1969) on a continuous space, whereas the interests of environmental engineers, as we saw in the previous paragraph, have been in the location of environmental service facilities, such as sewage treatment plants, on a discrete space. The main reasons explaining the difference in the methodological treatment of space are considered to be twofold. First, the difference in spatial locations as reflected in transport cost plays a more significant role in the location decisions of firms and

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households in the former discipline than in the latter. Second, the studies of former discipline are based on intraurban distributions of agricultural, industrial, and residential activities as exemplified in the theory of land rent and land use, whereas the latter mainly studies the interurban distribution of water qualities, subject to the given size of agricultural, industrial, and residential activities of each urban area.

In this paper,the optimum number and location of sewage treatment plants on a continuous space is analyzed, with the analysis based on the spatial variation in the waste-generating population and in the varying assimilative capacity of the receiveing body of water. Specifically, this paper intends to subsume the issue of sewage treatment plant location into a wider programme of enquiry, which could be termed an intraurban distribution of environmental quality. Since water quality as well as sewerage services constitutes an important part of the quality of life, there exists an important link between the location decisions of sewage treatment plants, and the location decisions of firms and households, which result in the intraurban population distribution. As the problem of the location choice of firms and households has been analyzed on a continuous space (for example, see Mills, 1980), a new approach is proposed to facilitate the integration of the sewage treatment plant location problem into the main body of urban economics.

This introducton has explained wh;y we treat the sewage treatment plant location problem by using a continuous spatial model, departing from the conventional way of analyzing the problem in terms of a discrete spatial model. In section 2 a theoretical model of sewage treatment plant location on a continuous space is presented, and its analytical structure is discussed, based on the assumptions of homogeneous space and of a homogeneous channel geometry of a river running parallel to a one-dimensional region. The model is applied in section 3 to a suburban region of the Tokyo Metropolitan region, which is considered to be one large urban area rather than a cluster of isolated urban areas; here the assumptions of homogeneous space and homogeneous channel geometry are both dropped for the numerical simulation of the model.

2 THEORETICAL ANALYSIS

2.1 A theoretical model of sewage treatment plant location

In this section, we consider the location of sewage treatment plants in homogeneous space, in which wastewater generators (consumers) with a homogeneous waste coefficient are evenly distributed in space and in which a single body of water is assumed with homogeneous channel geometry and no tributaries. The analysis is developed essentially in a Weberian framework on the basis of the following simplifying assumptions, which are written in reference to Norman(1979): (1) Economic inputs to sewage treatment are available in unlimited supply at fixed prices invariant by location. (2) These inputs are ubiquitous. (3) Demand for final commodities such as swimming or the water intake for a municipal water supply, is concentrated at a single point downstream of the body of water. (4) Transport of sewage to the plant is feasible in the direction of river flow, and transport cost is a function of volume and distance, where the volume of sewage is proportional to the distance transported, and where the transport cost of the final good is zero.

Specifically, we consider a one—dimensional region in which a constant volume, a_0, of sewage is generated per unit distance per unit time, and in which a river flows parallel to the linear region to the right. A river of length d links a given upstream point, M_1, with a downstream point, M_2; the marketpoint, M_3, is located at a fixed distance $\bar{d}$ downstream from M_2. Given the number of plants, n, plant one is located at a distance x_1 from M_1, and plant i at a distance x_i from the location point of plant $(i-1)$; plant n is assumed to be located at M_2. Futhermore, plant i is assumed to treat the sewage generated, q_i ($=a_o x_i$), along the distance x_i; and to discharge the treated sewage, q_i, with the waste load, $W_i(=wa_o x_i)$, into the river at the point which is a distance of $\sum_{j=1}^{i} x_j$ from M_1, where w is a given constant and a_0 is the population per unit distance, N, multiplied by the daily water consumption per capita, s_0. Here, we assume that consumers are evenly distributed only along the line between M_1 and M_2.

As to the model of river water quality, the linearized river is divided into a number of segments, each containing one sewage treatment plant and defined as the part of the line from that plant to the next one downstream. Under the assumptions of a temporal steady state, constant system parameters, and no distributional sources or sinks, the equation for river water quality, B_i, for segment i, is written (Thomann, 1972, p. 67),

$$B_i = B_i^0 \exp(-K_r x_i) \tag{1}$$

where K_r ($=k_r/u$) is the decay coefficient, k_r, divided by stream velocity, u. Specifically, B_i in equation (1) is the concentration of biological oxygen demand (BOD) in parts per million (ppm). Thus, the concentration decays exponentially with distance downstream, until a new waste discharge from a sewage treatment plant is encountered. In equation (1), the concentration, B_i^0, at the start of the segment is computed by dividing the total BOD load at the entrance of segment i by the river flow of that segment so that

$$B_i^0 = W_{i-1} + B_{i-1}(q_0 + \sum_{l=1}^{i-1} q_l)/(q_0 + \sum_{l=1}^{i} q_l) \tag{2}$$

where q_0 is the river flow at M_1. In terms of equations (1) and (2), the water quality at M_3 is written as,

$$B = \{W_0 \exp[-K_r(d+\bar{d})] + \sum_{i=1}^{n} W_j \exp[-K_r(d+\bar{d}-\sum_{k\leq j} x_k)]\} / (q_0 + \sum_{j=1}^{n} q_j) \tag{3}$$

where W_0 is the waste load at M_1. If we assume that the total population of a region as well as W_o and q_o is constant, the water quality at M_3 is affected by the second term of the numerator of equation (3) which is defined to be W_B^n:

$$W_B^n(x_1 \cdots x_n) = \sum_{j=1}^{n} b_0 x_j \exp(K_r \sum_{k\leq j} x_k) \tag{4}$$

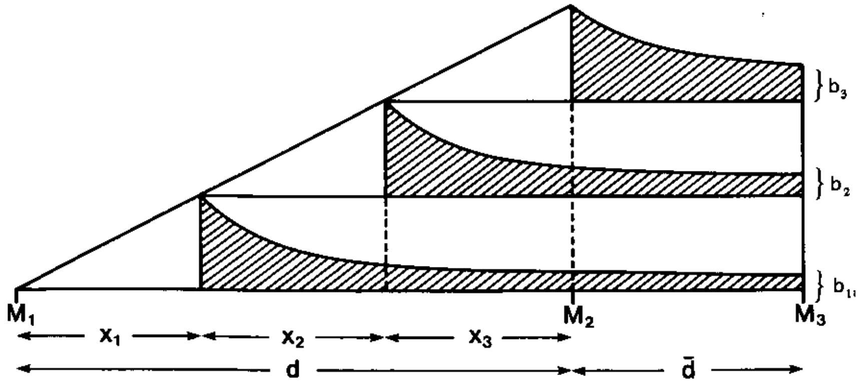

Fig. 1 A case of three plants on locational line.

where $b_0 = a_0 w \exp(-K_r(d+\bar{d}))$. Fig. 1 shows three plants on a straight line; W_B is equal to the sum of the vertical lengths, $b_1+b_2+b_3$, of the shaded area at M_3.

Before we proceed to the derivation of an optimum number of plants and optimal plant locations, the use of equation (1) for a model of river water quality needs an explanation. Equation (1) takes BOD as an indicator of river water quality and is of a much simpler form than the commonly accepted form of the dissolved oxygen−biological oxygen demand (DO−BO) relationship (Streeter & Phelps, 1925). National environmental quality standards for river water in Japan are specified for each classification of stream use, such as water supply and fishery, in terms of pH, BOD, suspended solids (SS), DO, and the number of coliform groups. To achieve quality standards, it is provided by law that each prefecture must establish its own comprehensive plan for improving sewerage systems for each drainage basin. The Ministry of Construction has instructed that, in principle, BOD be used for river and chemical oxygen demand (COD) for lakes or oceans as the target water-quality standard for establishing a comprehensive plan (Ministry of Construction, 1980). Based on this Japanese practice, we choose BOD as the water-quality variable.

An optimum number of plants, as well as optimal plant locatins, are derived by the following constrained maximization problem:

$$\text{maximize } U(C_t^i(x_1 \cdots x_i),\ W_B(x_1 \cdots x_i)) \tag{5}$$

subject to

$$\sum_{j=1}^{i} x_j = d \quad \text{for all } i \tag{6}$$

In equation (5), a regional utility function, U, is assumed to be associated with the multiple objectives of improved water quality (minimize W_B^i) and reduced total cost (minimize C_t^i). The function C_t^i is defined to be the sum of two cost terms:

$$C_t^i(x_1 \cdots x_i) = \sum_{j=1}^{i} (C_k(x_j) + C_p(x_j)) \tag{7}$$

where $C_k(x_j)$ is the cost of treating sewage at plant j, and $C_p(x_j)$ is the cost of transporting sewage through the sewers to plant j.

2.2 The case of convex cost functions

If the individual plant cost functin, $C_l(x_j)$, which is defined to be the sum of $C_k(x_j)$ and $C_p(x_j)$, is a convex function for $0<x_j<d$, then the maximization problem of equations (5) and (6) leads to the unique optimum solution in which the number of the plants, i, goes to infinity. Whatever the substitution relationship between C_t^i and W_B^i, both of the values of C_t^i and W_B^i decrease just by increasing the number of plants from i to $i+1$ for any i (see appendix for proof). Furthermore, the convexity of the individual total cost functin, $C_l(x_j)$, as well as the boundedness of each partial sum, $\sum_{j=1}^{i} C_l(x_j)$, assures the convergence of the infinite series

$$\lim_{i\to\infty} C_t^i(x_1 \cdots x_i) = \lim_{i\to\infty} \sum_{j=1}^{i} C_l(x_j) \quad \text{(by definition)}$$

But the limiting value of W_B^i is obtained as follows:

$$\lim_{i\to\infty} W_B^i(x_1 \cdots x_i) = \lim_{i\to\infty} \sum_{j=1}^{i} b_0\, x_j \exp(K_r \sum_{k\le j} x_k)$$

$$= b_0 \int_0^d \exp(K_r x)dx = b_0(\exp(K_r d)-1)/K_r$$

$$= W_B^{\infty} \qquad \text{(by definition)} \tag{8}$$

where the second equality sign comes from the theorem that, if a function f is monotonic on an interval, then the upper Rieman integral of f is equal to the Rieman integral of f on the interval (Rudin, 1964). The limiting value, W_B^{∞}, in equation (8) can also be derived from the following differential equation with distributed source (Thomann, 1972).

$$dW'_B/dx + K_r W'_B = a_0 w \tag{9}$$

The solution to equation (9) for $x = d$ is equal to

$$W'_B = a_0 w \exp(-K_r d)(\exp(k_r d)-1)/K_r \tag{10}$$

were the initial condition at $x = 0$ is assumed to be zero. We assume that people live along the line between M_1 and M_2, and that the solution to equation (9) is derived for $x = d$. The limiting value, W_B^{∞}, in equation (8) is then equal to W'_B multiplied by $\exp(-K_r d)$. In summary, if the individual total cost function is convex, the regional welfare is maximized by building an infinite number of treatment plants, that is, by employing the policy of treatiment at source of sewage generation.

2. 3 Case of nonconvex cost functions

In this section, we consider the following two cases of nonconvex cost functions: (1) the individual total cost function, $C_l(x_j)$, is convex for $0 \leqq x_j < x' < d$, and concave for $x' = x_j d$; (2) $C_l(x_j)$ is concave for $0 \leqq x_j < x' < d$, and convex for $x' \leqq x_j \leqq d$. In both cases, we assume, based on the long-run nature of the cost function, that $C_l(x_j) = 0$ for $x_j = 0$. The optimum solution for the first case is the same as the one in section 2. 2. For we can always find a point $x \leqq x'$ which has a smaller average cost than a point greater than x'. Then the value of regional welfare is improved by increasing the number of plants to infinity.

For the second case, we may improve the value of regional welfare just by increasing a number, i, of plants, provided that min $(x_1 \ldots x_i)$ is greater that x" and $\sum_{j=1} x_j = d$. But as soon as $\min(x_1 \ldots x_i)$ becomes less than x" , there are two offsetting forces at work, one tending to reduce the maximum value of $(x_1 \ldots x_i)$ preferably by increasing the number of plants, the other tending to increase the minimum value of $(x_1 \ldots x_i)$ possibly by decreasing the number of plants. Furthermore, because of the fact that the individual total cost function, $C_t(x_j)$, is concave for $0 \leqq x_j < x''$, we cannot increase the number of plants indefinitely, since the infinite series $\lim_{i\to\infty} \sum_{j=1} C_l(x_j)$ diverges. Thus an optimum number of plants can be derived by harmonizing two conflicting objectives wich are the least total cost expenditure and the greatest benefit derived from improved water quality. Although the optimum solution depends on the specific shape of the cost function, it can be derived by solving the following constrained maximization problem for $i = 1, 2, \ldots$

$$\underset{x_1 \ldots x_i}{\text{maximize}}\; U(C_t^i(x_1 \ldots x_i), W_B^i(x_1 \ldots x_i)) \tag{11}$$

subject to

$$\sum_{j=1} x_j = d; \qquad x_j \geqq \epsilon > 0 \text{ for } j = 1 \cdots i$$

were ϵ is a positive value chosen from a small neighborhood of zero.

Suppose the optimum value of equation (11) is denoted by $U(x_1^* \ldots x_i^*)$ Then the optimum number, n, as well as the optimum location of plants is obtained when these four conditions are satisfied:

(1) $U(x_1^* \ldots x_n^*)$is achieved for $x_j > \epsilon$ for $j = 1 \ldots n$

(2) $U(x_1^* \ldots x_{n+1}^*)$is achieved for $x_j \geqq \epsilon$ for $j = 1 \ldots n$

(3) $U(x_1^* \ldots x_n^*) > \max(U(x_1^*), \ldots, U(x_1^* \ldots x_{n-1}^*), U(x_1^* \ldots x_{n+1}^*))$

(4) The followng first-order and second-order conditions are satisfied for the vector of optimal values $(x_1^*, \ldots, x_{i-1}^*)$ for $i = 1, \ldots, n-1$; $j = 1, \ldots, i-1$,

$$\partial U(x_1^*, \ldots, x_{i-1}^*)/\partial x_j \leqq 0; \qquad x_j^* \, \partial U(x_1^*, \ldots, x_{j-1}^*)/\partial x_j = 0 \tag{12}$$

The Hessian matrix is negative definite at $(x_1^*, \ldots, x_{i-1}^*)$, where we have deleted one variable in terms of the restraint $\sum_{j=1} x_j^* = d$, and where equation (12) is allowed not to be strictly satisfied for $x_j^* = \epsilon$.

3 EMPIRICAL ANALYSIS

3. 1 Description of the study area and an extension of the model

In this section, a theoretical model of sewage treatment plant loction is extended to treat the problem of variable spatial distribution of population and channel geometry, in such a way that it can be applicable to a case-study area. The area under consideration is a basin of the Tama River in the Tama district of the Tokyo Metropolitan Region. The area consists of fifteen cities, four towns and one village with a total population of 1711298 in 1976. Fig. 2 describes the spatial distribution of poputation, the location of the existing and planned sewage treatmetn plants along the river, and the monitoring stations of water quality. In what follows, the region is divided into two subregions which consists of the right-hand bank region and the left-hand bank region of the Tama River. The Tama River has its source near the Tokyo-Yamanashi prefectural border and

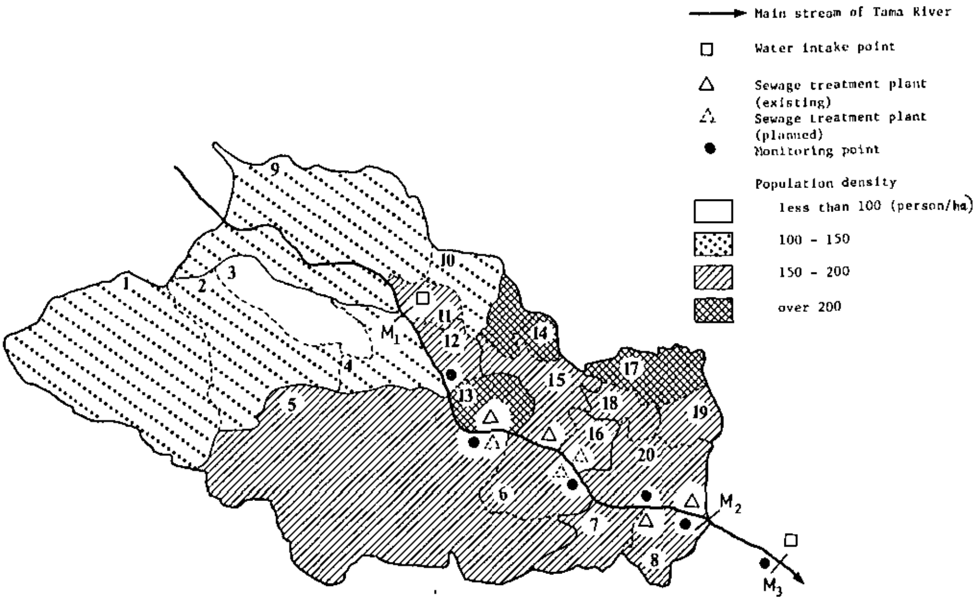

Fig. 2 The study area

flows southeastwards for 100km through the heart of the study area to the Bay of Tokyo.

Although not all the area is currently sewered, we transform the two dimensional area into a straight line of length 25.9km which starts at Hamura water intake (M_1), which supplies public water for most of the area, and ends at the downstream part in the area (M_2). The marketplace (M_3) is taken to be the location of another water supply plant at a distance of 7.6km from M_2. This plant does exist, but has changed its source of water supply from surface water to a shallow well because of the deterioration of surface-water quality.

For numerical simulation, we have to specify s_0, w, N, and K_r, and the specific form of the cost function: N and K_r are a function of distance variable, x. We assume that the daily consumption rate, s_0, of public water per capita is 0.3 tonne, and the BOD level, w, of the treated sewage is 0.00002 tonne m^{-3} (20ppm). The existing population distribution, N(x), and the observed distribution, $K_r(x)$, of the decay coefficient of BOD divided by stream velocity (abbreviated as the decay coefficient) are shown in Fig. 3 and Fig. 4, where the population distribution of each subregion is calculated in reference to the three planned sewered areas in each subregion. The first, second, and third sewered areas in the right-hand bank region consist of a group of cities-towns-village numbered 1 through 4, 5 and 6, and 7 and 8 in Fig. 2, respetively. In the left-hand bank region, a group of cities-towns numbered 9 through 13, 14 through 16, and 17 through 20 consist of the first, second, and third sewered areas. Table 1 shows the data for reaches in the Tama River, which are based on Ichikawa's work (1978) and in which the decay coefficients measured at six monitoring stations along the river vary between 0.0066 per km and 0.0405 per km. The difference in measured values of $K_r(x)$ is due mainly to the velocity variations of the river flow.

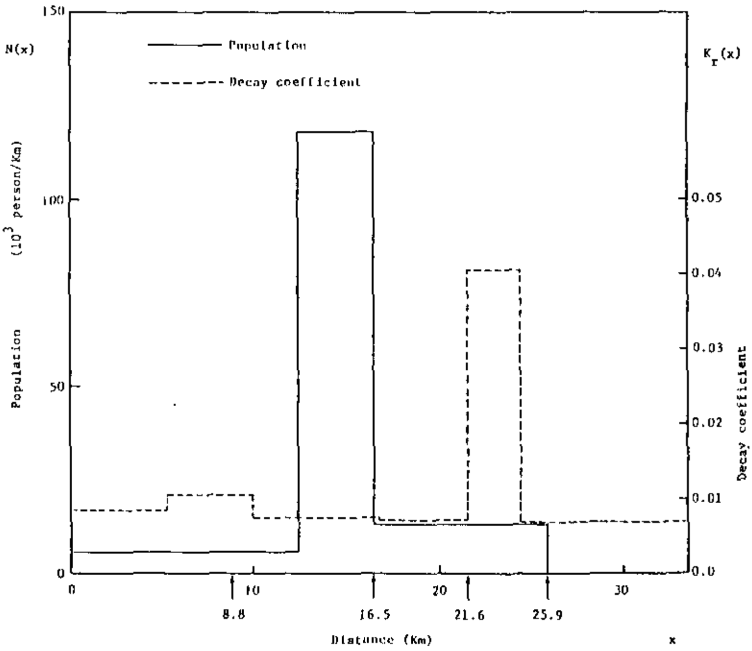

Fig. 3 Spatial distribution of population and decay coefficient of BOD: a case of the right-hand bank region

Because of the variable spatial distributon of the population, N(x), and the decay coefficient, $K_r(x)$, the theoretical model of section 2 must be modified. Speciffically, the water-quality models of equation (1) and equation (9) are rewritten as

$$B_i = B_0\exp(-\int_0^{xi} K_r(x)dx); \quad dW_B^{i}/dx + K_r(x)W_B^{i} = ws_0N(x) \tag{13}$$

respectively. Similarly, equation (3) is rewritten as:

$$B = \{W_0\exp(-\int_0^{d+\bar{d}} K_r(x)dx) + \sum_{j=1}^{n} W_j\exp(-\int_y^{d+\bar{d}} K_r(x)dx)\} /(q_0 + \sum_{j=1}^{n} q_j) \tag{14}$$

where

$$y = \sum_{k \leqq j} x_k$$

And equation (4) is also rewritten in the same manner as:

$$W_B^n(x_1 \ldots x_n) = \sum_{j=1}^{n} b_0W_j\exp(\int_0^{y} K_r(x)dx)$$

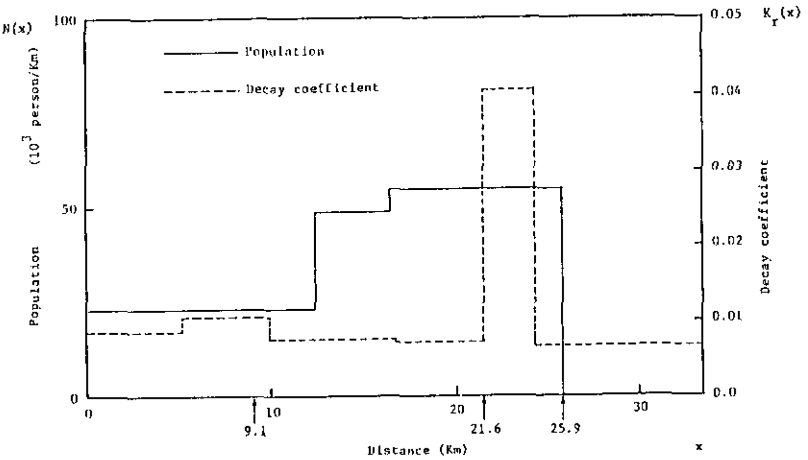

Fig. 4 Spatial distribution of population and decay coefficient of BOD a case of the left-hand bank region

Table 1 Data for reaches in the Tama River

Monitoring point	k_r (1/d)	u (km/d)	k_r/u (1/km)	x^a (km)
1	0.38	45.79	0.0083	5.3
2	0.39	37.15	0.0105	10.0
3	0.40	52.70	0.0076	16.8
4	0.41	57.02	0.0072	21.6
5	0.42	10.37	0.0405	24.4
6	0.42	63.94	0.0066	35.5

a) distance from the space point M_1

where

$$b_0 = \exp(-\int_0^{d+\bar{d}} K_r(x)dx)$$
$$W_j = ws_0N(x_j)x_j$$
$$y = \sum_{k \leq j} x_k$$

As to the cost function, the following treatment and transport cost functions are taken from the publication compiled by Japan Ministry of Construction (1980):

$$C_k(Q) = \frac{i(1+i)^{m_1}}{(1+i)^{m_1}-1}3.23Q^{0.719}+0.165Q^{0.697} \tag{15}$$

$$C_p(Q) = \frac{i(1+i)^{m_2}}{(1+i)^{m_2}-1}(574.8-290.4\times 10^{-3}Q^{0.5}+2222.3\times 10^{-6}Q) \tag{16}$$

where Q is the volume of treated or transported sewage with the unit of m^3 per day, i is the discount rate, and m_1 and m_2 are the payback periods of treatment plant and of sewers, respectively. In equation (15), the first term of the right-hand side reperesents the annual capital cost of plant and the second term the annual operation and maintenance cost, where the monetary unit is million yen per year. Equation (16) represents the annual capital cost of sewers, with the unit of million yen, for transporting Q units of sewage for a unit distance of one kilometer. The function of transport cost compiled by the Ministry of Construction, Japan is specified in terms of pipe diameter; however, we have transformed the pipe diameter into the flow variable by assuming that half of the pipe cross section is filled with wastewater with an average flow rate of one meter per second. If we substitute $Q = a_0$ x into equations (15) and (16) and assume a discount rate of 8% and a payback period of fifty years for m_1 and m_2, then we obtain the individual total cost function of $C_I(x)$, where $a_0 = N(x)s_0$ is no longer a constant, but a function of the population distribution. The cost function is plotted in Fig. 5 for a homogeneous population distributon, where N is calculated to be the total population of the right- hand bank region, divided by the distance, d.

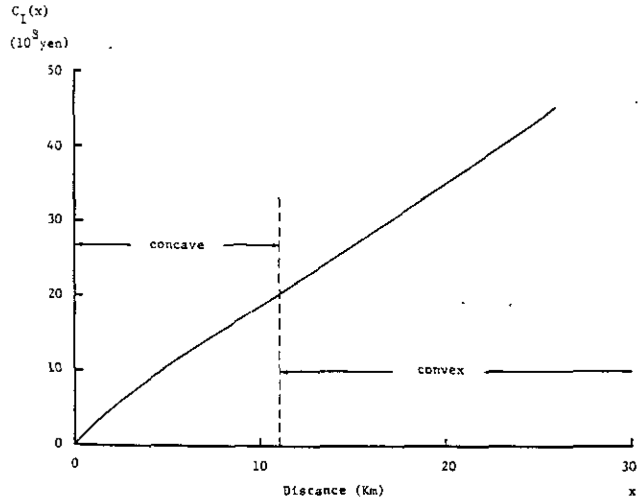

Fig. 5 Total cost function: a case of homogeneous space

3. 2 Computational results

Here, we assume a simple regional utility function of a linear form:

$$\max_{i} U(C_t^i,\ W_B^i) = \min_{i} (\lambda C_t^i(x_1 . . . x_i) + \mu W_B^i(x_1 . . . x_i))$$

where $\lambda \geqq 0$ and $\mu \geqq 0$ transform the monetary unit of million yen and the waste load of tonnes per day into utils, respectively. Since the minimization of the total BOD load, W_B^i, at the marketpoint is considered to be the maximization of the difference between an exogenously given desired level of BOD load and W_B^i, the smallest W_B^i means the greatest benefit to the region. Thus, the benefit-cost ratio or the willingness of the region to pay for beter water quality is represented by μ / λ.

Numerical simulations of the model were performed to analyze how the benefit-cost ratio, μ / λ, or the heterogeneity of population distribution and channel geometry affect the location and/or the number of sewage treatment plants. As to the solution procedure, the coarse-grid approach (Nemhauser, 1966) is used to obtain the optimum plant location for a given number of plants; this approach proceeds from a few widely spaced values to finer grids for each distance variable, x_i. The optimality of plant number is judged on the condition of otimality specified in section 2. 3. To simplify the numerical calculations, we assume that there exist two rivers running parallel to each other, with river characteristics identical to those of the Tama River, and that each of the two rivers receives the wastewater discharged from either one of two subregions, the right-hand bank region and the left-hand bank region. The numerical simulations were performed for alternative values of the benefit-cost ratio, μ / λ, and alternative spatial distributions of the population, N(x), and the decay coefficient, $K_r(x)$.

Table 2 summarizes the computational results for the right-hand bank region, for the optimum number, n, of plants and the optimum values of objective variables, C_B^n and W_B^n, defining the regional utility function. In Table 2, homogeneous N(x) corresponds to the case in which a uniform population distribution is assumed for the right-hand bank region with N equal to the total population of 688065 divided by the distance, d; heterogeneous N(x) corresponds to the existing population distribution shown in Fig. 3. But homogeneous $K_r(x)$ refers to the case in which a constant decay coefficient of $K_r = 0.0135$ per km is assumed for all locations over the range $(0, d+\bar{d})$; heterogeneous $K_r(x)$ refers to the observed decay coefficient distributon, $K_r(x)$, drawn in Fig. 3. Table 2 shows that as the willingness of the region to pay for better water quality increases, the optimum number, n, of plants increases with the consequent decrease in the amounts, W_B^n, of the total waste load at the market location. For any finite value of a benefit-cost ratio in Table 2, the largest regional utility is achieved in case 2 for the heterogeneous river characteristics; the second largest regional utility in case 3 is due to the existence of scale economies in sewage treatment. In Tabel 2 the solutions to the cases of $\mu / \lambda = \infty$ are derived analytically by solving equation (13).

Tabel 3 shows the effects of heterogeneity and a higher benefit-cost ratio on the optimum pattern of plant location. We first discuss the effects of heterogeneity in reference to the existing population distribution and the observed decay coefficient in Fig. 3 to which heterogeneity of Table 3 coressponds. Comparison of case 1 and case 2 shows that heterogeneity in the decay coefficient affects the plant location so as to take advantage of the largest decay coefficient yielded by the distance interval between the monitoring points numbered 4 and 5 in Table 1. The effects of heterogeneity in population distribution are clearly observed by comparing case 1 and case 3 in such a way that the first or the second treatment plant is located near the end of the second sewered area so as to exploit the scale economies in sewage treatment. These results and the results obtained from Table 2 enable us to conclude that the heterogeneity in river characteristics and in population distibution helps to improve (through the modification of plant locations) an

Table 2 Computational results for the right-hand bank region (1)

μ/λ		Case 1			Case 2			Case 3		
	$N(x) \longrightarrow$	homogeneous			homogeneous			heterogeneous		
	$K_r(x) \longrightarrow$	homogeneous			heterogeneous			homogeneous		
		n	C_t^n	W_B^n	n	C_t^n	W_B^n	n	C_t^n	W_B^n
0		1	45.053[a]	4.115[b]	1	45.053	3.927	2	44.679	4.038
16.67		2	46.730	3.784	2	46.881	3.545	3	46.662	3.687
33.33		3	49.387	3.678	3	49.179	3.435	3	46.691	3.686
∞		∞	∞	3.144	∞	∞	3.2917	∞	∞	3.211

[a] 10^8 yen per year

[b] ton per day

Table 3 Computational results for the right-hand bank region (2)

μ/λ		Case 1			Case 2			Case 3		
	$N(x) \longrightarrow$	homogeneous			homogeneous			heterogeneous		
	$K_r(x) \longrightarrow$	homogeneous			heterogeneous			homogeneous		
		x_1	x_2	x_3	x_1	x_2	x_3	x_1	x_2	x_3
0		25.9	0	0	25.9	0	0	12.4	13.5	0
16.67		13.4	12.5	0	19.1	6.8	0	10.5	6.0	9.4
33.33		9.2	8.6	8.1	10.88	10.72	4.3	9.5	7.0	9.4

environmental objective of better water quality and an economic objective of least cost burden, respectively.

Before we explain the effects of a higher benefit-cost ratio on the optimum pattern of plant locations, it is helpful to know the optimum plant location for a homogeneous case. Case 1, in Tabel 3, approaches, as the benefit-cost ratio increases, the pattern specified by the necessary condition for the following constrained minimization problem:

$$\underset{x_1 \ldots x_n}{\text{minimize}} \; W_B^n(x_1, \ldots, x_n),$$

subject to

$$\sum_{i=1}^{n} x_i = d$$

where W_B^n is defined in equation (4). The necessary condition for this problem is written as,

$$1 + K_r x_j^* = \exp(K_r x_{j+1}^*); \quad j = 1 \ldots n-1; \sum_{j=1}^{n} x_j^* = d \tag{17}$$

and the convexity of W_B^n corresponds to the sufficiency condition.
Equation (17) is rewritten as,

$$a_0 w (1 + K_r x_j) \exp(-K_r(d + \bar{d} - \sum_{k \leq j} x_k)) = a_0 w \exp(-K_r(d + \bar{d} - \sum_{k \leq j+1} x_k))$$

which shows that the increase of W_B^j due to the marginal increase of x_j is equal to the increase of W_B^{j+1} due to the unit increase of x_{j+1}. The law of the mean and the convexity of the exponential function enable us to derive the following condition from equation (17).

$x_j^* > x_{j+1}^*$ for any $x_{j+1}^* > 0$

Given the fact that the discharged waste load decays exponentially, any neighboring two distancs, say, x_j^* and x_{j+1}^*, are not the same distance, but differ in such a way that $x_j^* > x_{j+1}^*$. Keeping in mind the relationship specified in equation (17), let us examine case 1 in Table 3. As the value of the benefit-cost ratio increases, the location pattern approaches the pattern ($x_1^* = 9.135$, $x_2^* = 8.615$, $x_3^* = 8.150$,).

Last, the arrows in Fig. 3 and Fig. 4 indicate the optimum location pattern of sewage treatment plants for the case of the existing population distribution, the observed distribution of the decay coefficients, and given benefit-cost ratio of $\mu / \lambda = 33.33$. The significant difference in location pattern between Fig. 3 and Fig. 4 is caused by the more skewed population distribution in the right-hand bank region. Furtehrmore, the optimum number of plants in each subregion is different from the total number of existing and planned sewage treatment plants shown in Fig. 1. If we assume that the existing and planned plants on each side of the river bank are decided on the basis of a linear regional utility function and independently of the plant location on the other side of river bank, then we can say that the benefit-cost ratio of the left-hand bank region is greater than 33.3 and that of the right-hand bank region is less than 33.3. This seems to arise from the simple facts that the right-hand bank region has more population than the left-hand bank region, and that in our model the market is concentrated at one location.

4 CONCLUSION

In this paper, a theoretical model of sewage treatment plant location on a one-dimensional continuous space is presented. An empirical analysis to treat the problems of heterogeneity in intraurban population distribution, and the assimilative capacity of a river running parallel to a straight-line region, is then described. Numerical simulation reveals that the heterogeneity in assimilative capacity and population distribution work to improve an environmental objective of improved water quality and an economic objective of the least cost expenditure, respectively. Furthermore, a higher benefit-cost ratio or a higher willingness to pay for imporoved water quality leads to the situation in which the location pattern of sewage treatment plants is mainly regulated by the environmental objective. In contrast, a lower benefit-cost ratio leads to the situation in which the economic objective supported by scale economies in sewage treatment play a major role of regulating the location pattern of plants.

Last, althouh our approach is unconventional and rather simplified, it produces results which are not provided by the convetional approach. Our approach should facilitate the integration of the sewage treatment plant location problem into the main body of urban economics, and help to illustrate schematically the interrelationship between intraurban population distribution, variations in the waste assimilative capacity, and the location of sewage treatment plants.

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The authores acknowledge the valuable assistance provided by Professor M. Takahashi of Seikei University at the early stage of formulating the problem. We also thank Professor N. Sakashita of the University of Tsukuba, whose suggestions were essential in realizing our desire of treating the problem of regional water-quality management from the perspective of location theory. Finally, we thank Professor R. Funck of the University of Karlsruhe and three anonymous referees of Environment and Planning A for their constructive comments on preliminary versions of the paper; the usual disclaimers apply.

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APPENDIX : Proof of the monotonicity of C_t^i and W_B^i with respect to i

First of all, we note that the convexity of the individual total cost function ensures that there exists a minimum value of C_t^i for a given number, i, of plants. Let us denote the optimal location of plants by $x_1^*, \ldots, x_i^*$, and insert the (i+1)−th plant into an arbitrary point in such a way that $x_{i+1} = \delta x_{j+1}^*$ for $0 < \delta < 1$, and $1 \leqq j \leqq i$.

Then,

$$
\begin{aligned}
& C_t^{i+1}(x_1^* \ldots x_j^*, x_{i+1}, x_{j+1}^* - x_{i+1}, \ldots x_i^*) - C_t^i(x_1^* \ldots x_i^*) \\
& = C_I(x_{i+1}) + C_I(x_{j+1}^* - x_{i+1}) - C_I(x_{j+1}^*) \\
& \leqq \delta C_I(x_{j+1}^*) + (1-\delta) C_I(x_{j+1}^*) - C_I(x_{j+1}^*) = 0
\end{aligned}
$$

Next we go on to prove that we always decrease a value of W_B^i just by increasing a number of plants. Since W_B^i is a continuous real function for all points $(x_1, \ldots, x_i)$ of a compact metric space X, there exist points in X in which W_B^i attains its maximum and its minimum (Rudin, 1964). Let us denote the optimal locations of plants $x'_1, \ldots, x'_i$ and insert the (i+1)−th plant into an arbitrary point, say, at a distances s from the *i*−th plant, where $1 \leqq j \leqq i$, and $0 < s < x_{j+1}$. Then,

$$
\begin{aligned}
& W_B^{i+1}(x'_1 \ldots x'_j \; s \; x'_{j+1} - s \ldots x'_i) - W_B^i(x'_1 \ldots x'_i) \\
& = b_0 s \exp(-K_r(d + \bar{d} - \sum_{k=1}^{j} x'_k - s)) \\
& \quad + b_0(x'_{j+1} - s)\exp(-K_r(d + \bar{d} - \sum_{k=1}^{j+1} x'_k)) \\
& \quad - b_0 x'_{j+1} \exp(-K_r(d + \bar{d} - \sum_{k=1}^{j+1} x'_k)) \\
& = b_0 \exp(-K_r(d + \bar{d} - \sum_{k=1}^{j} x'_k)) s(\exp(K_r s) - \exp(K_r x'_{j+1})) < 0.
\end{aligned}
$$

Chapter 4

Economic Analysis of Water Quality Monitoring System

Y. Matsuoka and M. Naito

ABSTRACT

Optimal design of air and water quality monitoring system is one of the major issues in the environmental problems in Japan. With regard to the problem, there are two aspects. One is two aspects. One is to find where to allocate monitoring stations and the other is to evaluate how many stations are needed. The former has extensively been studied these several years while only little effort has been devoted to the latter. This is mainly attributed to the difficulty in evaluating the utility or benefit of information.

The present work is to propose a quantitative basis to decide the optimal amount of information. The criteria of the optimality is derived by the cost/benefit analysis. The benefit is defined here as the negative of economic loss resulting from a poor environmental management policy based on uncertain data.

To demonstrate the proposed method, Lake Kasumigaura is adopted to which an optimal number of sampling points and their spatial allocation have been calculated. About 40 points is estimated as optimal number in this case under an assumed water quality management scenario.

1 INTRODUCTION

Effective management of environmental quality requires a foundation of information on the states of the environment. A great effort has been made to construct a system for monitoring environmental water quality during the last decade in Japan. A lot of problesms, however, should be solved before a monitoring system is rationally designed and operated.

The most important one is to identify how much information the system could provide for the water quality management under a given expenditure of sampling and analyzing efforts. Coping with the problem, this study proposes a quantitative method to balance the utility of acquired data and the effort paid to obtain them from the view point of cost/benefit analysis (Matsuoka & Naito, 1983). In this method, the benefit of the data is measured as the reduction of economic loss of the water quality management program owing to reliable data. The benefit is compared with the cost of data acquisition to find the most effective level of water quality monitoring. In order to demonstrate the feasibility of the present method, an actual lake was adopted to which an optimal number of sampling points and their spatial configuration have been calculated.

2 DEFINITION OF THE BENEFIT AND COST OF WATER QUALITY MONITORING

It is of vital importance to evaluate how much contribution can be made by a monitoring system to water quality management. This can be attributed to the fundamental and general problem how to evalute the value of information. Our approach to the value of information is similar to the concept of "loss function" in the field of decision rules under uncertainty (Dorfman, 1962). Here we divide the actual net social benefit of water quality improvement into two parts,a "net benefit yielded under certainty", and a "loss". The net benefit yielded under certainty is the net benefit obtained where the water quality measurement for which the water quality management program was designed does not involve any uncertainty. The loss is the discrepancy between the actual net benefit which results when the measurement of water quality departs from a true water quality and the net benefit yielded under certainty. Then the value of information obtained through water quality monitoring is defined as the negative of the loss resulting from executing an *inappropriate water quality management policy based on uncertain information.* Here the expected net social benefit is written as

$$\hat{\Phi} = \mathrm{E}(\Phi(\mathrm{X})) = \int_0^\infty \Phi(\mathrm{X})\mathrm{prob}(\mathrm{X} \mid x_0)\mathrm{dX} \tag{1}$$

in which $\Phi(\mathrm{X})$ is the net social benefit brought about by applying a management policy decided based on the information X(=measured water quality), which usually scatters around the true water quality $\hat{x}_0$. $\hat{\Phi}$ is the expectation of $\Phi(\mathrm{X})$.

If there is no uncertainty in measuring the current water quality, the task of water quality management authority may be described as follows. By observing the current water quality X_1, the management authority takes action to inprove the water quality to X_2. In this situation we define the social benefit of maintaining water quality at X_2 to be $B(\mathrm{X}_2)$ and the cost of improving *water quality from* X_1 *to be* $C(\mathrm{X}_1, \mathrm{X}_2)$. *Furthermore we assume a management goal of the* authority is to select that level of water quality $\hat{\mathrm{X}}_2$ which maximize the net social benefit

$$\begin{aligned}\Phi(\mathrm{X}_1) &= \underset{\mathrm{X}_2}{\mathrm{Max}}\,\Phi(\mathrm{X}_1,\mathrm{X}_2)\\ &\quad \underset{\mathrm{X}_2}{\mathrm{Max}}\ (B(\mathrm{X}_2) - C(\mathrm{X}_1,\mathrm{X}_2)\\ &= B(\hat{x}_2) - C(\mathrm{X}_{1;}\,\hat{x}_2)\end{aligned} \tag{2}$$

In reality, there always exist uncertainty in water quality measurement. In this case, the task of management autority is to select that level of water quality $\hat{x}_2$ which maximize the difference between social benefit and the expected cost of water quality improvement

$$\begin{aligned}\Phi(\hat{x}_1) &= \underset{\mathrm{X}_2}{\mathrm{Max}}\ (B(\mathrm{X}_2)\ - \int C(\mathrm{X},\mathrm{X}_2)\mathrm{prob}(\mathrm{X} \mid \hat{x}_1, \sigma)\mathrm{dX}\\ &= B(\hat{x}_2) - \mathrm{E}(C(\hat{x}_2))\end{aligned} \tag{3}$$

However, if the observed water quality X_1 is different from the true water quality $\hat{x}_1$, the actual *level of target water quality may be different from* $\hat{x}_2$. That is, because of the uncertainty of observed water quality value X_1, even if we spend the needed cost $C(\mathrm{X}_1,\mathrm{X}_{2,})$ for water quality management program, the achieved water quality Y may not be equal to a taget water quality level X_2, where the target level is decided based on the available cost C and on the assumption that the observed water quality X_2 is the true value. Thus the attained water quality level Y is determined as follows

$$C(\mathrm{X}_1,\mathrm{X}_2) = C(\hat{x}_1,\mathrm{Y}) \tag{4}$$

Then the benefit of water quality monitoring is defined in terms of the "economic loss," *i.e.*,the difference between the net benefit resulting from the optimal management policy and that resulting from an inapproproate policy based on erroneous data as follows,

$$L = \Phi(\hat{x}_1) - \Phi(\hat{x}_1,\mathrm{Y}) \tag{5}$$

This definitional equation is explained in Fig. 1.

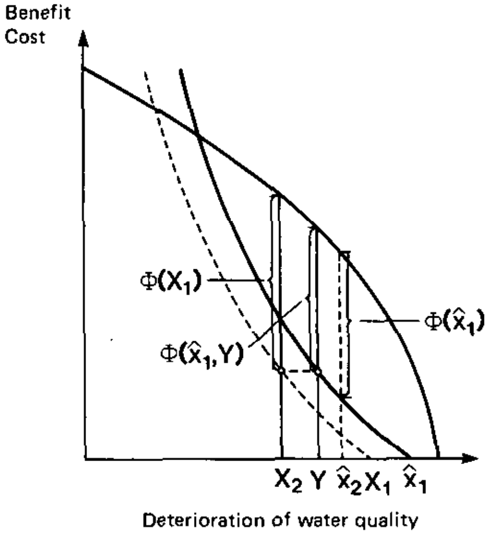

Fig. 1 Explanation of equation (5)

In general it is difficult and impractical to identify social benefit function explicitly in terms of water quality level. This is the major reason why benefit-cost analyses in this field have not fully succeeded. To make the situation more practical, the benefit function in this work is provided by a step function whose value is zero when water quality is worse than a certain level such as water quality standard X^* and is B_0 when the quality is better than the specified level. Then, the net benefit is given by,

$$\Phi(\mathrm{X}_1,\mathrm{X}_2)=B_0\mathrm{H}(\mathrm{X}_2\leq X^*)-C(\mathrm{X}_1,\mathrm{X}_2) \tag{6}$$

and

$$\mathrm{H}(\mathrm{X}_2\leq X^*)=\begin{cases}0, & \text{if } \mathrm{X}_2>X^*\\ 1, & \text{if } \mathrm{X}_2\leq X^*\end{cases}$$

and the loss of economic efficiency is written as follows:

$$\begin{aligned}L&=\Phi(\hat{x}_1,\ X^*)-\Phi(\mathrm{X}_1,\mathrm{Y})\\ &=B_0(1-\mathrm{H}(\mathrm{Y}\leq X^*))-\{C(\hat{x}_1,X^*)-C(X^*,P_0\mid\hat{x}_1,\sigma)\}\end{aligned} \tag{7}$$

where

$$P_0=\int_0^{X^*}\mathrm{prob}(\mathrm{Y})d\mathrm{Y}=\int_0^{\infty}\mathrm{H}(\mathrm{Y}\leq X^*)\mathrm{Prob}(\mathrm{Y})d\mathrm{Y}$$

and Prob(Y) is the probability density function of Y. This definitional equation is explained in Fig. 2, where the net benefit of achieved water quality when the measurement value is X_1 is equal to

$$\overline{\mathrm{CE}}=B_0-C(X^*,\ P_0\mid \mathrm{X}_1',\sigma)$$

and the net benefit of achieved water quality when the measurement value is X_1 is equal to

$$0-\overline{\mathrm{AB}}=-C(X^*,\ P_0\mid\mathrm{X}_1,\sigma)$$

Finally, the expected loss of economic efficiency adopted here is written by,

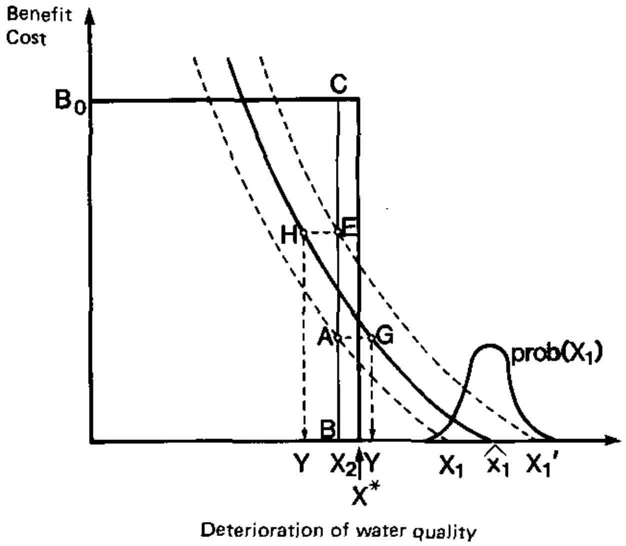

Fig. 2 Explanation of equation (7)

$$E(L)=B_0(1-P_0)-\{C(\hat{x}_1, X^*)-\int_0^\infty C(X^*, P_0 \mid X_1, \sigma)\,prob(X_1 \mid \hat{x}_1, \sigma)\,dX_1\} \qquad (8)$$

3 A CASE STUDY OF OPTIMAL WATER QUALITY MONITORING SYSTEM IN LAKE KASUMIGAURA

By means of the aforementioned cost-benefit concept, a practical case of Lake Kasumigaura water quality monitoring system is studied.

The target water quality level "0.07mg/l in total-P" is adopted, which is stipulated by Ibaraki-prefectural government. To attain the goal a management policy of the following scenario is assumed.

1) Water quality is represented by total-P.
2) Reduction ratio of waste water effluent in each category of sources is assumed proportional to the present effluent rate.
3) Two categories of sources, "domestic sewage" and "industrial waster", are adopted as the object of control.
4) The reduction of total-P in domestic sewage is to be attained by employing tirtially treatment process consisting of coagulation-sedimentation followed by high-rate sand filtration and/or expansion of the coverage area of the sewer system.
5) The reduction of the industrial wastewater is to be attained by facilitating secondary treatment plant (and tirtially if needed) in each factory.
6) Zero growth of population and industry is assumed.

The lake water quality estimation is made on the following simple completely mixed model,

$$V\,dc/dt=L_e+L_i-(Q_e+wA)c \qquad (9)$$

where c is lake water quality, V is water volume in the lake, L_e and L_i are inlet and inner-product load, Q_e is exit flow rate, w is settling velocity, and A is lake surface area.

The value of the parameters related to the lake and sources of pollution are listed in Table 1.

Now the investment needed to construct treatment facility should be estimated. The cost functions adopted herein are tabulated in Table 2. Shown in Fig.3 is the total cost evaluated in terms of the reduction ratio.

The marginal benefit functions is derived from equation (8) as

$$MB=-\frac{\partial}{\partial \sigma}[C(\hat{x}_1,X^*)-\int_0^{\infty}C(X^*,\ P_0 \mid X_1,\sigma)\mathrm{prob}(X_1 \mid \hat{x}_1,\sigma)dX_1] \tag{10}$$

The cost of water quality monitoring is defined as

$$\Gamma=\alpha\, n(\sigma)N+\beta \tag{11}$$

where α is a unit cost of water quality monitoring, β is a maintenance cost of monitoring system, N is the number of repetition of sampling, and $n(\sigma)$ is the number of monitoring points which is a function of σ. The relationship between n and σ is empirically obtained as follows,

$$\sigma^2=C/n-0.28a_1\sqrt{S}\cdot n^{-1.48} \tag{12}$$

Table 1 Parameters of Lake Kasumigaura

lake surface area	$171\mathrm{km}^2$
average depth	4m
drainage area	$1559\mathrm{km}^2$
population	605082
production of industries	6200×10^8 yen
production of fish caltivation	7093t/y
effluent rate	$10.99\times10^8\mathrm{m}^3/\mathrm{y}$
number of cattle	cows 22624, pigs 223695
current T-P level	0.102mg/l

(1980's level as standard)

Table 2 Cost function of wastewater treatmen

(10^6yen, L : m^3/d)

		construction	maintenance
sewage	secondary treatment	$463\ (L/1000)^{0.719}$	$20.3\ (L/1000)^{0.697}$
	coagulation-sedimentation	$108.3(L/1000)^{0.774}$	$10.6\ (L/1000)^{0.703}$
	rapid sand filtration	$107\ (L/1000)^{0.636}$	$10.99(L/1000)^{0.475}$
industrial wastewater	secondary treatment	$332\ (L/1000)^{0.7}$	$1.02L\times10^{-4}$
	tirtially treatment	$0.063L$	$0.270L\times10^{-4}$

where S is the area of lake in question, and C and a_1 are the parameters related to the variation horizontal of lake water quality. As to the theoretical background for the estimation precedure, see Matsuoka & Naito (1983). Then the marginal cost for water quality monitoring can be defined in terms of equations (11) and (12) as follows,

$$MC=d\Gamma/d\sigma=-2\alpha\,\sigma N/(C/n^2-0.414n^{-2.48}a_1\sqrt{S}) \tag{13}$$

An example of calculation of marginal benefit and cost are shown in Fig.4 and Fig.5, respectively. Combining these two results, the optimum number of monitoring stations can be obtained due to the procedure as illustrated in Fig.6. In this case of Lake Kasumigaura, it is noted that the optimum number of stations is suggested about 40 based on the proposed cost/benefit criterion.

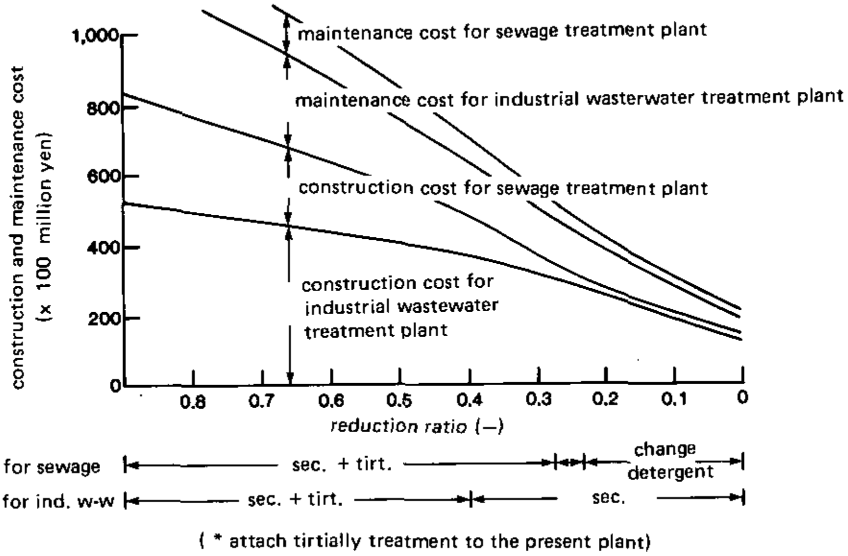

Fig. 3 Estimation of cost needed for reducing pollution load

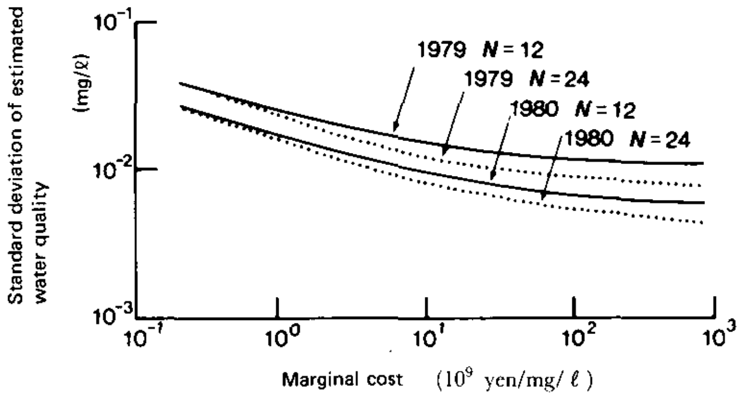

Fig. 4 Marginal cost for estimating lake water quality level

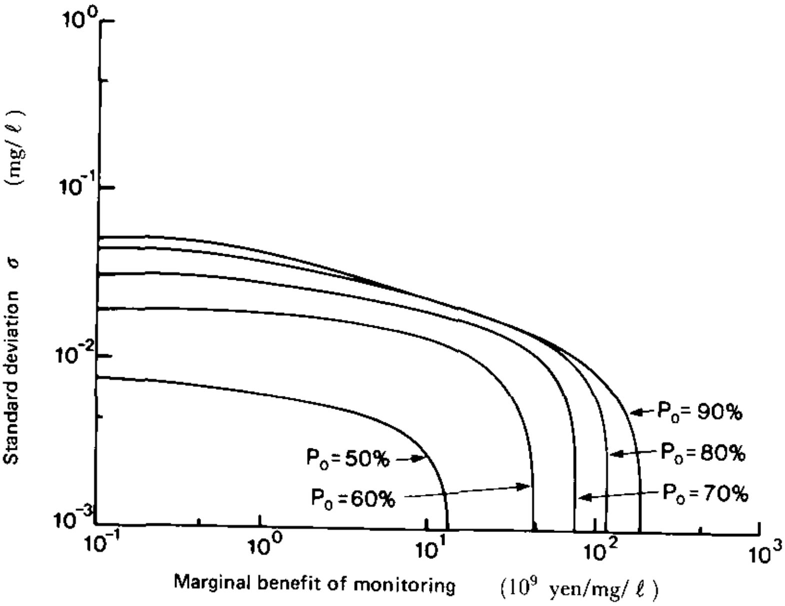

Fig. 5 Estimation of marginal benefit
(with attainment level P_0)

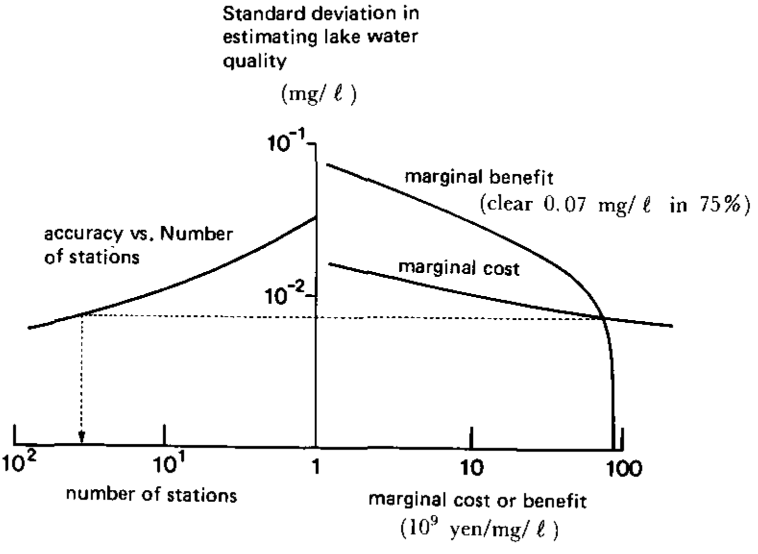

Fig. 6 Derivation of the optimum number of monitoring stations

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Chapter 5

Welfare Cost of Eutrophication-Caused Production Losses: A Case of Aquaculture in Lake Kasumigaura*

Y. Kitabatake

ABSTRACT

A general model for man's utilization of water resources is presented, in which the linkage between man's production activities and environmental systems is formulated based on Whitcomb's generalized joint production model and Kneese's transfer function. The general model is specified for a particular case of aquaculture in Lake Kasumigaura so as to evaluate in terms of the price data of 1978 the welfare cost of eutrophication-caused production losses under the assumption of horizontal demand curve.

1 INTRODUCTION

In a general model of regional water quality management in chapter 2, the stepwise function is assumed for the effects of environmental quality deterioration on man's welfare. That is, only if water quality satisfies an exogenously given environmental standard, the value of water quality to man's welfare takes some positive value, otherwise zero value. This way of handling the environmental effects is not valid for the situation in which the effects of improvements or deterioration in environmental quality on man's welfare varies among persons such as consumers and producers as well as among the type of effects such as human health and economic productivity of ecological system. Under this kind of situations, it becomes important to quantify the multidimensional nature of water usages, qualities and receptors so as to achieve an economically optimal level of water quality.

The purpose of this chapter is to present a methodology for estimating the effect of water quality deterioration on economic productivity of aquaculture. Specifically, in section 2, a general model for man's utilization of water resources is presented, which considers man's production activities, treatment at source of residuals discharged into a water body, pollution-caused damages on production activities, and environmental models. The model is specified in section 3 for a particular case of carp culture in Lake Kasumigaura, Japan. In section 4, a production function and a damage function are estimated based on the model. The equations are used to calculate the welfare cost of eutrophication-caused production losses when the horizontal demand curve is assumed and fishermen have no control over lake eutrophication.

This chapter reproduces the only paper (Kitabatake, 1982) we know of in which a production function and damage function are separately estimated and combined to find welfare cost of production losses. Thus while the study is region-specific, the model postulated in the paper is based on the conceptual framework of welfare economics and is believed to be general enough for application to other empirical studies.

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* Slightly adapted and expanded from "Welfare Cost of Eutrophication-Caused Production Losses: A Case of Aquaculture in Lake Kasumigaura, " by Y. Kitabatake. In Journal of Environmental Economics and Management **9**, 1982, pages 199-212. Copyrigth © 1982 by Academic Press, Inc. Reprinted by permission of the publisher.

2 A GENERAL MODEL FOR MAN'S UTILIZATION OF WATER RESOURCES

The production activities for the i-th economic agent utilizing water resources are represented by the following four equations:

$$F_1^i(Y^i, V_1^i, U^i, Q)=0 \tag{1}$$
$$F_2^i(D^i, V_2^i, U^i, Q)=0 \tag{2}$$
$$F_3^i(W^i, V_3^i, U^i)=0 \tag{3}$$
$$F_4(W^1 \cdots W^m, Q)=0 \tag{4}$$

where

Y^i	is the conventional outputs,
D^i	is the damages on output or the production losses,
W^i	is the residuals discharged into water body,
U^i	is the joint inputs, such as feeding food in aquaculture, appearing in all three equations for agent i,
V_1^i	is the ordinary inputs to the production of Y^i,
V_2^i	is the ordinary inputs expended to reduce the production losses,
$V_3{}'$	is the ordinary inputs to the treatment of residuals,
Q	is the water qualities of water body,
m	is the number of economic agents.

Equations (1), (2), and (3) are of implicit functional forms, postulated based on Whitcomb's generalized joint production model (Whitcomb, 1972), though we disregard for notational convenience the suffixes related to spatial dimension. Eq. (4) specifies the so-called transfer function (Kneese, 1975) which interrelates residuals variables to water qualities of a water body in question.

With a set of ordinary and joint input prices, the cost function, C^i (Y^i, D^i, W^i, Q), is derived for a cost minimizing agent *i*, from Eqs. (1), (2), and (3) subject to the constraints on Y^i, D^i, W^i, and Q. The cost is composed of the cost of producing the output Y^i, the cost incurred by keeping the production losses at the specified level of D^i, and the treatment cost incurred by keeping the residuals at the level of W^i. Then a Pareto optimal water quality level is derived, for given quantities of $(Y^1 \cdots Y^m)$ and $(D^1 \cdots D^m)$, by minimizing the sum of all the individual cost functions subject to the transfer function.

Previous empirical researches are mostly, in principle, concerned with the derivation of $(W^1 \cdots W^m)$ and Q from the cost functions of the form, $C^i(Y^i, W^i)$, and the transfer function, for given quantities of $(Y^1 \cdots Y^m)$. The notable examples are various studies done at the Resources for the Future (see Bower, 1977; Spofford *et. al.*, 1976).

If we assume that any economic agent i is unable to foresee, control and prevent production losses, then D^i and W^i do not enter his cost minimization calculation and the cost function is reduced to be a function of Y^i and Q. If we further assume that all economic agents belong to an industry and the industry demand curve is horizontal with a given price P, then the welfare cost is defined as the decrease in the producer surplus due to the production losses at the specified water quality

$$\int_{Y-D}^{Y}(P-MC)dy \tag{5}$$

where

$$Y=\sum_{i=1}^{m} Y^i$$

$$D=\sum_{i=1}^{m} D^i$$

MC is the horizontal sum of the individual marginal cost functions, $\partial C^i / \partial Y^i$

Fig. 1 explains graphically Equation (5) for the case of a competitive producer. As a general discussion of damage function estimation procedure, see Freeman (1979).

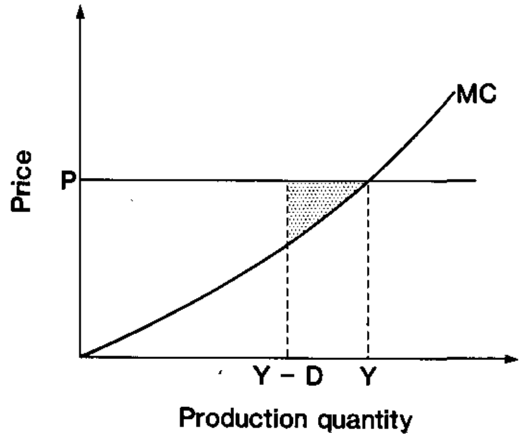

Fig. 1 Welfare cost as the decrease in the producer surplus

3 THE SPECIFIC MODEL FOR AQUACULTURE

3.1 The production function

Carp production quantity for an individual fish culture operator is a function of capital, labor, and feeding food. These three variables are considered to be joint inputs for a reason stated below. A variety of other factors, such as water qualities of his culture ground and size of liberation, which are represented by a parameter A, affect production. The production function is in the form of Cobb-Douglas production function

$$Y=AU_1^{\alpha}U_2^{\beta}U_3^{\gamma} \tag{6}$$

where α, β, γ are constants and U_1 is capital invested in culture operation, U_2 and U_3 are, respectively, labour and food expended throughout the culture season.

3.2 The damage function

From the viewpoint of dose-response relationship, the damage on carp production is mostly caused by periodic reduction of oxygen levels which have been observed to occur during summer periods in many eutrophic lakes. The damage quantification exercise is made extremely difficult, because of the lack of availability of hard scientific data derived from the continual monitoring of culture ground as well as of a variety of damage receptor's production mode. The eutrophication damage on carp production will occur under various circumstances and at various rates. Taking an aggregative approach to this dose-response relationship which ignores the details of death or illness, we postulate that the quantity of carp damage or the quantity of damage per carp production for individual operator is a function of two subsets of variables that are related to joint inputs and water quality of his culture ground, where an ordinary input such as capital invested in aeration devices is not formally included in the function due to the lack of reliable data. Though the joint inputs, in reference to the general model, should be restricted to feeding food, capital and labor are treated as joint inputs. For data on carp damages are obtained not through well-controlled laboratory experiments but through survey questionaire which are considered to be affected, among others, by surveyee's production mode.

Fig. 2 shows the description of the explained and explanatory variables used in the damage function. Two alternative forms are assumed for the damage function and are written as follows:

$$D=f_{21}(U_1, U_2, U_3, Q_1, Q_2, Q_3) \tag{7}$$

$$D/Y=f_{22}(U_1, U_2, U_3, Q_1, Q_2, Q_3) \tag{8}$$

where

Q_1 is temperature,
Q_2 is Secchi disk transparency,
Q_3 is chlorophyl l-*a* concentration.

Secchi disk transparency and chlorophyl l-*a* concentration are chosen, based on the study made by Carlson (1977), as the indicators of eutrophic status of a lake water. The former is characterized by its reliability in measurement and the latter by its superiority in estimating algal biomass. Though the fluctuations in dissolved oxygen as well as temperature is considered to be the primary source of stress for fishes in an eutrophic lake (Snieszko, 1974), the dissolved oxygen was excluded from the water quality variables for a reason stated below.

The Taylor's theorem shows that Eqs. (7) and (8) are approximated, for a fixed point (U_1^*, U_2^*, U_3^*, $\bar{Q}_1$, $\bar{Q}_2$, $\bar{Q}_3$) and in the small neiborhood of the point, by the following equations

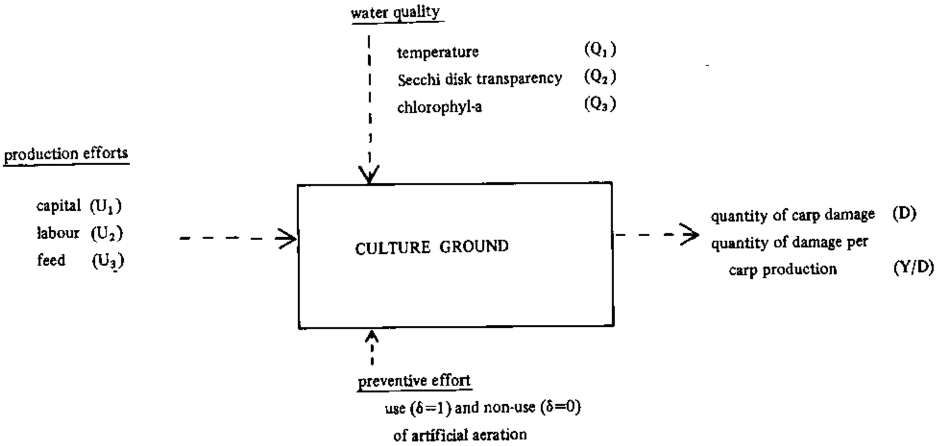

Fig. 2 Description of the explained and explanatory variables used in the damage function

$$D=f_{21}(U_1{}^*,\ U_2{}^*,\ U_3{}^*,\ \bar{Q}_1,\ \underline{Q}_2,\ \underline{Q}_3)+a_1(U_1-U_1{}^*)+a_2(U_2-U_2{}^*)$$
$$+a_3(U_3-U_3{}^*)+a_4(Q_1-\bar{Q}_1)+a_5(Q_2-\underline{Q}_2)+a_6(Q_3-\underline{Q}_3) \tag{9}$$
$$D/Y=f_{22}(U_1{}^*,\ U_2{}^*,\ U_3{}^*,\ \bar{Q}_1,\ \underline{Q}_2,\ \underline{Q}_3)+b_1(U_1-U_1{}^*)+b_2(U_2-U_2{}^*)$$
$$+b_3(U_3-U_3{}^*)+b_4(Q_1-\bar{Q}_1)+b_5(Q_2-\underline{Q}_2)+b_6(Q_3+\underline{Q}_3) \tag{10}$$

where f_{21} and f_{22} are assumed to have continuous partial derivatives up to the first order for the neighborhood of the point. In Eqs. (9) and (10), $U_1{}^*$, $U_2{}^*$, $U_3{}^*$ are, respectively, the optimal values of the variables related to joint inputs, under which the given quantity of carp, Y, is produced at the annual average temperature of $\bar{Q}_1$ with the least cost, provided that water quality represented by Secchi depth and chlorophyll-a is not ranked as eutrophic and indicated by $\underline{Q}_2$ and $\underline{Q}_3$. That is, Eqs. (9) and (10) show that the quantity of carp damage or the damage rate increases, if the joint inputs expended efficiently, with the progress of lake eutrophication. The exclusion of dissolved oxygen from the water quality variables rests on the fact that data on hypolimnetic dissolved oxygen could not be obtained from the study area, for which the minimum value of eutrophic lake conditions is available in Gakstatter *et al.* (1976).

3.3 The cost function

The cost function for an individual operator is derived by minimizing his production cost subject to the prodution function and is expressed as

$$C(Y)=w_1U_1{}^*+w_2U_2{}^*+w_3U_3{}^* \tag{11}$$

where

w_1	is the depreciation rate of capital,
w_2	is the unit labor cost,
w_3	is the unit feed cost,

provided that the elasticity coefficients α, β, γ are all positive. The derived cost function is a function of Y only, for the production function (6) does not formally contain any water quality variable.

4 EMPIRICAL ESTIMATE

4.1 Study area and data

Lake Kasumigaura in Japan is selected to study the eutrophication effects on aquaculture, which is famous in common carp culture and produced in 1976 36% of the total carp production, 23534 tons, in inland freshwater culture. It is a shallow lake with mean depth of four meters and is 200 km^2 in size, the second largest lake in Japan, and has mean hydraulic retention times of 200 days. Approximately 0.26 km^2 of the lake water surface was estimated to be occupied in 1978 by aquaculture. Fig. 3 describes a typical carp culture operation which involves the use of cages and pens constructed of nylon netting. Feed supply boxes are also shown in Fig. 3, which feed the fish continuously for some specified time period with the power of electric motor.

There are three sources of data for the empirical estimates of the model. The data on carp production, joint inputs, and damage are derived from the survey questionaire conducted independently by the National Institute for Environmental Studies (see Kitabatake & Aoki, 1980) and the Kasumigaura-Kitaura Fisheries Office of Ibaraki Prefecture (1977). These surveys were of self-reporting survey. In the former survey the questionaires were sent jointly through the fisheries cooperative associations and the private research company contracted by the Institute to

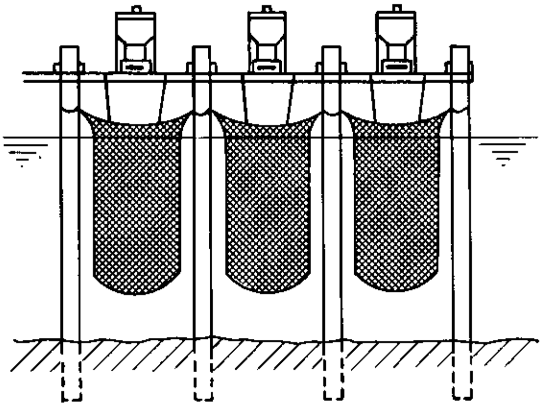

Fig. 3 Culture operation in Lake Kasumigaura

all of the fishery households engaged in fixed netting, trawl net, and carp culture operations, while in the latter they were sent through the fisheries cooperative associations to all of the fishery households engaged in carp culture. In this study, a part of the NIES survey data is utilized, which is related to carp culture. Table 1 summarizes the difference in design of surveys, where only the relevant part of the surveys are included. In the Kasumigaura-Kitaura Fisheries Office survey, data on the annual production were taken to be the difference between the sum of the carp quantity sold and the quantity existed at the end of the year and the sum of the quantity existed at the end of the previous year and the quantity of liberation.

The water quality data for Lake Kasumigaura were taken from the Ibaraki Prefectural Government (1978, 1979), and the water quality values associated with the transition from mesotrophic to eutrophic condition were assumed to be 2 meters for Secchi depth and 10 ppb for chlorophyll-*a*, based on Gakstatter *et al.* (1976).

4.2 The production function

Due to the lack of production data in the NIES survey, the production function is estimated in the following way. First, the relationship was statistically estimated via the source data of the Kasumigaura-Kitaura Fisheries Office survey between the annual production and the amount of feed input such that

$$\log Y = -0.155 + \underset{(16.095)}{0.899} \log U_3, \qquad N=31,\ R^2=0.899 \tag{12}$$

for an individual operator equipped with feed supply boxes and

$$\log Y = -0.220 + \underset{(27.559)}{0.937} \log U_3, \qquad N=59,\ R^2=0.930 \tag{13}$$

for those feeding with their hands, where the t statistics are in prentheses. In these regression analysis, the source data were excluded from the analysis, in which either the production or the feed input data were missing and in which the share of the synthetic food is less than 80% in terms of wet basis of the total feed input. Fig. 4 plots the regression lines for the range of values relevant to data. Feed conversion rate is estimated to be slightly high for operators feeding with their hands for feed input greater than 51.4 tons than those with feed supply boxes, though the range of values relevant to data reveals that the latter can expand the production up to 173 tons beyond the maximum level of 69 tons achieved by the former.

Second, the production over 4-month period is estimated through the production-feed input relations, (12) and (13), and the NIES data on the quantity of synthetic food input. Here, we assume that the higher temperature in the summer period of 1978 than that of 1976 does not affect the production-feed input relations. Then the production function was satistically estimated in terms of the estimated production levels and data on capital and labor inputs such that

$$\begin{array}{l} \log Y=-0.855+0.797\ \log U_1+0.196\ \log U_2 \\ \qquad\qquad\quad (5.004) \qquad\qquad (1.123) \\ \qquad\qquad\qquad\qquad\qquad N=43,\ R^2=0.8955 \end{array} \tag{14}$$

for an individual operator equipped with feed supply boxes and

$$\begin{array}{l} \log Y=-1.244+1.104\ \log U_1+0.113\ \log U_2 \\ \qquad\qquad\quad (5.451) \qquad\qquad (0.554) \\ \qquad\qquad\qquad\qquad\qquad N=37,\ R^2=0.594 \end{array} \tag{15}$$

for those feeding with their hands, where U_1 is capital input in 10^4 yen and U_2 is labor input in man-hours. Capital equipment input, which is the annual flow of capital services, is assumed to equal the stock of capital good in existence which is defined to be the sum of culture nets and feed supply boxes multiplied by their respective prices of 50 thousand yen for a culture net and 70 thousand yen for a feed supply box. Though culture nets and feed supply boxes last about three years, the stock of capital good in existence is assumed to be kept intact by operators'

Table 1 Design of survey questionaires[a)]

	NIES survey	Kasumigaura–Kitaura Fisheries Office survey
Survey period :		
	Between June 1978 and September 1978	Between January 1976 and December 1976
Executed period :		
	Between November 1978 and March 1979	Between March 1977 and September 1977
Items surveyed :		
carp production		X (ton/y)
labour input	X (man–hours/month)	
capital input	X (10^4 yen)	X (10^4 yen)
feed input	X (ton/month)	X (ton/y)
damage inflicted	X (10 kg/month)	
Number of respondents :	183	307
Return rate	0.52	0.94

a) The items surveyed are indicated by symbol "X".

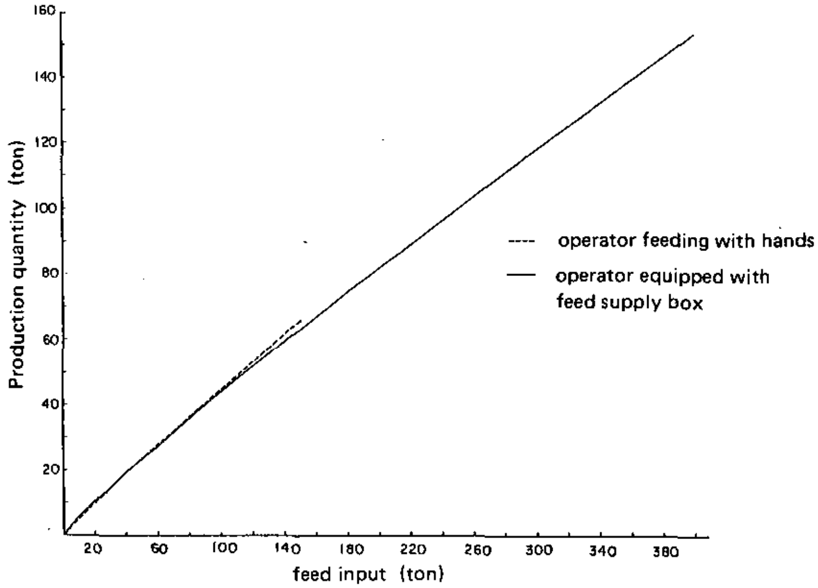

Fig. 4 Estimated relationship between carp production and feed input

maintenance activities. Thus the capital requirements for construction of supporting structure of culture cage and for purchase of electric motor are excluded from the estimation of capital input. Furthermore, the sample data were excluded from the estimation of Eqs. (14) and (15), in which some survey items were unanswered. The low t value for labor elasticity coefficient in Eq. (15) may be explained by the observational facts that operators feeding with their hands utilize, compared to those with feed supply boxes, more unpaid family labor, the quality of which is likely to vary greatly.

4.3 The damage function

Data used to estimate the damage functions specified in Eqs. (9) and (10) were gatherd, as noted in section 4.1, from the NIES survey and the official publication on water quality data of Lake Kasumigaura. Table 2 and 3 summarize the NIES survey results with respect to the cultured carp losses by symptoms and feeding methods, and to respondents' evaluation of causal factors, where respondents are identical to those whose data were employed for the estimation of production function in section 4.2. The 43 operators among the total of 80 respondents reported nonzero kg of monthly damage and the remaining 37 operators reported zero kg. Table 2 shows that 62% of the total losses is associated with the specified symptoms of "fish died in net" and "infected fish" which were likely to be caused by the deterioration of and/or daily and seasonal variation in water quality. On the other hand, the respondents' evaluation of causal factors reveal, as shown in Table 3, that the deterioration of water quality or algal bloom was believed by the majority of the respondents to be the significant damage factor. Based on these observations, data on the total losses taken from the NIES survey, which include both nonzero and zero kg of monthly damage for each of 80 operators, are likely to be explained, to some extent, by the water quality variables as specified in Eqs. (9) and (10).

As Fig. 5 shows, there are 18 monitoring stations in Lake Kasumigaura at which water quality data have been taken once a month from the surface of the lake water, where Lake

Table 2 Cultured carp losses by symptoms and feeding methods during the period from June 1978 to September 1978

Number of repondents	Number of respondents with positive amounts of carp losses	Symptoms fish died in net (t)	infected fish (t)	malformed fish (t)	stinking fish (t)	others (t)	Symptoms unanswered (t)	Total losses (t)
feed supply box								
43	30	32.1	4.5	0.8	0	16.3	14.6	68.3
hand feeder								
37	13	14.4	1.2	0	0	0	0.3	15.8
total								
80	43	46.5	5.7	0.8	0	16.3	14.9	84.1

Table 3 Percent distribution of respondents' responses to causal factors

Number of respondents	Total number of responses	Causal factors scarce amount of rainfall (%)	excessively high temperature (%)	deterioration of water quality or algal bloom (%)	variation of lake water and/or of water temperature (%)	inflow of toxic materials (%)	others (%)
80	140	17	11	65	4	3	0

Kasumigaura is a general term for two sublakes and called Lake Kasumigaura and Lake Kitaura. Due to the unavailability of water quality data for an individual culture ground, data for a nearby monitoring station or the average data of the several nearby stations were used. The number of operators is shown in parentheses in Fig. 5 and the solid arrow connects a monitoring station with its corresponding culture grounds and with its corresponding group of operators. Those data in the NIES survey were excluded from the analysis, whose corresponding water quality data were not substituted by any nearby monitoring station. Two dummy variables are employed in addition to variables specified in Eqs. (9) and (10) in order to take into account of the difference in the topography or any general feature of culture ground between the two sublakes of Lake Kasumigaura and of the difference between user and nonuser of aeration devices.

The stepwise, linear, multivariate regression procedure was used for determining the damage function specified in Eqs. (9) and (10), where the sample is split into two subsets from operators with feed supply boxes and those feeding with their hands. Furthermore, due to the low t-value of labor elasticity coefficient in Eq. (15), the sample means, $\bar{U}_1$ and $\bar{U}_2$, are utilized for U_1^* and U_2^* in Eqs. (9) and (10) for the latter subset. The regression results were as follows:

For operators equipped with feed supply boxes

$$\begin{array}{l} D=-49.203+0.127(U_1-U_1^*)+0.201(U_2-U_2^*/4)+5.819(Q_1-\bar{Q}_1) \\ \qquad\qquad (1.704) \qquad\qquad (2.679) \qquad\qquad (1.642) \\ \qquad\qquad\qquad\qquad\qquad\qquad N=152,\ R^2=0.068 \end{array} \qquad (16)$$

$$\begin{array}{l} D/Y=-15.673+0.006(U_1-U_1^*)+1.249(Q_1-\bar{Q}_1)-7.082(Q_2-\bar{Q}_2)-4.102\,\delta \\ \qquad\qquad (1.645) \qquad\qquad (6.559) \qquad\qquad (-4.680) \qquad\qquad (-3.311) \\ \qquad\qquad\qquad\qquad\qquad\qquad N=152, \quad R^2=0.331 \end{array} \qquad (17)$$

For operators feeding with their hands

$$\begin{array}{l} D=12.039+0.226(U_2-\bar{U}_2) \\ \qquad\qquad (3.816) \qquad\qquad N=72,\ R^2=0.172 \end{array} \qquad (18)$$

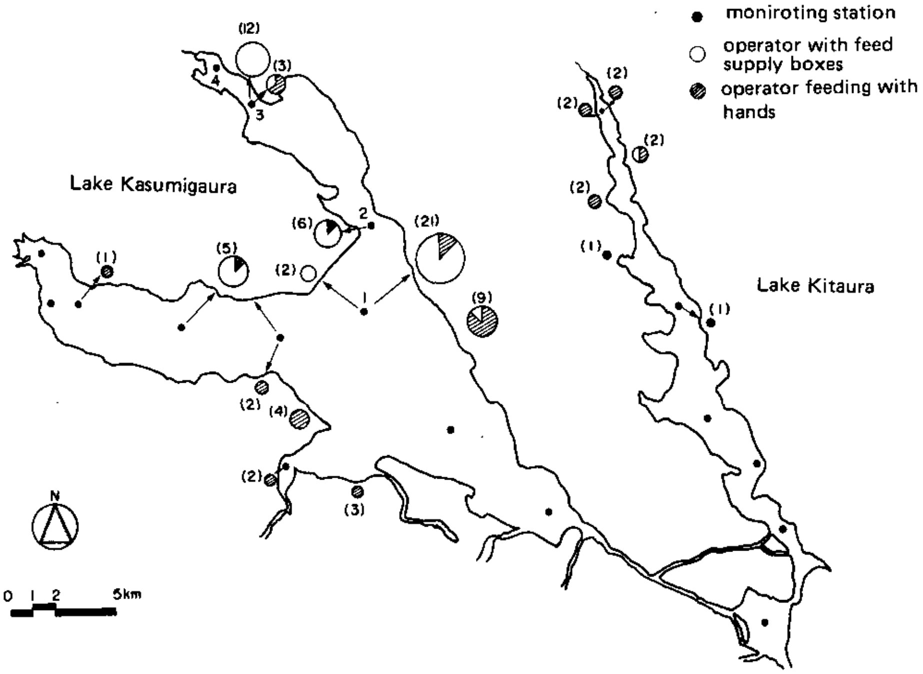

Fig. 5 Lake Kasumigaura, with the location of water quality monitoring stations and of selected carp culture operators

$$D/Y = \underset{(3.909)}{0.316+0.006}(U_2-\bar{U}_2) \qquad N=72,\ R^2=0.179 \qquad (19)$$

where all variables except Y, U_1^*, $\bar{U}_1$, and U_2^* are monthly data and the variables with symbol $*$ are the optimal values of the joint input variables. In each stepwise regression, the backward elimination procedure (see Hocking, 1976) was employed to select the "best" subset of explanatory variables, where "best" is defined in terms of changes in the residual sum of squares and the F values for inclusion and exclusion of variables are taken to be 2.0. The values below the regression coefficients are t statistics.

Some remarks on the regression results are in order. Water quality variables of temperature and Secchi depth and the dummy variable, δ, related to the use of aeration devices enter the "best" subset of explanatory variables only in an equation for operators equipped with feed supply boxes. That is, the damage rate for operators feeding with their hands is estimated to be independent of water quality variables. At this point, a question naturally occurs as to why the difference in feeding method should result in the elimination of water quality variable as an explanatory variable of the damage functions, since the water area being used and the associated water quality are the same for operators with both types of feeding. The answer to this question seems to lie in the figures shown in Table 2 that 91% of the total losses for the operators feeding with hands is represented by the symptom of "fish died in net," compared to 47% for the operators equipped with feed supply boxes. Though all cultured carp losses are considered to be the end result of an interaction among a noxious stimulus, a susceptible host and proper environmental conditions, the causality of symptoms other than "fish died in net" is particularly complex. This provides an answer to the question such that only the damage relationship for operators with feed supply box is explained by the water quality variable of Secchi depth which is considered to be a general indicator of lake eutrophication, where that for operators feeding with hands is supposed to be explained by such a specific water quality variable as hypolimnetic dissolved oxygen. Though a still large part of the total variation remains unexplained in Eq. (17), the sign of the regression coefficients for water quality and dummy variable is statistically significant at 1% level and is compatible with a priori expectations. As a monthly value of temperature rises above an annual value and Secchi depth decreases, below the specified value of 2 meters, the carp damage rate increases, while the use of aeration devices reduces the damage rate.

4.4 The cost function

For the derivation of cost function and the calculation of welfare cost function in the next section, the unit price-cost data of Table 4 are utilized. The unit price-cost data were mostly the average of data collected by interviewing the representatives of fisheries cooperative associations. Though labor data taken from the NIES survey contain both, but do not distinguish between employed labor and unpaid family labor, the unit cost for employed labor is applied to all labor inputs.

The cost function is defined in Eq. (11). Here, U_1^*, U_2^*, and U_3^* are obtained by substituting the estimated values for A, B, α, β, γ in Eqs. (12) and (14) into the following equations, where $B = 10^{\epsilon}$ and ϵ is the constant term in Eq. (12):

$$U_1^* = A^{-1/(\alpha+\beta)}(\beta w_1/\alpha w_2)^{-\beta/(\alpha+\beta)}Y^{1/(\alpha+\beta)} \tag{20}$$

$$U_2^* = A^{-1/(\alpha+\beta)}(\beta w_1/\alpha w_2)^{\alpha/(\alpha+\beta)}Y^{1/(\alpha+\beta)} \tag{21}$$

$$U_3^* = (Y/B)^{1/\gamma} \tag{22}$$

The the derived cost function is written as

$$C(Y) = 3.519Y^{1.007} + 22.323Y^{1.112} \tag{23}$$

Then cost function for an operator feeding with their hands is not derived, due to the fact that the estimated damage equations, Eqs. (18) and (19), are independent of water quality variables.

Though the cost incurred to minimize the production losses for given Y is formally zero, the dummy variable in Eq. (17) relating the use of aeration devices suggests that the qualitative evaluation of this specific cost is possible. Fig. 6 shows the two lines of zero damage rate for the alternative cases of use ($\delta = 1$) and nonuse ($\delta = 0$) of aeration deices, which is derived from eq. (17) under the condition of optimal production mode, and where the horizontal axis measures a monthly Secchi depth and the vertical axis the differnce between a monthly temperature and an annual average temperature. Annual average temperatures for station 1 and station 2 are 16.43°C and 16.96°C, respectively. Above each line, the damage rate becomes positive and the half-shaded region in Fig. 6 shows the positive domain. Fig. 6 also depicts the trajectories of monthly water quality for monitoring stations 1 and 2 shown in Fig. 5, where these two stations represent the best and the worst station in terms of Secchi depth among the stations utilized in the estimation of

Table 4 Unit price-cost data for the year of 1978

Year	P 10^4 yen per ton	w_1 capital depreciation rate	w_2 10^4 yen per man-hour of employed labour	w_3 10^4 yen per ton
1978	44.5	0.333	0.125	13.5

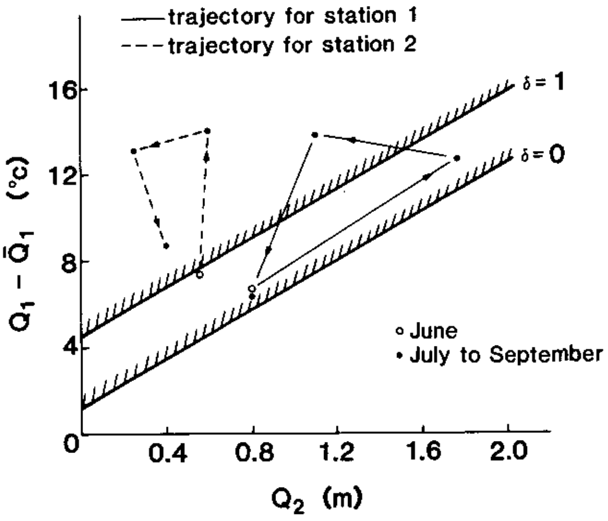

Fig. 6 Domain of positive damage rate for the alternative cases of use and non-use of aeration devices

damage functions. This shows that the use of aeration devices is effective in reducing the number of months with positive damage rate. In other words, the cost incurred to minimize D for given Y is equal to the annual cost related to the use of aeration devices for all operators in the study area.

4.5 The welfare cost calculation

The welfare cost calculation is based on the cost function of Eq. (23) derived for a representative aquaculture operator equipped with feed supply boxes, where the cost function for an operator feeding with their hands does not enter the welfare cost calculation due to the no eutrophication-caused production losses estimated. Welfare cost is calculated for the following two cases: (i) a representative operator i produces the optimal quantity of 218.95 tons which maximizes his profit, given the output price of 445 yen per kg; (ii) he produces thew quantity of 37 tons which is the average of the operators equipped with feed supply boxes in the NIES survey. The wide range of about 220 tons to 40 tons between the optimal quantity and the average quantity needs some explanation. First the average quantity is calculated based on the ptoduction-feed input relation, (12), and the NIES data on the quantity of synthetic food input over a 4-month period, where the optimal quantity corresponds to the optimal annual production level. The estimated average quantity is smaller than an annual average quantity, for feeding of food usually lasts over 7 or 8 months from March or April to November. The second explanation rests on the large number of licenced operators relative to the given water surface area available for aquaculture in Lake Kasumigaura. If there were free entry into and exit from the aquaculture operation and no administrative constraint on the water surface area available for auaculture, the annual average quantity, which is estimated to be about 2 × 37 = 74 tons, would have been close to the optimal quantity, where the administrative restraint on the water surface area is necessitated by the existence of competitive uses such as fixed netting and trawling.

Then Eq. (5) enables us to calculate numerically the welfare cost of eutrophication-caused production losses for the first case, where Y and D are equal to 198 × 218.95 tons and 0.039 × 198 × 218.95 tons, respectively. Here, the damage rate is calculated, based on equation (17) and the water quality trajectory for station 1 shown in Figure 6, provided that every culture operator is assumed to locate near station 1. The calculated welfare cost is 154 × 10^4 yen, which correspond to the number of aquacuture operators multiplied by the shadow region in Figure 1. The welfare cost for the second case, on the other hand, is calculated to be 2284 × 10^4 yen where Y and D are equal to 198 × 37 tons and 0.039 × 198 × 37 tons, respectively.

In this paper we have assumed in order to calculate the welfare cost, that a competitive aquaculture operator is unable to foresee, control and prevent production losses. Appendix 1 to this chapter modefies this assumption and shows how the optimum production quantity is affected by this modification.

5 CONCLUDING REMARKS

In this paper production functions and eutrophication-caused damage functions for aquaculature in Lake Kasumigaura are estimated. The equations are used to calculate, given the price data of 1978, the welfare cost of production losses from the eutrophication of Lake Kasumigaura under the assumption of horizontal demand curve.

In spite of the lack of reliable information on water quality levels in culture grounds as well as on dose-response relationships for cultured carp, physical damage functions are estimated for two types of culture operators, that are operators with feed supply boxes and those feeding with their hands, where the damage data were collected through the survey questionaire. The estimation indicates that the operators feeding with their hands are not affected by the eutrophication of the lake. On the other hand, the physical damafe rate per output quantity is estimated, for operators equipped with feed supply boxes, to be negatively related to Secchi depth which is an indicator of eutrophic status of the lake.

Finally, the paper shows that the welfare cost calculation for aquaculture industry in Lake Kasumigaura is affected by two factors that are the measures taken by operators to prevent the production losses and whether or not the industry is competitively organized.

ACKNOWLEDGEMENTS

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APPENDIX 1 Modification of the assumptions

Our estimated damage rate function, equation (17), shows that the rate of production damage depends on the water quality variables, Q_1-$\bar{Q}_1$ and Q_2-$\underline{Q}_2$, and on the use ($\delta = 1$) or non-use ($\delta = 0$) of aeration devices, provided that an aquaculture operator equipped with feeding box invests the right amounts of production capital (U_1) for a given production quantity (Y).

If we assume that 1) the annual cost of utilizing aeration device is w_4, 2) an aquaculture operator considers the estimated damage rate function (17) as a deterministic relation, and 3) water quality variables are exogenously given uncontrollable factors to the individual operator, but he can decide whether he will use or not use the aeration devices, then the competitive aquaculture operator will decide his production mode so as to

$$\underset{Y,\ \delta}{\text{Maximize}}\ \pi = PY - C(Y) - P(f_{22} + b_4(Q_1 - \bar{Q}_1) + b_5(Q_2 - \underline{Q}_2) + b_7\delta)Y - w_4\delta$$

where C(Y) is specified in equation (23) and, f_{22}, b_4, and b_5 and b_7 are, in reference to equation (9), the estimated coefficients in equation (17). Since the coefficient b_7 takes the negative value, it is apparent that the operator will decide to use the aeration device if the economic value of production damage avoided is greater than the annual cost of aeration devices, $-Pb_7Y - w_4 > 0$. Furthermore, if the operator located on a culture ground where the estimated damage rate becomes positive, his optimum production quantity will be reduced, as the marginal cost curve in Figure 1 now shifts upward.

Fig. A1 shows the net revenue function, PY-C(Y), and the economic value of estimated production damage, P(D/Y)Y, for a competitve aquaculture operator equipped with feeding box and aeration device, and located near station 1 of Lake Kasumigaura. This figure reveals that the optimum production quantity decreases from 218.95 tonnes to 145 tonnes.

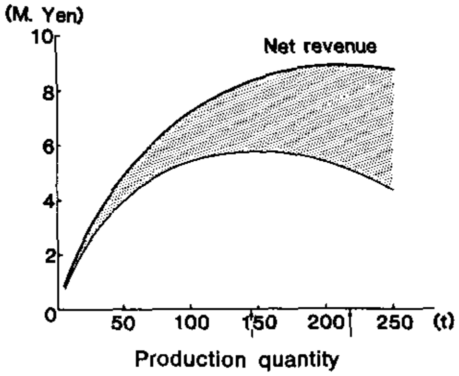


Fig. A1 Estimated net revenue and revenue losses for an operator equipped with feed supply box and aeration device at station 3

Chapter 6

Economic Analysis of the Utilization of Fishery Resources with Predator-Prey Relationship: A Case of Trawling in Lake Kasumigaura

Y. Kitabatake

ABSTRACT

A dynamic model of fishery resources with a predator-prey relationship and the models of man's utilization of fishery resources are constructed based on observational data and research findings for Lake Kasumigaura, Japan. The analysis of the models, based on the estimated individual production functions for trawling operation, shows that the existing biomass structures of Lake Kasumigaura reflect the individual fisherman's economically rational response to given technological, economic and ecological conditions pertaining to Lake Kasumigaura.

1 INTRODUCTION

As explained in chapter 1, the environment's main functions, from man's point of view, consist of supplying aethetic goods, supplying natural resources, and supplying a "sink". Lake Kasumigaura is unique in such a sense that all of the three functions coexist, though the first function is rather weak compared to the second and the third function. The second function is composed of the utilization of lake water resources and of biological resources. Various land-based activities such as industry, household, agriculture use water taken from the lake for their production or consumption activities, while fishermen engaged in aquaculture utilize a certain volume of water for nurturing their cultured fish. As a byproduct of this kind of water resource utilization processes, various kinds of pollutants and/or nutrients are discharged into the lake.

On the other hand, fishermen are also engaged in the utilization of fishery resources of the lake. Though this kind of utilization of biological system does not discharge any kind of pollutants and/or nutrients into the lake, their utilization processes do have a significant impact on the ecological structures of the lake and the impact may deteriorate the quality as well as quantity of lake environmental resources. For example, the decrease in the pelagic species population coupled with the increase in the demersal species population may deteriorate the lake water quality, for the latter species can feed on the bottom deposits and the nutrients are reinjected into the lake water by fishes' excretion process.

In this sense, the second and the third functioins of the environment are closely related to each other. Ikeda and Yokoi (1980) analyzed the model dealing with the impact of nutrient enrichment in the Seto Inland Sea on the fishery resources. In their study, exogenously givin nutrient is assumed to affect the carrying capacity of plankton population and the death rate of small as well as large fish population. The behaviour of each population level is described in differential equations and the stability, as well as the sensitivity with respect to nutrient enrichment, of equilibrium points of differential equations are checked. Their model like most of fishery models rather simplifies man's behavioural characteristics such that catching of each fish species, for the unit time period, by fishermen is assumed to be some constant multiplied with the corresponding fish population, and to be independent of catching of the other species. Here we deal with a case where there is a decision making involved on the side of fisherman to choose which species to catch.

Especially, we deal with the interactions between fisherman's behavioural characteristics represented 'by economic efficiency and ecological charactersitics of the fishery resources, and clarify the economic rationale for the kind of operation pattern existed in trawling in Lake Kasumigaura in which fishermen spend the greater part of their licensed trawling hours for the trawling of demersal species. This chapter presents an extension of the author's previous work on the same subject (Kitabatake, 1982).

2 A SUMMARY OF THE FISHERY MANAGEMENT OF LAKE KASUMIGAURA

The introduction of diesel-powered trawling in 1966, which substituted the traditional method of sailing trawling on most of Lake Kasumigaura and Lake Kitaura, had a significant impact on the interspecies relationships in Lake Kasumigaura. Fig. 1 shows 1) the annual water quality variation in terms of Secchi depth in Lake Kasumigaura, 2) the annual variation of pelagic fish, represented by pond smelt, and 3) that of demersal fish, by goby and freshwater shrimp in each of two lakes. Fig. 2 shows the operation areas of the lakes. The main fishing

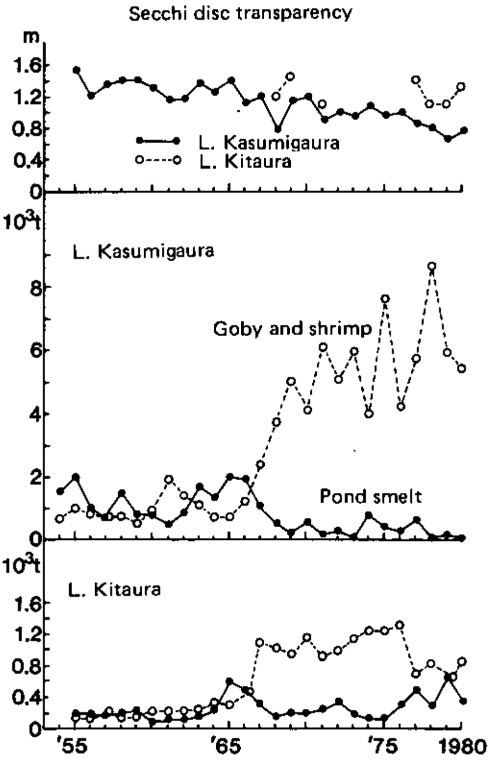


Fig. 1 Trend of fish catch and transparency
Secondary Source: Kitabatake (1983)

methods in use include fixed netting, trawling, and an indigenous fishing method of ” Isaza-gorohiki ami’ in which the net is hauled near the lake bottom toward an anchor for the distance of 400 to 1000 metres. In 1978, 74% of the total pond smelt catch, 43% of the total goby catch, and 26% of the total freshwater shrimp catch was taken by trawling.

Fig. 3 and 4 show the biological aspects of fishery resources at Lake Kasumigaura. The seasonal variations of stomach contents of pond smelt is shown in Fig. 3, whereas Fig. 4 depicts the seasonal variations of population densities of prey species. Furthermore, fishing by means of the trawl method is restricted to the period between 21 July and 31 December, during which time, as shown in Fig. 3, pond smelt are observed to eat juvenile goby and freshwater shrimp larvae as well as opossum shrimp which has little market value. The above observations and research findings strongly suggest that there is a predator-prey relationship between the pelagic species of pond smelt and the demersal species of goby and freshwater shrimp and that the introduction of disel-powered trawling on Lake Kasumigaura has had favorable impacts on the growth of demersal fish at the expense of the pelagic fish of pond smelt which has the higher market value.

Fig. 5 and table 1 show the economic characteristics of trawling in Lake Kasumigaura. First, the estimated variable cost function of trawling is shown along with the sample data in Fig. 5, where the estimation is based on the survey data (Kitabatake, 1981, 1983). The figure reveals that there is no significant difference in economic efficiency, in terms of variable cost per value of catch, of trawling in two lakes, where for those samples with high value of catch the data are not reliable due to the possibility of poaching. On the other hand, Table 1 summarizes the average catch by species for sampled fishery households. Contrary to situation in Fig. 5, there exists large difference in the catch by species between trawling in Lake Kasumigaura and trawling as well as sailing trawling in Lake Kitaura. From these observations, we know that, although the cost

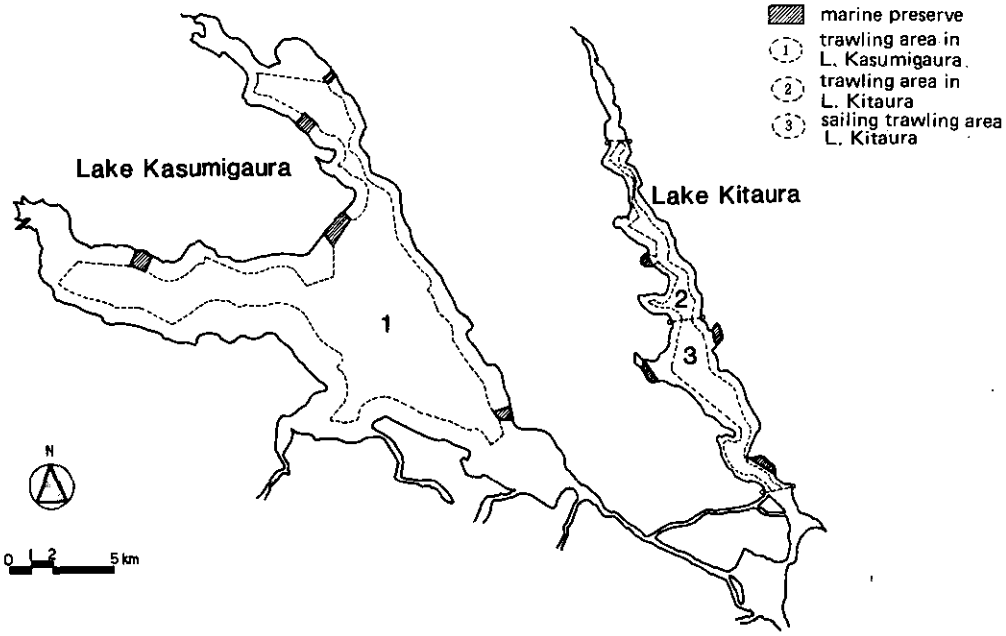


Fig. 2 Licenced operation area in L. Kasumigaura and L. Kitaura

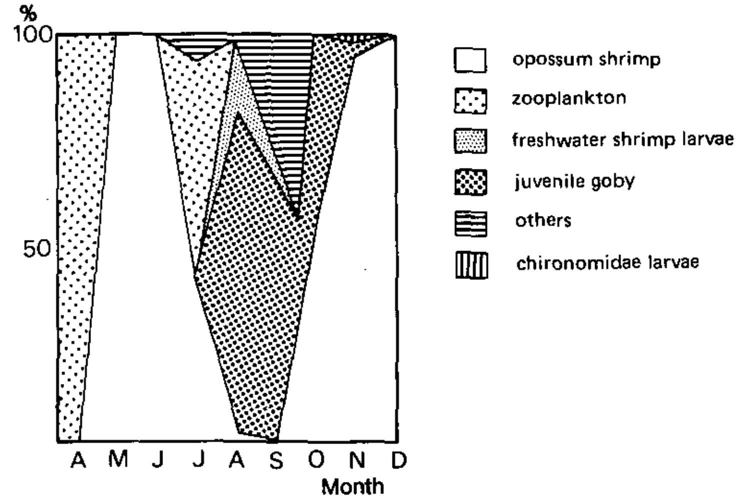


Fig. 3 Seasonal variation of stomach contents of pond smelt from April (month 4) to December (month 12)
Source : Suzuki and Ida (1977)

effectiveness of trawling in two lakes are almost same, economic viability of trawling in Lake Kasumigaura rests on demersal species, whereas that in Lake Kitaura on pelagic species of pond smelt.

3 THE MODEL OF FISHERY RESOURCES

3. 1 The biomass equations without the effects of fishing

The following Voltera equations are postulated for the growth and population of pelagic and demersal species in lake water.

$$dX_1/dt = -a_1X_1 + b_1X_1X_2 \quad (1)$$

$$dX_2/dt = a_2X_2(1-X_2/\bar{X}_2) - b_2X_1X_2 \quad (2)$$

The assumptions underlying *these equations are now summarized*, and are based on Smith (1974):

(1)populations can be adequately represented by a single variable, which ignores differences of age, sex, and genotype;

(2)the gross change in population can adequately be described by deterministic equations, which ignore random fluctuations in the environment with time;

(3)the effects of interactions between species are instantaneous;

(4)in the absence of pelagic species, the demersal species would follow the logistic equations, with intrinsic rate of increase a_2 *and carrying capacity* $\bar{X}_2$; *and*

(5)the rate at which the demersal species are eaten is proportional to the product of the demersal and the pelagic populations.

The dynamics of the system, represented in equations (1) and (2), is shown in figure 6. If the parameters a_1, a_2, b_1, b_2, and $\bar{X}_2$ are all positive constants and fixed, and that a stationary state *denoted* by $(\tilde{X}_1, \tilde{X}_2)$ in Fig. 6 exists in the first quadrant, then it can be shown that the pelagic and demersal populations converge to the stationary state as t goes to infinity , where the stationary state is written as follows:

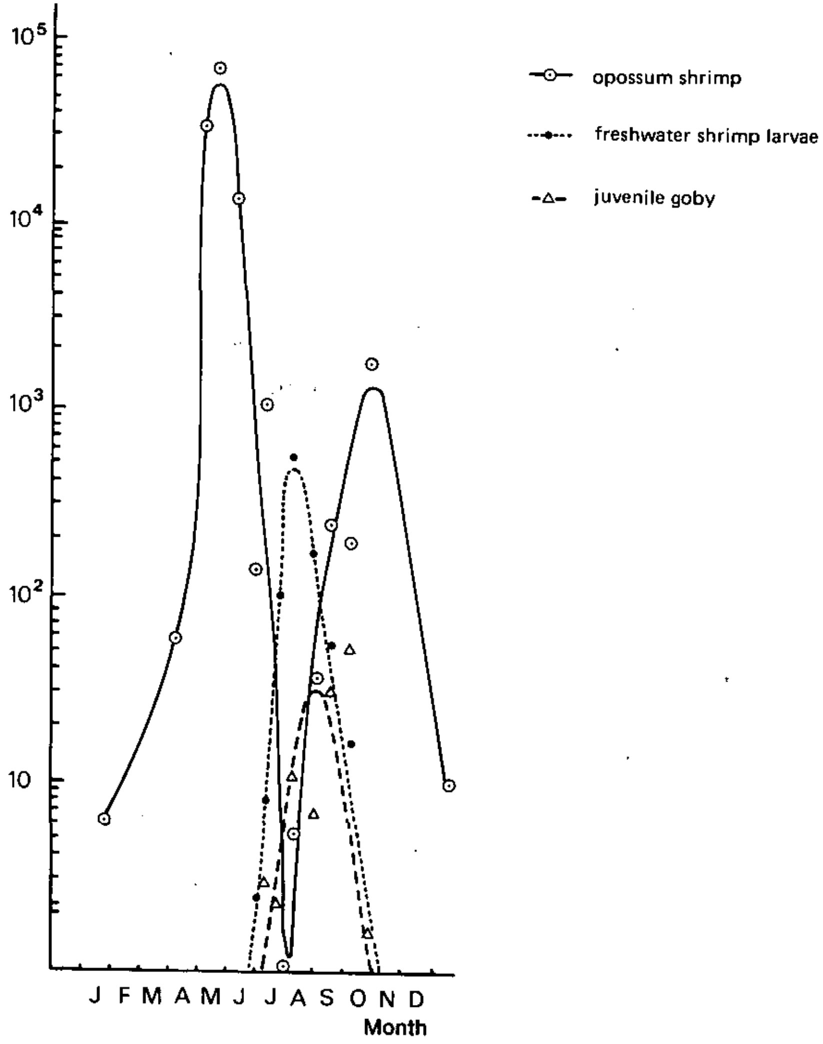


Fig. 4 Population density variation of prey species
Source : Suzuki and Ida (1977)

Table 1 Average catch by species for the period of four months
—July to September, 1978

unit: kg/fishery household

Species	Trawling in L. Kasumigaura	Trawling in L. Kitaura	Sailing trawling in L. Kitaura
Pond smelt (500yen/kg)	328.3	1580.0	2531.3
Icefish (1200yen/kg)	14.0	5.9	66.1
Goby (115yen/kg)	2646.4	164.7	52.6
Freshwater shrimp (165 yen/kg)	549.3	48.8	89.5
Others	7.9	8.8	0

Source: Kitabatake (1981)

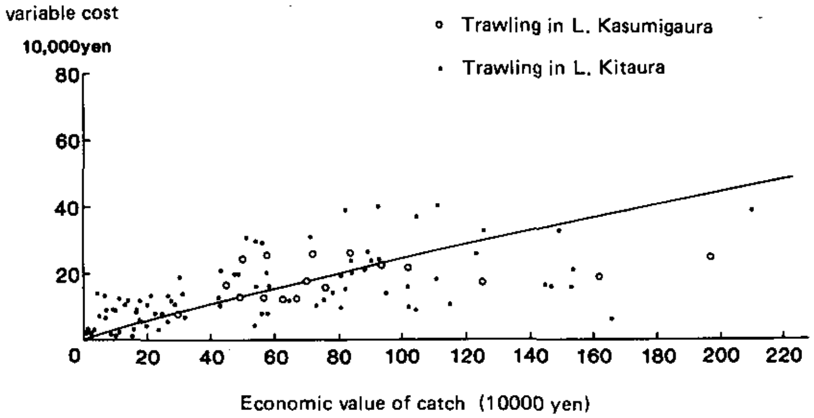


Fig. 5 Estimated variable cost function

$$\tilde{X}_1 = a_2(1-\tilde{X}_2/\overline{X}_2)/b_2 \qquad (3)$$

$$\tilde{X}_2 = a_1/b_1 \qquad (4)$$

and the reader is referred to Leung and Wang (1976) for a proof.

3. 2 The biomass equations including the effects of fishing

The introduction of fishing activities modifies equations (1) and (2) as follows,

$$dX_1/dt = -a_1X_1 + b_1X_1X_2 - n_1Y_1 \qquad (5)$$

$$dX_2/dt = a_2X_2(1-X_2/\overline{X}_2) - b_2X_1X_2 - n_2Y_2 \qquad (6)$$

where Y_1 and Y_2 are the catch rates of pelagic and demersal species, respectively, by an individual fishery household, and where n_1 and n_2 are the number of fishery households engaged in catching the pelagic and demersal species, respectively. The production functions are expressed as follows:

$$Y_1 = k_1X_1^{\beta_1}U_1^{\alpha_1} \qquad (7)$$

$$Y_2 = k_2X_2^{\beta_2}U_2^{\alpha_2} \qquad (8)$$

Where k_1, k_2, α_1, and α_2, β_1, and β_2 are constants. A fishery household is assumed to own a diesel-powered boat to catch, during any time interval Δt, $Y_1\Delta t$ of pelagic species and $Y_2\Delta t$ of demersal species by expending U_1 and U_2 of labour force owned by the fishery household, respectively. Thus the amount of pelagic and that of demersal species caught by a fishery household are assumed in equation (7) and (8) to be a function of the stock of pelagic species and labour.

The behaviour of the system described by equations (5) through (8) is analyzed graphically in Fig. 7 and 8, for given values of n_1, n_2, U_1, and U_2. The stationary points can be obtained by equating the right-hand side of each equation to zero. We can obtain three kinds of stationary point

(X_1^*, X_2^*) for $X_1^*, X_2^*>0$, $(0, X_2^*)$ and $(0, 0)$.

Though, for each of these three kinds of stationary point, the stability analysis can be executed, we will execute it for the first kind only in the following. Fig. 7 shows the alternative curves for $\dot{X}_1=0$ and $\dot{X}_2=0$ for the different values of parameters β_1 and β_2. The phase diagrams are drawn

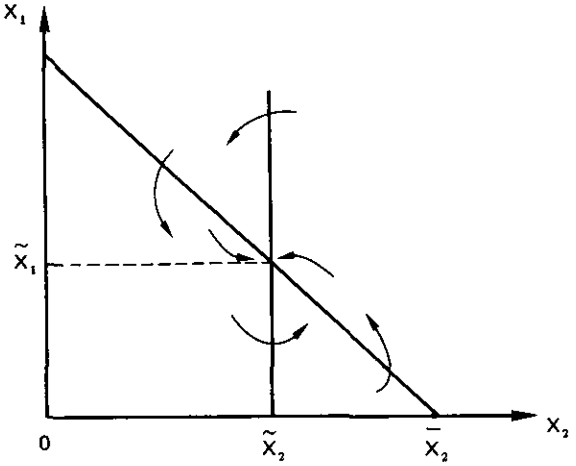


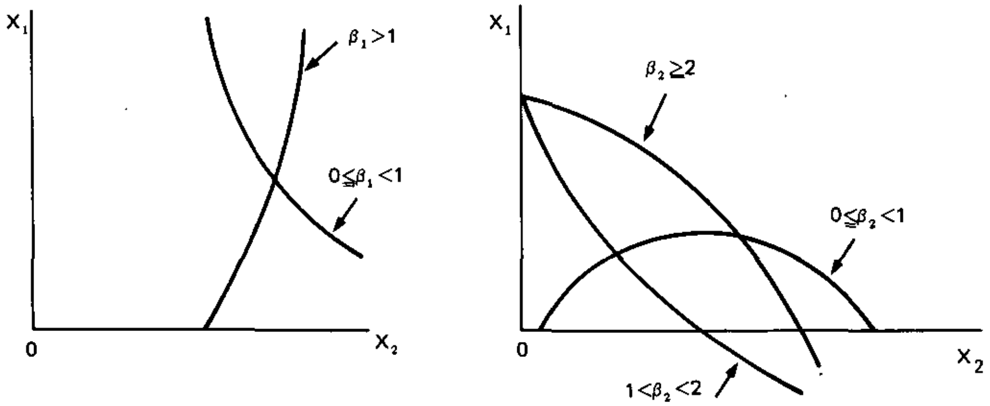
Fig. 6 Stationary state without fishing, and possible phase portraits

in Fig. 8. In case of $0 < \beta_1 < 1$, there exists the possibility of multiple equilibria as shown in Fig. 8c. The stability of a stationary point S follows from the negative angle at which the $\dot{X}_1 = 0$ and $\dot{X}_2 = 0$ lines intersect and is assured by checking that both eigenvalues of the linearized equations (5) and (6) at S have negative real parts (see Coddington & Levinson, 1955). The stability condition is written as follows.

$$a_2 X_2/\overline{X}_2 + (\beta_1 - 1) n_1 k_1 X_1^{\beta_1 - 1} U_1^{\alpha_1} + (\beta_2 - 1) k_2 X_2^{\beta_2 - 1} U_2^{\alpha_2} > 0 \qquad (9)$$

which is clearly satisfied if $\beta_1 \geqq 1$ and $\beta_2 \geqq 1$.

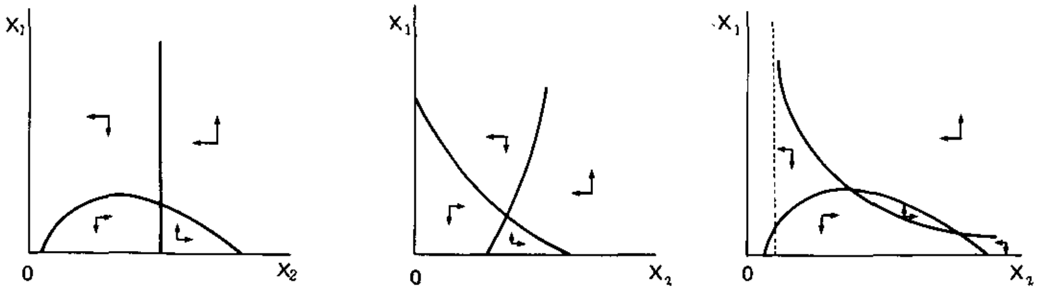
In what circumstances will the extinction of pelagic or demersal species be prevented ? It is clear from Fig. 8 that the extinction of either species will not arise if the intersection of the curve of $\dot{X}_2 = 0$ and the horizontal axis gives the two distinct positive values of X_2, for the line of $\dot{X}_1 = 0$



(a) the curves for $\dot{X}_1 = 0$

(b) the curves for $\dot{X}_2 = 0$

Fig. 7 Alternative isoclines of differential equations



(a) $\beta_1=1,\ 0\leqq\beta_2<1$　(b) $\beta_1>1,\ 1<\beta_2<2$　(c) $0<\beta_1<1,\ 0\leqq\beta_2<1$

Fig. 8 Isosectors for the system including fishing

assures $X_2^*>0$, provided that the stability condition is satisfied. Especially, we know for an intersting case of $0<\beta_2<1$, if the following conditions

$$(1-\beta_2)\overline{X}_2/(2-\beta_2)>D$$

$$a_1/b_1>D$$

$$\beta_1\geqq 1$$

where

$$D=(a_2/(\overline{X}_2(1-\beta_2)n_2k_2U_2^{\alpha_2}))^{1/(\beta_2-2)} \tag{10}$$

are satisfied, there exists the stable solution with positive values.

4 MODELS OF FISHERY RESOURCE UTILIZATION

4. 1 The model for a myopic competitive fisherman

As to the individual rationality of fisherman, it seems quite natural to assume that "the individual fisherman attempts to maximize his net revenue flow at all times, based on the current conditions pertaining to stock abundance, prices, costs, regulations, and so on" (Clark, 1985, p.147). Thus, in our case, the net revenue from the month's fishing are written as

$$\pi=P_1Y_1+P_2Y_2-w(U_1+U_2) \tag{11}$$

where P_1 and P_2 are, respectively, the average price per unit of pelagic and demersal species, w the average wage rate per unit of labour, and Y_1 and Y_2 are the production function for pelagic species and for demersal species, respectively.

According to our hypothesis, for given values of X_1, X_2, P_1, P_2, and w, the individual fisherman maximizes π subject to the upper limit on the monthly labour hours,

$$0\leqq U_1+U_2\leqq\bar{U} \tag{12}$$

using monthly level of efforts $(U_1^*,\ U_2^*)$.

4. 2 A dynamic model for fishery management

For simplicity, assume that all fishermen have identical production functions, Y_1 and Y_2. Then the intraseasonal optimization model for a fishery sector is

$$\text{maximize}\ \pi=\int_0^T(P_1n_1Y_1+P_2N_2Y_2-w(n_1U_1+n_2U_2))\exp(-rt)dt \tag{13}$$

subject to equations (5)−(8), (12), and to

$$X_i(t) \geqq 0 \quad \text{for } 0 \leqq t \leqq T$$
$$X_1(0) = \underline{X}_1,\ X_2(0) = \underline{X}_2$$

in which r is the relevant social rate of discount.

The optimal control model (13) can be solved by using the first-order conditions for optimizing the current-value Hamiltonian, H. H is written as,

$$\begin{aligned} H = {} & d_1X_1^{\beta_1}U_1^{\alpha_1}+d_2X_2^{\beta_2}U_2^{\alpha_2}-d_3U_1-d_4U_2 \\ & +\phi_1(-a_1X_1+b_1X_1X_2-n_1k_1X_1^{\beta_1}U_1^{\alpha_1}) \\ & +\phi_2(a_2X_2(1-X_2/\overline{X}_2)-b_2X_1X_2-n_2k_2X_2^{\beta_2}U_2^{\alpha_2}) \end{aligned}$$

The first-order conditions are written as

(1) $\dot{X}_i = \partial H/\partial \phi_i$

(2) $\dot{\phi}_i = r\phi_i - \partial H/\partial X_i$ for $i = 1, 2$

(3) $U_1(t)$and $U_2(t)$maximize $H(X_1(t), X_2(t), \phi_1(t), \phi_2(t))$ subject to the constraints $U_1(t) \geqq 0$, $U_2(t) \geqq 0$, $X_1(t) \geqq 0$, and $X_2(t) \geqq 0$.

(4) $\phi_i(T) \geqq 0$, $\phi_i(T)X_i(T) = 0$, for $i = 1, 2$.

The sufficient condition (see Arrow & Kürz, 1970) is not satisfied, for the integrand in model (13) and the right-hand sides of equations (5) and (6) are not concave in the variables X_1, X_2, U_1, U_2, taken together. The right-hand side of equation (5) become concave if α_1, $\beta_1 > 1$ and the concavity of the integrand requires α_1, $\beta_1 < 1$, which are quite contradictory. Thus the optimal path of the problem is not discussed in this paper.

If a fishery household consistently maintains the constant labour units of U_1 and U_2, the biomass equations (5) and (6) will reach a stationary state where $\dot{X}_1 = 0$ and $\dot{X}_2 = 0$, provided that stability condition (9) is satisfied. Depending on the values of U_1 and U_2, therefore, there will be a sequence of stationary states. The stationary solution to the dynamic model (13) is derived by choosing the most profitable stationary state at which the long-run profit for a group of fishery households is maximized.

The stationary state(X_1^*, X_2^*) is derived from equations (5) through (8) such that

$$X_1^* = e_2(\overline{X}_2 - X_2^*) - e_3U_2^{\alpha_2}X_2^{\beta_2-1} \tag{14a}$$

$$X_2^* = \tilde{X}_2 + e_4U_1^{\alpha_1}X_1^{\beta_1-1} \tag{14b}$$

where

$$d_1 = P_1n_1k_1,\ d_2 = P_2n_2k_2,\ d_3 = n_1w,\ d_4 = n_2w$$
$$e_1 = \overline{X}_2\tilde{X}_1/(\overline{X}_2-\tilde{X}_2),\ e_2 = \tilde{X}_1/(\overline{X}_2-\tilde{X}_2)$$
$$e_3 = \tilde{X}_1\overline{X}_2n_2k_2/(a_2(\overline{X}_2-\tilde{X}_2)),\ e_4 = \tilde{X}_2n_1k_1/a_1$$

By substituting X_1^* in (14b) into (14a), equations (14a) and (14b) are reduced to the equation $F(X_2^*) = 0$. The root (X_2^*) of the equation $F(X_2^*) = 0$ is, in practice, obtained by such an approximation method as the method of successive approximation (McCracken & Dorn, 1966).

The substitution of the stationary state (X_1^*, X_2^*) into the integrand on the right-hand side of model (13) leads to the following form for the long-run optimization problem for a group of fishery households:

$$\text{maximize } \pi = d_1X_1^{*\beta_1}U_1^{\alpha_1}+d_2X_2^{*\beta_2}-d_3U_1-d_4U_2 \tag{15}$$

subject to equation (12)

where X_1^* and X_2^* are functions of U_1 and U_2 as specified in (14).

The sufficiency condition for the optimum is satisfied if the long-run profit function in problem (15) is a concave function of U_1 and U_2. Unfortunately, the sufficiency condition is difficult to prove. Thus the optimum solution to problem (15) is to be found by numerical analyses.

5 EMPIRICAL ESTIMATES

Catch and production-effort data for empirical estimations of equation (7) are taken from the survey questionnaire conducted by the National Institute for Environmental Studies (NIES)(Kitabatake & Aoki, 1980), the survey period of which was four consecutive months, June to September, of 1978, and in which the questionnaires were sent for self-reporting survey to all of the fishery households engaged in fixed netting, trawling, Isàza-gorohiki ami, and carp culture operations. In this study, a part of the NIES survey data is utilized, which is related to trawl netting. The pond smelt population for each of three consecutive months of 1978, over which catch and effort data is available for trawling, is estimated on catch and effort data taken from source data of the Ibaraki Statistics and Information Office (1980), and on observations made by Hamada (1978) that nearly 90-99% of the pond smelt population is estimated to be taken by fishermen every year. Table 2 shows the estimated monthly population of pond smelt.

On the other hand, catch and production effort data for empirical estimation of equation (8) are taken from the survey questionaire conducted by NIES (Kitabatake *et al.*, 1984), the survey period of which was April 1981 to March 1982, and in which ten experienced fishermen, employing the specific fishing gears of Isazagorobiki ami and trawling, were asked to write down the daily results of fishing operation. The items included in the survey were: (1) the type of fishing gears employed; (2) the fishing efforts involved, such as fishing hours per day; (3) the species composition of the catch; (4) the area of trawling. As to the monthly variation of demersal fish population, we refer to the study done by Onuma *et al.* (1984). Fig. 9 shows the spatial distribution of seven sampling points in Lake Kasumigaura where they collected by the use of a towning net 112 samples during the period from April 1981 to April 1982. Then they investigated the species composition, standing crop and prey organism compositon in the stomachs of the benthic fishes. Table 3 shows a list of fishes caught during the study period. From this table, we know that "Chichibu" (goby) and "Tenagaebi" (freshwater shrimp) are two dominant demersal species. Fig. 10 shows seasonal variation of the carapace length distribution of the prawn for "Tenagaebi" , where Fig. 11 shows seasonal variation of body length distribution of the Chichibu. From these figures, we know that the significant change in age distribution occurs in both species during summer season. Table 4 shows the estimated standing crop of main demersal species. The estimated production function for pond smelt is as follows:

$$\begin{aligned} \ln Y_1 = -9.318 &+ \underset{(3.47)}{0.696} \ln U_1 + \underset{(2.18)}{0.610} \ln F_1 + \underset{(4.68)}{1.096} \ln X_1 \\ & R^2 = 0.5327, \quad N = 57 \qquad (16) \end{aligned}$$

Table 2 Estimated monthly populations of pond smelt

	Lake Kasumigaura			Lake Kitaura (trawling area)		
	July	August	September	July	August	September
Catch per fishing days (kg/d)	6.68	1.46	0.71	59.85	27.39	12.30
Estimated population (kg)	52662	39760	8689	101226	60837	27837

Source: Kitabatake (1982)

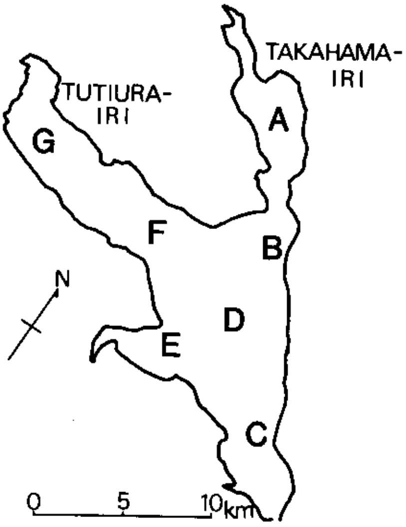


Fig. 9 Spatial distribution of seven sampling points (A-G) in Lake Kasumigaura
Source : Onuma, Takahashi, Suzuki, and Huzitomi (1984)

Table 3 A list of Fishes caught by the towing net from April 1981 to April 1982 in Lake Kasumigaura
F indicate the appearance frequency of each fish in 112 samples

Japanese Common Name	Species Name	F	Number		Weight	
			No.	%	Wet (g)	%
Wakasagi	*Hypomesus transpacificus nipponensis*	59	1558	0.1	2367.7	0.5
Shirauo	*Salangichthys microdon*	31	60	0.0	80.1	0.0
Kinbuna	*Carassius auratus subsp.*	61	788	0.0	17049.6	4.0
Koi	*Cyprinus carpio*	11	35	0.0	427.9	0.1
Motugo	*Pseudorasbora parva*	2	3	0.0	2.5	0.0
Tamoroko	*Gnathopogon elongatus*	2	2	0.0	0.6	0.0
Dojo	*Misgurunus angillicaudatus*	1	1	0.0	7.2	0.0
Ukigori	*Chaenogobius annularis*	80	4345	0.3	6965.0	1.0
Juzukakehaze	*Rhodoniichthys laevis*	66	9408	0.8	4827.3	1.0
Chichibu	*Tridentiger obscurus*	112	348840	28.0	161585.3	33.0
Ashishirohaze	*Aboma lactipes*	112	37714	3.0	20198.9	4.0
Yoshinobori	*Rhinogobius brunneus*	6	8	0.0	1.4	0.0
Bora	*Mugil cephalus*	1	1	0.0	0.6	0.0
Kurumesayori	*Hemiraphus Kurumeus*	25	81	0.0	374.9	0.1
Hakuren	*Hypophthalmichthys molitrix*	1	1	0.0	2.3	0.0
Unagi	*Anguilla Japonica*	1	1	0.0	2.8	0.0
Otamajakushi	*Rana catesbeiana*	8	8	0.0	62.4	0.0
Tenagaebi	*Macroblachium nipponense*	112	842150	68.0	275177.3	56.0
Crayfish	*Procambarus clarkii*	4	4	0.0	65.3	0.0
Total			1245008		489199.2	

Source : Onuma, Takahashi, Suzuki, and Huzitomi (1984)

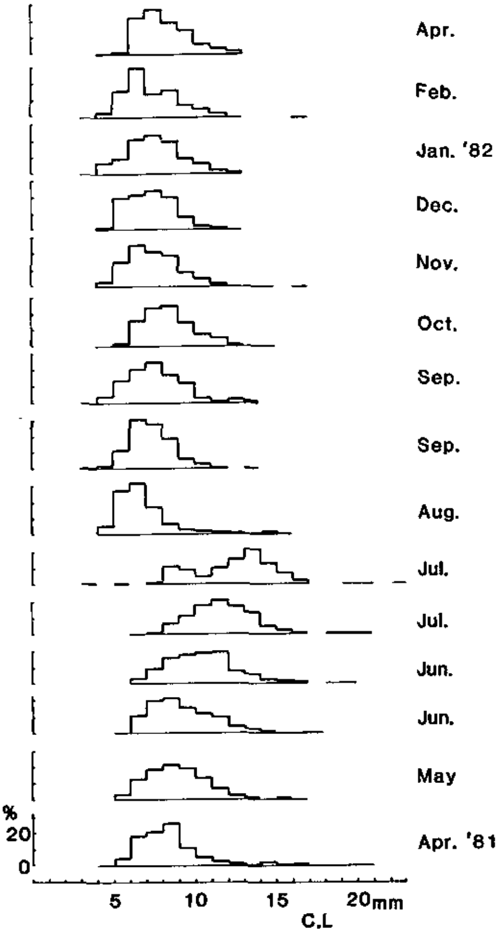


Fig. 10 Seasonal variation of the carapace length distribution of the prawn in Lake Kasumigaura
(Each graduation unit on the vertical axis represents 10%)
Source : Onuma, Takahashi, Suzuki, and Huzitomi (1984)

where the t-values are given in brackets, and

Y_1 is the monthly catch,

U_1 is the monthly fishing labour hour which is the number of persons engaged in operations of capture multiplied by trawling hours,

F_1 is the monthly consumption of diesel oil in terms of the number of fuel cans(200 litres).

Equation (16) is estimated on data taken from Lake Kasumigaura and Lake Kitaura, provided that the difference in topography of fishery grounds between the two sublakes is assumed to have no effects on the technological efficiency in the catch of pond smelt. In the regression analysis, only those samples have been chosen whose catch contain more than 80% in terms of wet weight basis of pond smelt for the estimation of equation (16).

Table 5 compiles the data for estimating the production function for demersal species, where the sample data were excluded, in which some survey items such as the trawling area were

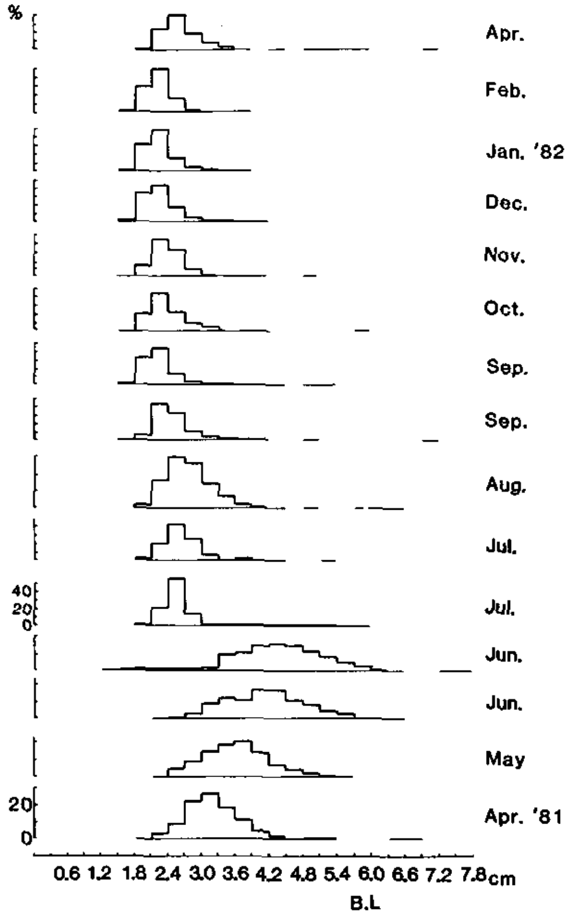


Fig. 11 Body length distribution of the Chichibu in Lake Kasumigaura
(Each graduation unit on the vertical axis represents 10%)
Source : Onuma, Takahashi, Suzuki, and Huzitomi (1984)

unanswered. Sample points listed in the sixth column of Table 5 corresponds to those points in Fig. 9. From Table 5, the production function for demersal species is estimated as follows:

$$\text{Log } Y_2 = -2.3678 - 0.07909\text{Log}Z + 0.63839\text{Log}X_2 + 1.1765\text{Log}U_2$$
$$(-1.129) \qquad (2.841) \qquad (6.166)$$
$$R^2 = 0.7682, \quad N = 20 \qquad (17)$$

where

Y_2 is the catch of demersal species over 20days period in July to October

Z is the catch of pond smelt over the same period

U_2 is the fishing labour hour over the same period

X_2 is the estimated demersal species population over the same period.

In the regression analysis, only those samples have been chosen whose totaol catch contain more than 80% of goby and freshwater shrimp.

Substituting the sample mean data of F_1 and Z into equation (16) and (17) and multiplying

Table 4 Standing crop of main species caught by the towing net in each area of Lake Kasumigaura

(wet weight mg/m^2)

Species		Date	A	B	C	D	E	F	G	Average
Chichibu	'81	Ⅵ−22	345	693	1088	307	287	191	119	433
		Ⅴ−13	333	770	1439	671	413	621	148	628
		−27	332	440	1511	647	715	308	116	581
		Ⅵ−10	113	80	449	622	193	34	92	226
		−24	23	155	514	628	281	109	1	244
		Ⅶ−15	104	334	352	804	131	755	373	408
		−29	1186	2982	1550	1440	754	252	319	1212
		Ⅷ−19	1282	1467	1721	445	344	1184	655	1013
		Ⅸ− 9	1470	1064	369	116	42	710	777	649
		−30	915	935	478	67	137	210	318	437
		Ⅹ−21	1261	1021	1062	602	246	355	326	696
		Ⅺ−25	3369	2017	2160	1890	565	1219	499	1674
		Ⅻ−23	305	1431	457	770	182	438	14	513
	'82	Ⅰ−19	14	578	752	309	44	22	2	245
		Ⅱ−15	17	524	360	651	32	16	3	229
		Ⅳ− 1	3	125	165	35	12	99	52	70
Tenagaebi	'81	Ⅳ−22	599	1882	1053	173	110	255	302	625
		Ⅴ−13	1810	1131	1839	367	401	517	487	936
		−27	2046	932	1433	587	653	339	318	901
		Ⅵ−10	1299	828	503	999	884	199	780	785
		−24	1167	1150	1040	1297	954	792	750	1021
		Ⅶ−15	132	1089	1221	1449	116	724	1498	890
		−29	1432	911	867	200	954	320	1356	863
		Ⅷ−19	1053	1713	1009	1201	941	1166	2441	1361
		Ⅸ− 9	790	6195	2658	1531	2283	4037	3737	3033
		Ⅸ−30	2648	5795	3154	339	3147	2370	1947	2771
		Ⅹ−21	822	699	2664	1470	1189	1860	1373	1439
		Ⅺ−25	699	114	1733	808	1145	665	586	821
		Ⅻ−23	492	208	1091	4495	365	1103	46	1114
	'82	Ⅰ−19	16	1270	776	1238	137	151	36	546
		Ⅱ−15	166	433	781	712	887	80	22	440
		Ⅳ− 1	5	161	158	77	4	102	175	97

Source : Onuma, *et al.* (1984)

Table 5 Data for the estimation of production function of catching demersal species

No. of fisherman	time period	Catch of demersal species (kg)	Catch of pelagic species (kg)	Fishing hour (h)	Sampling points related to trawling area	Estimated demersal species population (kg)
1	7/21−8/10	423.2	10.8	34	B−G	128793.6
	8/11−8/31	94.0	7.0	3	F,G	456647.1
	9/1−9/20	768.8	4.5	15	F,G	776534.9
	9/21−10/10	2358.8	20.1	63	F,G	406253.3
2	7/21−8/10	578.7	18.3	25	B−G	128793.6
	8/11−8/31	1890.2	0.1	33	B−E	370667.3
	9/11−9/20	2291.1	0.1	37	A−G	617471.4
	9/21−10/10	2982.2	2.7	42	B−G	573366.3
3	7/21−8/10	713.0	80.0	22	B−G	128793.6
	8/11−8/31	311.0	11.5	11	B−G	399315.5
	9/1−9/20	2203.0	16.0	29	B−G	657350.5
	9/21−10/10	2212.0	31.8	34	B−G	573366.3
4	7/21−8/10	400.5	18.2	27	B−E	404911.7
	8/11−8/31	1234.5	5.5	27	B−E	370667.3
	9/1−9/20	2568.0	0.1	27	B−E	597783.4
	9/21−10/10	4762.4	14.3	30	B−E	656931.2
5	7/21−8/10	407.9	44.2	30	A−G	128793.6
	8/11−8/31	149.0	11.2	11	A−G	399310.5
	9/1−9/20	1489.5	8.7	37	A−G	657350.5
	9/21−10/10	1262.2	22.4	53	A−G	573366.3

U_2 by 1.5 so as to transform the length of the period into a month, the following production functions are obtained:

$$Y_1 = 1.471 \mathrm{x} 10^{-4} U_1^{0.696} X_1^{1.096} \tag{18}$$

$$Y_2 = 0.00604 U_2^{1.1765} X_2^{0.63839} \tag{19}$$

where U_i are monthly labour hours.

6 WHY DO GOOD OLD DAYS HARDLY RETURN ?

6. 1 The case of a myopic competitive fisherman

For the maximization of net revenue equation (11) subject to the constraint (12), price and cost data must be specified. The price data, $P_1 = 500$ yen per kg and $P_2 = 140$ yen per kg, are estimated by interviewing the fishermen. The wage datum, $w = 653$ yen per labour hour, is estimated from the Ministry of Agriculture, Forestry and Fisheries(1980b).

Fig. 12 and 13 summarize the computation results, in which the total profit curve, the profit curve of catching pelagic specy, and the profit curve of catching demersal species are drawn as the function of U_1+U_2, that of U_1, and that of U_2, respectively. In both figures, the current restriction of monthly operation time ($U = 60$ h)is assumed. The difference in two figures rests on

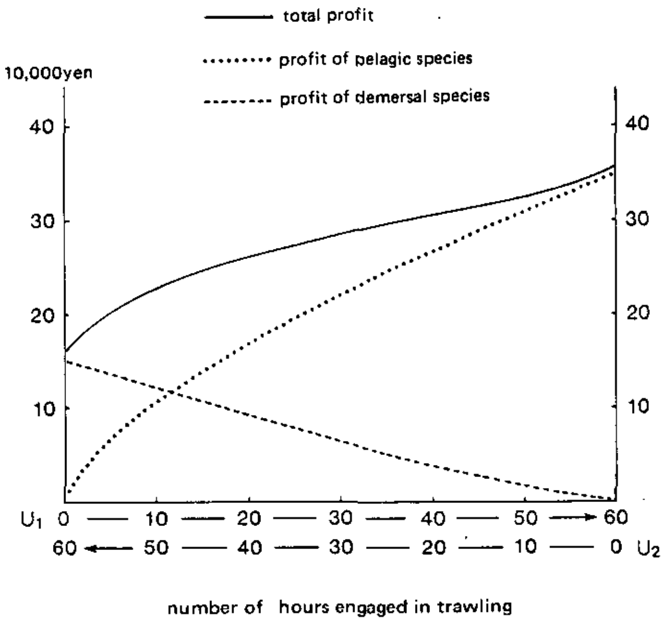


Fig. 12 Profit curves of fisherman
— Case of relative abundancy of pelagic species —

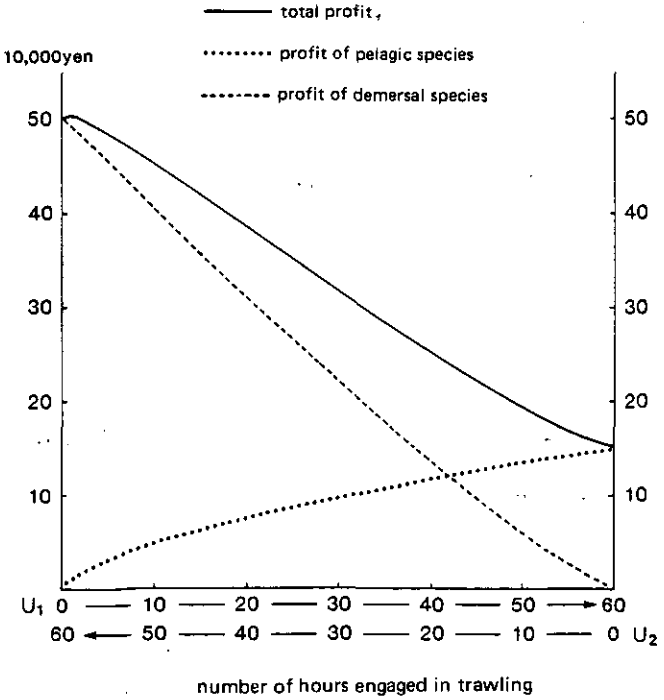


Fig. 13 Profit curves of fisherman
— Case of relative abundacy of demersal species —

the assumed values of X_1 and X_2 in equations (17) and (18). Fig. 12 corresponds to the case of $(X_1, X_2) = (101226, 128793)$, where tha value of X_1 is the estimated pond smelt population in July in Lake Kitaura (see Table 4) and that of X_2 the smallest value of estimated demersal species population in Table 5. Fig. 13 corresponds to the case of $(X_1, X_2) \fallingdotseq (52662, 657350)$, where the value of X_1 is the estimated pond smelt population in Table 5. Thus Fig. 12 respesents the case of relative abundancy of demersal species population such as that of pond smelt population such as that of Lake Kitaura, while Fig. 13 represents the case of rerative abundancy of Lake Kasumigaura.

The optimal peration patterns for individual fisherman are calculated as follows:

For fisherman in Lake Kitaura,

$U_1 = 60$ h, $U_2 = 0$

$Y_1 = 778.04$ kg $Y_2 = 0$ $\pi = 349{,}842$ yen

For fisherman in Lake Kasumigaura,

$U_1 = 1$ hr, $U_2 = 59$ hrs,

$Y_1 = 22.0$ kg $Y_2 = 3788.5$ kg, $\pi = 502{,}207$ yen

These computation results correspond rather well to the survey data listed in Table 1 and Table 4, and imply the two things: 1) the kind of operation pattern as well as the dominance of pelagic species over demersal species, which existed in Lake Kasumigaura under the fishing method of sailing trawling, is hardly realized as long as a myopic competitive fisherman employ diesel-powered trawling, even if the restriction of operation time is imposed; 2) when we consider the difference in reproduction rate between pelagic specy of pond smelt and demersal species, the optimal operation pattern for Lake Kitaura is to decrease the pelagic species population relative to the demersal species population, eventually. Thus, the reason why in Lake Kitaura the relative abundancy of pond smelt population has been observed seems that trawling area is restricted to the northern half of the lake and the topography of the lake is more complex than that of Lake Kasumigaura as shown in Fig. 2. In this sense, the results of public decision to open the whole part of Lake Kitaura to diesel-powered trawling in 1983 would be quite interesting.

6. 2 The case of long-run profit maximization

In this section, the long-run profit optimization problem for a group of fishermen, which is specified in equations (14) and (15), is calculated numerically for the case of Lake Kasumigaura.

Before specifying the parameter values, substituteion of equations (18) and (19) into the differential equations (5) and (6) needs an couple of comments. First, equations (18) and (19) were estimated in terms of monthly or twenty days period data from July to September or to October, Since it has been assumed that there are continous fishing activities, differential equation (5) and (6) should be considered to simulate with the unit time of month (720 hours) a sequence of three months, July to September, for subsequent years. Second, labour hours u_1 and u_1 in equations (18) and (19) are transformed into labour units u_1 and u_2 by dividing by the unit time of 720 hours:

$$Y_1 = 0.0143 u_1^{0.696} X_1^{1.096} \tag{20}$$

$$Y_2 \fallingdotseq 13.89486 u_2^{1.1765} X_2^{0.63839} \tag{21}$$

For numerical computation of the long-run optimization problem, the thirteen constants of the system n_1, n_2, α_1, α_2, β_2, k_1, k_2, β_1, a_1, a_2, $\tilde{X}_1$, $\tilde{X}_2$, and $\bar{X}_2$ should be specified. Six of them, α_1, β_1, α_2, β_2, k_1, k_2 are estimated in equations (20) and (21), whereas n_1 and n_2 are estimated on data taken by the Ministry of Agriculture, Forestry and Fisheries (1980a) such that $n_1 \fallingdotseq n_2 \fallingdotseq 295$. It is assumed that $\tilde{X}_1 = 1125800$kg, $\tilde{X}_2 = 1384000$kg, and $\bar{X}_2 = 12378000$kg, which were derived on the basis of the following two assumptions. First, the stationary state $(\tilde{X}_1, \tilde{X}_2)$ of pelagic and demersal fish populations is assumed to be approximated by the state that existed before 1965 (prior to the introduction of diesel-powered trawling). Specifically, $\tilde{X}_1$ is assumed to be equal to the 10 year (1956 to 1965) average of the pond smelt catch divided by man's exploitation rate of 95%, and $\tilde{X}_2$ to equal the ten year average of the goby and freshwater shrimp catch divided by man's exploitation rate of 70%. Second, the carrying capacity, $\overline{X}_2$, of demersal species is assumed to be the goby and freshwater shrimp catch of 1978 divided by man's exploitation rate of 70%. In the above estimates, the assumed exploitation rates are based on Hamada (1978). The constant a_1 was assumed to be given by $a_1 = 0.167$, a figure based on the report by Kasebayashi and Nakano (1961) that the number of two-year-old fish is very small, on *average being only 0.02-0.4% of the total number of fish. Since differential equation* (5) *and* (6) are assumed to simulate the sequence of three months, July to September, a_1 is estimated to be 1/6. The a_2 is calculated in the following way. First we transformed the variables $\tilde{X}_1$, $\tilde{X}_2$, $\overline{X}_2$, X_1, X_2, by dividing by $\tilde{X}_1 = 1125800$kg, into $\tilde{x}_1$, $\tilde{x}_2$, $\bar{x}_2$, x_1, x_2, respectively. Then the stationary relationship of equation (4) enables us to calculate

$$b_1 = a_1/\tilde{x}_2$$

The value of b_2 is calculated, based on the estimated relationship derived from the data ranging from the year 1956 through 1979 and plotted in Fig. 2 of $X_1 = 1287.6 - 0.169X_2$, where the regression coefficient is utilized to assume the relation $b_1/b_2 = 0.1691$. Finally, the a_2 is calculated to be 0.903 in terms of the stationary relationship of equation (3).

The optimum solution, which satisfies the stability condition of equation (9), to the long-run optimization problem (15) is obtained as follows,

$$U_1^* = 14.4\text{hrs},\ U_2^* = 38.16\text{hrs},\ \pi^* = 380.3 \text{ million yen},$$
$$X_1^* = 1.89\text{t},\ X_2^* = 6133.55\text{t}$$

Since the sum of U_1^* and U_2^* is less than the current restriction, 60 hours, on operation time, this solution is also valid for the case of restricted operation time.

Thus, even if we assume the kind of group rationality represented by the long-run profit maximization problem, the above numerical simulation clearly shows that the good old days do not return in Lake Kasumigaura, provided that the dominant factors explanining the level and *composition of fishery resources* in Lake Kasumigaura are the predator-prey relationships and fishermen's behaviours in trawling, which our postulated model tried to simulate.

7 CONCLUDING REMARKS

In this chapter, the model of fishery resources with a predator-prey relationship and the models of man's utilization of fishery resources are constructed for the case of Lake Kasumigaura, and which are based on observational data and research findings. As to the latter models simulating the behavioural characteristics of fisherman, two models are used, which are the model for a myopic competitive fisherman, and the model for a long-run profit maximizing fisherman. The individual production function of pelagic species (pond smelt) and of demersal species (Chichibu and Tenagaebi) are estimated, for the fishing method of diesel-powered trawling.

Both the myopic model and the long-run profit maximization model insist that the kind of operation pattern as well as the dominance of pelagic species over demersal species, which existed in Lake Kasumigaura under the fishing method of sailing trawling, is hardly realized as long as fihsherman employs diesel- powered trawling. This is mainly due to the estimated form of *production function in which both the procuction function of pelagic specy and that of demersal* species depend on the respective population level. This stock dependency of production efficiency in trawling operation forces to bend down the curves of X_1 against X_2 in figures 6-8 for which the growth rate of demersal species population becomes zero, and which forces the stationary population level of demersal species in the biomass equations including the effects of fishing to be greater than that in the biomass equations without the effects of fishing as shown in equation (12).

Thus, even if the current biomass structures of Lake Kasumigaura is known to be unfavourable for preventing the eutrophication of lake, we have to keep in mind in devising. management measures that the existing biomass structures reflect individual fisherman's economically rational response to given technological, economic, and ecological conditions pertaining to fishery resources in Lake Kasumigaura.

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This chapter reports one of the works executed in a research group on the structural situations and the functional role of fish in the ecosystem of Lake Kasumigaura, in the special research project concerning the eutrophication of Lake Kasumigaura. The research group consisted of scientists from three different institutions, NIES, the Freshwater Fisheries Experiment Station, Ibaraki Prefecture, and the Ocean Research Institute, University of Tokyo. This chapter would not have been written without the valuable experiences obtained in this research group, and, especially, without the fishermen's cooperation in our research activities. Thus, the author expresses his sincere thanks to the fishery cooperatives in Lake Kasumigaura and to the members of the research group, especially, to Dr. S. Kasuga, Mr. J. Takahashi, and Professor S. Tanaka. The author also wishes to express his thanks to Professor Jiro Kondo, former Director of NIES, who initiated my interest in the integration of ecological and economic models.

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Chapter 7

Socio-Economic Analysis of National Park Regions

S. Nishioka

ABSTRACT

Under the area designation system of Japanese National Park, conflict between private property right and nature conservation policy has a profound influences on National Park management. Almost all bottlenecks preventing the sound National Park management originate from zoing system, as are exampled in the following Chapters. To review the general view of this situation nationwides, managerial figures like financial indices, stability of population, allocation of labour power of municipalities in National Park regions (MNP) were surveyed in this Chapter. Depopulation seemed to be the most influential factor to introduce destructive developments into National Park region. To guide those depopulated municipalities into conservation type management, some public policy should be required that is based upon the characteristics of each National Park. The grouping of National Park shown in this study is based on categorization by conserving potentialities and value of the natural resources may suggest the neccesity of this kind of policy.

1 INTRODUCTION

1. 1 National Park in Japan

The natural environment in Japan is conserved under the jurisdiction of the legal institutions described in Fig. 1. The covering range of each law is schematicaly indicated here. The Environment Agency is in charge of conserving nature in country side mainly, and urban park and agricultural field and foresty are in the hands of Ministry of Construction and Ministry of Agriclture, Forest and Fishery, respectively.

Two laws were enacted to preserve natural land areas. The Nature Conservation Law was enacted in 1973, the first half of which prescribes the basic ideology of Japanese nature conservation policy. This law aims to protect more wilder areas than those areas protected by Natural Parks Law indicated below. Under this law, wilderness areas; nature conservation areas and prefectural nature conservation areas are designated. Especially, five wilderness area of totally 5,631 hectares were designated until March 31, 1985.

The Natural Parks Law designates 27 National Parks (2.02 million hectares, 5.4% of the area of the Country), 54 Quasi-National Parks (1.29 million hectares, 3.4% of the area of the Country), 298 Prefectural Nature Parks (2.01 million hectares, 5.3% of the total area of the Country). Fig. 2 shows the location of National Parks. Those designation of Nature Parks are based on the following criteria:

National Park: The place of greatest natural scenic beauty, worthy of the names of the typical scenic beauty of Japan.

Quasi-National Park: The place of great natural scenic beauty next to the National Park

Prefectural Nature Park: The place of fine scenic beauty designated by the prefecture.

The aims of this law is to conserve scenic areas, to promote their utilization, and to contribute the health, recreation and culture of people. These aims differ from that of Nature

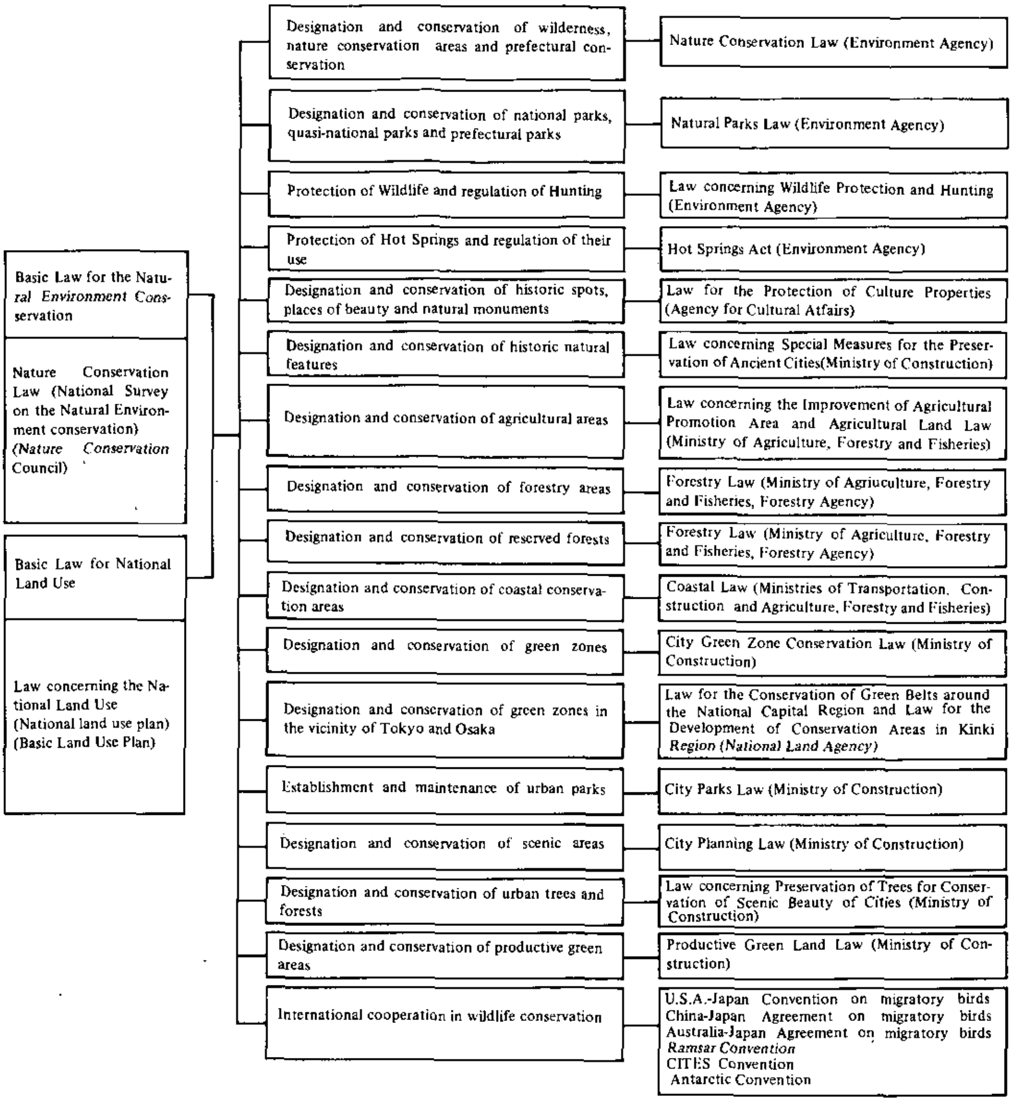


Fig. 1 Legal institution of Nature Conservation (JEA, 1985)

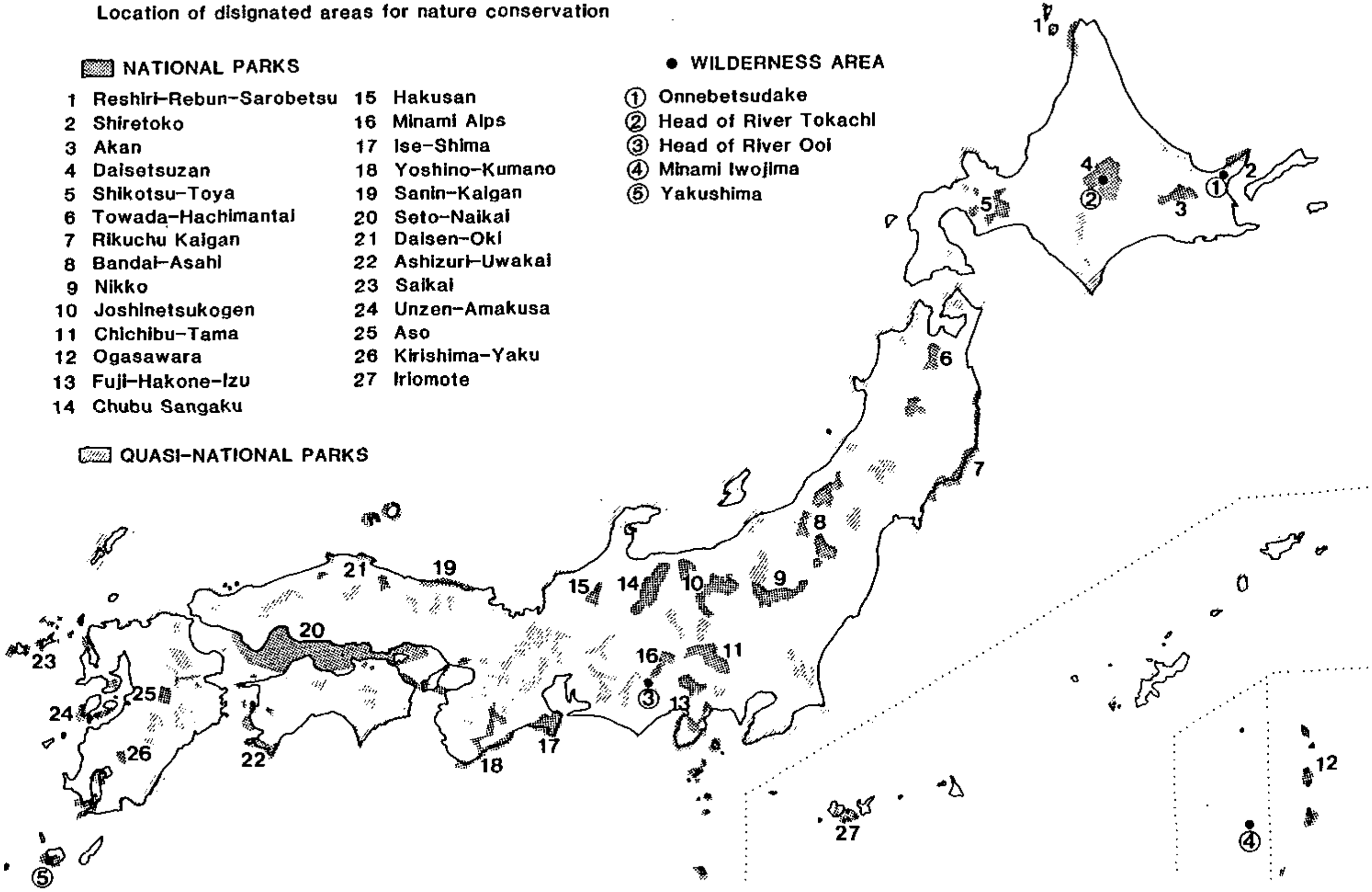


Fig. 2 Location of designated areas for Nature Conservation(JEA, 1985)

Conservation Law.

1. 2 Area zoning system of National Park

Natural Parks in Japan bases upon "Zoning" on private or on public owned area. When Director General of Environment Agency designate the National Park areas, he must seek the opinion of the Council on Nature Conservation (Natural Parks Law, Article 10). Furthermore, in designating a park area and in executing the park work, Article 3 of Natural Parks Law requires the State that the proprietary right, mining rights and other property rights shall be respected, and that the adjustment between the land development and other public interest shall be taken into consideration. This zoning system were established in 1931 when the National Parks Law, the law preceding the Natural Parks Law, was enacted first. At that time there were some controversies whether to adopt state owner system modelling after United States or to introduce zoing system as in Europian countries. The government selected zoning system in consideration of Japanese land use situation, and applied the principle of "restriction of land owners' right for the sake of public use" after German law. By means of zoing system the government can restrict land owners property right.

The zoned area is classified into several class categories (Fig. 3), and the sets of regulation on owners' activities are posed to each class. In such a situation, always happen the conflicts between preservation and use.

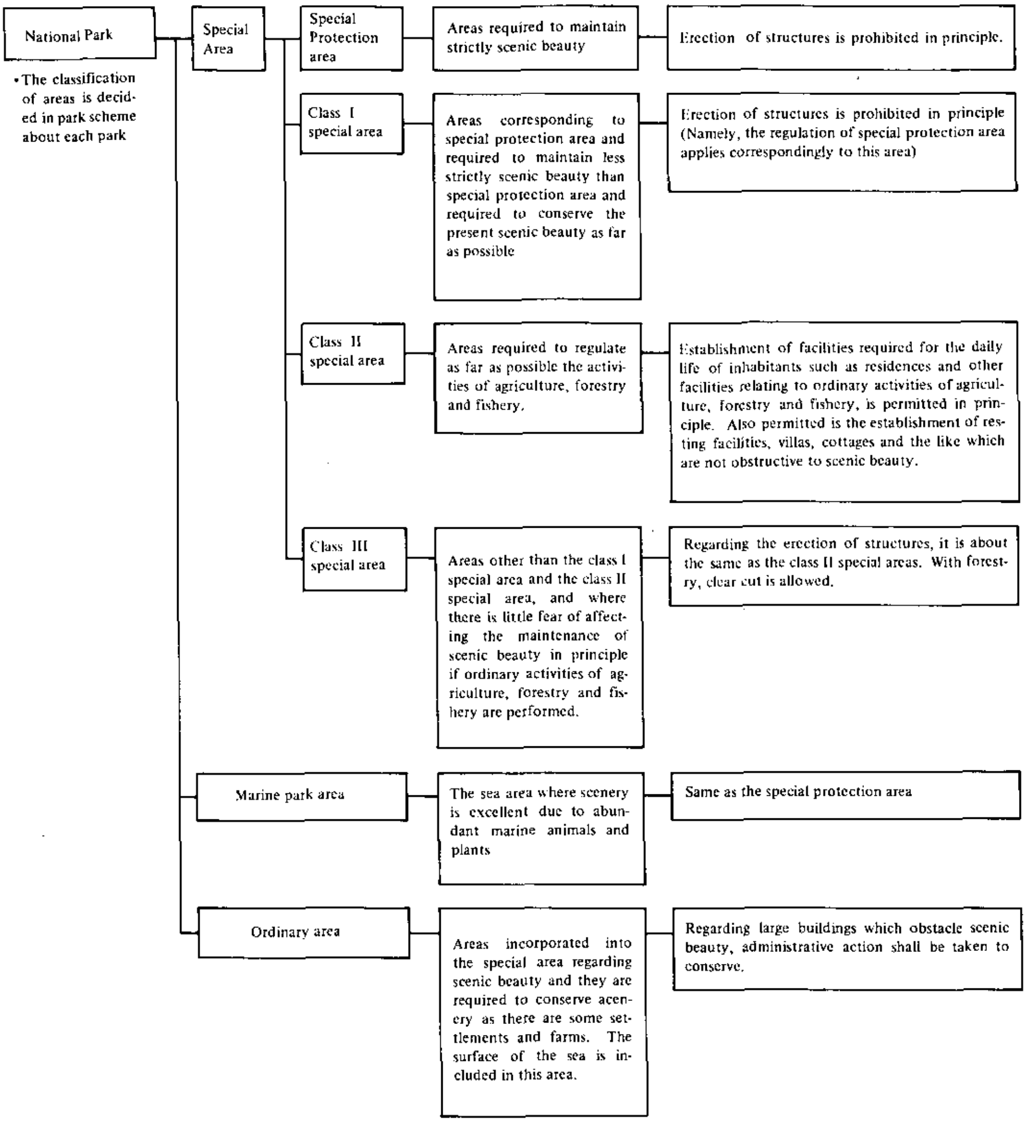
1. 3 Conflicts under zoning system

The number of visitors to the National Parks in past 20 years has increased to keep pace with economic prosperity of Japan and also with enlargement of designated Park areas (Fig. 4), but in recent five yars or so it is becoming flat. Land owners' efforts to attract more visitors drive them to develop new recreational areas such as skiing ground or country cottage. And their efforts to stem the flow-out of young people to the urban areas introduce energy facilities, industries and construction works like large scale forest roads. In late 1960's many protest movements arosed against such developments, and almost all of those movements were overwhelmed by the big wave of "Rebuilding Plan of Japanese Islands". In 1971 Environment Agency of Japan was instituted, and backed by nationwide protests it succeeded to check and modify some of the development plans, but still to the radical protestants it was far from final goals, as exampled by the case of Minami Alps large scale forest road (see Chap. 9). One of the reasons that lead those movements unsucceeded was that the protestants paid little considerations on the living bases of land owners in the area. To keep sound management of National Park, it is inevitable to step into the economic foundations of land owners, and to search the compatible way with their bases of living—that was one of the lessons learned from 1970's idealistic nature conservation movements.

2 BACKGROUNDS AND PURPOSE OF THIS STUDY

In recent years some controversies on National Park Policy, which situated at the summit of nature conservation policies of Japan, arose in relation of the construction of large scale forest road, the construction of energy facilities, the development of cottage lands and skiing grounds and so on. Through those debates, two questions on current National Park policy were raised; one in its planning stage, another in its operational stage.

The first point in issue is, comparing with other administrative plannings such as energy demand-supply plan, the National Park policy has no definite basic long-range plan to cope with them, so that little adjustments is available in low matured stage of planning. For instance, in case of assessment of hydro-electric plant, power companies propose only one specified location as



National Park

- The classification of areas is decided in park scheme about each park

Special Area	Special Protection area	Areas required to maintain strictly scenic beauty	Erection of structures is prohibited in principle.
	Class I special area	Areas corresponding to special protection area and required to maintain less strictly scenic beauty than special protection area and required to conserve the present scenic beauty as far as possible	Erection of structures is prohibited in principle (Namely, the regulation of special protection area applies correspondingly to this area)
	Class II special area	Areas required to regulate as far as possible the activities of agriculture, forestry and fishery.	Establishment of facilities required for the daily life of inhabitants such as residences and other facilities relating to ordinary activities of agriculture, forestry and fishery, is permitted in principle. Also permitted is the establishment of resting facilities, villas, cottages and the like which are not obstructive to scenic beauty.
	Class III special area	Areas other than the class I special area and the class II special area, and where there is little fear of affecting the maintenance of scenic beauty in principle if ordinary activities of agriculture, forestry and fishery are performed.	Regarding the erection of structures, it is about the same as the class II special areas. With forestry, clear cut is allowed.
Marine park area		The sea area where scenery is excellent due to abundant marine animals and plants	Same as the special protection area
Ordinary area		Areas incorporated into the special area regarding scenic beauty and they are required to conserve acenery as there are some settlements and farms. The surface of the sea is included in this area.	Regarding large buildings which obstacle scenic beauty, administrative action shall be taken to conserve.

Fig. 3 Classification of areas in National Park, and regulation of activities(JEA, 1985)

available place without offering any alternatives, and trifle latiudes remain in the hands of National Park administratives' side to change the proposed plan, such as changes of color of facilities, restriction to the height of buildings, replacement of the approaching road, etc.

The environmental assessments of hydro-electric power facilities along one river stream are done one by one, which overlooks the combined total impacts of facilites built adjascently along one river. Also there are no established methods to assess the impacts caused by overpresence of large facilites like nuclear plants planned in Natural Parks.

One of the reasons that nature coservation side can not reject those develompent plan in its early stages results from the lack of nation-wide evaluation of National Parks. In addition to lack of legal procedure to check the development plans, insufficient finacial supports for compensation for private land owners prevent ideal zoning procedure, because land owners are reluctant to be restricted by the designation on their lands as National Park and want to hold free-hand right to utilize their lands. Governmental investment on the National Park area is not so enough to guide or control the land owners (Table 1).

The second point of debate is financial vulnerability of municipalities in the National Parks area which causes conflicts between development and conservation in allocating their land resources to secure income.

Under federal ownership system as in United States, the management of National Park is fully in the hands of federal government. But under the zoning system as in Japan and in some European countries, the actural management of National Park region and the decision of allocating resources in the area, are mainly left in the hands of municipalities in designated areas, so that either in planning stage or operational left stage Central Government can not neglect intensions of those municipalities.

In this Chapter, we discuss how those vulnerabilities distribute among municipalities in National Park regions, and how they influence the sound management of National Park, with cases on Hase and Ashiyasu Villages in Minami Alps National Park, and Shari Town in Shiretoko National Park.

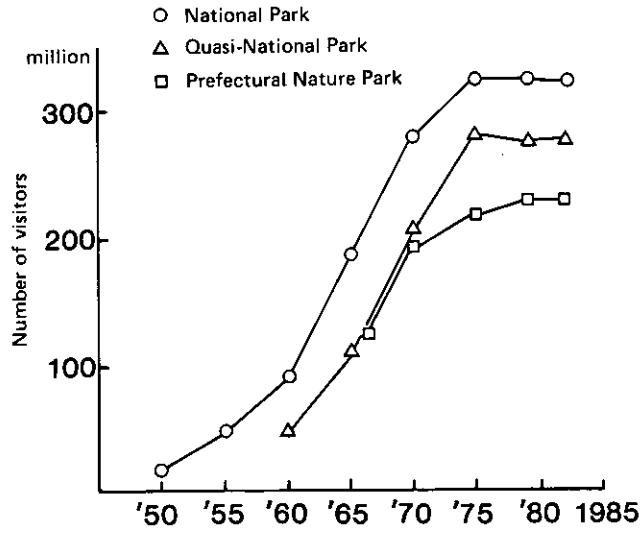


Fig. 4 Number of visitors to Natural Parks

Table 1 Investment on Natural Park

unit: 100 milion yen

	FY 1975	FY 1982
Environment Agency	6	10
local governments	200	255
Central Government (except JEA)	32	175
Private sectors	183	380
Total	421	820

Source : Nature Conservation Bureau, JEA (1984)

3 ANALYSIS OF MANAGERIAL BASIS OF NATIONAL PARK

3. 1 Framework of this study

Framework of this study is shown in Fig. 5. Municipalities allocate their inherent resources such as land, forest, labour and etc. to realize their managerial goals. One of the most important goals to be attained is to retain their population at least as it is, especially to keep young people within their village. Another goal of importance is to strengthen employment opportunities and tax bases such as property tax gained from energy facilities. The attainment of these goals can be measured by managerial indices like increasing of population, income per capita, ratio of younger generations in total population, financial index and etc.

On the other hand, governmental administratives of National Park have different goals from those of municipalities to protect outstanding landscapes and promote utilization of them (Natural Parks Law, Article 1). Degrees of natural vegetation, observed number of precious species, number of visitors are some examples of the managerial indices that represent the sound National Park management.

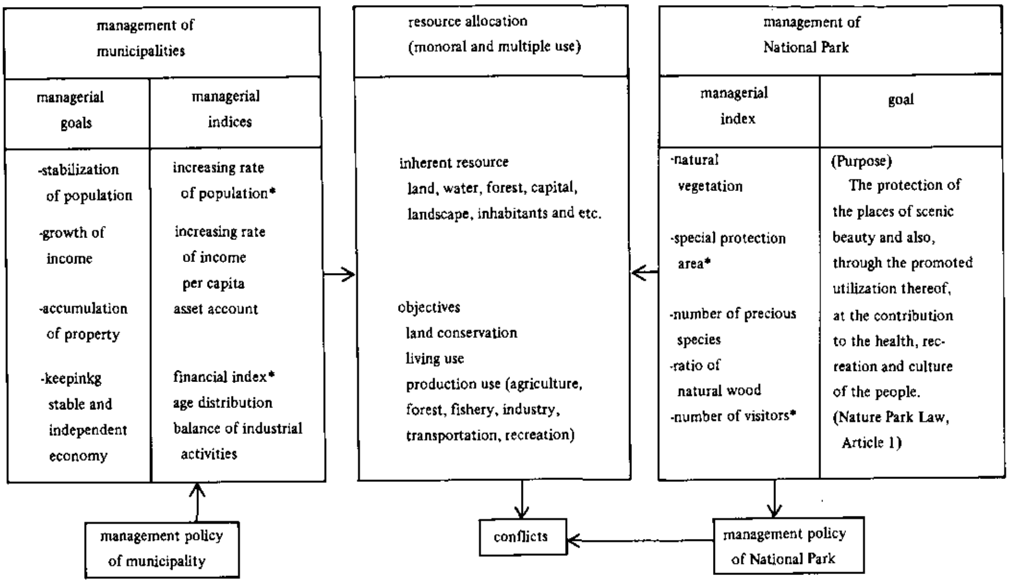
The managerial goals of municipality and National Park sometimes conflict and sometimes cooperate with each other. Analysis of the effect of resource allocation to management of the area shown in the central part of Fig. 5 is the core of this study, but here in this report we discuss first through the general view of managerial situations of National Parks in Japan along this framework.

3. 2 Data and method used for analysis

Out of 531 municipalities that are located in the area designated as the National Parks, 188 municipalities are selected as MNPs (Municipalities with tight relation to National Park). Those MNPs have less than 30,000 populations each, more that 20% National Park area in its administrative district, and so the influences of National Park designation seem to be consequented to their socio-economic situations.

Three municipalities which are to be focused in the following chapters have been selected as cases. The town of Shari in Shiretoko National Park is introduced in chapter 8 as one of the birth places of National Trust movement in Japan, and the villages of Hase and Ashiyasu in Minami Alps National Park are mentioned in chapter 9 in relation to the construction of large scale forest road.

Financial data of those MNPs were taken from "Financial Status of Municipalities" edited by the Ministry of Home Affairs. Data related to National Park were offered by Nature Conservation Bureau of Japan Environment Agency. Table 2 explains the outline of employed data.



* indices used in this study

Fig. 5 Framework of study – analysis of managerial basis of municipalities in Natironal Park

By quantifying those managerial items, which are shown with asterisk in the frame shown in Fig. 5, MNPs are characterized in comparison with those of municipalities of the same scale. Adding to this managerial data of the municiplities, managerial indices of National Parks such as the ratio of special preserving area and number of visitors were used to classify various National Parks as the basis of operating National Park policy more effectively.

4 RESULTS OF ANALYSES AND DISCUSSIONS

4. 1 Socio-economic Situations of MNPs

Total population living in MNP amounts to 1.6 millions and those living within the National Park designated regions are 0.34 millions. Those figures are rather small comparing to the total population of Japanese 120 millions, but about 2/3 of National Park regions were maintained by those small number of people. Comparing those MNPs' managerial data with that of municipalities of same scale (with population less than 30,000), MNPs have less population on the average and show distinct depopulating trends (Table 3).

Generally speaking, MNPs have small percentage of population in primary industry, which have been decreasing and provided to secondary and tertiary industries. Those were farmers, fishermen and woodmen that take care of natural resources while they are capturing products from fields, seas and forests. So this decrease of primary industry population sometimes means the abandonment of managerial responsibility of natural resources in the area. Ashiyasu Village have only 6 woodmens families to maintain its 148 square kilo-meters land, Oguchi and Yoshinodani

Table 2 Analysis of Managerial Basis of Municipalities in National Parks

—Data Sources

1. National Park data—Nature Conservation Bureau(1975): Survey of Municipalities in National Park. Natural Parks Planning Division
2. Population and Financial Indices—Ministry of Home Affairs(1975, 1980): Financial Status of Municipalities(1975, 1980)

—Municipalities Investigated

1. located in National Park designated regions
2. population under 30,000
3. *More than 20% of the area is occupied by National Park area*
   (The designation of National Park influenced the municipality's production and living basis considerably)

	number	population in municipality (thousand)	population in N.P. area (thousand)
municipalities investigated	188	1,600	340
all municipalities located in National Park area	531	11,000	

* The National Park area contained in the municipalities investigated covers 67.5% of the total National Park area(20,200km^2)

Villages has less than 0.7 persons of primary industry per their one square kilometer lands.

The ratio of the population engaged in primary industry to the total population of municipalities' area, which repressents the effort to preserve natural resources, goes below one person per square kilometer of MNPs area. In Ashiyasu Village, this figure goes down to 0.31, second to Oguchi Village in Hakusan National Park.

The ratio of population in secondary industry are high in Minami Alps National Park region (Table 3), and the most part of this figure is occupied by construction labour like in road constructions and in repairing works of it, with small factory labours at an electric company recently introduced.

The tertiary industry means service industry like in hotels and leasure facilities. Many rich municipalities that possess excellent natural resources for sight-seeing can allocate large portion of their population to those services.

Financial indices of MNPs show rather better position than other municipalities averagely, but the range of their distribution is so wide as shown in Fig. 6. There are some rich municipalities with precious natural resources like hot springs, outstanding landscapes or historical places, which benefit their financial positions so much and lift the average figure of the total MNPs. Many MNPs including Ashiyasu and Hase, have financial indices less than 0.2. This means that only 20% of financial sources are internally supplied, such as residential tax and property tax, and that they heavily depend on governmental subsidies.

4. 2 Relations among managerial indices

After investigating those indices, the relations among those managerial goals are examined. Fig. 6 shows the correlation between the increasing rate of population and the financial index, the two most important indices of municipalities' management. No clear relation can be seen between

Table 3 Managerial Basis of Municipalities in National Park

		all municipalites (population under 30,000)	municipalities in National Park		Ashiyasu V. (Minami Alaps)		Hase V. (Minami Alps)		Shari T. (Shiretoko)	
			1975	1980	1975	1980	1975	1980	1975	1980
Total Number		2,554	189	188						
Population (av.)		10,059	8,264	8,069	699	637	2,911	2,697	15,996	15,795
increasing rate of population	%/y	1.89	−4.58	−3.26	−16.7	−8.9	−11.9	−7.4	−4.1	−1.3
ratio of population in primary industry	%	36.3	40.8	32.1	16.7	7.1	47.7	30.5	38.6	32.3
ratio of population in secondary industry	%	28.3	21.9	25.3	57.2	55.2	29.3	36.8	22.9	22.2
ratio of population in tertiary industry	%	35.2	36.0	41.1	25.8	37.7	23.0	32.7	38.5	45.4
financial index	%	0.310	0.290	0.321	0.100	0.108	0.190	0.199	0.340	0.384
Ratio of National Park area to total municipal area					72.8		21.9		31.7	
Ratio of special protection Area and Class I special Area to total National Park Area					0.35 (Yamanashi, Nagano)				0.6	

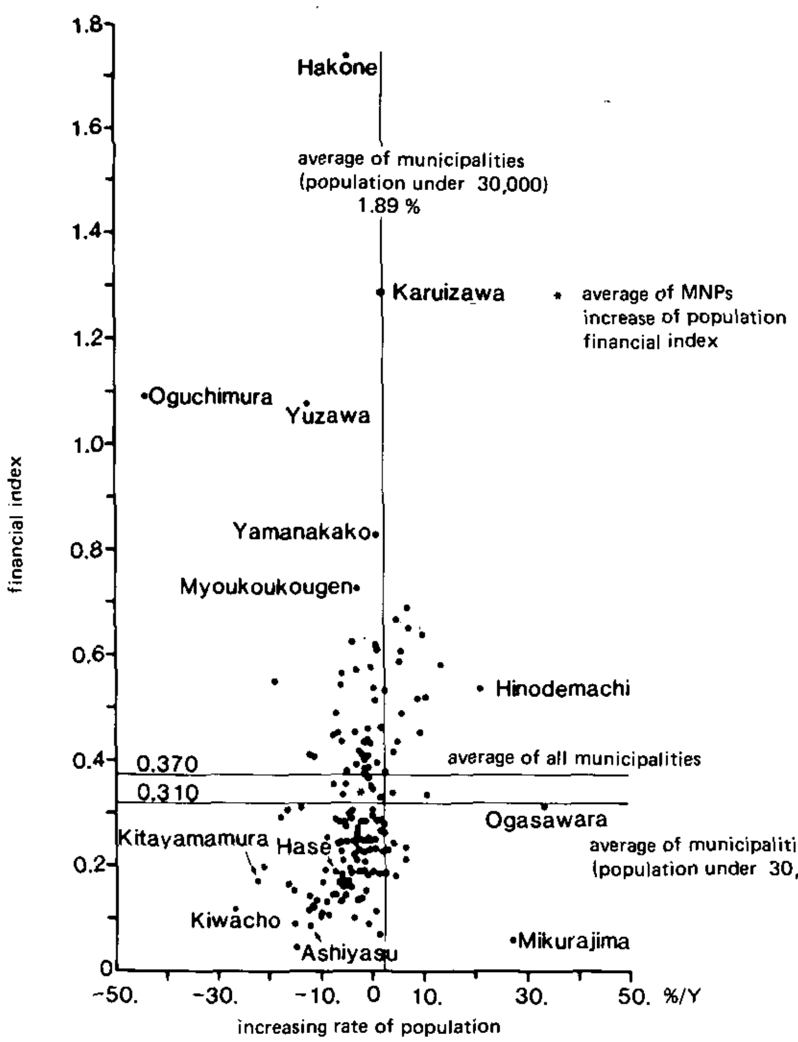


Fig. 6 Relation between increasing rate of population and financial state of municipalities in National Park (1980)

these two. This means that even if the financial situation improved much, it has little power to prevent depopulation by itself.

Industrial structure, the allocation of human resources of MNPs, has some relationship with their financial situations. There are few MNPs that have large primary industry population and high financial index value at the same time. The portion of secondary industry has little correlation with financial situation. There are some wealthy municipalities with large portion of tertiary industries. Excellent natural resources seem to contribute much to maintain the good financial positions in those municipalities.

Concluding from those figures, the managerial basis of MNPs should be regarded fragile, and depopulation phenomena originate most serious contradictions between nature conservation and regional development. Excluding some wealthy MNPs like Hakone, Karuizawa, Yuzawa and Yamanaka-ko which have in their area famous villa lands or hot springs, many other MNPs tend to be obliged to introduce labour absorbing industries to prevent flow out of younger population, which sometimes result in the destructions of natural resources. To those financially fragile municipalities, construction works such as large scale forest road or power generation plants offers the remedy of immediate effect, accompanying moreover with huge property tax income in case of power plant. But so far, those efforts to attain the double goals, which are the prevention of flow out of population and the improvement of financial situation, seem unsucessful. Although many MNPs achieved the improvement of their financial situations, difficulties still remain in keeping the stable populations.

In case of Ashiyasu Village, the ratio of the number of people engaged in the secondary industry shares more than half, and most of them are absorbed in the road construction work and transportation work, who are mainly flowed out from forestry work. In Hase Village, newly extended road served the convenience of commuting to neighbourhood towns, Takatoh and Ina, which acceralated flow out, and changes its industrial structure to secondary industry, remaning their forest land unmaintained.

Contrast to these two villages in Minami Alps National Park, the town of Shari in Shiretoko National Park is rich in fishery and agricultural lands that prevent rapid flow out of population.

Those considerations imply that natural resources in itself, even though precious as designated as National Park, are not sufficient to nourish the municipality's management base, and suggest the necessity of some subsidiary policies to MNPs in order to maintain the national natural treasures, in addition to the designation.

4. 3 Grouping of National Parks by their managerial specifications

The investigations into managerial situation of MNPs lead to the discussions of the strategic policy to strengthen the managerial basis of them. From the analysis above, MNPs can be classified into two. Self sustainable municipalities with rich natural resources in its area, and insustainable ones who need some aids to direct their efforts into nature conservation. To the former no subsidiary needed, but rather some precautions should be paid to prevent overuse of their rich resources. To the latter some effective guidance and subsidy may be necessary to promote conservation activites compatible with managerial goals of MNPs. To rationalize this priority policy, some classification or grouping of National Parks should be proposed to find out the degrees of necessity of govermental support.

National Parks in Japan can be grouped as in Table 4, using managerial indices of MNPs and National Parks. One axis defining this grouping represents the type of resources inherent to National Park, which can be determined in consideration to the size of special preserving area, number of the visitors and so on. The types of inherent resources distribute from a conservation type to one end, which has large special preserving area and less visitors, and a recreational type to the other end that has contrary characteristics to the former.

Another axis difining the grouping is the potentialities of nature conservation each National Park has. This axis is ranked by the managerial indices of the MNPs constituting the National Parks. As concluded before, those municipalities that have poor managerial indices tend to use their natural resources for the development purpose, especially in the way incompatible with nature conservation. So this axis are scaled qualitatively according to the potential strength of MNPs in the region.

National Parks were grouped roughly into five distinct categories by those two axes. Famous sight-seeing places and National Parks near Metropolitan region, like Fuji Hakone, Aso and Chichibu, are grouped into the recreational type. Towada, Bandai, Kirishima are grouped into the conservation type with high preserving potentialites. The group of conserving type with little preserving potentialities are consisted of National Parks in Hokkaido, Minami Alps and

Table 4 Grouping of National Parks

		Nature Preservation Potential High		Low
		Towada		Daisetsu, Akan
	Conservation	Bandai	Shiretoko	Rishiri, Hakusan
	Type	Kirishima	Cyubu-sangaku	Minami-Alps
Type of			Nikkou, San-in, Daisen	
Asset			Saikai, Jou-Shinetsu	
	Recreational		Chichibu	
	Type		Shikotsu, Fuji-Hakone	
			Aso, Unzen	

Hakusan. This group may be the National Parks that need some carefully planned park management plan to keep their natural resources environmentally sound.

ACKNOWLEDGEMENTS

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Chapter 8

Economic Analysis of Demand Behaviour Related to Nature Conservation

Y. Kitabatake and S. Nishioka

ABSTRACT

One representative "National Trust" movement in Japan is the one started by the town of Shari since 1977 in order to purchase and replant some of the deforested land in Shiretoko Natrional Park, which were originally cultivated and later deserted by farm settlers and some of which were bought by land developers. As of March 1984, 18409 persons donated the total sum of 187 million yen and 473 ha of the land has been purchased by the town. In this paper, economic aspects of donor's concern for nature conservation are analyzed, theoretically and empirically. On theoretical sides, we made a qualitative analysis of current consumption vs nature conservation in terms of an optimal control type model, and then reviewed the concept of option value. On empirical sides, data on people's concern for nature conservation are gathred in two routes, one is a questionaire to donors of Siretoko environment fund campaign, the other data related to actual behaviour which are the number of visits by donors of different regions to the reforestation festival held every year by the town of Shari. Based on these data, economic rationale for giving donation to Shiretoko environment fund campaign are clarified within the theoretical framework.

1 INTRODUCTION

As explained in chapter 7, natural parks including national parks in Japan are designated without affecting the private ownership of the lands in question and consequently in most natural park areas multple use of lands dominate, where use includes outdoor recreation, wood production, watershed, wildlife, and in situ energy or mineral production. Currently 5.138 million ha of lands are disignated as natural parks, where 2.015 million ha are as national parks, 1.127 million ha as quasi-national parks, and 1.996 million ha as prefectural natural parks. 78% (4.030 million ha) of the natural park areas are forest lands.

Under this situation, several local governments as well as private organization initiate the movement similar to the National Trust in UK to invite contributions on a nationwide basis to purchase and conserve privately owned places of natural beauty. For a comprehensive report on the repressentative National Trust movements in Japan, see Nishioka and Kitabatake (1986). One representative national environment fund campaign is the campaign started by the town of Shari in Hokkaido Prefecture in order to purchase and replant all of the deforested land in Shiretoko National Park, which were originally cultivated and later deserted by farm settlers and some of which were bought by land developers.

Fig. 1 shows changes in the number of donors Shiretoko environment fund campaign. As of March 1984, 18409 persons donated the total sum of 186.9 million yen, where the unit of donations is 8000 yen and roughly corresponds to the price of 100m^2 of land in Shiretoko.

In this chapter, we deal with economic analysis of the following two problems:

Problems 1 - As Fig. 1 shows, the monthly curve for the number of donors rises sharply in Novemver 1980. Kitabatake & Nishioka (1984) clarified through the questionaire analysis that this sharp rise was caused by the article written in Japan's leading newspaper of Asahi Shimbun,

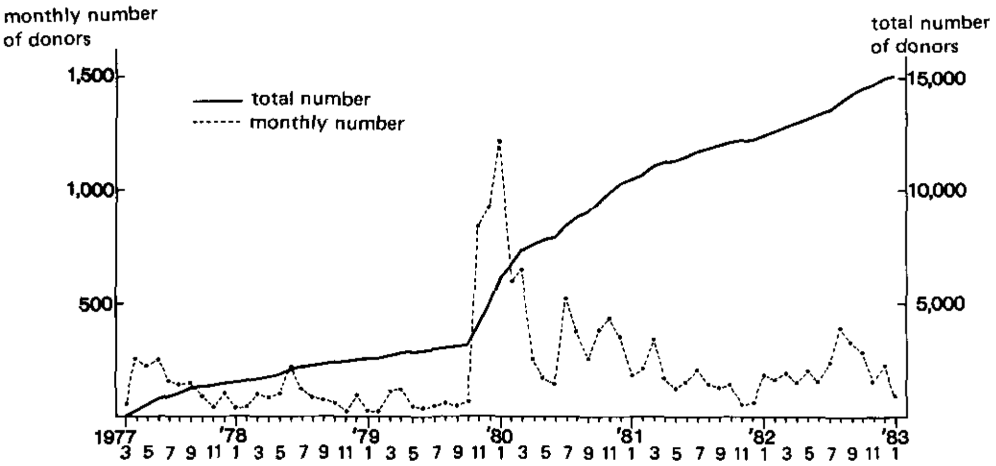


Fig. 1 Changes in the number of donors to Shiretoko environment fund campaign
Source: Documents compiled by the town of Shari, Hokkaido Prefecture

which introduced Shiretoko environment fund campaign in such a way that the public's sense of crisis was raised at the loss of precious and splendid nature. Is it possible to build an economic model which explains the people's sharp response to the information given by the newspaper ?

Problem 2 - The legal status of the National Trust in UK was clearly determined by the National Trust Act of 1907. The most important part of the Act was "the clause which enabled the Trust to declare its land and buildings inalienable, which meant that they could not be sold or given away. This was an important safeguard to those who were thinking of giving the Trust the right to regulate public access to the aquired properties by such means as charging entrance fee. In case of Shiretoko environment fund campaign, the lands purchased by people's donation are owned by the town of Shari, and there is currently no law which assures those lands will be kept forever by the town. Furthrmore in case of Shiretoko campaign, there is a free rider problem. The land in question is part of Shiretoko National Park and there is no means to regulate public access to it. However, there are some aspects of a club-like commodity. The benefits, which are given to every donor, include (1) free copy of news reporting the progress of campaign and published once a year, (2) the right of participation to the reforestation festival held once a year in which every participant, if he can go to Shiretoko on a specified day, may plant a tree on the acquired land, and (3) the possible psychological satisfaction gained by looking at his name plate at the site. Under these situations, is there any economic rationale to donate the amount of 8000 yen to acquire the private land for recovering the original wilderness-type landscape ?

2 DYNAMICS OF ARTIFICIAL RESTORATION OF NATURAL ENVIRONMENT

In this section, we try to answer Problem 1, based on a simple dynamic model. The private lands in question which Shiretoko environment fund campaign has tried to buy up and replant are originally cultivated lands and are somewhat amenable to artificial restoration. That is, the case we deal with here is not a type of the undisturbed natural environments that are prized for their unusual scenic features and fragile ecosystems.

We assume an economy of n households with identical, strictly concave, additive utility function

$$U(C(t), S(t)) = u^1(C(t)) + u^2(S(t)) \tag{1}$$

The instantaneous commodity units consumed is C(t) and the state of natural environment is represented by S(t), where the following properties of the utility function are assumed:

$$u_c^1 = du^1/dC > 0, \quad u_{cc}^1 < 0, \quad \lim_{c\to 0} u_c^1 = +\infty$$
$$u_s^2 > 0, \quad u_{ss}^2 < 0, \quad 0 < \lim_{S\to 0} u_s^2 < \infty \tag{2}$$

Here we assume that zero consumption case is intolerable to the households, while the level of natural environment is allowed to take zero value.

The stock of natural environment, S, accumulates at a gross rate of $an(\bar{Y}\text{-}C(t))$, and decumulates at a percentage rate b applied to S, where $\bar{Y}$ is a given income and a and b are given constants. Hence, the net accumulated rate of natural environment (forested land) is

$$dS/dt = an(\bar{Y} - C(t)) - bS(t) \tag{3}$$

The social welfare problem is to choose C(t) so as to maximize

$$\int_0^\infty \exp(-\lambda t)(u^1(C) + u^2(S))dt$$
$$\text{subject to (3) and } 0 < C(t) \leqq \bar{Y} \tag{4}$$

where λ is the continous rate of discount. The current value Lagrangian for the autonomous system ($\bar{Y}$ fixed in time) is

$$L = u^1(C) + u^2(S) + p(an(\bar{Y} - C) - bS) + q(\bar{Y} - C) \tag{5}$$

where the state variable (S), control variable (C), and auxiliary variables (p, q) are undersrood to be functions of time. The Maximum Principle (Arrow & Kürz, 1970, p.48-49) states that there exists an auxiliary variable p and Lagrangian multiplier q such that L is maximized with respect to C and such that p satisfies the differential equation and the transversality condition

$$dp/dt = (\lambda + b)p - u_s^2 \tag{6}$$

$$\lim_{t\to\infty} \exp(-\lambda t)p(t) \geqq 0, \quad \lim_{t\to\infty} \exp(-\lambda t)p(t)S(t) = 0 \tag{7}$$

Necessary conditions for maximization of L are

$$u_c^1 - anp - q = 0 \tag{8}$$

$$q(\bar{Y} - C) = 0, \quad \bar{Y} - C \geqq 0, \quad q \geqq 0 \tag{9}$$

From (8) and (9), the following relationships hold:

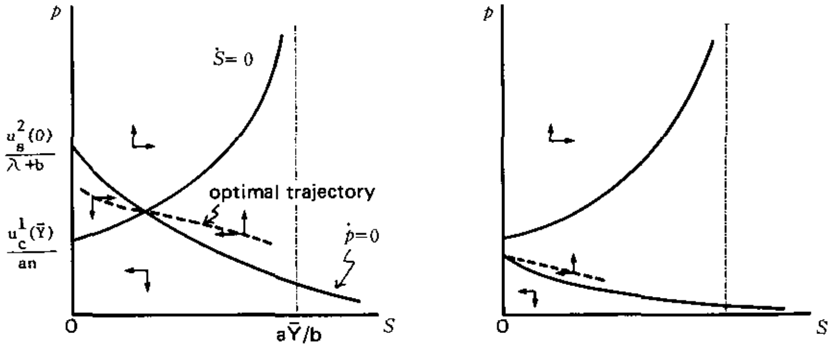
for the case of no saving($\bar{Y} = C$),

$$q = u_c^1 - anp \geqq 0 \quad \text{or} \quad p \leqq u_c^1(\bar{Y})/an \tag{10}$$

for the positive amount of saving ($\bar{Y} > C > 0$),

$$q = u_c^1(C) - anp = 0 \quad \text{or} \quad C \text{ is a function of } p. \tag{11}$$

Therefore the motion of the system in the phase space (p, S) is governed by the differential equations,



(a) Internal solution

(b) Boundary solution

Fig. 2 A phase diagram for the path of solution

$$dS/dt = \begin{cases} an(\bar{Y}-C(p))-bS & \text{for} \quad \bar{Y}>C>0 \quad (12) \\ -bS & \text{for} \quad Y=C \quad (13) \end{cases}$$

$$dp/dt = (\lambda+b)p-u_s^2 \tag{14}$$

Fig. 2 shows a phase diagram for the path of solutions to the differential equations (12)−(14), where $\dot{S}=0$ curve coincides with the vertical axis for the value of p specified in (10) which corresponds to the case of no saving. Figure 2a corresponds to the case of

$$anu_s^2(0)/(\lambda+b)>u_c^1(\bar{Y}) \tag{15}$$

and Fig. 2b to the case of

$$anu_s^2(0)/(\lambda+b)\leqq u_c^1(\bar{Y}) \tag{16}$$

In each case, for a given initial value of $S(t_o)$, it can be shown that there exists $p(t_o)$ such that there is an optimal path through $(p(t_o), S(t_o))$ converging to (p^*, S^*) which is a saddle-point.

Equation (15) is a social cost-benefit rule for stationary policy and specifies the positive stock level of recovered natural environment. The RHS of (15) indicates the change in the current flow of utility if the rate of comsumption at $C=\bar{Y}$ is decreased marginally. Along at stationary policy the marginal decrease, ΔC, of consumption implies that the stock of natural environment increase from zero level to an ΔC for all future time. Thus the LHS of (15) is the present value of the flow of additional ecvironmental benefit. Thus if the marginal utility of consumption at no saving situation is less than the present value of marginal utility of recovered environment, then the long-run stationary level of natural environment take a positive value.

The following summarizes the results of a comparative statical analysis of the steady state with respect to changes in the values of given constants:

$$dS^*/d\bar{Y}>0 \tag{17}$$
$$dS^*/db<0 \tag{18}$$
$$dS^*/da>0 \tag{19}$$
$$dS^*/d\lambda<0 \tag{20}$$

The increase in a given income level ($\bar{Y}$) or in the recovery-saving ratio (a) leads to an increase in the stationary level of natural environment, while the increase in destruction rate (b) or in the rate of discount (λ) leads to a decrease in the stationary level of S^*.

Based on the above discussions, we may present three answers to Problem 1. One answer is related to the introduction of Shiretoko environment fund campaign by Asahi Newspaper. That is, we may judge that newspaper's introduction was effective in such a sence that readers of the newpaper judged that an effectiveness of donation (a) was high in the case of Shiretoko. The second answer is related to our questionaire analysis showing that donors are concerned more with the state of natural environment in their children's days than with that for immediate future. This implies that λ is small for many donors. The third answer is related to equations (15) and (17). That is, we may suspect that donors either judged that the marginal benefit of natural environment stock is greater than the marginal utility of consumption, or that their income become large enough for (15) to hold.

3 OPTION PRICE AND EXPECTED CONSUMER SURPLUS

In this section we try to answer Problem 2, based on the concept of potion value and an empirical estimate of expected consumer surplus.

3. 1 Theoretical background

The concept of option value was first introduced by Weisbrod (1964). Freeman Ⅲ (1984) summarizes what Weisbrod argued as follows: "an individual who was unsure of whether he would visit a site such as a national park would be willing to pay a sum in excess of his expected consumer surplus to guarantee that the site would be available. "The sum which an individual is willing to pay in excess of his expected consumer surplus (E(CS)) is defined to be option value (OV). That is,

$$OV = OP-(E(CS))$$

where OP is "the maximum sum the individual would be willing to pay to preserve the option to visit the site before his own demand uncertainty was resolved.

We assume, as Smith (1983) did, that individual preferences can be described by two states: (a) demanding the services of the site with u_1 ( ); and (b) not demanding the services of the site with u_2 ( ). Each state's utility function has two arguments, income (Y) and a variable indicating access to the site's services, with d implying the services are available and $\bar{d}$ implying they are not. We further assume that the prices of goods, which are complementary or substitute to the site's services, and income ($\bar{Y}$) are constant across states and in the future. If the latter assumptions are relaxed, we face a number of scenarios concerning the sign of option value, as discussed by Freeman Ⅲ (1984).

Table 1 summarizes the alternative levels of utility achieved in each of four cases. If we specify the probablity that an individual demand the site's services as π_1, and the probability of not demanding as π_2, then the expected utilities for the states defined by the availability and the lack of availability of the site are, respectively, defined to be

$$U_{\mathrm{I}}(Y) = \pi_1 u_1(Y, d) + \pi_2 u_2(Y, d)$$
$$U_{\mathrm{II}}(Y) = \pi_1 u_1(Y, \bar{d}) + \pi_2 u_2(Y, \bar{d})$$

We also assume that each u_i ( ) is concave and the site's service is a normal good. Then we may naturally imagine that the relationship $U_{\mathrm{I}}(Y) > U_{\mathrm{II}}(Y)$ holds. With this framework, the option price is defined to be that amount which would assure the following equality

$$U_{\mathrm{II}}(Y) = U_{\mathrm{I}}(Y-OP) = \pi_1 u_1(Y-OP, d) + \pi_2 u_2(Y-OP, d) \qquad (21)$$

The payment of OP corresponds, in our case, to the donation to Shiretoko environment fund

Table 1 Alternative perspectives on utility

Supply / Demand		(Uncertainty about future availability) Site is	
		not available	available
(Uncertainty about future demand) An individual	do demand	$u_1(Y, \bar{d})$	$u_1(Y, d)$
	do not demand	$u_2(Y, \bar{d})$	$u_2(Y, d)$

campaign, which is assumed to assure the preservation of land for park services.

As an alternative to the payment of OP, we may suppose the purchase of a club-like commodity. That is, anybody who wants to see the site to be preserved for park services can join a club such as "Live the Shiretoko's Recovered Nature" club, where each club member, before entering the club, agrees to pay a ceutain amount when he visits the iste. Furthermote, we may assume that only those persons who either paid OP or is a member of the club are allowed to *enjoy the iste's services. The each club member will pay up to his consumer surplus which enables* the following equality to hold

$$U_{II}(Y) = \pi_1 u_1(Y-CS_1,\ d) + \pi_2 u_2(Y-CS_2,\ d)$$
$$= \pi_1 u_1(Y-CS_1, d) + \pi_2 u_2(Y, d) \qquad (22)$$

, where $CS_2 = 0$, for his consumer surplus is zero if he does not visit the site. In the following section we try to estimate CS_1. We then compare OP(= 8000 yen) with the expected consumer surplus of $\pi_1 CS_1$.

3. 2 Empirical estimate of consumer surplus

As explained in Problem 2, there are some aspects of a club-like commodity in Shiretoko environment fund cmpaign. One is the reforestation festival held every year at the site. The town of Shari has recorded the list of participants to the festival for past six years. In this section we try *to make an estimate of actual consumer surplus by the Hotelling-Clawson-Knetsch travel cost* method (Clawson & Knetsch, 1966; Knetsch & Davis, 1966).

In order to apply the travel cost method, the whole country is divided into nine regions at varying distances from the town of Shari. The cost of visiting the town, P, is calculated in terms of transportation cost (a round trip). The number of visits (X) to the reforestation festival per unit of donor population (Z), in this case per hundred donor population, is then plotted in Fig. 3. The following is the statistically estimated relationship:

$$\ln P = 4.4530 - 0.73311 \ln(X/Z) \qquad (23)$$
$$(40.374) \quad (-8.062)$$

$$N = 9, \quad R^2 = 0.9182$$

We can now proceed to construct the demand curve for the site by relating added cost (ΔP) to total attendance (X'), based on (23). That is, for each region with a given value of Z and P, we first calculate X' by substituting ($P + \Delta P$) for P in (23). Fig. 4 plots estimated number of visits (X') at differeent added cost level (ΔP). The estimated number of 982 visits (persons) for zero added cost is somehow close to the actual number of 913 persons.

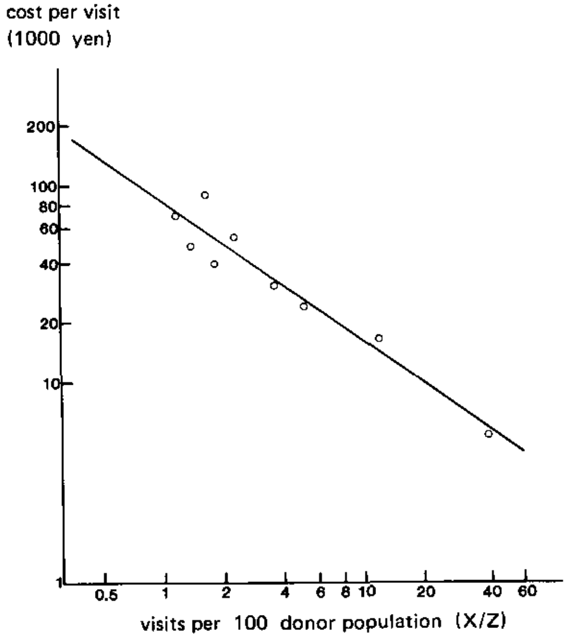


Fig. 3 Demand curve for whole recreation experience for the site of Shiretoko environment fund campaign

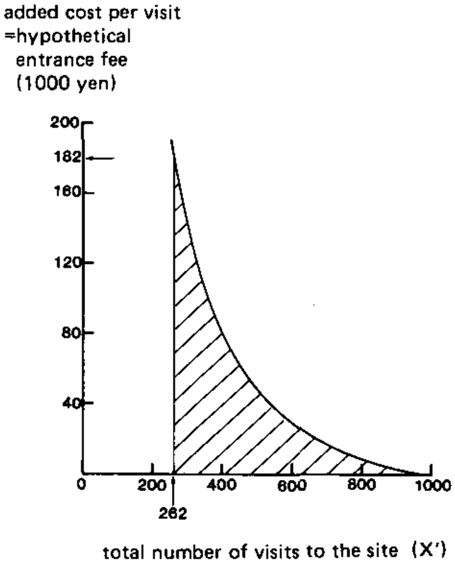


Fig. 4 Estimated effect of added cost on the total visits to the site

If we assume that participants to the festival from town of Shari which amounts to 262 persons, will visits the site regardless of the amount of added cost, we may calculate consumer surplus for participants from nine regions. The estimated consumer surplus is about 31.3 million yen for 651(913-262) persons, or about 48 thousands yen per person. Thus the expected consumer surplus can be written as

$$E(CS) = \text{prob. (one visit)} \times 48080 + \text{prob. (two visits)} \times 2 \times 48080 + \cdots$$

Our questionaire analysis shows that about 2.7% of the sampled donors (1395) outside the town of Shari have participated the reforestation festivals held in past six years and that average of the sampled donors is about 40 years old. If we assume that donors outside the town of Shari may participate a festival at most once in 30 years (40-70 years old), then the probability of one visit, on the average, becomes 13. 6%. Under these conditions, option value becomes positive as follows,

$$\begin{aligned} OV &= PO - E(CS) \\ &= 8000 - 0.136 \times 48080 = 1451 > 0 \end{aligned}$$

Thus we may answer Problem 2, based on section 3. 1 and our rough estimate of expected consumer surplus. That is, there is an economic rationale behind people's donation to Shiretoko envirnonment fund campaign. Donors have shown, on their own foot, that they were willing to pay an option price of 8000 yen in order to eliminate the uncertainty about the site's availability for park services. This statement does not deny the possibility that to some donors the donation of 8000 yen has already been recovered or is a recoverable amount just by participating the reforestation festival once or twice.

4 CONCLUDING REMARKS

In this paper, we tried to clarify an economic rationale hidden behind the people's donation to a representative "National Trust" movement in Japan. In so doing, we hypothesized as to the donors's behaviour that the speed of recovery of a natural environment in question and the uncertainty of supply of national park services in good condition are the significant factors affecting the economic decision of whether to donate 8000 yen or not by giving up the current consumption.

Theoretical as well as empirical analysis done in this chapter presented the results complying with our hypothesis. Thus we may clarify an economic rationale as flollows: donors, who are more or less concerned with the welfare of distant future, judged that the effectiveness of donation in recovering the willderness beauty is high in the case of Shiretoko environment fund campaign and that the amount of donation is not an expensive one such that it can be recoverable just by participating a reforestation festival held once a year.

This hypothetical conclusion is, of course, based on the assumptions that a donor's income and prices of such goods as transport services are constant in the future and that donors are homogeneous. Furthermore our analysis does not consider explicitly the relationship between an ecological value of the site in question and people's donation behaviour. Particularly we did not compare the case of Shiretoko with the similar case of national environment fund campaign such as Tenjinsaki environment fund campaigen from the viwpoint of varying degree of the site's ecological value. Therefore, there are at least two further tasks to be done in order to clarify people's demand behaviour related to nature conservation. One is a theoretical study which integrates the dynamics of physico-ecological characteristis of natural environment and the uncertain aspects of people's demand behaviour as well as of the future availability of the environment. The other is an empirical study which clarifies the relationships between the qualitative aspects of nature conservation and the intensity of people's demand such as the willingness to pay for nature conservation.

ACKNOWLEDGEMENTS

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Chapter 9

Economic Analysis of a Large-Scale Multipurpose Forest Road in Minami Alps National Park

Y. Kitabatake

ABSTRACT

One of the representative dispute cases of nature conservation vs development in Japan is reviewed and the economic aspects of the case is analysed in terms of the historical data on development benefits. Furthermore the chapter makes clear the characteristics and future tasks of the Japanese national park system as the area designation system.

1 THE CASE AND ITS CHARACTERISTICS

Minami Alps National Park, which was established in 1964, consists of about 35783 ha of land, located in western Yamanashi Prefecture and eastern Nagano Prefecture. 50.1% of the land is the lands belonging to prefectures, 39.4% of the land is the national forest lands, and the remaining 10.5% of the land is privately owned. The delination of park boundary line reflects a bitter debate between the officials in charge of national park service and the private as well as public land owners. The boundary line does not coincide with the uniform geographic region known as the Minami Alps Mountains, especially in the southern parts of the park which are mostly owned by a large private logging company. Minami Alps National Park is a predominantly forested area and provides magnificent mountain scenery, the presence of rare species and willd animals, and the opportunity for recreation in a wild setting.

The management of national park consists of 1) preparation of a park scheme, in consultation with the prefectural governments and the related Governmental agencies, 2) project review and parmit system, 3) provision of facilities so as to increase park use, and 4) guidance services for users. The park scheme for Minami Alps National Park classifies the total park lands into four categories as shown in Table 1. Approximately a half of the park lands is classified as Class Ⅲ Special Area in which ordinary forestry activities as well as public works projects are permitted.

In June of 1968, Japan Forest Development Corporation(JFDC) applied to the Ministry of Welfare for a permit to build a large-scale multipurpose forest road across the Minami Alps National Park land in the expectation of 1) the reduction of traffic distance between two regions of Kōfu and Ina, 2) the development of undeveloped forest areas, 3) the enhancement of primary products distribution in the two regions, and 4) the increase in recreation activities. Notice of the application attracted a little national attention at that time. In December of 1968, the head of the national park division of the Ministry of Welfare approved with the condition: JFDC should present a detailed construction plan for the area designated as Class I Special Area, before the construction of that section is undertaken. The approved road construction project consists of two parts which are the improvement of the existing forest road and the construction of a new road, where the newly constructed part is shown in Fig. 1 in terms of two arrowheads.

"A rather rapid change in societal attitudes towards pollution occured in the late sixties"

Table 1 Classified areas in the Minami Alps National Park

Land use category	Overall intensity guideline	Areas (ha)	(%)
Special protection area	no site modification	9266.4	25.9
Special area			
Class Ⅰ	in principle, no site modification	5443.8	15.2
Class Ⅱ	little site modification such as selection cutting of less than 30%	4082.3	11.4
Class Ⅲ	moderte site modification (agricultural and forestry use are usually permitted)	16990.0	47.5
total		35782.5	100.0

(OECD, 1977, p. 16). Gresser *et al.* (1981, p. 29) wrote on this point as follows: "by 1970 citizens from all walks of life were challenging the morality of environmentally destructive industrial developments. Against economic growth they now weighed new concerns such as the sanctity of human life, individual dignity, and the integrity of local communities. "The Environment Agency was newly established in 1971, to which the National Park Division was transfered as the Nature Conservation Bureau from the Ministry of Welfare.

In June of 1974, JFDC presented to the Environment Agency the detailed construction plan for a permit to build a road across area designated as Class I Special Area of the national park. It has passed not so long time since the 1973 Stockholm Conference on the Human Environment. This time, notice of the presentation soon attracted national attention and several conservation groups opposed strongly to the construction of that section of the road, where the majority of local residents supported the construction. In recognizing the importance of the issue, the Director General of the Environment Agency asked in December of 1974 the Nature Conservation Council, which is the principal advisory organ to the agency's director general in the field of nature conservation, to comment on the issue.

A significant factor to which the change of public attitudes toward the road construction projects in the forest area can be ascribed, is the increase in imported forest products on domestic market. Fig. 2 shows the aggregate price index for "all-lumber" and "all commodities, " where the latter index reflects the general price level in the economy. Several distinct trends in lumber prices are evident in Fig. 2. From 1952 through 1961 lumber price index exhibited far greater variation than the general price level, where the domestic foresters were the dominant supplier of lumber products. The ratio of imported wood to the total wood supply increased gradually from the value of 17.5% in 1961, and to the value of 29% in 1965. More than a half of the total supply was shared by the imported wood in 1969 and the imported wood increased to 69% in 1979 (Akai, 1980).

In reference to this decrease in the share of domestic products in the total wood supply and to the construction of Chuo free way connecting Tokyo and Nagoya, the expected benefits of the construction project have been modified from the 1967 verson (JFDC, 1967) to the 1974 version (JFDC, 1974) as follows: 1) improvement of the forest management conditions of the area, 2)

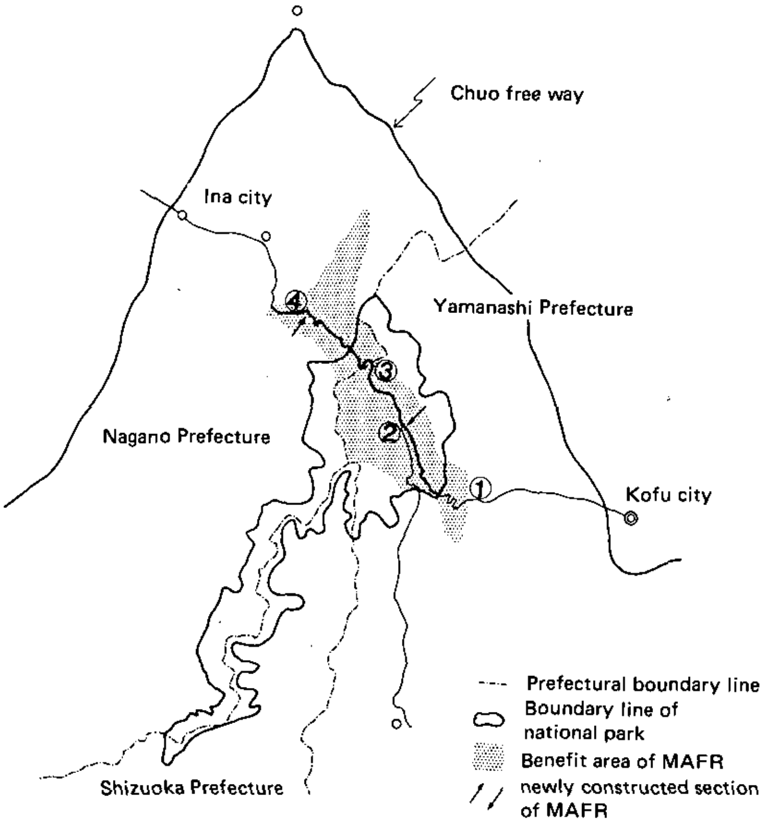

Fig. 1 Location of Minami Alps National Park

strengthening the time-honored economic and social relationships between Kōfu region and Ina region, and 3) improvement of the economic and social conditions of the local communities which have been depressed economically and socially due mainly to their isolated location.

People can go from the city of Kōfu to the city of Ina in about one hour via Chuo free way (see Fig. 1), which is much shorter than the time consumed in the Minami Alps Forest Road (MAFR). This is the reason why the first item in the 1967 version disappeared from the 1974 version. The items 2 and 3 in the 1967 version are modified into items 1 and 2 in the 1974 version, respectively. Change of the item from the development of undeveloped forest areas to the improvement of forest management conditions is related to a general problem of Japan's forest management, that is the existence of vast area, 9.90 million ha (41% of the total forest land), of artificial regeneration forest lands. Fig. 3 shows the age-class distributon of artificial regeneration forest lands, where one age-class corresponds to one to five years in terms of the age of trees. About one half (4.75 million ha) of artificially regenerated forest lands needs the intermediate treatmeht such as cleaning, weeding and thinnings.

The debate in the Nature Conservation Council continued more than three years, since December 1974. Meantime, the Forestry Agency which is the competent authority of JFDC presented the revised version of the construction plan in which the width of road is reduced from 4 meters to 3.5 meters. The Nature Conservation Council presented in April of 1978 the report to

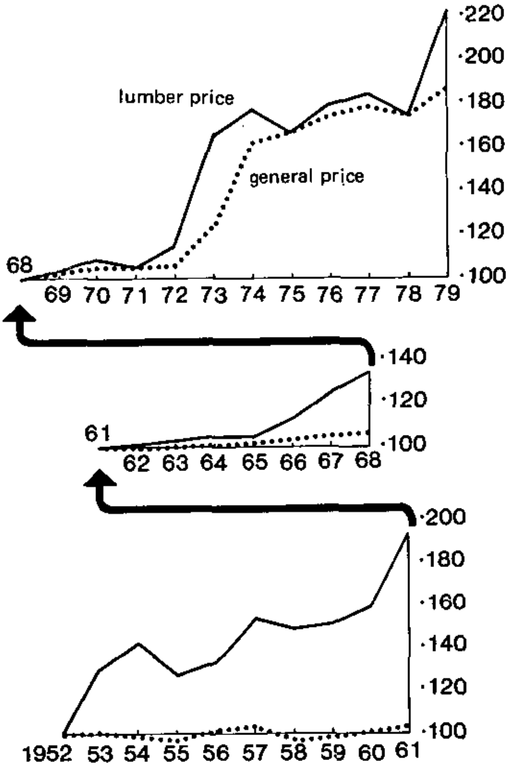

Fig. 2 Long-term trend of lumber price index

Source: .Nihon Ringyo Chosa kai (1981). Forest and Forestry in Japan.

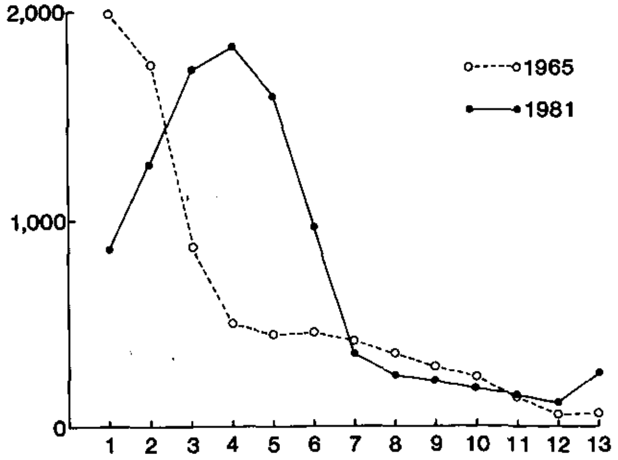

Fig. 3 Age-class distribution of artificial regeneration forest in Japan

Source: Nihon Keizai Chosa Kyogikai, Japan's Forest and Forestry Policy, 1982 (in Japanese)for the year of 1965, and the documents compiled by Japan Forestry Agency for the year of 1981.

the Director General of the Environment Agency, in which the following opinions were expressed: 1) if the construction plan of MAFR had been presented not 10 years ago but now, the general opinion of the council members would be negative to the approval of the construction plan; 2) in recognizing the fact that 97% of the total length (56.5km) of the road has already been built, the Council could not reach an unanimous opinion; 3) one opinion favored the construction with the condition that the strengthenment of nature conservation measures were taken in order to prevent the possible damages to the natural environments after the opening of MAFR; 4) the other opinion opposed to the construction of the remaining portion of MAFR for the reason that the benefit expected from the completion of MAFR was considered far less than the damage expected to the natural value of the area affected by the construction.

In August of 1978, the Director General of the Environment Agency approved the completion of MAFR with the several conditions. The most important condition was the prohibition of private automobiles during whole recreational season for the newly constructed portion of MAFR which is indicated by two arrowheads in Fig. 1.

2 ECONOMIC ANALYSIS OF MAFR

2. 1 Revenue and cost data

The total benefit area of MAFR as shown in Fig. 1 consists of 21700 ha. The benefit area included in Minami Alps National Park is 12900 ha, where 83% of 12900 ha is Yamanashi Prefectural Forest abbreviated as YPF, and the remaining area is the National Forest. In this chapter an economic analysis of MAFR is executed in terms of the data related to YPF. The reason for the exclusion of the areas included in Nagano Prefecture is related to the construction history of MAFR. As indicated before, the ②-④ portion of MAFR in Figure 1 was newly built since 1968, where the ①-② portion called the Norogawa Forest Road (abbreviated as NFR) was constructed over the time period of 1952 and 1961. Thus the various kinds of forest related activites such as logging, recreation, and erocion control have been observed in YPF, since the early stage of the construction of NFR.

Fig. 4 shows the time series data of the revenues of forest-related activities and the construction and maintenance costs of NFR and MAFR, where the erosion control revenue is equal to the public expenditure of erosion control by the Forestry Agency, the recreation revenue is calculated to be the number of visitors multiplied with the average consumption expenditures, and the sale value of lumbers. As to the public expenditure on erosion controls, our data do not contain the expenditure by the Ministry of Construction. The data are supplied by the various departments of Yamanashi Prefecture and JFDC. These revenue data are plotted since the year 1956. The study area of YPF is a kind of basin surrounded by high mountains. The year of 1956 is the year when NFR passed through one of the surrounding mountains and reached the eastern end of the basin area. The cost data in Figure 4 reflects the construction of NFR for the period of 1952 through 1961 and that of MAFR for the period of 1969 through 1980, where the huge cost data in 1982 is the restoration costs of MAFR damaged by typhoon.

The data in Fig. 4 are the nominal value data. Fig. 5 shows the time series data on the total revenues and total cost in real value terms, where the data are modified in terms of wholesale price index (1980 average = 1.0). Fig. 6 is calculated from Figure 5 and shows the net revenue data in real values. This figure clearly shows that the maximum annual net revenue over 31 years period is achieved in the year 1967, the year when the construction of MAFR began. The sudden decrease in net revenue in 1968 is caused by the decrease in wood sale and in recreasion expenditure, as known from Figure 5. The annual net revenue increases for several years since 1971. For the bus services by a private company became available for the section between the city

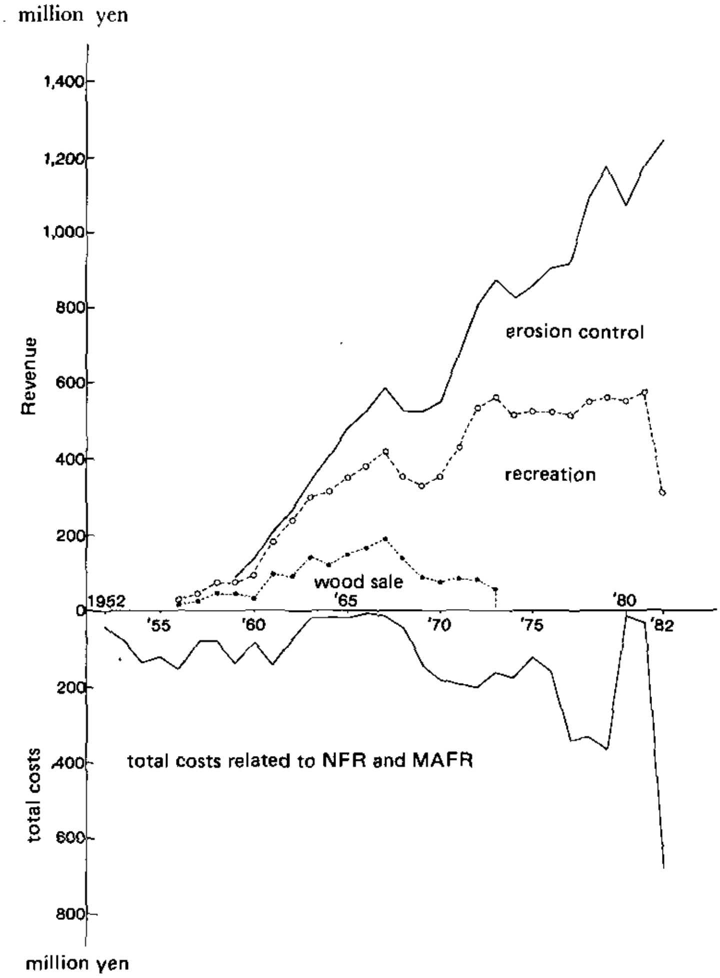

Fig. 4 Revenue and cost data (nominal value)

of Kofu and the terminal point of NFR (point ② in Fig. 1), after the improvement works of NFR were completed.

The above explanation of Fig. 5 and 6 makes clear that there exists various factors such as the change of traffic mode to recreation sites, the interrelationships between the construction of NFR and MAFR, and the interrelationships between the construction of NFR and MAFR, and the occurrence of natural hazards such as typhoon, which makes the execution of any kind of ex-post cost-benefit analyis of the road construction projects in froest areas diffecult. Furthermore, according to the officials of JFDC, any kind of quantitative cost-benefit analysis was not officially required for the construction of large-scale multipurpose forest roads such as MAFR. Thus in the following we like to pinpoint three problems in executing a cost-benefit analysis of MAFR, which are 1)the difference in the cost composition between NFR and MAFR and the choice of investment criteria, 2) the problem of determining the scale of development, 3) the problem of evaluating the multiproduct development project, and 4) the problem of income

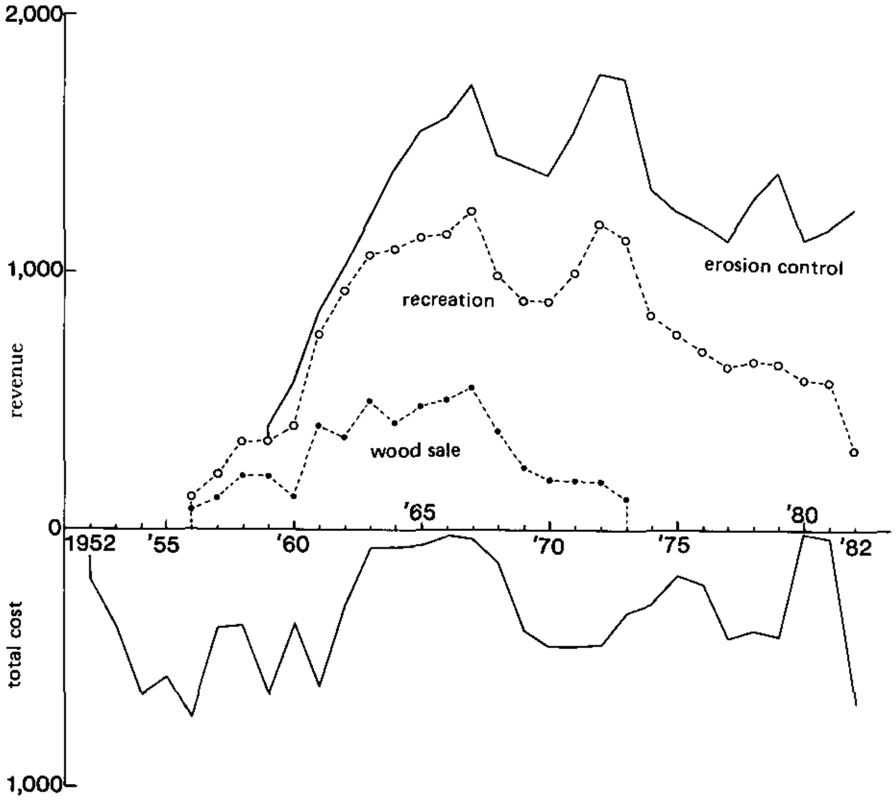

Fig. 5 Revenue and cost data (real value) unit : million yen

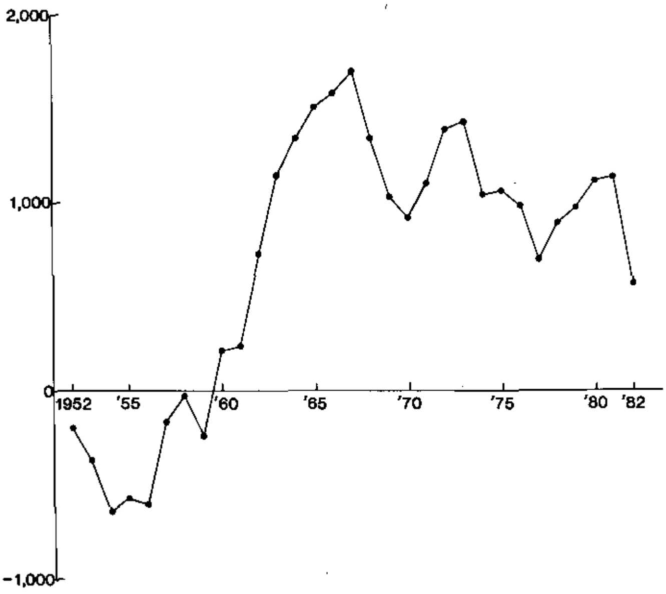

Fig. 6 Net revenue data (real value) unit : million yen

distribution. These four problems are considered to play important roles in executing an ex ante cost-benefit analysis of a similar case.

2. 2 Difference in cost composition and choice of investment criteria

Eckstein (1971, chap. 3) examined the formal difference between the two investment criteria of the benefit-cost ratio and the rate of return, and stressed that from the viewpoint of efficient use of limited public expenditure, the former criterion is favorable. If we specify the variables as follows: B = benefits received annually; C = annual costs, including the charge on capital; K = fixed investment such as the total construction costs of a forest road; O = operating, maintenance, and routine replacement costs incurred anually; i = interest rate; T = amortization period, then the benefit-cost ratio is written as

$$B/C = B/(O + a_{iT} K)$$

where

$$a_{iT} = \left[\sum_{t=1}^{T} \frac{1}{(1+i)^{t}} \right]^{-1}$$

and the rate of return, r, is determined as as to satisfy

$$K = \sum_{t=1}^{T} \frac{B-O}{(1+r)^{t}}$$

Eckstein also showed that the benefit-cost ratio criterion is particularly favorable to projects with low value of O/K and the rate of return criterion is favorable to projects with high value of O/K.

Table 2 presents, in nominal value, the construction costs, maintenance cost, and the costs of restoration of the roads damaged by natural hazards, for each of NFR and MAFR. The table also shows the length of constructed roads, where the number in parenthesis represents the length of improved roads. . The reason why the positive amounts of construction costs along with zero length of constructed road appears in Table 2 in 1974 through 1977 lies in the fact that various kinds of restoration works were done during this time period to restore the environmental damages caused by the road construction works, where during this time period hot debate was being done among the members of the Nature Conservation Council as to the merits and demerits of the completion of MAFR.

Though the construction costs as well as the maintenance and restoration cost vary over time, we proceed to calculate from Table 2 the values of O/K for NFR and MAFR. For simplicity we calculate O and K in terms of nominal value and do not discount the data. As to NFR, K is equal to 1059.22 million yen and O is calculated to be the four year (1963-66) average of the maintenance and restoration costs and equal to 15.6 million yen. Thus O/K for NFR is 0.0147. As to MAFR, K is equal to 2418.481 million yen and O is 239.116 which is calculated to be the three year (1980-82) average of the maintenance and restoration costs. O/K for MAFR is equal to 0.0989 which is about 6.7 times larger than the value of O/K for NFR. It is clear from Table 2 that the larger O/K value for MAFR is caused by the huge restoration costs incurred in 1982. In order for the O/K value of MAFR to be equal to that of NFR, O value for MAFR must be equal to 35.55 million yen, implying that the probability of the restoration cost incurred in 1982 must be 0.028 (once in 36.3 years).

Table 2 Construction, maintenance and restoration costs for NFR and MAFR

unit : million yen

year	length of constructed roads	construction cost NFR	construction cost MAFR	maintenance cost NFR	maintenance cost MAFR	restoration cost NFR	restoration cost MAFR
1952	4.359	42.0					
53	3.51	72.3				5.87	
54	0.724	132.3				2.13	
55	0.894	120.3					
56	2.978	153.8					
1957	2.62	80.0				0.20	
58	2.334	80.0				1.93	
59	1.549	73.4				67.29	
60	1.375	84.5					
61	1.208	144.7				3.38	
1962	1.168	76.0				0.31	
63				17.42		1.05	
64				18.03		0.95	
65				13.29		5.02	
66				6.16		0.36	
1967	0.300		11.31	1.58			
68	0.453		43.24				
69	5.4879		145.07				
1970	0.6469(0.39)		176.82				6.09
71	1.4466(9.15)		195.94				
72	0.5109(11.122)		201.34				
73	0.491 (3.477)		161.54				
74			168.38				9.84
75			117.11				7.05
76			160.74				
77			335.60				7.92
1978	0.0593		334.93				
79	0.6026		366.48				
1980				7.06			2.19
81				9.49			21.97
82				11.00			665.64

2. 3 Scale of development

One more problem of the cost-benefit analysis is to determine the scale of development. Usual procedure for the determination of the scale of a project is based on maximizing the difference between benefits and costs. In reference to Freeman (1979, chap. 1) the benefit of a development project can be defined to be the sum of the monetary values assigned to various effects of development by all individuals directly or indirectly affected by the project, where the evaluation of net benefits of development project is based on the demand functions for the effects of develoment as explained in section 2.4.

Our interest here is in examining whether the extension (and improvement) of NFR, is economically speaking desirable or not. Since the rightward movement on the horizontal axis of Figure 6 corresponds to the increasing scale of development (the total length of constructed road), we may consider that the horizontal axis roughly correspond to the scale of development. Though the vertical axis is not the net benefit of development but the net revenue of development, Fig. 6 is considered to approximate a figure describing the net benefit of the logging road construction project in YPF as a function of the scale of development. Then Fig. 6 shows clearly that the optimal scale of development would be the construction of NFR only. For the annual net revenue data, which are assumed to equal the net benefit of development, after 1967 in Fig. 6 are less than that in 1967.

2. 4 Evaluation of multiproduct development project

The above discussion neglects both the difference in the economic meaning of "revenue" and "benefit" and that there may be interrelationships among various efeects of development project. In reference to Schulze *et al.* (1981), individual person's utility for utilizing the natural environments of Minami Alps National Park may be specified as a function of levels of activities $A_1 \ldots A_n$ and environmental qualities $Q_1 \ldots Q_m$

$$U = U(A_1 \ldots A_n Q_1 \ldots Q_m) \qquad (1)$$

Then the individual is assumed to engage in and/or select environmentally related activites so as to maximize (1) subject to his budget constraint

$$Y - \sum_{i=1}^{n} P_i A_i = 0 \qquad (2)$$

where Y is his total disposable income for environmentally related activities and P_i the price or cost of activity i. Lagrangian function is the

$$L = U(A_1 \ldots A_n Q_1 \ldots Q_m) + \lambda \left(Y - \sum_{i=1}^{n} P_i A_i\right).$$

providing the first-order conditions

$$\partial U / \partial A_i - \lambda P_i = 0 \quad \text{for } i = 1 \ldots n \qquad (3)$$

$$Y - \sum_{i=1}^{n} P_i A_i = 0 \qquad (4)$$

If the utility function is assumed to be strictly increasing and quasi-concave in A_i and Q_j, and the Jacobian associated with equations (3) and (4) is assumed nonzero, then equations (3) and (4) may be solved (in principle) for the "ordinary" Marshalian demand functions

$$A_i^* = h_i(P_1 \ldots P_n Q_1 \ldots Q_m Y) \quad \text{for } i = 1 \ldots n \qquad (5)$$

the* denoting optimal values.

Substituting (5) into (1), we obtain the indirect utility function

$$U^* = U(A_1^* \ldots A_n^* Q_1 \ldots Q_m Y) = V(P_1 \ldots P_n Q_1 \ldots Q_m Y) \qquad (6)$$

giving the maximum value of utility assosiated with a given price-quantity-income vector (P, Q, Y) = ($P_1 \ldots P_n Q_1 \ldots Q_m$ Y). The change of individual utility caused by the marginal change of (P, Q, Y) is written from (6) as follows;

$$dV = \sum_{i=1}^{n} (\partial V / \partial P_i) dP_i + \sum_{j=1}^{m} (\partial V / \partial Q_j) dQ_j + (\partial V / \partial Y) dY \qquad (7)$$

Development projects such as NFR and MAFR are considered to affect the time path of (P, Q, Y)-vector in $n+m+1$ dimensional space. If a development project transforms (P, Q, Y) to (P', Q', Y'), then the corresponding change in individual utility is written as the following line integral

$$\Delta V = \int_C \left(\sum_{i=1}^{n} (\partial V / \partial P_i) dP_i + \sum_{j=1}^{m} (\partial V / \partial Q_j) dQ_j + (\partial V / \partial Y) dY \right) \qquad (8)$$

where C is some path of prices, quantities and income between (P, Q, Y) and (P', Q', Y').

As an illustraive example, two alternative paths are drawn in Fig. 7, where the path of M_0 M_1 M_{11} corresponds to the case of no construction of the final portion of MAFR and the path M_0 M_1 M_{12} to the case of construction of MAFR. P and Q in Fig. 7 may correspond to the access cost of

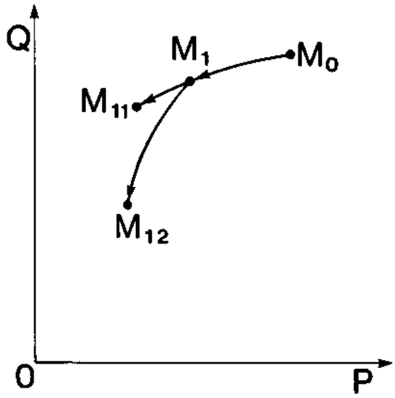

Fig. 7 Two alternative paths of price and environmental quality

recreation and the quality of scenic beauty, respectively. The available evaluation methodology to evaluate these two alternative paths, which utilizes market-related data, is to assume the independence of evaluation path. In other words, all we may do are to compare not two paths but two states such as (M_0, M_{12}) or (M_{11}, M_{12}). Formally speaking, we first estimate the systems of demand functions for A_1 through A_n, and check the integrability conditions of the system of demand functions. If the integrability conditions (the independence of path conditions) are satisfied, then the expenditure function for a representative indivdidual person can be derived from the system of demand functions, based on which we may calculate the change in net benefits caused by the change of one state of the other state. As to the details of the methodology, see Freeman (1979, chap. 3), Mckenzie (1983), and Silberberg (1972).

The above discussion made clear the following: in order to evaluate the multiproduct development project or to determine whether development projects such as NFR and MAFR have increased people's welfare of not, it is necessary for us to estimate the demand functions for environmentally related activities such as erosion control and recreation for each homogeneous group of individuals.

2. 5 Project evaluation and income distribution

As explained in section 1, most of the expected benefits of MAFR are intangible benefits and are related to regional or local welfare. In this sence, we can not disregard redistribution objective in project enaluation. If we denote an aggregate net benefit and a local net benefit as NB^0 and NB^1, respectively, then overall project benefits are expressed as the weighted sum of aggregate net benefit and redistributional benefits, where weights represent the relatiive importance of two objectives.

Though we have not collected systematically the data on redistribution benefits, one thing is clear. That is, MAFR works as employment creation, particularly for elder workers, and contributes to the improvement of economic conditions of the local community. According to the village headman of the village of Ashiyasu, about 40 to 100 persons are employed in restoration works of MAFR and erosion control in YPF, where the village's total labour force is about 400 persons.

Granted that the redistribution benefits are important factors in the cost-benefit analysis of MAFR, a question naturally occurs whether or not current employment pattern are the best pattern in achieving the redistribution objective.

3 RELATIONSHIPS BETWEEN DEVELOPMENT AND PARK SCHEMES

In this section we like to review the history of forest utilization in YPF and its relationships with the park scheme for Minami Alps National Park. Though the histry of forest utilization in YPF goes well back to the Tokugawa period where woods from the area were used to bulid Edo Castle. it was after the construction of NFR when the regular wood production had taken place.

Fig. 8 shows the results of three-dimensional study of the aerial photographs taken in 1947 and 1956 by an interpreter using a stereoscope, where the interpretation was done by the specialist in Nakanihon Air Service Company contracted by the National Institute for Environmnetal Studies. In drawing Fig. 8, we used as the base map the map compiled by Geographical Survey Institute, Ministry of Construction. Figure show the spatial variation of special denuded lands, ordinary denuded lands, felling areas with planting, and felling areas without planting. Figure also shows the rivers and the designated class of park scheme. From this figure, we know that the area has a lot of denuded lands, and wood production was done along the lower part of the Norogawa river.

Fig. 9 shows the state of YPF in the year 1980 just after the completion of MAFR. In comparing Fig. 8 and 9 we know that the various kinds of forest-related activities had taken place during the time period of 1956 and 1980. The area of wood production has expanded greatly, mostly along the MAFR. A large number of erosion control dams have been constructed. Several hydroelectric plants were constructed.

As to the relationships with the designated class of park schemes, we may notice the following distinctive features: 1) the area designated as the Special Protction Area is mostly characterized as the special denuded lands, where any kind of forestry activities including erosion control are considered to be techologically impossible; 2) wood productions were done in those areas designated as Class Ⅲ Special Area; 3) erosion control activites were understandably done in those areas below the denuded lands and near such facilities as forest roads and hydroelectric dams; 4) the higher class zone designation is given to those areas used as mountain roads, even if they are affected by wood production.

From this comparison, a question naturally occurs, based on the discussions, especially of section 2.4 and 2.5. Though the current park schemes reflects the existed or planned development activities in the year of national park designation, is the current park scheme a desirable scheme from the viewpoint of increasing people's satisfaction with utilizing the natural environmnet of Minami Alps National Park as well as of improving the economic conditions of local communities ? This is considered to be a representative question which the current Japanese national park system as the area designation system faces. Thus, our main future task is to investigate the following questions: 1) Does the value (people's willingness to pay for utilization and/or conservation) of national park increase or not by improving the land use category of the park in more ecologically sound way ? 2) Is there any way where the welfare of local communities are improved by enhancing the aforementioned value of the national park ?

4 CONCLUSION

In this chapter, one representative dispute case of nature conservation vs development is analyzed, where the case is the construction of a large-scale forest road called MAFR in Minami Alps National Park. The four main conclusions are as follows: 1) the economic analysis of the case supports, based on the availabele data on the net revenue of development, the Nature Conservation Council's opinion on the construction of MAFR saying that if the construction plan

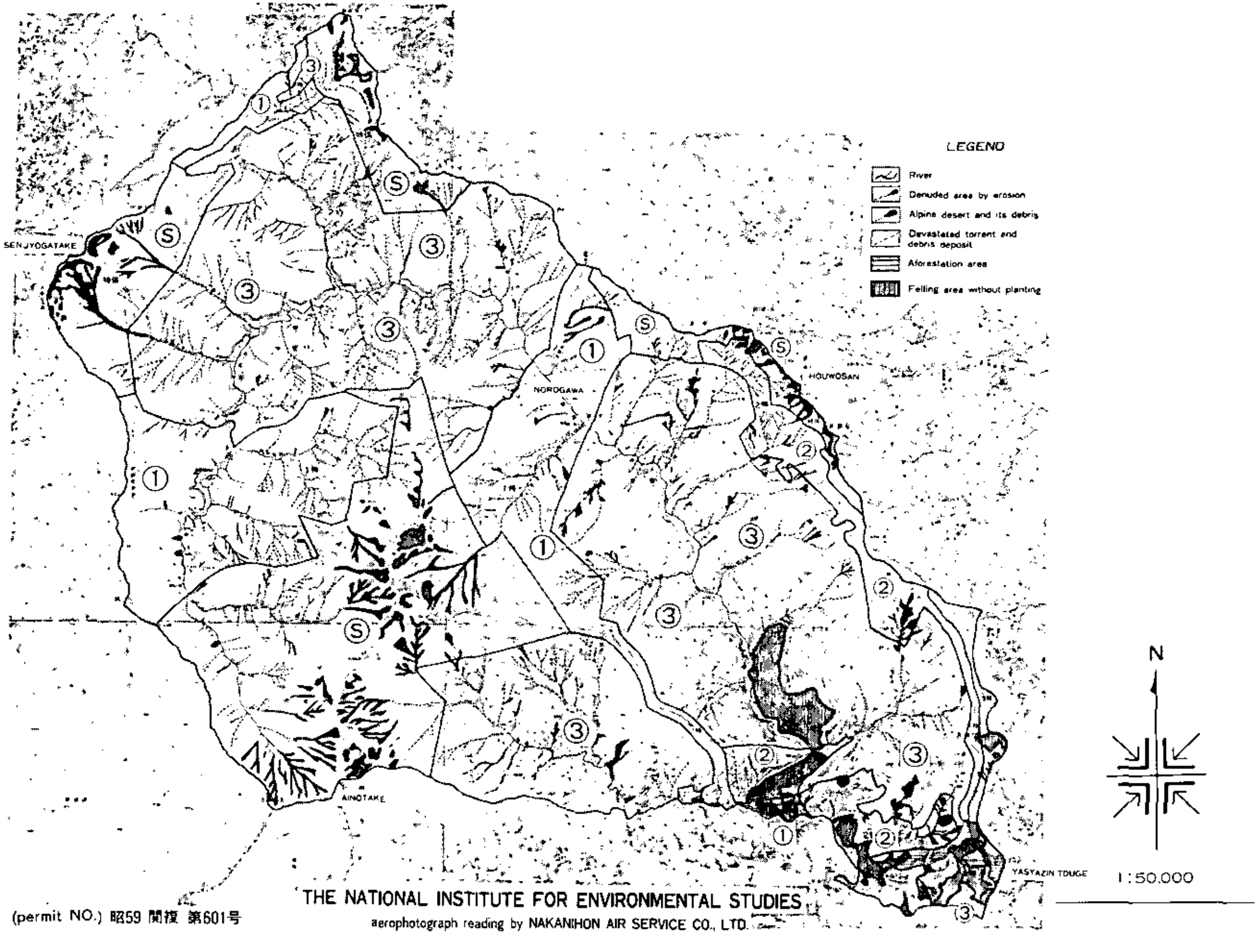

Fig. 8 State of Yamanashi Prefectural Forest in 1956

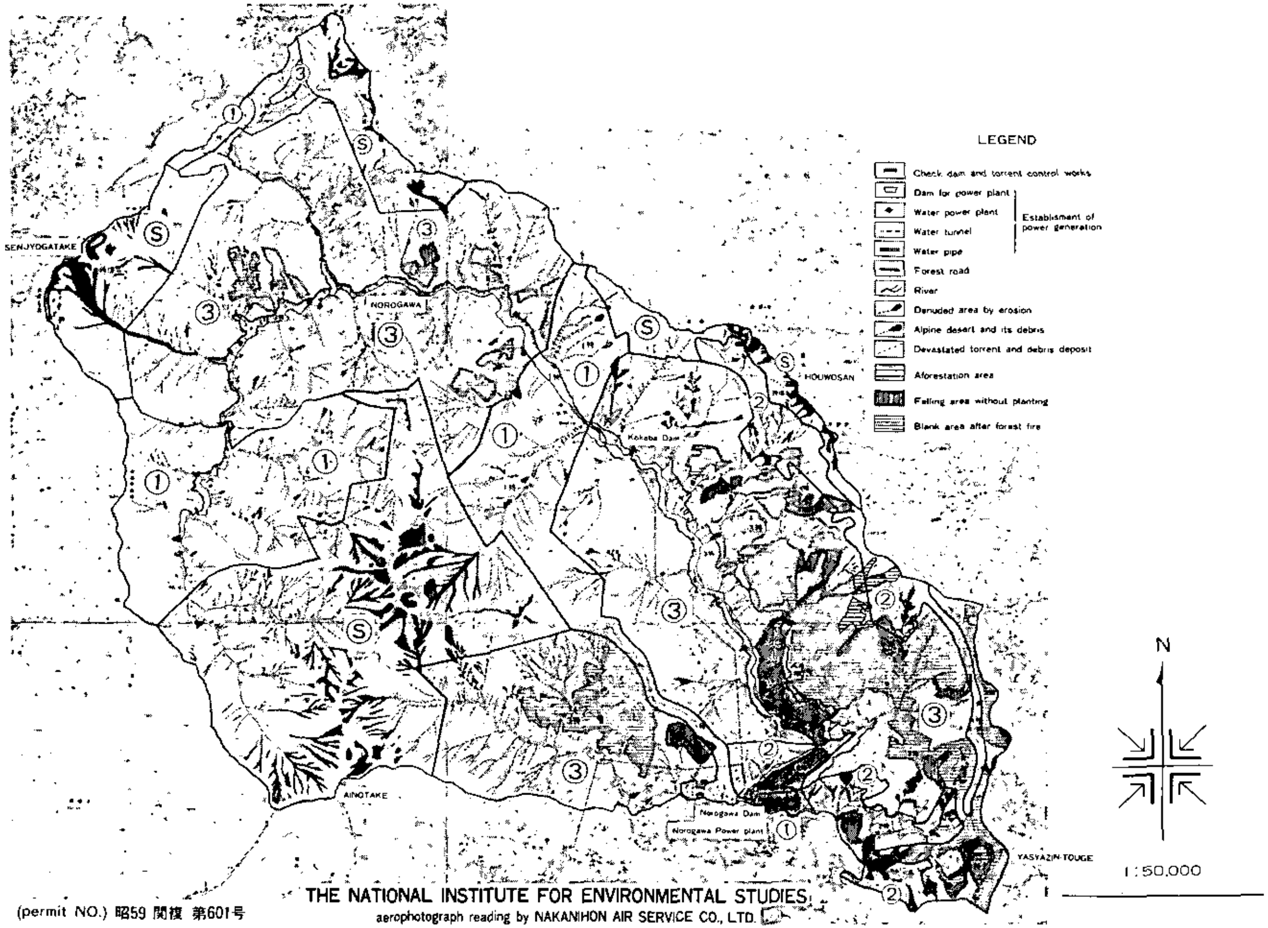

Fig. 9 State of Yamanashi Prefectural Forest in 1980

of MAFR had been presented not 10 years ago but in 1978, it would not be approved. Though the Council considered all the effects of the construction of MAFR including the intangible effects such as environmental damages, our analysis considered the tangible economic effects only. 2) Since the developmnet projects such as MAFR generates various effects such as erosion control, recreation, and wood production, the comprehensive economic evaluation of the project requires to estimate the demand functions for these effects. 3) A preliminary cost-benefit analysis of NFR and MAFR makes clear thta the ratio of the maintenance and restoration costs to the construction cost is higher in MAFR than in NFR and implies that the economic viability of MAFR depends on whether the large restoration costs of MAFR yielded in the year 1982 occurs frequently or seldom occurs. 4) The three-dimensional study of the aerial photopraphs taken in years before the construction of NFR and in a year after the construction of MAFR presents a future research theme concerning the park scheme of Minami Alps National Park; Is the current park scheme a desirable one from the viewpoint of increasing national welfare as well as of improving regional welfare of the surrounding region.

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Chapter 10

Editor's Concluding Remarks

From an economist's point of view, problem of environmental conservation is recognized as follows: The environment is one of scarce resources which must be utilized to conform to the objective of our society, that is, to enhance people's welfare. As long as three types of environmental resources supplied by the environment are scarce resources, man's utilization of environmental resources must be economized, where an evaluation criterion is related to people's welfare. Difficulty in economizing the use of the environment lies in the fact that it is difficult to separate three types of environmental resources into different commodities. In other words, it is difficult to utilize one type of environmental resources without jeopardizing the use of the other types of environmental resources. Thus if we want to maintain the state of the environment at certain state, we need to understand the interrelationships between the state of the environment and man's utilization of environmental resources. Based on this understanding, we may proceed to devise an economically efficient, environmentally sound, and socially acceptable measures for environmental conservation.

Although the arguments in this report appear to be fragmentary in the topics discussed, each chapter has tried 1) to clarify an economic mechanism through which people utilize or conserve the environment, and 2) to practice the analytical methodologies to tackle economic aspects of environmental conservation.

Anybdy who once studied the economic aspects of environmental conservation may remember how a management authority in charge of environmental conservation is going to determine its management goal, that is, to choose an optimum level of environmental quality, Q. A typical argument assumes that the mnagement authority will choose that level of environmental Q so as to maximize the net social benefit of environmental quality

$$\mathrm{NSB}(\alpha,\beta) = \max_{Q} \{\mathrm{B}(Q;\alpha) - \mathrm{C}(Q;\alpha,\beta)\} \tag{1}$$

where B(Q; α) is the social benefit of environmental quality, for given frame of socio-economic systems represented by parameter α such as the scale and composition of waste generating activities. C(Q; α, β) is the conservation cost of environmental quality, for given frame of socio-economic system α, given range of waste-treatment thchnologies represented by parameter β. In order to simplify the argugents, we may write the social benefit function as

$$\mathrm{B}(Q;\alpha) \triangleq \mathrm{B}(\alpha) - \mathrm{D}(Q;\alpha,\delta) \tag{2}$$

where B(α) is the gross social benefit of the given frame of socio-economic systems, and D(Q; α, δ) represents the economic valuation of environmental damages on the socio-economic systems for given range of damage prevention technologies represented by parameter δ. In terms of three types of environmental resource utilization, D( ) corresponds to a part of the cost, which is affected by Q, of the utilization of type 1 and type 2 resources, and C( ) to the cost of the utilization of type 3 resources. As the environmental quality deteriorates (Q becomes small), generally speaking, the quantity as well as quality of such environmental resources as water for municipal water supply and recreational attractiveness of the site is jeopardized, and, consequently, D( ) increases, ceteris paribus, as Q becomes small. On the other hand, as the environmental quality is allowed to deteriorate for given values of α and β, then the cost of utilizing the "sink" ability of the environment, or, the cost of residuals treatment decreases. Thus, C( ) decreases, ceteris paribus, as Q becomes small.

Fig. 1 describes an illustrative case of B( ), C(Q; α, β) and D(Q; α, δ) curves, where E curve is the sum of C( ) and D( ) curves. Fig. 2 describes the net benefit function, B( )−D( ), and the cost of residuals treatment function, C( ). In this report we have not dealt with the case of toxic substances or of global environmental pollution, in that the net benefit of environmental quality may not take a positive value at $Q = 0$. The optimum environmental quality is determined so as to minimize the sum of damage and treatment costs in Fig. 1, and so as to maximize the difference between the net benefit and the treatment cost in Fig. 2. In case that a desired environmental quality is predetermined in such a way that D( ) is assumed to take zero value, the task of management authority is simplified to determine the minimum cost (C) way of treatment system. This situation is shown in Fig. 3.

We proceed to summarize what we learn from each chapter based on these three figures. Chapter 2 is essentially the application of Fig. 3 to the problem of lake water quality management. Chapter 5 is devoted to the problem of estimating a damage function in Fig. 1. Here we learn that we cannot disregard in estimating damage function D(Q; α, δ) an interrelationship among water quality Q and parameters α and δ, where parameters α and δ represent characteristics of receptor activities(aquaculture) such as production mode (α) and use/non-use of damage prevention devices(δ).

In looking at chapter 2 and chapter 5, especially Fig. 11 in chapter 2 and Fig. 6 in chapter 5, we also learn that it is not so eassy to apply Fig. 1 in real setting. Fot the variables in damage function may not be the same variables in treatment cost function. Even if water quality variables are the same in two functions, we need some evaluation criterion to choose a specific distribution over space of water quality and damage cost.

Chapter 3, chapter 4 and chapter 6 report the application studies of Fig. 2, where chapter 3 deals with the problem of treatment plant siting and assumes a net benefit function in Fig. 2 to be a linear function of water quality. Chapter 4 deals with the problem of the optimum water quality monitoring system, where the net benefit function and the marginal cost function of wastewater treatment in Fig. 1 in chapter 4 are drawn as the function of the deterioration of water quality (−Q). Chapter 6 does not deal with enviromental quality itself. Instead, the horizontal axis represents the state of fishery resource stocks characterized by prey-predator relationships. A benefit function is revenue of fish catch and a cost function is cost of fish cach. This chapter is hoped to play a role of prelude to an integrative treatment of resource and environmental conservation.

In chapter 7 through 9, we saw rather different aspects of environmental problems. Here we saw the problem dealing with an adequacy of existing institutional framework in nature preservation. The main difference between the case of national park regions and the case of aquatic environments lies in the fact that in the former case land ownerships are clearly defined, while in the latter it is difficult to define such a right. Especially, in the former case conservation goal as well as measures is clearly defiend and have the long history in operation as explained in chapter 7, while in the latter case conserbation goal as well as measures is difficult to determine and to enforce due to the variability of environmental media as well as the lack of clearly defined propertyship. Neverthless Fig. 2 still applies to chapter 9, where the horizontal axis represents the scale of development in national park areas.

Chapter 8 deals with the problem of consumer preferences or demand for nature conservation, a kind of public good. This chapter plays a role of prelude to estimating the net benefit function of nature conservation. Our interest in chapter 8 was to clarify under what situation an individual person donate and what factors influence him to donate the money for National Trust movement. Here we learn that donors to a representative National Trust

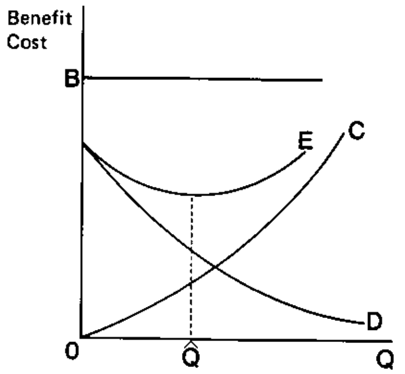

Fig. 1 Determination of optimum environmental quality as the minimization of the sum of treatment cost and damage cost

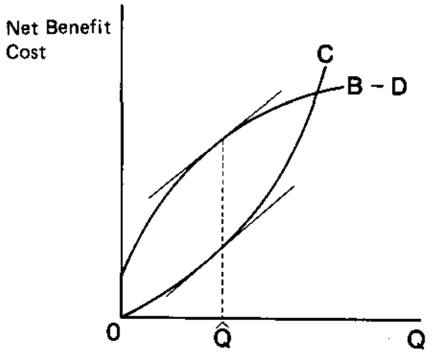

Fig. 2 Determination of the optimum environmental quality as the maximum net social benefit

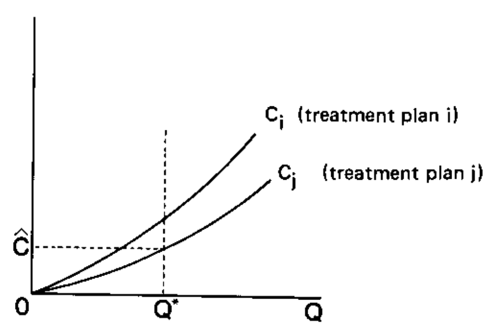

Fig. 3 Determination of the minimum cost treatment system given an environmental quality standard

movement in Japan show by their own foot that National Trust movement is worth the cost of donation. One of the remaining tasks in the theoretical aspects of this problem is to relate our analysis to the existing body of related literatures such as median voters' demand analysis (Decon and Shapiro, 1975).

Finally, the editor of the report gratefully acknowledges the constructive as well as thoughtful comments given by the referees of the editorial board of NIES (the usual disclaimers apply), and wishes to express his thanks to Ms. S. Tamura for her drawing many many figures used in this report.

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人間による環境資源利用の経済分析
―水環境と国立公園地域を対象にして―

北畠　能房[1]　(編)

本報告書に収録された研究は過去10年間にわたって当研究所総合解析部でなされた一連の経常研究，及び特別研究「陸水域の富栄養化に関する総合研究」(昭和52-54年度)，「陸水域の富栄養化防止に関する総合研究」(昭和55-57年度) でなされた諸研究のうち，環境資源利用の経済分析に係る研究成果を選択的にとりまとめたものである。

自然環境を機能的に捉えれば，環境は１) 廃物の拡散・貯留・同化，２) 経済活動に必要な原材料の供給，３) 人間生存の支援サービスの提供，４) アメニティー・サービスの提供，といった人間にとって有用なサービスを提供している。しかも，これらのサービスが利用できないときは，エネルギー資源といった他の資源に依存せねばならないか，ないしは人間の生存自体が危うくなりかねない，という意味で環境サービスは人間にとって有用な資源の一つである。しかし，個々の環境サービス利用間に相互作用のありうることと，個々の環境サービス利用が公共財的性格を強くもつために適正な価値づけのもとで個々の利用の無駄を排除するといったことがしにくく，そのために個々の環境サービス利用を放任しておくと，総体としての環境資源の量的・質的低下をきたしかねない。したがって，個々の環境サービス利用の特性を把握すると共に，総体としての環境資源の質の維持ないし向上をはかるために効果的な公共関与策の在り方をさぐることは，宇宙船地球号のさきゆきが不透明になっている現在，ぜひとも必要なことと考えられる。

上の観点で研究を進めるに当たって様々なアプローチが考えられるが，ここではシステム分析の考えに倣って，１) 種々の機能を持つ環境に対する人々のニーズの把握，２) ニーズに基づいて環境資源の管理目標及び管理主体を同定する，３) 個々の環境サービス利用の特性を解明するとともに，それをふまえて管理目標を達成するための効果的な手段の同定をはかる，４) 目標-手段関係の妥当性をチェックする，という四つのステップで環境資源管理にアプローチすることを考えた。

本報告書の第Ｉ部では水環境を対象とし，第二部では国立公園地域の森林環境を対象として，上述した四つの研究ステップのいずれかの問題を個別に取り扱うことを試みた。主たる事例として水環境と国立公園地域を取り上げたのは，各種の環境資源を所有権設定の有無，資源利用の地域的広がりという２軸で分類した場合に特徴的な事例と考えられるからである。

本報告書の要約であるが，第Ｉ部は五つの章 (２章～６章) から成っている。まず第２章 (地域水環境管理モデルの分析例；北畠能房，宮崎忠国，中杉修身) において，水質の環境基準及び地域の経済フレームが与えられたときに，排水処理に要する総費用が最小になるという意味で，最も効率的な処理体系及び総費用の公平な費用負担方式を求めるという，水環境管理の分

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[1] 国立公害研究所　総合解析部　〒305 茨城県筑波郡谷田部町小野川16番２

野における伝統的な問題を取り扱う。この種の問題は，通常，数理計画問題として定式化されるものであるが，ここでは，経済理論的背景をふまえて問題の定式化を行うとともに，霞ヶ浦高浜入水系を対象として，数値計算を行った。

第2章において所与条件として仮定されているものを緩めていくのが，以下の三つの章である。まず，第３章（連続空間上での下水処理場の立地分析；北畠能房，宮崎忠国）は，“二つの公共処理場の立地点は所与”という仮定を緩めるものである。特にこの章は，水環境として河川をとり，沿岸の人口分布や河川の自浄能力のばらつき，それに，下水処理の費用効果比率によって，下水処理場の最適数や立地点がどのように変化するかを，理論面，実証面から解析したものである。

第２章で暗黙のうちに仮定されているのに，“所与の確定的な環境基準”がある。第４章（水質モニタリング・システムの経済分析；松岡　譲，内藤正明）は，これに関して，水質測定に伴う不確実性に関する問題を扱う。水質測定の精度はモニタリング点を増やせば増やすほど高くなりうるが，一方，そのために支払う費用も高くなる。そこで，ここでは，水質測定の精度を向上さすことによる便益と，水質測定の精度を向上さすことの費用とのからみで，費用効果の観点からみて最も効率的なモニタリング方式を求めるという問題を定式化するとともに，霞ヶ浦について試算を行った。

第２章で求めた効率的な廃水処理体系は，外生的に与えられた環境基準の関数であった。それでは，環境基準の望ましい水準はどのように求められるのであろうか。環境経済の分野における一つの典型的な考えは，各環境水準のもとで生ずる環境被害額と，その水準に保持するのに必要な廃水処理費用の和が最小になるような水準を望ましいとするものである。ところが，この考え方の難点は，廃水処理費用に比べて環境被害額の定量化が難しいことにある。こうした背景をふまえて，水質汚濁が生産活動に及ぼす被害関数計測の理論と，霞ヶ浦における養殖業を例としての試算結果を報告するのが，第５章（生産活動に与える富栄養化影響の経済的評価；北畠能房）である。

第６章（捕食・被食関係をもつ漁業資源利用の経済分析：霞ヶ浦漁業を例として；北畠能房）は環境経済学と資源経済学の接点になりうる一つの問題を扱っている。本研究所で過去10年にわたって行われた霞ヶ浦に係る特別研究や茨城県内水面水産試験場での長年の研究において，徐々に明らかになってきたように，水環境中の生物，特に魚類と水質とは，魚類による底泥からの栄養塩の摂取と水中への尿の排せつという行為や，食物連鎖の過程等を通じて，密接に関係しあっている。それゆえ，水質をある水準に保持するという管理目標は，漁民による漁業資源の利用という経済行為と無関係とはいえない。こうした視点にたって第６章は，霞ヶ浦漁業を対象として，漁民による漁業資源の利用行動の解明を理論面，実証面から行ったものである。

このように，第Ⅰ部は前述したシステム分析の四つのステップのうち，主として第３ステップにかかわる問題を扱っている。

第Ⅱ部は三つの章（７～９章）から成っている。まず，第７章（国立公園地域の社会・経済分析；西岡秀三）では我が国の国立公園制度（システム分析の第１，第２，第３ステップ）の概要紹介がなされるとともに，特にシステム分析の第２ステップに関して，国立公園で規定される自然環境資源の管理目標を，管理主体の一翼を担う（国立公園に関係する）市町村の経営

基盤の全国的状況把握と分析結果を報告している。

自然保護に対する人々のニーズの把握（システム分析の第1ステップ）に関しては，本研究所研究報告第90号が詳細に報告しているが，第8章（自然保護に係る需要行動の経済分析：北畠能房，西岡秀三）は，ナショナルトラスト運動への拠金の経済合理性という問題を理論面，実証面から分析したものである。

第9章（南アルプス国立公園における大規模多目的林道の経済分析：北畠能房）は，第3ステップ及び第4ステップの例として，国立公園区域での林道建設を対象として，林道建設の事後的な費用便益分析を試みるとともに，過疎問題と国立公園制度とのかかわりについても若干の考察を試みている。

最後の10章（編者のまとめ；北畠能房）は，主として経済学的視点から，各章の内容をとりまとめたものである。

国立公害研究所特別研究成果報告

第 1 号　陸水域の富栄養化に関する総合研究 ── 霞ヶ浦を対象域として ── 昭和51年度.（ 1977 ）

第 2 号　陸上植物による大気汚染環境の評価と改善に関する基礎的研究 ── 昭和51／52年度　研究報告.（ 1978 ）

（改　称）

国立公害研究所研究報告

※第 3 号　A comparative study of adults and immature stages of nine Japanese species of the genus *Chironomus* (Diptera, Chironomidae). (1978)
（日本産ユスリカ科 *Chironomus* 属９種の成虫，サナギ，幼虫の形態の比較）

第 4 号　スモッグチャンバーによる炭化水素—窒素酸化物系光化学反応の研究 ── 昭和52年度　中間報告.（ 1978 ）

第 5 号　芳香族炭化水素—窒素酸化物系の光酸化反応機構と光酸化二次生成物の培養細胞に及ぼす影響に関する研究 ── 昭和51，52年度　研究報告.（ 1978 ）

第 6 号　陸水域の富栄養化に関する総合研究（Ⅱ）── 霞ヶ浦を中心として. ── 昭和53年度. .（ 1979 ）

※第 7 号　A morphological study of adults and immature stages of 20 Japanese species of the family Chironomidae (Diptera). (1979)
（日本産ユスリカ科20種の成虫，サナギ，幼虫の形態学的研究）

※第 8 号　大気汚染物質の単一および複合汚染の生体に対する影響に関する実験的研究 ── 昭和52，53年度　研究報告.（ 1979 ）

第 9 号　スモッグチャンバーによる炭化水素 - 窒素酸化物系光化学反応の研究 ── 昭和53年度　中間報告.（ 1979 ）

第 10 号　陸上植物による大気汚染環境の評価と改善に関する基礎的研究 ── 昭和51～53年度　特別研究報告.（ 1979 ）

※第 11 号　Studies on the effects of air pollutants on plants and mechanisms of phytotoxicity. (1980)
（大気汚染物質の植物影響およびその植物毒性の機構に関する研究）

第 12 号　Multielement analysis studies by flame and inductively coupled plasma spectroscopy utilizing computer-controlled instrumentation. (1980)
（コンピュータ制御装置を利用したフレームおよび誘導結合プラズマ分光法による多元素同時分析）

第 13 号　Studies on chironomid midges of the Tama River. (1980)
Part 1. The distribution of chironomid species in a tributary in relation to the degree of pollution with sewage water.
Part 2. Description of 20 species of Chironominae recovered from a tributary.
（多摩川に発生するユスリカの研究
── 第１報　その一支流に見出されたユスリカ各種の分布と下水による汚染度との関係 ──
── 第２報　その一支流に見出された Chironominae 亜科の20種について ──）

第 14 号　有機廃棄物，合成有機化合物，重金属等の土壌生態系に及ぼす影響と浄化に関する研究 ── 昭和53，54年度　特別研究報告.（ 1980 ）

※第 15 号　大気汚染物質の単一および複合汚染の生体に対する影響に関する実験的研究 ── 昭和54年度　特別研究報告.（ 1980 ）

第 16 号　計測車レーザーレーダーによる大気汚染遠隔計測.（ 1980 ）

※第 17 号　流体の運動および輸送過程に及ぼす浮力効果 ── 臨海地域の気象特性と大気拡散現象の研究 ── 昭和53，54年度　特別研究報告.（ 1980 ）

第 18 号 Preparation, analysis and certification of PEPPERBUSH standard reference material. (1980)
(環境標準試料「リョウブ」の調製，分析および保証値)

※第 19 号 陸水域の富栄養化に関する総合研究（Ⅲ）── 霞ケ浦（西浦）の湖流 ── 昭和53，54年度．（1981）

第 20 号 陸水域の富栄養化に関する総合研究（Ⅳ）── 霞ケ浦流域の地形，気象水文特性およびその湖水環境に及ぼす影響 ── 昭和53，54年度．（1981）

第 21 号 陸水域の富栄養化に関する総合研究（Ⅴ）── 霞ケ浦流入河川の流出負荷量変化とその評価 ── 昭和53，54年度．（1981）

第 22 号 陸水域の富栄養化に関する総合研究（Ⅵ）── 霞ケ浦の生態系の構造と生物現存量 ── 昭和53，54年度．（1981）

第 23 号 陸水域の富栄養化に関する総合研究（Ⅶ）── 湖沼の富栄養化状態指標に関する基礎的研究 ── 昭和53，54年度．（1981）

第 24 号 陸水域の富栄養化に関する総合研究（Ⅷ）── 富栄養化が湖利用に及ぼす影響の定量化に関する研究 ── 昭和53，54年度．（1981）

第 25 号 陸水域の富栄養化に関する総合研究（Ⅸ）── *Microcystis*（藍藻類）の増殖特性 ── 昭和53,54年度．（1981）

第 26 号 陸水域の富栄養化に関する総合研究（Ⅹ）── 藻類培養試験法によるＡＧＰの測定 ── 昭和53，54年度．（1981）

第 27 号 陸水域の富栄養化に関する総合研究（Ⅺ）── 研究総括 ── 昭和53，54年度．（1981）

第 28 号 複合大気汚染の植物影響に関する研究 ── 昭和54，55年度 特別研究報告．（1981）

第 29 号 Studies on chironomid midges of the Tama River. (1981)
Part 3. Species of the subfamily Orthocladiinae recorded at the summer survey and their distribution in relation to the pollution with sewage waters.
Part 4. Chironomidae recorded at a winter survey.
(多摩川に発生するユスリカ類の研究
── 第３報 夏期の調査で見出されたエリユスリカ亜科 Orthocladiinae 各種の記載と，その分布の下水汚染度との関係について ──
── 第４報 南浅川の冬期の調査で見出された各種の分布と記載 ──)

※第 30 号 海域における富栄養化と赤潮の発生機構に関する基礎的研究 ── 昭和54，55年度 特別研究報告．（1982）

第 31 号 大気汚染物質の単一および複合汚染の生体に対する影響に関する実験的研究 ── 昭和55年度 特別研究報告．（1981）

第 32 号 スモッグチャンバーによる炭化水素－窒素酸化物系光化学反応の研究 ── 環境大気中における光化学二次汚染物質生成機構の研究（フィールド研究１）── 昭和54年度 特別研究報告．(1982)

第 33 号 臨海地域の気象特性と大気拡散現象の研究 ── 大気運動と大気拡散過程のシミュレーション ── 昭和55年度 特別研究報告．（1982）

※第 34 号 環境汚染の遠隔計測・評価手法の開発に関する研究 ── 昭和55年度 特別研究報告．（1982）

第 35 号 環境面よりみた地域交通体系の評価に関する総合解析研究．（1982）

第 36 号 環境試料による汚染の長期モニタリング手法に関する研究 ── 昭和55，56年度 特別研究報告．（1982）

第 37 号 環境施策のシステム分析支援技術の開発に関する研究．（1982）

第 38 号 Preparation, analysis and certification of POND SEDIMENT certified reference material. (1982)
(環境標準試料「池底質」の調製，分析及び保証値)

※第 39 号 環境汚染の遠隔計測・評価手法の開発に関する研究 ── 昭和56年度 特別研究報告．（1982）

第 40 号　大気汚染物質の単一及び複合汚染の生体に対する影響に関する実験的研究 ── 昭和56年度　特別研究報告．（1983）

※第 41 号　土壌環境の遠隔計測と評価に関する統計学的研究．（1983）

※第 42 号　底泥の物性及び流送特性に関する実験的研究．（1983）

※第 43 号　Studies on chironomid midges of the Tama River. (1983)

Part 5. An observation on the distribution of Chironominae along the main stream in June with description of 15 new species.

Part 6. Description of species of the subfamily Orthocladiinae recovered from the main stream in the June survey.

Part 7. Additional species collected in winter from the main stream.

(多摩川に発生するユスリカ類の研究

── 第 5 報　本流に発生するユスリカ類の分布に関する 6 月の調査成績とユスリカ亜科に属する15新種等の記録 ──

── 第 6 報　多摩本流より 6 月に採集されたエリユスリカ亜科の各種について ──

── 第 7 報　多摩本流より 3 月に採集されたユスリカ科の各種について ──)

第 44 号　スモッグチャンバーによる炭化水素－窒素酸化物系光化学反応の研究．── 環境大気中における光化学二次汚染物質生成機構の研究（フィールド研究 2）── 昭和54年度　特別研究中報告．（1983）

第 45 号　有機廃棄物，合成有機化合物，重金属等の土壌生態系に及ぼす影響と浄化に関する研究 ── 昭和53年／55年度　特別研究報告．（1983）

第 46 号　有機廃棄物，合成有機化合物，重金属等の土壌生態系に及ぼす影響と浄化に関する研究 ── 昭和54／55年度　特別研究報告　第 1 分冊．（1983）

第 47 号　有機廃棄物，合成有機化合物，重金属等の土壌生態系に及ぼす影響と浄化に関する研究 ── 昭和54／55年度　特別研究報告　第 2 分冊．（1983）

※第 48 号　水質観測点の適正配置に関するシステム解析．（1983）

第 49 号　環境汚染の遠隔計測・評価手法の開発に関する研究 ── 昭和57年度　特別研究報告．（1984）

※第 50 号　陸水域の富栄養化防止に関する総合研究（Ⅰ）── 霞ヶ浦の流入負荷量の算定と評価 ── 昭和55～57年度　特別研究報告．（1984）

※第 51 号　陸水域の富栄養化防止に関する総合研究（Ⅱ）── 霞ヶ浦の湖内物質循環とそれを支配する因子 ── 昭和55～57年度　特別研究報告．（1984）

※第 52 号　陸水域の富栄養化防止に関する総合研究（Ⅲ）── 霞ヶ浦高浜入における隔離水界を利用した富栄養化防止手法の研究 ── 昭和55～57年度　特別研究報告．（1984）

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── 第1部　日光国立公園の湖のユスリカの生態学的研究 ──
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