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COMPREHENSIVE SIMULATION MODEL OF A TROPICAL
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OF THE YUCATAN CONTINENTAL SHELF

presented by

Juan Carlos Seijo G.

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Doctoral degree in Resource Development

Major professor
Manfred Thullen

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# COMPREHENSIVE SIMULATION MODEL OF A TROPICAL DEMERSAL FISHERY: RED GROUPER (*Epinephelus morio*) OF THE YUCATAN CONTINENTAL SHELF

BY

JUAN CARLOS SEIJO G.

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Resource Development

1986

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ABSTRACT

COMPREHENSIVE SIMULATION MODEL OF A TROPICAL DEMERSAL FISHERY: RED GROUPER (Epinephelus morio) OF YUCATAN CONTINENTAL SHELF

BY

Juan Carlos Seijo G.

Management of renewable resources such as ocean fisheries, is a complex process requiring understanding of resource biology and ecology as well as the economic and institutional factors affecting behavior of fishermen as resource users.

Different approaches have been used to aid decision-making through modelling efforts such as: the surplus yield approach, the bioeconomic approach and the dynamic pool approach. It is also recognized that the approaches mentioned above involve only a partial conceptualization of the fishery resource system. Therefore, the major objective of this dissertation was the development of a comprehensive simulation model integrating biological, economic, and institutional factors. The systems simulation methodology was applied to model a tropical demersal fishery: red grouper (Epinephelus morio) of the Yucatan continental shelf. The following steps were taken: (1) identification of the fishery system, (2) design of causal and block diagrams to conceptualize the mathematical model, (3) data collection for parameter estimation and curve fitting, (4) building the

mathematical and computer model, (5) conducting stability and numerical error analysis, (6) validating the model, (7) conducting sensitivity analysis, (8) applying Monte Carlo analysis to estimate confidence intervals for model inputs and important performance variables, and (9) conducting simulation experiments to observe the impacts of alternative management strategies. In order to deal with the uncertainty inherent in ocean fisheries, random variables were generated with an exponentially autocorrelated probability density function. This modelling effort involved the design of a feedback loop to estimate population structure and recruitment over time. Concerning fishing effort, the distributed DELAY model was applied to model vessel entry and exit to the fishery. The comprehensive nature of the validated model allows for observing the dynamic behavior of performance variables such as fish biomass, fishery yield, net revenues of different types of vessels, direct employment, availability of seafood in coastal communities and export earnings.

## DEDICATION

To Cecilia, Juan Carlitos and Adrianita who always have been a source of love and encouragement.

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I wish to express my deepest gratitude to Dr. Manfred Thullen for his motivating guidance, support for a broad academic development, and friendship.

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# CHAPTER I

# INTRODUCTION

Management of renewable resources such as ocean fisheries is a complex process that requires understanding of resource biology and ecology as well as the economic and institutional factors that affect the behavior of fishermen as resource users.

Developing coastal states like Mexico have substantially increased their fishing effort in order to provide their growing population with domestic protein rich food. In addition, ocean fisheries are also perceived as important sources of foreign exchange by most developing nations, which can help to alleviate foreign debt problems.

In order to sustain the yield of fisheries resources over time and protect the fragile ecosystems in which they live, an integration of biologic, ecologic, economic and institutional factors is required to aid the decision-making process. Therefore, the purpose of this study is the development of a comprehensive model as a tool for fisheries resource management using the systems simulation approach.

To deal with the factors mentioned above, the following topic areas will be discussed in this chapter: (1) the Law of the Sea Treaty and resulting property rights and obligations of coastal states, (2) the inherent characteristics of ocean fisheries and the major issues involved in managing this renewable resource, (3) the way the Mexican Government has legislated the use and allocation

of its major fisheries and, (4) a brief discussion of the role that the systems simulation approach can play, when conducting impact analysis of fisheries management decisions.

Finally, study objectives and a summary of the research approach are also presented in this chapter.

## Law of the Sea Treaty: Rights and Obligations

In April 1982, 130 nations signed the Law of the Sea Treaty which included recognition of 200 miles jurisdiction to coastal nations. This newly acquired Exclusive Economic Zone involves a set of property rights as well as obligations that each coastal nation needs to satisfy.

One rationale behind this treaty dealing with biotic resources was the international concern of over-exploitation of fisheries resources in the last three decades. Because of the common property character that existed before 1982, fisheries resources beyond the 12-mile Territorial Sea and Contiguous Zone were owned in common by all coastal States capable of harvesting them. This yielded satisfactory results under conditions of light use of fish stocks, which prevailed in most areas prior to World War II. With a few localized exceptions, biological depletion did not occur as a consequence of unrestricted harvesting in the marine fisheries.

As Joung (1982:139) has pointed out:

> Since the supply of fish was usually unlimited relative to demand, individual harvesters did not need to fear that competitors would catch any fish that they left unharvested. Therefore, individual fishermen could decide upon an optional rate of harvest over time without experiencing undue pressures to overinvest in the short run in order to maximize their share of a finite supply of fish.

After the Geneva Conventions of 1958 and 1960 that emerged from the United Nations Conferences on the Law of the Sea (UNCLOS I and II), many issues remained controversial. Among them were the concern of fisheries development and conservation. As soon as it became clear that the third UNCLOS conference, which started on December 3, 1973, would establish a 200 miles Exclusive Economic Zone, unilateral extensions began to develop at an increased rate (Ross, 1982). Mexico in 1976 was among the countries that claimed 200 miles of Exclusive Economic Zone (EEZ) before UNCLOS III was convened. It should also be mentioned that a large number of bilateral agreements had been reached between 1976 and 1980 between coastal states who wished to continue to carry out operations in those areas (Johnston, 1981). This was the case in the agreement between Mexico and Cuba concerning the harvesting of red grouper (Epinephelus morio)[1] in Yucatan's Continental Shelf. Most of these agreements were designed to define the terms and conditions under which vessels of one country could continue to be authorized to fish in the EEZ of another country.

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After UNCLOS III was signed, a number of obligations on coastal nations resulted from the Treaty. Among them, Article 61 established that coastal nations had to ensure: (1) That maintenance of living resources in their EEZ was not endangered by overexploitation, (2) That populations of harvested species were maintained or restored to levels that would produce sustainable yield levels and, (3) That populations harvested and interdependent fisheries were maintained above levels at which their reproduction become seriously threatened (Johnston, 1981).

Article 61 further established that another major objective of the treaty was to provide for the harvesting of the entire allowable catch of living resources within the EEZ; "The portion in excess of the domestic harvesting capacity shall be made available by agreement to foreign fishing subject to coastal regulations" (Burke, 1983:31).

The above statement implied a permanent obligation of coastal nations to conduct research efforts to determine the amount of fish biomass in their EEZ. Then, they must establish the portion of the exploitable population that could be harvested domestically and the portion that could be made available as surpluses to foreign fishing fleets, through a yearly fish quota that would be established by agreement.

In order to conduct yearly analysis of fish population dynamics and to predict impacts of alternative harvesting policies and regulations, there is a current effort to build

dynamic computer models to simulate the complexities of ocean fisheries (Grant et al., 1981; Allen and Mc Glade, 1986; Gislalon et al., 1982).

## Common Property Resources

The problem of the "commons" has been widely discussed in the literature concerning open access to renewable resources (Harding, 1973; Gordon, 1954; Eckert, 1979). According to Howe (1979:241) there are two conditions for the existence of a common property resource: "(1) unrestricted access to the resource system by all those who care to use it, and (2) some kind of adverse interaction among the users of the [ecosystem]" (i.e., the creation of externalities among users). Fishing externalities are understood as external effects caused by individual fishermen but not included in their accounting system. Agnello and Donnelley (1976) have recognized three types of negative externalities in most fisheries:

(i) Stock externalities. This type of externality occurs when entry affects the magnitude of fish population and hence the harvesting costs of other fishermen.

(ii) Crowding externalities. Arise when vessel congestion on the fishing grounds increases marginal catch costs.

(iii) Fishing gear externalities. Exist when the type of gear used changes the population dynamics of the target species and associated bycatch.

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In the case of ocean fisheries, there are a number of other inherent resource characteristics requiring further discussion in order to understand interdependencies among resource users.

<u>High Exclusion Costs and Free Rider Behavior</u>

Because migratory characteristics of most ocean fisheries involve high costs of excluding others from exploiting the resource, a fisherman may not benefit by postponing a catch with the expectation of catching a larger and probably more valuable fish later, since that fish is likely to be caught in the meantime by another fisherman. Given that sustainable yield is only reached when, for any specific fishery size, the harvest per period is just equal to the natural growth (Munro, 1981) of each cohort of the population structure, species can be decimated if fish are caught more rapidly than they can reproduce. However, a single fisherman cannot affect the size of the stock by reducing his rate of catch unless all or most other participants in the fishery agree to abstain proportionately (Eckert, 1979).

Without an agreement to limit catches, the main result of a single fisherman's reduced rate of catch is to lower the costs of other fisherman without necessarily increasing his benefits. Consequently, each fisherman is likely to increase the rate of catch and thus contribute to destruction of the fishery, an undesired long-run result by all fishermen involved.

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It seems, using Schelling's (1978) terminology, that the micro-motive of an individual fisherman is not consistent with the macro-result that he and the other fishermen desire. That is, micro-motives seem to result in aggregate fishing behavior that no one involved with the fishery would want. The fishery sustainable yield, which is the long-run preferred result by all fishermen, is usually dominated by marginal benefits of an individual fisherman's increased harvesting rate (dominant production function) or by uncertainty of future resource availability.

The sustainable yield choice will have higher payoffs only when the number of individual fishermen selecting it reachesa certain threshold. This threshold is the point at which the level of biomass over time is sustained by the appropriate fishing effort of most fishermen involved in the fishery.

As is also recognized in the literature, the size of the group of fishermen is a relevant factor affecting the avoidance of this social trap (Schmid, 1978). If the group is large, a fisherman may be an <u>unintentional</u> <u>free</u> <u>rider</u> given that he doesn't see how to avoid the macro-result (fishery destruction) when he cannot be sure that other fishermen will act in concert. If the group is small, exclusion costs are not lower, but the non-contributing fishermen are easier to identify, therefore reducing the number of free riders (Schmid, 1978).

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The higher degree of consciousness may thus allow for the possibility of avoiding or getting out of this social trap.

Besides group size, another factor that may play an important role in trying to avoid Hardin's (1973) "tragedy of the commons" is the learned behavior of fishermen where they do not calculate benefits of increasing harvesting rate apart from themselves. They rather behave consistently with the community shared objective of sustaining the yield of the fishery in question. This involves conditioning or adjusting the intertemporal preferences in resource use of each individual fisherman to those shared by most members in the community. This may take place when the level of overexploitation affects all fishermen involved and voluntary collective action is sought by most members of the community to prevent resource depletion.

### High Transactions Costs

Marine fisheries also involve high transaction costs which generate another source of attenuation of property rights that prevent the market from allocating fisheries resources over time in such a manner that net present value of the fishery is maximized. It should be mentioned, however, that when talking about net present value of the fishery, intertemporal choices of individual fishermen should be taken into account through different rates of discount reflecting different prices of time. The time preference of "traditional fishermen" (fishermen of coastal rural communities who use small boats and rudimentary fishing gear) in the use of resources might be quite higher trap.

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Transactions costs involve a group of costs discussed in the literature as information costs, enforcement or policing costs and contractual costs (Schmid, 1978; Randall, 1981).

Ocean fisheries involve <u>high information costs</u> that result from interdisciplinary research efforts of biologists, oceanographers, fisheries economists, system scientists, among others, needed to keep track of (1) fish population dynamics, (2) spatial and temporal distribution of fish species, and (3) changes in physical and chemical factors that affect the distribution of fish in the marine ecosystem.

Managing this type of renewable resource also involves <u>enforcement or policing</u> costs that result from enforcing fisheries regulations and protecting fishing property rights. Usually these costs tend to be so high that rights granted to future generations (through regulations that are aimed at sustaining and even increasing the yield of the resource over time) and to fishermen of today (through allocation of exclusive property rights) may become <u>empty rights</u>.

In general, these type of costs are more binding in developing coastal nations which normally lack either sufficient enforcement means or sophisticated facilities

such as remote sensing capabilities to monitor uses of ocean resources.

Finally, in cases of countries such as Mexico, where there have been legislative efforts to foster collective forms of organizations in the fisheries sector, <u>contractual costs</u> may become a significant variable. Costs involved in organizing a fishermen cooperative for voluntary collective action are usually substantial. An important analytical issue concerns identifying who pays for the contractual costs, the fishermen or the State (which fosters this form of organization).

The fisheries economics literature usually advocates the allocation of private property rights to individuals to overcome the depletion problem. Many regulatory schemes have been advocated to deal with this problem. Some can be classified as regulating catch composition and others as regulating catch size (Pearse, 1980; Scott, 1979).

Some of these institutional structures have been applied by the Mexican government which has conducted a number of legislative efforts to sustain the yield of its major fisheries and at the same time increase welfare of coastal rural communities by allocating them exclusive property rights to those fishery resources.

To better understand how Mexico is dealing with the management of its fisheries (since Mexico is the case study in this research) one needs to review its historical background. Thus, the following section includes a brief discussion of the major fisheries policies implemented by

Mexico since the first quarter of this century.

## Mexico: Ocean Fisheries Policies

The first Fisheries Law of Mexico was issued by President Calles in 1925 to regulate both marine and fresh water fishing. This law reflected concerns about the need for establishing closed seasons for different fish species, and the establishment of harvesting zones, coastal zones refuges and fish sanctuaries. In 1932, the Government of President Ortiz Rubio promulgated a new Fisheries Law, by which "The protection of the state was granted to fishermen organized in groups, with the goals of improving economic and social conditions" (Banco Nacional de Comercio Exterior, 1981:417). The following year, by-laws governing application of this law were issued. "Reserved fisheries zones" and "common exploitation zones" were established. The former were to be conceded preferentially to collectively organized fishermen. The latter were to be reserved exclusively to fishermen organized in cooperatives so as to ensure their own subsistence (op cit., p.417). In 1947, President Miguel Aleman granted exclusive rights to fishermen's cooperatives to exploit nine species of economic importance, among which were shrimp, oyster, queen conch and lobster (Departamento de Pesca, 1977).

After these laws were established, "There was frequent questioning as to the application of fisheries legislation, it being argued that what it envisaged, redistribution

through allocation of exclusive property rights, was scarcely turned into practical achievements" (Banco Nacional de Comercio Exterior, 1981:418). It seems that the 1947 provision of exclusive exploitation rights given to cooperatives for certain species, was not a sufficient condition for them to exercise their rights and strengthen their organizations. High costs of excluding other fishermen who do not have the right to harvest these specific set of species may have caused an empty right to be conveyed to traditional fishermen organized in cooperatives. Additionally, high transaction costs involved in organizing cooperatives, may have prevented many traditional fishermen from getting organized.

In the period 1971-1979, a series of laws were issued by the federal government which included creation of a State owned bank (BANPESCA) and a State owned corporation (PROPEMEX). In addition, in 1982 the Mexican banking system became expropriated by the federal government. As a result, the public sector is the only financing source for fisheries investment projects.

It should also be recognized that at the beginning of Mexico's legislative effort in the fisheries sector, the federal government was hoping to achieve a change in performance via factor ownership transfers (e.g., fish species reserved for traditional fishermen), but failed to recognize the total institutional framework, which can offset the effect of change in factor ownership.

Despite these legislative efforts, incomes of traditional fishermen may be reduced in the long-run, given that they have not been able, as yet to avoid the "tragedy of the commons." Two of the reserved species for traditional fishermen cooperatives, queen conch (Strombus gigas) and spiny lobster (Panulirus argus) have been reported as overexploited in the coastal area of Quintana Roo, Yucatan (Fuentes et al., 1986; Cruz et al. 1985). Harvesting of both species is being regulated by the Ministry of Fisheries. In addition, one major fishery of Yucatan Continental Shelf, the red grouper (Epinephelus morio), seemed to have reached its maximum sustainable yield in 1972 and since then the catch per unit of effort has been slowly decreasing (Chavez, 1983).

A factor that may be affecting behaviors of traditional fishermen is the high information cost involved in keeping track of fish population dynamics and migratory patterns as well as information related to factors that affect fish ecosystem performance. Research and extension programs on fisheries ecosystems of different areas, may help reduce these high information costs. It should be recognized however, that all these efforts to reduce transactions costs faced by traditional fishermen require that they be borne by government, hence a subsidy from the government to the fishermen. People not interested in fish or equity problems may become unwilling riders when paying their taxes.

Concerning the use of ocean fisheries, the Mexican

Government, in October 1983, issued the "National Food Program 1983-1988". This program began by first recognizing the current extreme malnutrition status of 19 million Mexicans as indicated by their deficits in consumption of calories and proteins. Second, the program addressed the serious concern of the increasing dependence on basic food products from external suppliers. During 1980-1982, the import/total production ratio for basic food stuffs was, 19% for corn, 30.6% for beans and 40.6% for sorghum. Food imports have increased substantially in the last 20 years. In the 1965-1969 period Mexico imported 283 thousand tons of basic grains, oleaginous grains and sorghum, while in the 1980-1983 period the country imported 20 million tons of the same food products (Comision Nacional de Alimentacion, 1983). It should also be recognized that Mexico's high rates of population growth have contributed substantially to this food deficit.

One of the main characteristics of this food program, as contrasted to ones developed before 1982, is recognition of the increasing and relevant role that the fisheries sector may play in the alleviation of Mexico's malnutrition and foreign debt problems. In addition to agriculture, adequate management of ocean fisheries resources may provide an alternative nutritional supplement to Mexican food programs, with the long-run objectives of prevention of hunger and malnutrition.

Mexico's fisheries sector has been growing dramatically in the last 10 years. Mexico's fish catch increased from

254 thousand metric tons in 1970 to 1 million 254 thousand metric tons in 1980 (F.A.O., 1981:41; Secretaria de Pesca, 1986). Also, domestic fish consumption has increased substantially. Direct fish consumption increased 63% in the period 1976-1980 (Secretaria de Programacion y Presupuesto, 1982). It should be mentioned, however, that in relative terms fish consumption represents a very small component of the average Mexican diet. This diet is based mainly on corn, beans and beef produced inland where the majority of the population has been settled for centuries.

This substantial and promising growth of the fisheries sector requires a study of the biological, ecological and economic interdependencies involved in ocean fisheries resources in order to predict impacts of alternative resource management strategies.

## Impact Analysis of Fisheries Management Decisions

Fisheries resource managers lack information concerning fish population dynamics and information about the linkages involved between the alternative institutional structures (management variables) and the performance of the fishery system.

Different approaches have been used to aid the decision-making process through modeling efforts such as the surplus yield approach (Schaefer, 1954), the bioeconomic approach (Gordon, 1954) and the dynamic pool approach (Beverton and Holt, 1956). An additional methodology

involves the use of system simulation to estimate the performance of alternative management strategies. This type of modelling effort requires a <u>comprehensive</u> <u>approach</u> that involves biological, economic, and institutional dimensions in order to provide integrated guidelines for renewable resource management (Ervik et al., 1981; Walters, 1980).

Concerning the need for comprehensive fisheries modelling Richard C. Hennemuth, Director of the Northeast Fisheries Center at Woods Hole, has pointed out: (Cited by Gulland, 1981)

> Successful management, the fulfillment of expectations, will depend to a large extent on adequate advice based on good models. The simpler models include only one effect. There are no interactions and multiple effects are ignored. Regulations of fishing mortality on a single-species stock assumes no interactions with any other component of the system.

Gulland (1981) further argues that few general descriptions of the complete fisheries management system have been given in the literature and suggests that models of complete systems do not exist. Rather there are a number of models describing individual parts of the system; these can be grouped into:

(i) Biological models describing fish stocks and their ecosystems.

(ii) Bioeconomic models describing the interdependencies between fish stocks and fisheries revenues and costs under a set of static equilibrium conditions;

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involves the use of system simulation to estimate the performance of alternative management strategies. This type of modelling effort requires a comprehensive approach that involves biological, economic, and institutional dimensions in order to provide integrated guidelines for renewable resource management (Ervik et al., 1981; Walters, 1980).

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This type of models would result in what Anderson (Op. cit) calls "bioregunomic" models of fisheries.

(iii) Models describing actual operations of individual elements of the fishing industry ashore and at sea.

It should be mentioned, however, that a balanced combination of "reductionist" and "holistic" approaches[2] may allow the possibility of integrating biologic, economic and institutional factors needed to approach reality in the modeling effort.

## Study Objectives

The major objective of this study is development of a comprehensive model that integrates biological, economic and institutional factors using a system simulation approach. Research results are intended to provide guidelines to decision-makers responsible for managing ocean fisheries over time. Also, the resulting simulation model may be of interest to the academic community interested in renewable resource modeling.

In order to achieve the main objective, this research effort involves: (1) development of a simulation model of the red grouper fishery which specifies the biological, economic and institutional factors which may determine the

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2 "Reductionists" advocate for the use of partial and highly specific modeling, while those that use the "holistic" approach advocate for a comprehensive representation of reality.

performance of the fishery over time, and (2) simulation of performance criteria such as:

(i) Net revenues received by different groups of fishermen over time.

(ii) Income and employment levels of coastal communities over time;

(iii) Sea food availability in coastal rural communities.

(iv) Level of fish biomass over time;

(v) Fish export revenues.

Given the above stated objectives, the following section discusses the research approach used in this study.

## Research Approach

In order to achieve the above stated study objectives the research approach used in this study involved the following activities.

(i) Review the literature on fish population dynamics, especially for the red grouper in the Gulf of Mexico;

(ii) Review literature on surplus yield and bio-economic models as well as dynamic pool models of fisheries. Also, review available regulatory schemes for ocean fisheries management.

(iii) Build a system causal diagram representing biological, economic, and resource management subsystems specifying interface variables that link the overall model;

(iv) Specify system implicit form equations;

(v) Interview decision-makers from the Ministry of Fisheries to identify their objectives and explore their alternative policy options.

(vi) Collect data from primary and secondary sources to estimate parameters and specify the fishery system of explicit equations.

(vii) Build block diagrams to represent the red grouper fishery and specify the corresponding set explicit equations.

(viii) Develop a mathematical model for the fishery.

(ix) Develop a computer program that represents the specified mathematical model.

(x) Conduct stability analysis.

(xi) Conduct sensitivity analysis.

(xii) Apply Monte Carlo analysis to obtain a set of statistics which provides an estimate of uncertainty in system performance.

(xiii) Analyze model results.

(xiv) Validate the model.

(xv) Run the model using different resource management strategies and analyze resulting performance.

(xvi) Derive conclusions and recommendations.

The above activities are discussed in greater detail in Chapter III, which deals with research methods.

## CHAPTER II
## REVIEW OF THE LITERATURE

In order to build a comprehensive model of the red grouper fishery of the Peninsula of Yucatan, it was necessary to review the literature dealing with the biology and population dynamics of the resource, the economic and institutional factors that affect fishermen behavior, and major approaches used to model ocean fisheries. To accomplish this, the following set of topic areas are discussed in this chapter: (1) Population dynamics and biology of the red grouper, (2) The surplus yield approach, (3) Bioeconomic models of fisheries, (4) Fisheries management and regulation, and (5) Fisheries dynamic pool models.

### Population Dynamics and Biology of the Red Grouper (Epinephelus Morio)

There are numerous and diverse processes at work in the marine ecosystem, effecting its biotic components in a variety of ways. The major processes effecting the biomass of a given fish species like red grouper (Epinephelus morio) are the following (Laevastu and Larkin, 1981; Pitcher and Hart, 1982):

(i) Growth of individual fish. This process is affected by temperature, availability of proper food and changes with age of the species.

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### Population Dynamics and Biology of the Red Grouper (*Epinephelus Morio*)

There are numerous and diverse processes at work in the marine ecosystem, affecting its biotic components in a variety of ways. The major processes effecting the biomass of a given fish species like red grouper (*Epinephelus morio*) are the following (Laevastu and Larkin, 1981; Pitcher and Hart, 1982):

(1) Growth of individual fish. This process is affected by temperature, availability of proper food and changes with age of the species.

(ii) Recruitment[3]. This process is dependent on biotic factors such as spawning success, size of spawning stock and mortality of eggs and larvae from various causes including predation. It is also a function of non-biotic factors such as currents and physical and chemical conditions of estuaries and coastal lagoons.

(iii) Post-larval and juvenile fish predation by other species and by cannibalism.

(iv) Mortality from old age, spawning stress and disease.

(v) Migrations including in-migration and out-migration with respect to a given geographical area.

(vi) Predation by other fish species in the red grouper ecosystem.

(vii) Predation by man. Fishing mortality.

In addition, for the purpose of understanding the biotic marine environment, it should be recognized that the variables mentioned above should also be taken into account globally for all species in the regional ecosystem. As Laevastu and Larkin (1981:6) have pointed out:

> Although populations of some may decrease while others increase with time, the standing stock of the total biomass of finfish in a given region fluctuates relatively little. The total biomass is determined by the total availability of phytoplankton, zooplankton, and benthos as the bulk food and determine the so-called "total carrying capacity" of any given region.

---

3 Recruitment of new fish to the exploitable population.

It should be mentioned however, that for the purpose of this study, the model that follows basically takes into account the red grouper fishery. To attempt to include in one model all the biotic and abiotic components of a given regional ecosystem goes beyond the objectives and feasibility of building a comprehensive model that also takes into account economic and institutional factors. Nevertheless, it could have been desirable, if data were available, to model the by-catch component (incidental catch) of the red grouper fishery. This by-catch includes species such as yellowtail snapper (Ocyurus chrysurus) and white grunt (Haemulon plumieri).

Concerning the specific characteristics of the red grouper of the Gulf of Mexico, Rivas (1970) and Solis (1969) have published that this fish species is probably the most abundant and commercially important grouper in the Gulf of Mexico. The red grouper, which is called "mero" in Mexico, "cherna americana" in Cuba, "red grouper" and "sea bass" in the U.S., lives primarily in the rocky and coral reef bottoms of the continental shelf. Its center of abundance is Florida and Yucatan's continental shelves (Moe, 1969). According to Rivas (1970), its average weight is 6.6 pounds with the largest specimens weighing up to 38.5 pounds.

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Habitat

The red grouper is an important member of the benthic, sublittoral community of the eastern Gulf of Mexico. It is found only on rocky and reef bottoms within depths of 10 to 400 feet. It frequently occupies crevices, ledges and caverns that are formed by the rugged limestone reefs. These reefs normally extend 2 to 8 feet above the sand and shell bottom (Moyle and Cech, 1982; Moe, op. cit.). The location dependence of red grouper to hard bottoms or substrates has been also pointed out by Smith (1961).

Spatial and Temporal Distribution.

For resource analysis purposes, the distribution in space and time of red groupers is an important input for delimiting the study region as well as for the modeling process. It has been reported that seasonal distribution of groupers in the Yucatan continental shelf exhibit a local migratory pattern from east to west during summer and fall and from west to east during winter and spring. This seasonal distribution might be caused by inflows of cold waters comming from the Yucatan Channel. Analysis of age composition of the catch show two distributional gradients: one, from west to east where larger groupers are found in the eastern part of the shelf, another, showing juveniles in shallow waters and adults in deeper waters. (Valdez and Padron, 1980; Garcia and Miranda, 1975; Rivas, 1970).

Depth Distribution. Studies conducted by Rivas (1970) of the BCF Exploratory Fishing and Gear Research, found that red grouper occurs in the northern Gulf in a depth range of 4 to 62 fathoms with a mean depth of about 22 fathoms. In this area about 70% of the records extend from 13 to 31 fathoms. In the southern Gulf (as discussed in Study Region section), the range extends from 2 to 58 fathoms, with a mean depth of 29 fathoms. In this area 70% of records extend from 25 to 33 fathoms. This fish distribution was also pointed out by a study made in the Campeche Bank of the Peninsula of Yucatan (Doi, Mendizabal and Contreras, 1981).

Seasonal Abundance. As with most fisheries, seasonal fluctuations of water temperature cause seasonal occurrence of red groupers in the Gulf of Mexico. The above mentioned studies found that temperature fluctuations in the Gulf do not reflect four marked seasons, but basically two major ones: the cold season (November through April) and the warm season (May through October).

With respect to the southern Gulf, Jarvis (1935) stated that in the Campeche Bank, the biggest of the grouper catch, including red grouper, is made between October and April. Carranza (1959) has pointed out that off the coast of Quintana Roo (in the Peninsula of Yucatan), the greater catches are made during December and January.

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Temperatures and Occurrence of Red Grouper. Fish occur at different temperature ranges according to season. In the northern Gulf, during cold season, bottom temperatures at mean depth of 22 fathoms range from 61°F to 65°F. During warm season, temperatures range from 63°F to 84°F with mean 67°F. In the southern Gulf, during cold season bottom temperatures at mean depth of 29 fathoms range from 73°F to 78°F with a mean of 76°F. During warm season, temperatures range from 68°F to 82°F with a mean of 77°F (Rivas, 1968).

Reproduction, Recruitment and Growth

According to a study of the biology of red grouper, Moe (1969) found that this fish species is a protozynous hermaphrodite. Information concerning sex, aging and growth of red grouper presented in Moe's paper provided relevant data for the population dynamics subsystem developed in this study.

It was also found that recruitment occurs in the northern Gulf when young red groupers leave the near shore reef environment at about 30 cm of length at 3 years of age corresponding to attainment of sexual maturity. Length frequency distributions taken in the Campeche Banks fishing peaks at about 30 cm and sharply declines at 42 cm. This indicates that the Mexican Fishery is composed primarily of 1 to 3 year old fish on the near shore banks and excludes the older, large fish in the offshore deeper waters (Bardach, 1958; Solis, 1969). Therefore, recruitment of red grouper to the fishery in Yucatan's continental shelf occurs at age one.

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Chaves and Arreguin (1986) estimated recruitment to the spawning stock at age three and provided upper and lower bounds to their estimates. This recruitment interval is presented as follows:

$R \pm 7.677$

$R = 33.09 \times 10^6$ organisms

Where: R = Average Recruitment

Concerning growth, parameters have been estimated for red grouper using Von Bertalanffy's growth equation by a number of authors. The estimated equations are presented as follows (Moreno, 1980:12).

Doi et al.(1981):

$L=80.2 \quad 1-e^{-0.159(t+1.21)}$ (cm) $\qquad W=0.0000138L^{3}$ (kg)

Moe(1969):

$L=67.2 \quad 1-e^{-0.179(t+0.499)}$ (cm) $\qquad W=0.0000366L^{2.9294}$ (kg)

Muhlia (1976):

$L=928.04 \quad 1-e^{-0.112(t-0.09)}$ (mm) $\qquad W=0.00014791L^{2.5895}$ (g)

Where:

L = Length

W = Weight

Predation and Fishing Mortality

Doi, Mendizabal and Contreras (1981) estimated total mortality to be 48% for the red grouper of the Campeche Bank. No predation mortality information was found for this species.

With respect to fishing mortality, factors that determine the levels of fishing effort and corresponding fish catch are discussed in sections dealing with open access and regulated fisheries. In both of the above mentioned reports, fishing mortality was estimated in the interval of [.15 to .24]. The available information concerning natural and fishing mortality suggests the need for estimating both types mortalities for each age cohort in the population structure, in order to conduct meaningful "cohort survival analysis".

Stock Assessments

There are a number of total biomass estimations available for the Campeche Bank (Klima, 1976; Doi, Mendizabal and Contreras, 1981). The latter provided a figure of 138,000 metric tons. This estimate was also reported in the second joint meeting of the West Central Atlantic Fisheries Commission (Comision de Pesca para el Atlantico Atlantico Centro-Occidental, 1981:41) It should be mentioned that for the purpose of this study, simulation runs will be conducted using the figure mentioned above as biomass initial value.

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## Fisheries Modelling

The literature on fisheries modelling deals with three classical approaches: (1) The surplus yield approach, (2) The bioeconomic approach, and (3) The dynamic pool approach.

### Surplus Yield Model

This method involves a black box approach to modelling which is concerned only with inputs and outputs to the biomass of fish population. Biomass regeneration, considered as a single process, is the basis of the first and simplest type of model, called surplus yield, surplus production, or the Schaefer model (1954).

Versions of the surplus yield model differ in their choice of exact form of the rate of change of biomass in the population (Pitcher and Hart, 1982). The most common forms are those developed by Schaefer, Fox and, Pella and Tomlinson. Schaefer's (1954) classical model used logistic growth, an S-shaped curve, similar to Graham's (1935) model. Schaefer growth of biomass is presented in equation (1):

$$\frac{dB(t)}{dt} = k\, B(t)\, (1 - (B(t)/B_{\infty}) - C\,(E,q) \qquad (1)$$

Where:

$B(t)$ = Fish biomass in time t.

$B_{\infty}$ = Maximum biomass which could be supported by the environment.

$k$ = Biomass growth rate

$C(E,q)$ = Fishing mortality rate

$E$ = Fishing effort.

q = Catchability coefficient

Fox (1970) used the Gompertz curve. Fox's growth equation is the following:

$$\frac{dB(t)}{dt} = k\ B(t)\ (-\ln\ (B(t)/\ B_{\infty})) - C(E,q) \qquad (2)$$

Pella and Tomlinson (1969) developed a model version whose growth in biomass was continuously variable in shape, which involves fitting an additional parameter, m.

$$\frac{dB(t)}{dt} = k\ B(t)\ (1 - B(t)^{m-1}/B_{\infty}) - C(E,q) \qquad (3)$$

According to Pitcher and Hart (1982:225): "It is crucial to realize that predictions of maximum and optimum yield from these types of models depend entirely on the exact form of the growth function, so it is very important to choose the one which best resembles the growth of the stock in question."

<u>Advantages</u> <u>and</u> <u>Limitations.</u> The major practical advantage of surplus yield approaches is that they require only catch and effort data, the type of information accumulated over many years in most fisheries. As Pitcher and Hart (1982:232) have pointed out:

> MSY (Maximum Sustainable Yield) is seductively easy to calculate, in fact no biologists need be employed in the fishery and managers do not even have to get their hands and feet wet in examining actual fish. However just as the assumption of a single biomass regeneration function provides the surplus yield approach with its attractive simplicity and practical advantages, it is also the root of its major and dangerous disadvantage.

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The major shortcoming of this approach is the result of ignoring real biological processes which actually generate biomass through time. It is well known that changes in biomass are made up of contributions from the separate but interacting processes of recruitment, growth and mortality, which were pointed out at the beginning of this Chapter. In addition, population processes may be altered by different age structures in the fish population and age structure is also ignored by the surplus yield approach (Jensen, 1973).

Assumptions. Some of the most relevant assumptions involved in the "Surplus Yield Model" are the following (Tyler and Gallucci, 1980; Zubey and Jones, 1978):

1. The model deals only with equilibrium yield, meaning that stock structure and age distribution of the catch have stabilized at the current level of fishing effort. Therefore, high rates of change in fishing effort levels will invalidate application of the model.
2. Biotic and non-biotic factors affecting resource ecosystem are assumed constant.
3. The rate of recruitment and the natural mortality rate are assumed constant regardless of stock size.
4. The rate of population growth is assumed independent of the age composition of the population.
5. The time lag between spawning and recruitment of progeny to the catchable stock is not involved in the model.

Extensions of the Surplus Yield Model. There have been a number of extensions to Schaefer's method, some of which are

summarized as follows:

-Pope (1972) extended the surplus yield model in order to deal with multi-species fisheries, where multiple species are being caught in the same fishery at the same time.

-Walter (1973) pointed out that the rate of change in biomass now was likely to be influenced by past biomass just as much, or even more, than by current biomass level.

-Walter (1978) made a further important advance by considering the actual fishing effort which should be used when variable recruitment is incorporated in the Schaefer Model.

-Beddington and May (1977) and Schnute (1977) included environmental randomness in the surplus yield model.

-Hilborn (1979) and Uhler (1980) have compared Schnute's method with the standard estimation techniques using simulation approaches. They found that Schnute's method is the least likely to be biased.

As can be observed from the above section, neither the original model nor current extensions of the surplus yield method, have developed the fishing effort function, C (E,q), more than specifying it as the result of constant fishing effort, E, and the catchability coefficient, q, using a particular gear.

Bioeconomic Models of Fisheries

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It should also be mentioned that another common denominator in the fisheries economics literature is recognition of the failure of market institutions to utilize common property resources in a way which maximizes individual benefits without exhausting the fishery itself (Gordon, 1954; Crutchfield, 1969; Clark, 1976; Anderson, 1977; Bell, 1978).

In the discussion that follows, both open access equilibrium and regulated equilibrium are analyzed to illustrate the need for government intervention in the management of ocean fisheries.

<u>Open Access Equilibrium.</u> In models of market-oriented free enterprise economies, the fishing industry is characterized by the following assumptions:

(i) Fish are homogeneous

(ii) There are numerous vessels and buyers of fish, and

(iii) Investment required to enter most fisheries is be in equilibrium. Biological equilibrium of the fish stock is attained when additions through individual growth and recruitment are balanced by reductions through natural and fishing mortality. Economic equilibrium of the fishery is achieved when revenues equal cost such that there is no incentive for fishing boats' entry or exit. The two equilibrium conditions are interrelated because fishing mortality affects stock growth and because stock size affects catch per unit of effort, and consequently revenue per unit of effort (Anderson, 1984; Clark, 1985).

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(i) Fish are homogeneous

(ii) There are numerous vessels and buyers of fish, and

(iii) Investment required to enter most fisheries is relatively small.

From the above assumptions, in Figure 1, the demand and supply for fisheries products is presented as follows:

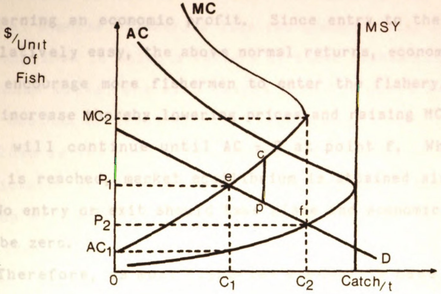


Figure 1. Open Access Equilibrium. (Adapted from Bell, 1980)

The intersection of DD, the demand curve, and MC, the marginal cost curve (Point e) is of particular interest. At that point, price is $P_1$ and the corresponding total revenue (TR) is $P_1C_1$. At that level of harvest, average cost is $AC_1$ and $TC_1 = (AC_1)C_1$. Therefore, TR>TC and consequently at point e fishermen would be earning an economic profit well above normal. However, at point e, society through individual action has allocated units of effort so that marginal cost producing the last fish is equal to what consumers are willing to pay.

Any production to the right of e is sub-optimal, since the marginal cost of producing the last fish exceeds the price consumers are willing to pay, or that c>p. Point e is called MEY or Maximum Economic Yield.

It should be mentioned, however, that MEY is unstable with a common property resource since TR>TC and fishermen are earning an economic profit. Since entry to the fishery is relatively easy, the above normal returns, economic rent, will encourage more fishermen to enter the fishery. Catch will increase thereby lowering prices and raising MC and AC. Entry will continue until AC = D at point f. When this point is reached, market equilibrium is attained since TR = TC. No entry or exit should take place and economic profits will be zero.

Therefore, as most fisheries economists have pointed out, the free enterprise system will lead in the case of common property resources to overproduction and consequently to an excess number of fishermen and vessels in the fishery. As a result, with this excessive fishing effort the fishery may reach levels of exhaustion and in some cases to depletion of the fish species.

It should be mentioned that open access equilibrium can also be analyzed when considering multispecies fisheries, like in the case of the red grouper (*Epinephelus morio*) fishery of the Peninsula of Yucatan that also involve substantial amounts of catch of white grunt (*Haemulon plumieri*) as well as yellow tail snapper (*Ocyurus chrysurus*), among other species.

Open Access Equilibrium of Multispecies Fisheries. May et al.(1979), Anderson (1977), Pauly (1979), Rothschild (1967) recognized that in some fisheries the gear comes into contact with stocks of different species and, as a result, a mixed catch is obtained. This is usually the case in tropical demersal fisheries like red grouper using handlines and longlines in which a variety of other fishes (like those mentioned above) are also caught from the coral reefs and rocky bottoms of tropical ocean ecosystems.

This is the case of a traditional fishery of the Port of Chicxulub in the Peninsula of Yucatan, which consists of a group of boats[4] with non-discriminatory gear, harvesting fish from a number of independent species such as red grouper, yellow tail snapper, and white grunt, among others.

The quantity caught of either type of fish depends upon the effort used the size of the respective populations, and the degree to which the fish species associate with one another.

Each species may have a normal <u>population equilibrium curve</u> as represented in Figure 2.

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[4]Usually of 1-3 tons of capacity and 18 to 24 feet of length.

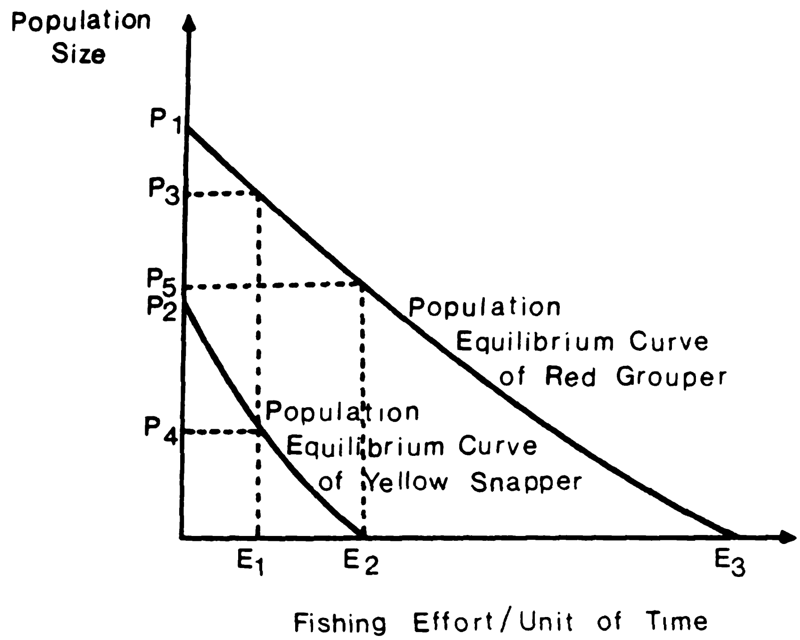


Figure 2. Population Equilibrium Curves of Multispecies Fisheries.

Applying Anderson's (1977) analysis of multispecies fishery to this case, we can observe from Figure 2 the following:

(i) Without predation by man, red grouper will have a natural population equilibrium size of $P_1$. Similarly, the natural population equilibrium curve of yellow snapper will be $P_2$.

(ii) With fishing effort $E_1$ a new equilibrium will be reached, at lower population size, like $P_3$ and $P_4$

respectively.

(iii) When fishing effort reaches $E_2$, the stock size of yellow snapper will be zero but that of red grouper will be $P_5$.

(iv) When fishing effort reaches $E_3$, the population of red grouper will also be destroyed.

It should be pointed out that Anderson's analysis assumes equal catchability of the two species. The downward sloping shape of the population equilibrium curve reflects the resulting smaller levels of fish population as fishing effort increases.

In the same manner we can also derive the _sustained yield curves_ for each species, using the _surplus yield approach_ discussed in the preceding section. The total sustainable yield from the fishery is the sum of those from both species. In Figure 3 we can observe that with fishing effort $E_1$, the equilibrium yield of red grouper will be $Y_1$. With this same level of effort, traditional fishermen will also be harvesting $Y_2$ units of yellow snapper. Consequently, the total sustainable yield at this level of $Y_1$ and $Y_2$. The total revenue earned will depend on the relative prices of the two species.

The fishery will reach maximum sustainable yield, MSY, at the level of effort where the sum of the individual sustainable yield is a maximum.

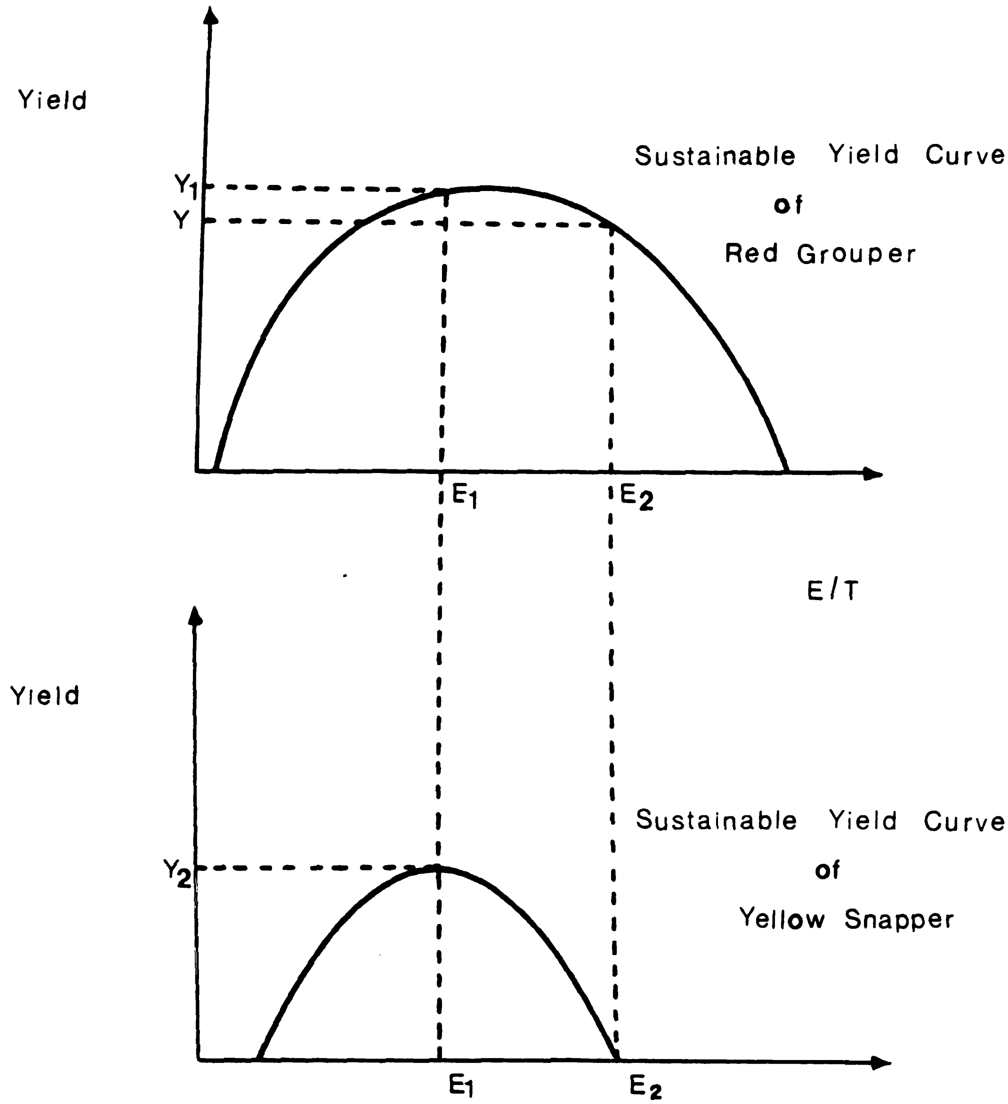


Figure 3. Sustainable Yield Curves of the Two Species
Source: After Anderson (1977)

It should be mentioned, however, that to operate at MSY in a multispecies fishery makes even less sense than in fisheries of a single specie, because that criteria does not take into account the relative market values of the two species.

This consideration leads to the representation of the Maximum Economic Yield criteria, MEY, which would take into account the relative prices of both red grouper and yellow snapper.

As a result, we obtain a sustainable total revenue curve for the fishery by the vertical summation of the revenue curve of two species. This is represented in Figure 4. The shape of this curve depends upon: (1) the shape of the individual yield curves and (2) the relative prices of the two types of fish.

From Figure 4 we see that the shaded area corresponds to the revenue earned from yellow snapper[5]. Beyond fishing effort $E_2$, yellow snapper is exhausted and consequently revenue is obtained only from red grouper.

The <u>open access bioeconomic equilibrium</u> of the fishery is achieved at that level of effort where total sustainable revenue,TR,equalstotalcost,$TC_1$.

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[5]Below the shaded area the revenue is derived from the grouper catch.

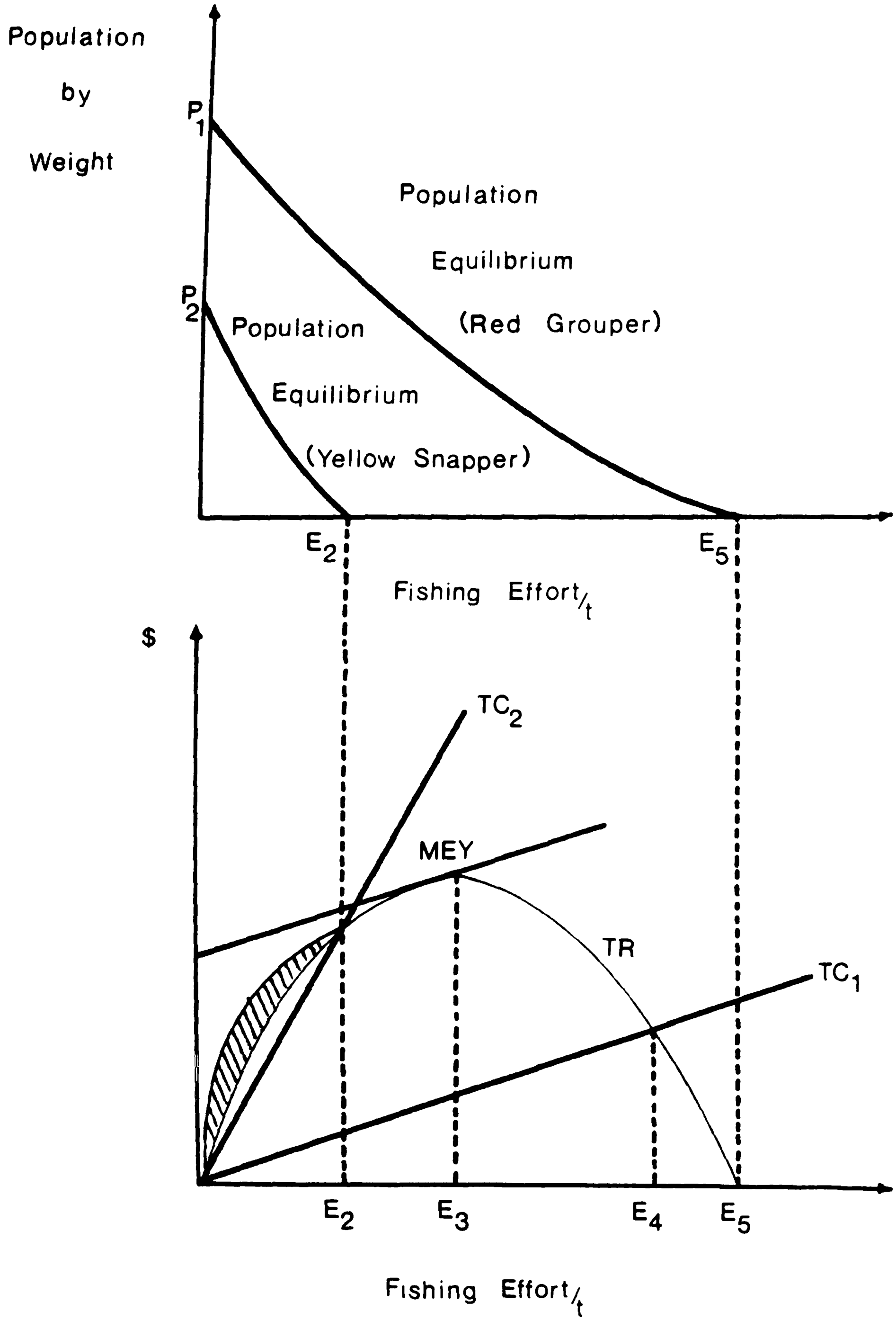


Figure 4. Maximum Economic Yield of Multispecies Fisheries
Source: Adapted from Anderson (1977)

In a multispecies fishery, this equilibrium corresponds to fishing effort $E_4$ (See Figure 4), which is greater than level $E_2$. This results in the elimination of the yellow snapper fishery. Consequently, open access equilibrium may lead to the <u>depletion of the smaller stock</u> in a multispecies fishery. In addition, red grouper (the bigger of the two populations) will also be harvested beyond the point of maximum economic yield[6] $E_3$. Fishing effort will be expanded to the point where TC equals TR which correspond to effort $E_4$.

It should be mentioned however, that in the case in which the relative price cost structure is such that the cost intersects the revenue curve to the left of $E_2$, the open access fishery will utilize both species.

On the other hand, if a cost curve still intersects the revenue cost to the right of $E_2$, the use of <u>government regulations</u> that shift the total cost curve to the left up to TC (see Figure 4) may cause that: (1) the fishery utilizes the two species, and (2) the depletion of the smaller stock will be prevented.

In addition to the analysis presented above, Wilson (1982) has discussed an institutional approach to the complexities of multispecies fisheries, pointing out the relevance of transactions costs and the form of organization.

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[6]At this point, the slopes of the TC and TR curves are equal, and consequently marginal revenue equals marginal cost.

It should also be mentioned that a number of authors have applied the Lotka-Volterra model to multispecies fisheries to determine the possibility of existence of predator-prey relationships as well as competition. All of these analyses indicate the need for management strategies that take into account the high diversity nature of tropical demersal ecosystems.

The need for government intervention to avoid the "tragedy of the commons" which is more dramatic in the case of multispecies fisheries, leads the discussion to the next section which deals with recent theoretical developments of what is called "regulated equilibrium."

## Regulated Equilibrium

Recognition of the need for regulating commercial fisheries to overcome market failure involved in open access equilibrium has resulted in a number of research efforts in the fisheries economics literature (Hannesson, 1978; Crutchfield, 1979; Clark, 1980; Anderson, 1983).

In his "Preliminary Theory of Fisheries Regulation Development," Lee G. Anderson (1983:2) pointed out that:

> A theory of regulation development should focus on various aspects of the regulatory process so as to describe what can be called a regulatory equilibrium position. Given the structure of prices and costs, the population dynamics of the fish stock, and ease of exit and entry, this equilibrium will be a function of the regulation techniques used and the way they are enforced.

Even though Anderson recognizes that the important aspects of the regulatory equilibrium will be the level of output, the efficiency of production and the administrative output, the efficiency of production and the administrative and enforcement costs, he fails to recognize what Professor Schmid (1978) has defined as "substantive performance" of alternative policy actions. Substantive performance is evaluated in terms of the distribution of wealth effects of available public choices.

But before getting into the discussion of criteria for evaluating an ocean fisheries regulatory system, it seems appropriate to list some other goals that a society may wish to attain in fisheries management:

(i) Maintenance of balance of payments equilibrium

(ii) Reduction in structural unemployment

(iii) Provision of recreational activities

(iv) Regional and community nutritional improvements,

The above mentioned desired outcomes of fisheries management may be used as system performance variables in addition to achieving bioeconomic equilibrium through time.

### Fisheries Dynamic Pool Approach

In addition to the surplus yield and bioeconomic models discussed above for both independent and multi-species fisheries, more complex models have been developed to represent the dynamic nature involved in the management of renewable resources.

The dynamic pool approach has been characterized basically by (1) the separation of processes which alter fish population biomass to be described explicitly as components in the model, and (2) the population age structure.

The simplest formulation of the theory of fishing (Russell, 1931 - from Cushing, 1968), clearly identified the four main processes taking place in the fishery. Two of these, recruitment of new individuals (R) and tissue growth (G), added to stock biomass, whereas the other two processes, natural mortality (M), and mortality from fishing (F), reduced stock biomass.

Pitcher and Hart (1982:251) developed a diagrammatic model of a fishery with the loss and gain rates correctly identified (Figure 5). The solid lines of Figure 5 represent _flow_ of biomass and broken lines represent _influences_ which alter the rates of change. It should be mentioned that net migration has been included in the diagram to make it more realistic.

Each of the five processes in fishing could be broken down or decomposed into submodels, and a major issue in the modeling process is to decide how far this decomposition should go. It can be observed that the "recruitment submodel" could be elaborated to include egg and fry survival and growth and survival of the prerecruit stages. Concerning recruitment of tropical demersal resources, Pauly (1986) suggests that one consider spatial differences in recruitment and seasonal fluctuations of recruitment. Natural mortality, representing losses to predators, senescence and disease, could further depend upon predators' feeding habits, pollution and spawning stress.

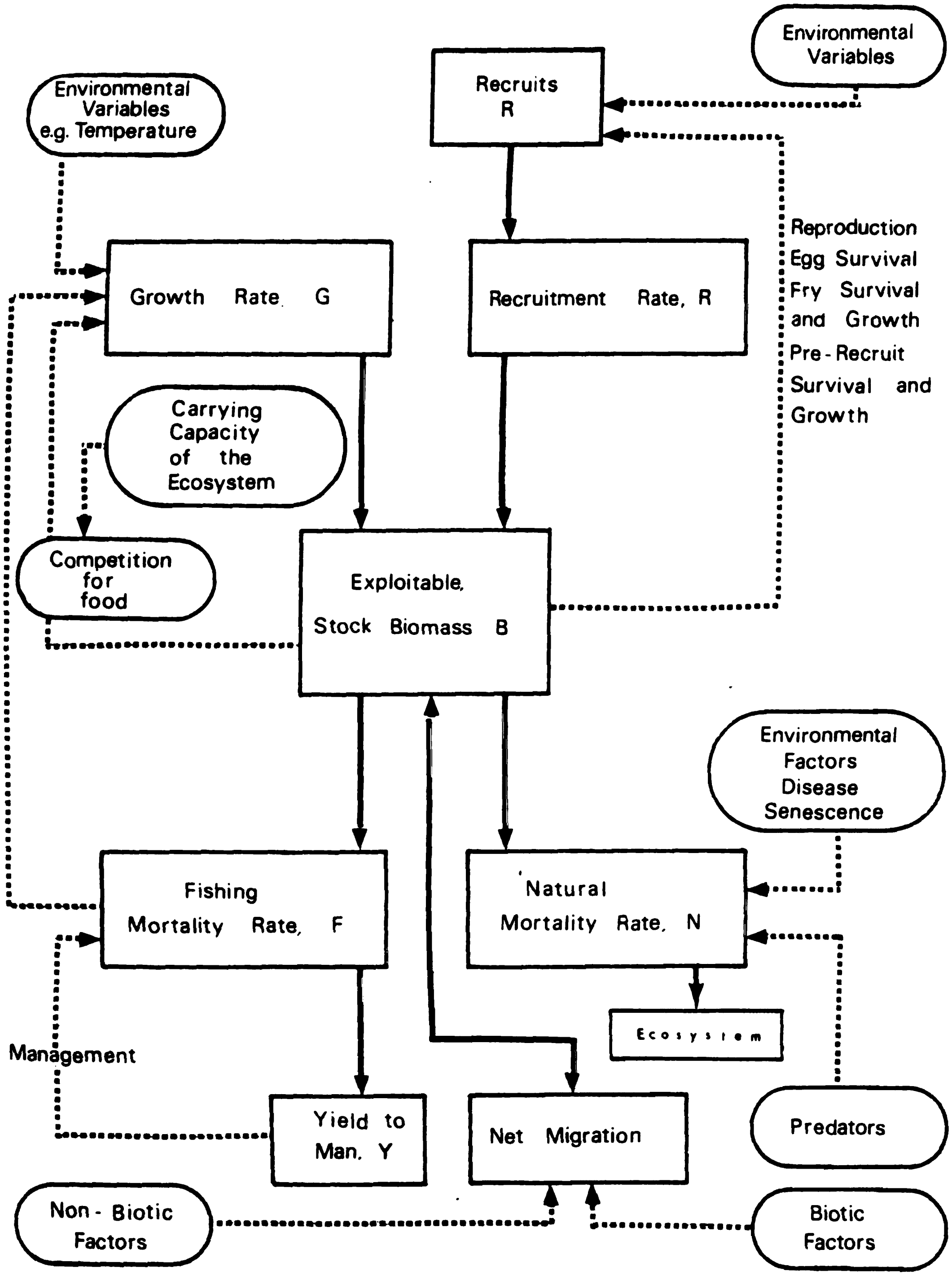



Figure 5. Diagram of the Main Processes Modelled by the Dynamic Pool Approach to Fisheries Management. Source: After Pitcher and Hart (1982).

The fishing mortality rate could also constitute a sub-model by making it a function of time varying fishing effort of different groups of fishermen which use different technology and consequently involve various levels of catch per unit of effort, CPUE. In addition, the number of vessels in the fishery may vary over time, because of the entry and exit mechanisms that take place when TR $\neq$ TC.

Net migration could also be further decomposed when making it a function of biotic as well as non-biotic factors which determine the spatial and temporal behavior of species.

The dynamic pool models are based on the initial works of Beverton and Holt (1957) and are basically presented as a set of four integral equations, which lead up to a function estimating the yield from the fishery.

-The first equation states that the total numbers of fish in the stock in time t, N(t), are given by the integral of numbers at all ages i:

$$N(t) = \int_{tr}^{t} N_i(\tau)\, d\tau \qquad (4)$$

Where:

tr = age of recruitment to the fishable stock.

t = the maximum age of fish in the stock.

$N_i(t)$ = numbers of fish of i different ages.

- A similar integral gives the numbers caught, C(t), as:

$$C(t) = \int_{tr}^{t} F_i(\tau)\ N_i(\tau)\ d\tau \tag{5}$$

Where: tr is the actual age at first capture by the gear used in the fishery.

$F_i(t)$ is the instantaneous rate of fishing mortality on age i.

- The biomass, B(t), of the fish stock can be calculated as:

$$B(t) = \int_{tr}^{t} N_i(\tau)\ W_i d\tau \tag{6}$$

Where: $W_i$ is the mean weight of fish aged i.

- The total yield, Y(t), from the fishery can be expressed as:

$$Y(t) = \int_{tr}^{t} F_i(\tau)\ N_i(\tau)\ W_i\ d\tau \tag{7}$$

Equation (4) is the general yield equation underlying all dynamic pool models.

In order to solve equation (4) analytically, Beverton and Holt had to make a number of simplifying assumptions and choose suitable functions for F(t), N(t), and Wi.

Assumptions. Among the assumptions, the one that must be relaxed is concerned with assuming constant fishing mortality. It fails to account for forces that may influence harvesting behavior of fishermen over time.

This assumption might have severe effects on policy impact analysis of fisheries management programs, because:

(1) In the case of marine commercial fisheries one of the most important controllable variables within the model is the fishing mortality or harvesting rate. This implies that when a comprehensive simulation model is run to measure impacts of different policy instruments, _it may provide misleading outputs_ as a result of not taking into account:

   (a) _environmental attitudes_ of different groups of fishermen regarding their intertemporal preferences in the use of fish resources.

   (b) The _different types of technology_ used by the different groups of fishermen.

   (c) The _rates of response_ of fishermen communities to institutional changes and innovations.

(2) The _socio-economic impact analysis_ of different policy instruments cannot be carried on efficiently when the social dimension of a model is highly aggregated if not neglected. This type of analysis is especially useful in countries where the government is playing an increasing role in controlling the use and development of renewable natural resources. For instance, it is fundamental to be able to measure the distribution of income and employment effects of alternative courses of action.

Extensions of the Beverton-Holt Model. There have been extensions to the Beverton-Holt model, some of which are summarized as follows.

-Clayden (1972) simulated the fishing effort and catches of 15 coastal nations over 23 years. Ten dynamic pool models were built and run, each of which had 15 sub-models representing the fishing efforts of each of the fleets. Fishing mortality was assumed proportional to effort and constant over all ages in the fishery.

-Garrod and Jones (1974) developed a simulation model for the Arcto-Norwegian cod fishery describing growth by a conventional von Bertalanffy curve but included a Ricker recruitment equation.

-Walters (1969) also used a Ricker curve in the simulation of the Arctic cod stock. The Ricker curve used by Walters was not as complex as the version used by Garrod and Jones. Wilson (1979) used a randomized recruitment sub-model on a freshwater seine and trawl fishery.

-Swartzman et al. (1983) developed a fisheries management algorithm which included an age structured stochastic recruitment sub-model. This effort provides a significant aid in the analysis of fisheries that exhibit substantial environment-dependent recruitment variability.

Smith et al.(1982) built a simulation model that incorporated the human dimension through a decision-making feedback mechanism. This modeling effort included some of the biological and social factors that affect fisheries resources and their use over time.

## Fisheries Management Alternatives

Fisheries management involves a decision-making process that faces a set of regulatory problems that could be classified as follows:

### Regulating Catch Composition

In open access fisheries (unregulated fisheries) fish may be harvested even when they are too small, or fishing in certain locations at certain times may interfere with spawning and recruitment, thereby reducing yield that could be achieved with discriminating fishing, even with the same amount of effort. As a result, fisheries agencies in most coastal countries have imposed: (1) minimum mesh sizes and other controls on gear selectivity, (2) introduced closed seasons and (3) restricted fishing in certain areas like estuaries, to protect and enhance the productivity of fish stocks (Pearse, 1980).

### Regulating Catch Size

The determination of the *desired level of catch* is an important concern to fisheries management. It should be mentioned however, that in addition to the Maximum Sustainable Yield (MSY), and the Maximum Economic Yield (MEY) criterias discussed above, authorities in Canada, United States and other coastal countries have adopted the "optimum yield" criteria. The latter criteria has been developed to provide the maximum benefit to the nation in accordance to biological, economic and socio-cultural considerations.

In order to control catch size, coastal nations have usually adopted a variety of regulations that affect _total amount of fishing effort_. But, to effectively manipulate control variables to attain a desired level of catch, it seems appropriate to first determine variables that determine total fishing effort and then consider the main types of regulations that affect those variables.
As recognized by Anderson (1977), fishing effort is a function of:

(i) The _number_ of fishing boats
(ii) Their individual _harvesting power_ (type of fishing gears)
(iii) Their _spatial distribution_, and
(iv) The total _time_ spent fishing.

Given that the fishing effort is a function of the above mentioned variables, the set of regulations that seem to affect them may be classified as (1) Limited entry of fishery (Rettig and Ginter, 1978), (2) Gear selectivity, (3) Fish quotas, (4) Taxes and/or subsidies, and (5) Restricted fishing areas.

_Maintaining Efficiency in the Fishing Process_

A third source of regulation efforts is related to the concern that most coastal states have of achieving and maintaining economic efficiency in fishing. The problem of _overexpansion_ is often seen as one of too many vessels, but as pointed out be Pearse (1980), "it is only a superficial manifestation of the more fundamental economic problems of excessive employment of labor and capital, and therefore excessively high opportunity cost fishing."

It should be mentioned, however, that whether labor inputs are or are not excessive is also a function of the socio-cultural context of the fishing community. This is the case, for instance, of traditional fishing communities which have a segment of the fishing industry exercising fishing effort for mainly "subsistence" purposes.

Redistributing Wealth

Some countries, such as Mexico, have designed institutional structures to foster redistribution of wealth. This has been done by allocating exclusive property rights on specific fisheries to groups of low income fishermen. In the case of Mexico, this allocation of property rights has fostered collective organizations by requiring fishermen to form fishing cooperatives to be subject to exclusive fishing rights and state subsidies.

Other types of problems in ocean fisheries that have usually called for regulatory schemes include interventions to: (Scott, 1979)

- Protect product quality
- Improve working conditions
- Prevent monopolistic practice

In summary, there are four major sets of government interventions discussed in the literature of fisheries regulations, each of them attempts to solve specific problems of coastal fisheries. An appropriate combination of interventions that regulate the composition and size of the catch, and maintain efficiency in the fishing process may be used to achieve <u>some</u> goals of the regional community. However, as mentioned in the section on regulated equilibrium, there are other desired outcomes or goals that decision-makers may wish to attain such as reduction in structural unemployment, redistribution of wealth, etc. Inclusion of the additional goals as system desired outputs requires that alternative regulatory schemes be evaluated in terms of their <u>impact</u> on those performance variables.

After discussing alternative modeling efforts and management strategies, the following chapter will present a comprehensive simulation model based on the systems simulation approach.

# CHAPTER III

# RESEARCH METHODS

The research approach used in this study is presented through the discussion of the following sections: (1) the study objectives, (2) the study region, (3) the systems simulation approach used for the development of the red grouper fishery model, (4) data collection for parameter estimation, (5) development of mathematical and computer models, (6) sensitivity analysis and model validation, (7) Monte Carlo analysis for the estimation of uncertainty in system performance, and (8) simulation of resource management alternatives.

## Study Objectives

Given the context of the problem, the main objective of this study is the integration of biologic, economic and institutional factors using a system simulation approach to provide an operational simulation model for demersal fisheries resource management. An additional objective involves conducting dynamic impact analysis to simulate the effect of alternative management strategies on a set of performance variables. These include red grouper biomass, fishery yield, net revenues of traditional and modern vessels, direct employment, food availability in coastal rural communities, and export earnings.

The following section discusses the study region selected for this research effort.

## Study Region: Yucatan Continental Shelf

The geographical study region selected for this research project is the continental shelf of the Peninsula of Yucatan. Boundaries of this region involve both political/administrative and ecological considerations (see Figure 6). The area covering this region is consistent with the regionalization developed by the Ministry of Fisheries for planning purposes. There are ten ports included in this region: Celestun, Sisal, Chuburna, Chelem, Progreso (Yucalpeten), Chicxulub, Telchac, Dzilam Bravo, Rio Lagartos and El Cuyo. The major target fish in these ten ports is the red grouper (*Epinephelus morio*). It accounts for 27.9% of the total fish catch in the State of Yucatan (Secretaria de Pesca, 1984). The study region also takes into account the migratory patterns of this species and the fishing grounds most commonly selected by the different types of fishermen of this coastal area.

### Study Region: Fish Distribution

According to Rivas (1970), the depth range in which red grouper is found in the Gulf of Mexico is between 3 to 58 fathoms. In the Southern Gulf, about 70% of red grouper records extend from 25 to 33 fathoms. Juveniles of the red grouper population occur in shallower than the mean depth, while the adult population is usually found deeper than the


Figur

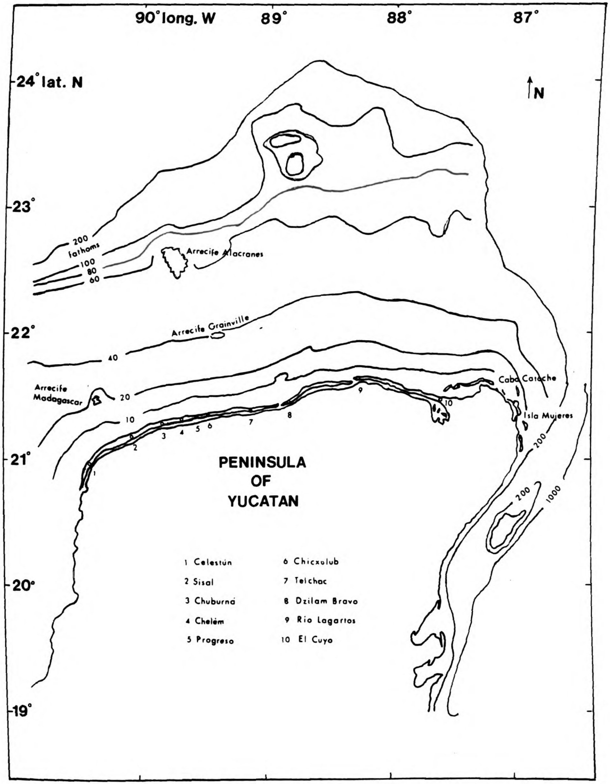



Figure 6. Study Region: Yucatan Continental Shelf.

mean depth. Those weighing less than 3 pounds were recorded in depth of less than 15 fathoms, and those weighing an average of 11 pounds were taken at more than 40 fathoms.

One interesting feature of this study region is the fact that different types of fishermen apply their fishing effort at different depths because of the size characteristics of their fishing vessels. Most traditional fishermen use boats with capacity of 1 to 3 tons and consequently tend to fish closer to the shore (usually at depths of 3 to 15 fathoms, where most of the juvenile population is found) as compared with fishermen organized in cooperatives or private fishermen which own larger and more capital intensive vessels.

### Fishing Effort Characteristics in the Study Region

This study region is characterized as hosting different types of fishermen involving different: (1) sizes of vessels and fishing gear, (2) levels of catch per unit of effort and, (3) age composition of the catch.

The fishermen involved in the red grouper fishery can be grouped by type of technology in two major categories: those who use traditional fishing methods in small vessels (22 to 30 feet long) and those who use capital intensive technology in larger vessels (40 to 75 feet long). Given that these two groups apply different fishing effort, they usually have different catch levels per unit of effort. Currently there are 1500 fishing vessels that have the characteristics of the smaller Type I vessel. However, it is estimated that only approximately 970 are applying their fishing effort to the red grouper fishery. The rest are focusing on other coastal fisheries such as shark, lobster, anchovie, sea trout, snook, king and spanish mackarel, etc.

Concerning the larger Type II vessels, approximately 230 are oriented to the red grouper fishery while the rest are targeting red snapper and shrimp species (Secretaria de Pesca, 1984). A more detailed description of fishing effort by type of vessel is presented in the survey results section of Chapter IV.

The approach selected to study the above described fishery is presented in the following section.

## Systems Simulation Approach

The system simulation approach is a problem-solving process of "obtaining particular time solutions of a mathematical model corresponding to specific assumptions regarding model inputs and values assigned to parameters" (Manetsch, 1982:8-1). Shannon (1975) defines simulation as the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system or of evaluating various strategies for operating the system.

The primary reason for using simulation is that many models cannot be adequately analyzed by standard mathematical techniques such as Laplace transformation (Payne, 1982; Manetsch and Park, 1982). This is usually the case when the interactions between variables are nonlinear or when random effects are inherent in the system.

As recommended by Professor Manetsch (1975) there are a number of basic steps involved in the process of system modeling. They are discussed in the following subsections.

## System Identification

This major step results from linking the statement of needs and a specific statement of the problem to be solved, which was discussed in the above sections and is summarized as follows.

In coastal communities in Mexico, located in the Peninsula of Yucatan, there are mainly two groups of fishermen. One group that could be described as "modern" fishermen (fishermen cooperatives and private sector corporations) who use capital intensive technologies and more complex fishing gear, and another group represented by "traditional" fishermen (fishermen of coastal rural communities) who use small boats and rudimentary fishing gear. The former base their fishing effort using state owned fleets or private sector boats. These are business oriented fishermen having as their major goal profit maximization. The latter group is involved in fisheries primarily for subsistence purposes.

Another important actor in this fisheries community is the federal government represented by the Ministry of Fisheries.

The major goals of the Mexican government concerning the fisheries sector can be described as follows: (Secretaria de Programacion y Presupuesto, 1983:304)

(i) To contribute to improvement of the nutritional levels of the population;

(ii) To generate employment mainly in depressed or stagnant coastal regions;

(iii) To increase the inflow of foreign exchange through exports of fisheries products;

(iv) To promote regional and community development to improve the standards of living of fisheries workers;

(v) To sustain the yield (biologic and economic) of its major fisheries over time.

Both groups of fishermen as well as decision-makers from the Ministry of Fisheries lack information concerning the population dynamics of the red grouper and impacts on the yield of the fishery over time resulting from their fishing efforts and regulations respectively.

Figure 7 identifies the fishing system, including definition of exogenous and controllable inputs, design parameters, and desired and undesired outputs.

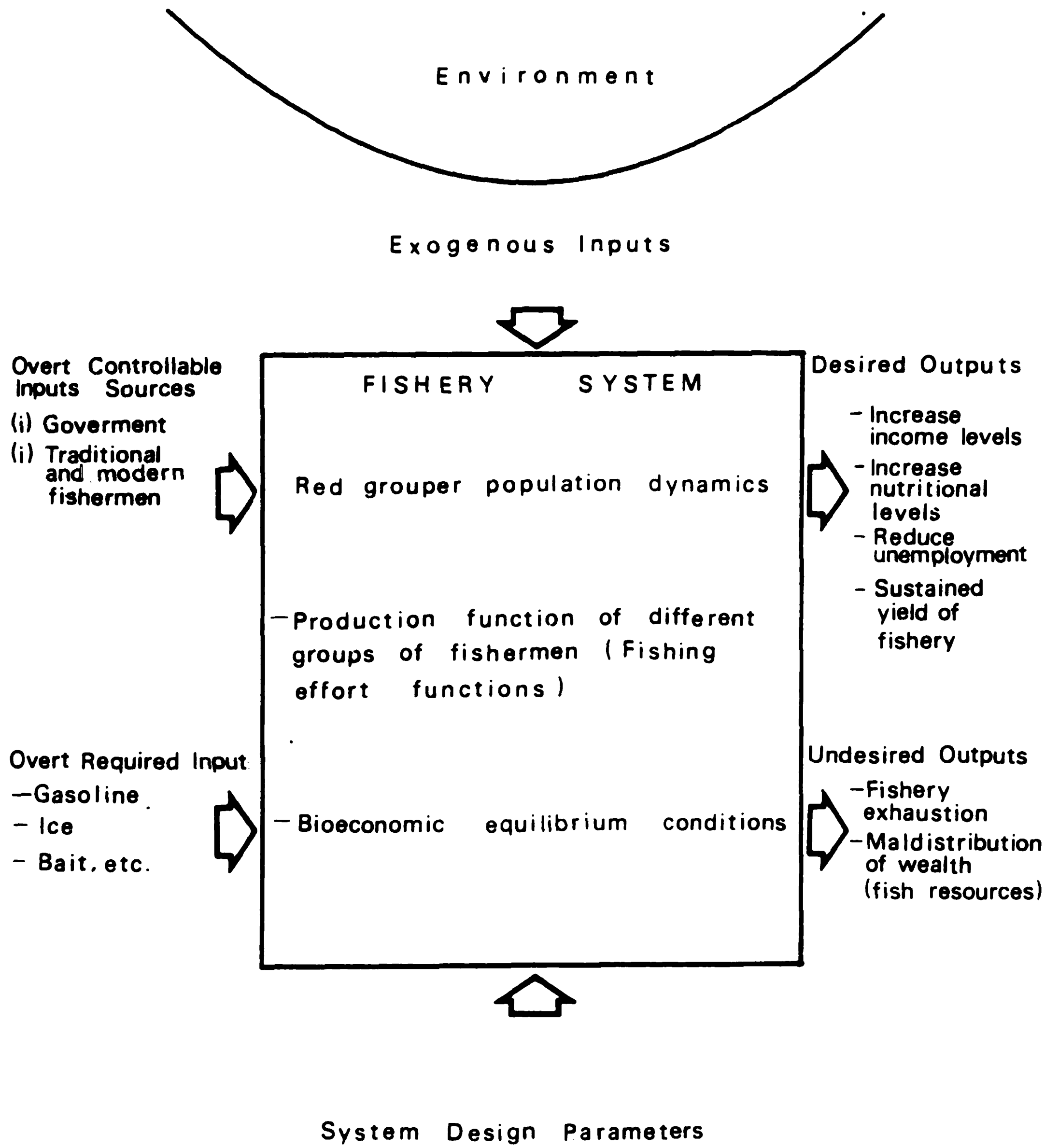



Figure 7. Red Grouper Fishery: System Identification

Desired Outputs. The system desired outputs are the following:

a. Increase local income and employment in the regional community. This desired output is measured in terms of:
   - Direct income effect in the Yucatan fishing community by type of fishermen. Pesos/year
   - Community Employment Level by type of fishermen. Man hours/year

b. Increase community food availability.
   - Community fish availability from traditional fishermen catch. Tons of fish/year

c. Increase profit of both traditional and modern fishermen.
   - Net revenues received by type of fishermen. Pesos/year

d. Increase export earnings.
   - Red grouper export earnings. Dollars/year

e. Sustain the yield of the red grouper fishery over time.
   - Biomass level. Tons/year

Undesired Outputs. The fishery system undesired outputs and corresponding performance variables are the following:

a. Dissipation of economic rent.
   - Economic rent by type of fishing vessel. Pesos/year

b. Exhaustion of the red grouper fishery.
   - Red grouper biomass level. Tons/year

c. Exhaustion of other species resulting from mixed catch.
   - Yellowtail snapper and white grunt biomass. Tons/year.

Environmental (Exogenous) Inputs

a. Weather conditions in the Gulf of Mexico.

- Wind in miles/hour
- Seasonal bottom water temperatures. Celsius degrees.

b. Government budget constraint.

- Fisheries Development Bank budget to finance fishing vessels (pesos/year)

c. Prices of red grouper for local market, processing and export market in pesos/ton and dollars/ton respectively.

Overt (Controllable) Inputs. Includes variables that can be managed during system operation to alter the performance of the system in providing desired outputs.

(i) Ministry of Fisheries

- Regulations affecting the size of fish caught. Minimum size of fish in cm.
- Regulations affecting the amount of fishing effort. Maximum number of fishing vessels/year with specific types of fishing gear.
- Allocation of the Ministry of Fisheries budget for: (1) financing vessels and fishing gears, (2) research and extension programs, (3) public investment in coastal infrastructure. Pesos/year.
- Direct investments in fishing fleets. Pesos/year.

(ii) Traditional and Modern Fishermen

- Amount of time dedicated to the fishery. Days/year
- Type of fishing gear used.

- Exit and entry to the fishery.
- Number of fishermen per boat. Man-hours/year
- Capability of changing to another fishery if necessary.
- Willingness to use new technology if available.
- Conservation attitude of different groups of fishermen representing their intertemporal preferences in the use of resources.

Overt (Necessary) Inputs. Inputs necessary in order for the system to function. This type of input basically includes gas and oil, fish bait, ice and food. They are an important component of the fishery variable costs.

Design Parameters. Important decision variables which are attributes to the system structure and have an impact upon the system desired output.

a. Selected classification of groups of fishermen according to their fishing technology.
b. Production functions or fishing efforts of different types of fishermen according to size of vessel used (length in feet), effective fishing time (days/year), types of fishing gear, and labor (man-hours/year).

c. Red grouper population dynamics

- Application of the "cohort survival method" (Ricker, 1975;Isard, 1975; Pitcher and Hart, 1982) taking into account the dynamic behavior of fishing mortality.
- Red grouper size in length and weight as a function of biological age using Von Bertalanffy growth equation estimates for red grouper of Yucatan's continental shelf (Doi et al., 1981).

After the system was identified, the model was decomposed into subsystems in order to handle its complexity.

## Model Decomposition

This model was decomposed into three system substructures that interact to provide the overall system its unique behavior. Figure 8 shows the red grouper fishery system decomposed into three interacting subsystems. Figure 8 emphasizes the interface variables, which are the outputs of one subsystem that acts as inputs to the other subsystem(s).

As shown in Figure 8, interface variables between the biological and economic subsystem are fishing effort (t) and fish catch (t). Interface variables between the economic and institutional subsystem are export earnings (t), net profits per type of vessel (t), employment (t), management policies and regulations. Finally, fish biomass (t) becomes the interface variable between the biological and resource management subsystems.

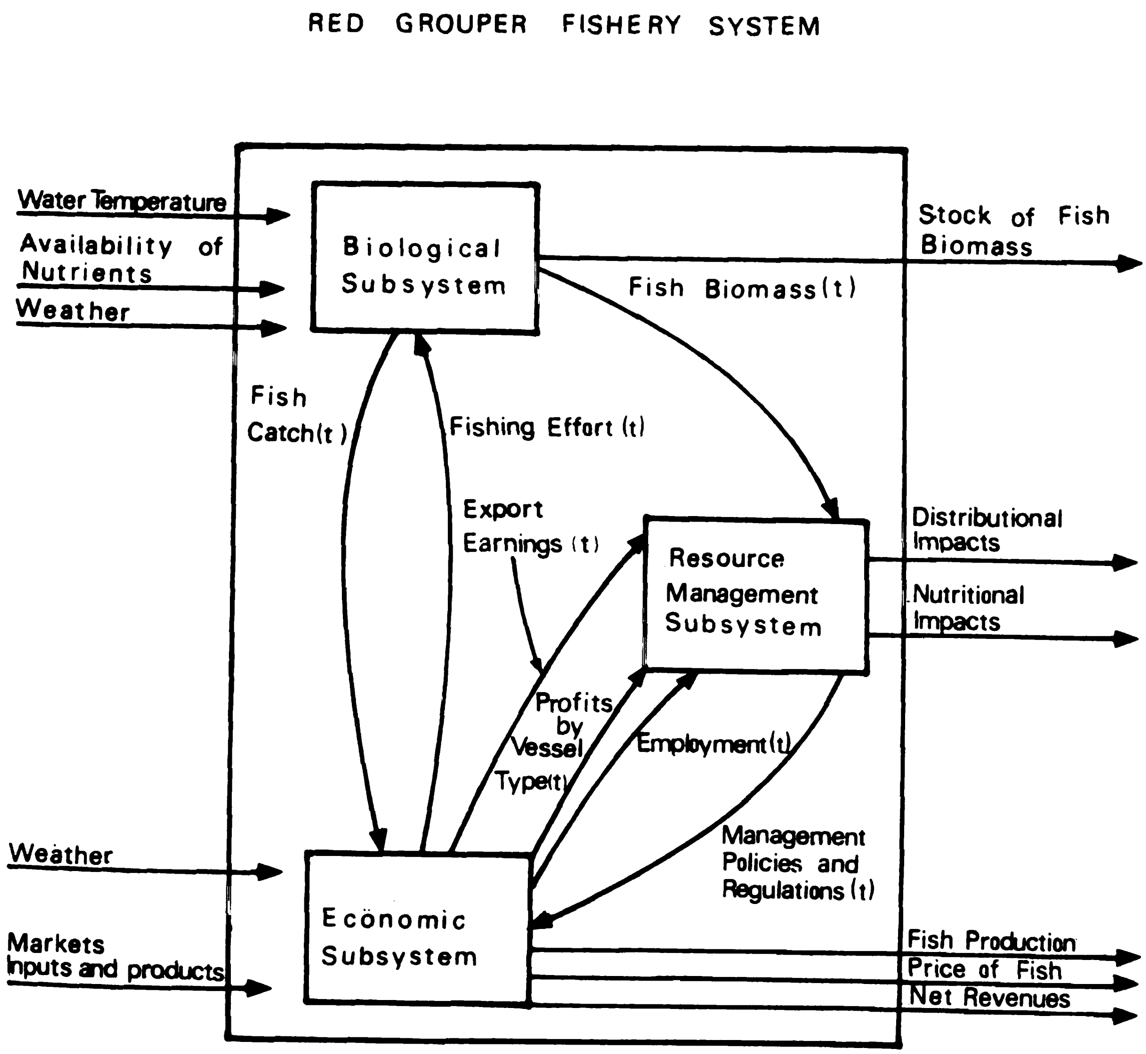



Figure 8. Major Components of the Red Grouper Fishery.

System Causal Diagram

The above system decomposition is presented in more detail in the system causal diagram shown in Figure 9. In this causal diagram, solid lines represent flows of fish in kilograms, solid lines with a $ sign on them represent flows of pesos, and broken lines represent influences which alter the rates of change. In the left side of the diagram, the biological subsystem is expressed with the four main processes that determine the amount of fish biomass over time: recruitment and growth that add biomass to the fishery and natural and fishing mortality that reduce the level of biomass over time. These four processes are further specified by including variables affecting each of them.

In the economic subsystem fishing effort is made a function of the type and number of fishing vessel and fishing gears used, the number of effective fishing days and labor per type of vessel. Total costs involved in the different fishing effort functions are obtained by estimating the corresponding fixed and variable costs. Total revenues result from the catch allocated to local market and processing. It can also be observed from the diagram that a component of the catch goes for subsistence consumption in the coastal communities.

Exit and entry of different types of vessels is also represented in the model through linkages between net revenues and number of vessels.

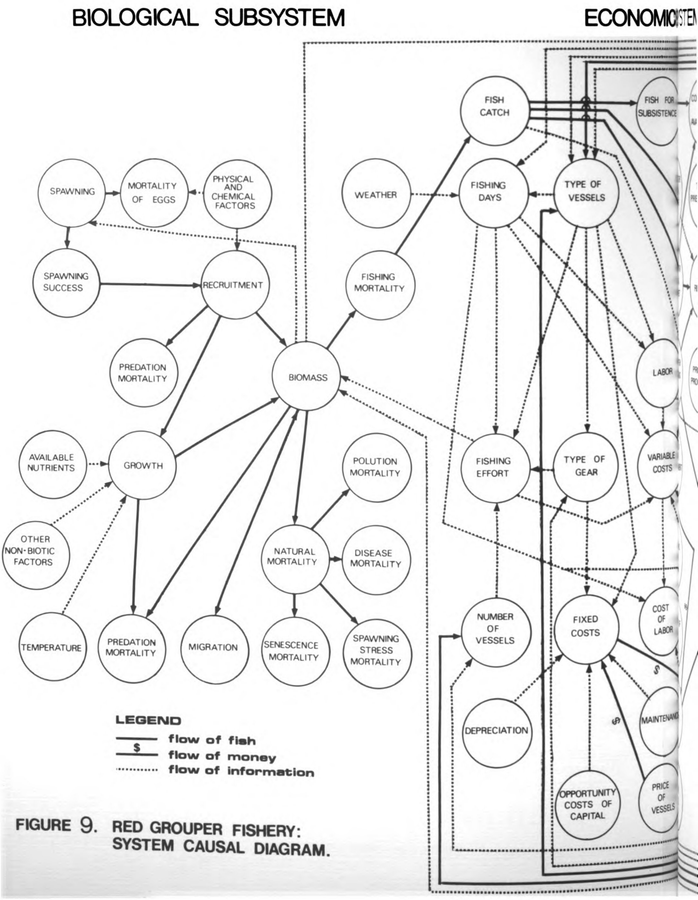
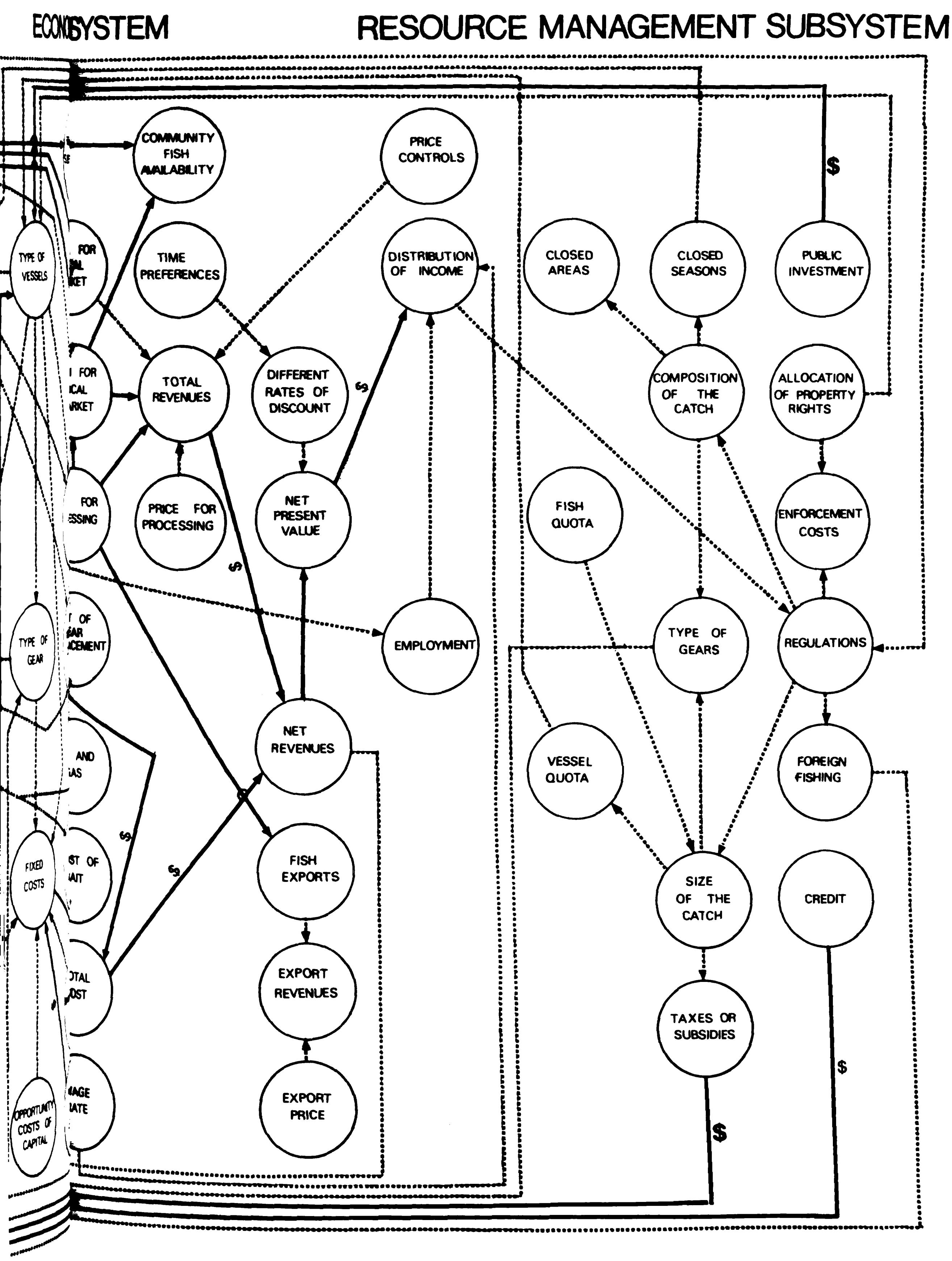



FIGURE 9. RED GROUPER FISHERY: SYSTEM CAUSAL DIAGRAM.



RESOURCE MANAGEMENT SUBSYSTEM
COMMUNITY FISH AVAILABILITY
PRICE CONTROLS
TYPE OF VESSELS
TIME PREFERENCES
DISTRIBUTION OF INCOME
CLOSED AREAS
CLOSED SEASONS
PUBLIC INVESTMENT
$
TOTAL REVENUES
DIFFERENT RATES OF DISCOUNT
COMPOSITION OF THE CATCH
ALLOCATION OF PROPERTY RIGHTS
PRICE FOR PROCESSING
NET PRESENT VALUE
FISH QUOTA
ENFORCEMENT COSTS
TYPE OF GEAR
EMPLOYMENT
TYPE OF GEARS
REGULATIONS
NET REVENUES
VESSEL QUOTA
FOREIGN FISHING
FIXED COSTS
FISH EXPORTS
SIZE OF THE CATCH
CREDIT
EXPORT REVENUES
TAXES OR SUBSIDIES
OPPORTUNITY COSTS OF CAPITAL
EXPORT PRICE

In addition to biomass level, fish production, net revenues by type of vessel (and corresponding technology) as well as how those revenues are distributed among different groups of fishermen are input variables to the resource management subsystem. With these stimula, the resource management subsystem response involves allocation of property rights and regulations that affect both the composition and size of the catch, i.e. influences management decisions of private firms.

In order to conduct quantitative analysis of the relationships presented in the causal diagram of Figure 9, data were collected to fit equations and estimate model parameters.

## Data Collection and Analysis

Data were collected from both primary and secondary sources to estimate parameter and fit equations of the mathematical model that will be presented in the next section.

### Primary Data Sources

Primary data sources were used to obtain information mainly about traditional fishermen, given that there was no information available on their fishing effort and catch as well as their cost and revenue functions. As a result, a survey was designed and implemented in the study region.

Survey Design. In order to obtain the required data, a questionnaire (see Appendix A) was developed and applied in four of the 10 ports that allocate fishing effort to the red grouper fishery. The ports selected were Chuburna, Chelem, Progreso and Chicxulub. These ports were chosen because they host most traditional vessels involved in harvesting red grouper. The sample size was estimated using information from a presampling effort conducted in the port of Chicxulub. From this data set, the standard deviation of relevant parameters such as effective fishing time, number of fishermen per vessel and fish catch were used to estimate sample sizes and select the larger sample. The standard deviation that provided the larger sample size was the one associated with effective fishing time and this was the sample size eventually selected.

Therefore, in order to be $(1-\alpha)\%$ confident that the error $|\bar{x}-\upsilon|$ does not exceed a value d, the required sample size from an assumed normally distributed population is the following (Battacharya and Johnson, 1977):

$$n = \left[\frac{Z_{\alpha/2} \cdot \sigma}{d}\right]^2$$

Where:

$n$ = Sample size

$\alpha$ = Significance level

$Z_{\alpha/2}$ = Value obtained from the normal probability table.

$\sigma$ = Standard deviation

d = Specified error bound

$\bar{x}$ = Sample mean

$\upsilon$ = Population mean

For a 95% confidence level ($\alpha = .05$), an error d = .30 of an hour and a standard deviation $\sigma$ = .816, the required sample size estimated was n = 28.

It was obtained applying the above equation:

$$n = \left[\frac{(1.96).816}{.30}\right]^2 = 28.42$$

After the sample size was determined, a list of traditional fishermen was obtained from the Ministry of Fisheries branch in the State of Yucatan, and a number was assigned to each fishermen listed . Then, in order to give each member of the population the same opportunity of being included in the sample, 28 random numbers were generated from a calculator and used to select the fishermen to be interviewed.

When the survey was being implemented some of the randomly selected fishermen were not available to be interviewed. In these cases, additional random numbers were generated to select substitute fishermen to be included in the sample.

Secondary Data Sources

For information concerning modern fishermen, datawere obtained from a fisheries research institution located in Progreso, Yucatan (Burgos and and Lope, 1984).

It should also be mentioned that to supplement these data, interviews were conducted with "modern" fishermen of Yucalpeten (where landing of vessels takes place) mainly to obtain costs and revenues information. In addition, information was also obtained from government publications dealing with fisheries statistics (Gobierno del Estado de Yucatan, 1983; Secretaria de Pesca, 1984; Secretaria de Programacion y Presupuesto, 1982).

## Mathematical and Computer Model

A more detailed statement of the system is presented in Figure 10, a block diagram for the red grouper fishery system. The purpose of the diagram is to explicitly define: (Manetsch, 1975)

a. Model components in terms of their input and output variables.
b. Interactions among model components in terms of specific variables.
c. Model exogenous variables and their points of impact upon the system.
d. Policy variables (controllable inputs) and their points of impact upon the system.
e. Performance variables to be used by decision makers to evaluate system performance.

This block diagram also facilitates analysis of a complex system of equations where multiple interactions are involved. To follow this diagram, Table 1 presents a definition of variables and parameters of the diagram and their corresponding units of measurement.

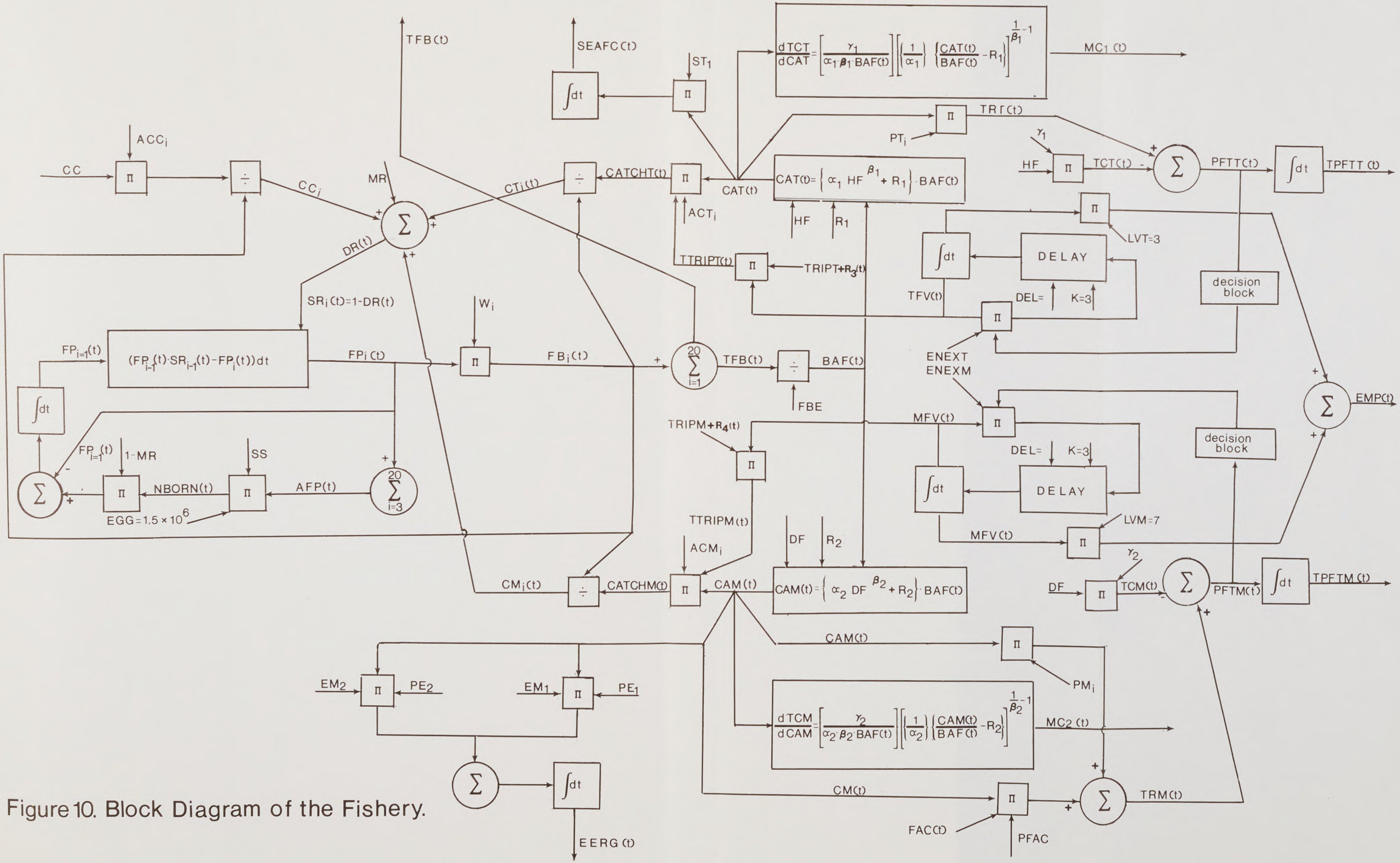



Figure 10. Block Diagram of the Fishery.

Table 1. Block Diagram: Variables and Parameters

| Symbol | Description | Unit of Measurement |
|---|---|---|
| ACCi | Composition of foreign vessel catch by age i | % |
| ACTi | Composition of traditional vessel catch by age i | % |
| ACMi | Composition of modern vessel catch by age i | % |
| ACTFV(t) | Number of traditional vessels entry or exit per unit of time t | #/t |
| ACMFV(t) | Number of modern vessels entry or exit per unit of time t | #/t |
| $\alpha_1$ , $\beta_1$ | Production function parameters of traditional vessels | kg |
| $\alpha_2$ , $\beta_2$ | Production function parameters for modern vessels | kg |
| AFB(t) | Adult fish biomass in time t | Tons |
| AFP(t) | Adult fish population in time t | # of fish |
| BAF(t) | Relative biomass availability factor in time t | % |
| CAM(t) | Catch of modern vessels per trip in time t | Tons/trip |
| CAT(t) | Catch of traditional vessels per trip in time t | Tons/trip |
| CATCHT(t) | Total catch of traditional fishermen in time t | Tons/year |
| CATCHM(t) | Total catch of modern fishermen in time t | Tons/year |
| CC | Total catch of Cuban fishermen based on a yearly quota | Tons/year |
| CCi | Fishing mortality by age i from Cuban fishermen catch | %/year |

| Symbol | Description | Unit of Measurement |
|---|---|---|
| CMi | Fishing mortality by age i from modern fishermen catch | %/year |
| CTi | Fishing mortality by age i from traditional fishermen catch | %/year |
| DEL1 | Mean delay of traditional vessel entry or exit to de fishery | Years |
| DEL2 | Mean delay for modern vessel entry or exit to the fishery | Years |
| DF | Average effective fishing time per trip (modern vessel) | # of days |
| DRi(t) | Total mortality rate of fish of age i in time t | %/year |
| DT | Time increment | t |
| EERG(t) | Export earnings from red grouper | Dollars/year |
| EGG | Average number of eggs per gonad | # of eggs |
| EGGS(t) | Spawned eggs in time t | # of eggs/t |
| EM1 | Red grouper fillet for export market | % |
| EM2 | Frozen red grouper for export market | % |
| EMP(t) | Direct employment in time t | persons/year |
| ENEXT | Entry or exit parameter for traditional vessels | % of total vessels |
| ENEXM | Entry or exit parameter for modern vessels | % of total vessels |
| FBi(t) | Biomass of fish of age i in time t | Tons |
| FPi(t) | Fish population of age i in time t | # of fish |

| Symbol | Description | Unit of Measurement |
|---|---|---|
| FRi(t) | Fishing mortality rate of fish of age i in time t | %/year |
| FST(t) | Fish for subsistence consumption in time t | Tons/t |
| FMT(t) | Fish for local market from traditional vessel catch in time t | Tons/t |
| FPT(t) | Fish for processeng from traditional vessel catch in time t | Tons/t |
| FMM(t) | Fish for local market from modern vessels catch in time t | Tons/t |
| FPM(t) | Fish for processing from modern Vessels catch in time t | Tons/t |
| FAC(t) | By-catch of red grouper fishery in time t | Tons/t |
| $\gamma_1$ | Constant in total cost equation of traditional vessels | Pesos/ton |
| $\gamma_2$ | Constant in total cost equation of modern vessels | Pesos/ton |
| $\gamma_3$ | Average number of fishermen per traditional vessel | #/vessel |
| $\gamma_4$ | Average number of fishermen per modern vessel | #/vessel |
| HF | Number of effective fishing time per trip (traditional fishermen) | # of hours |
| K | Order of the distributed delay | -- |
| Li | Average length of fish at age i | cm |
| MC1(t) | Marginal cost of traditional vessels | Pesos/ton |
| MC2(t) | Marginal cost of modern vessels | Pesos/ton |
| MFB(t) | Juvenile fish biomass in time t | Tons |
| MFP(t) | Juvenile fish population in time t | # of fish |

| Symbol | Description | Unit of Measurement |
|---|---|---|
| MFV(t) | Modern fishing vessels in time t | # of vessels |
| MR | Natural mortality rate | %/year |
| NBORN(t) | Fish population of age 0 in time t | # of fish per year |
| PE1 | Export Market price of red grouper fillet | Dollars/ton |
| PE2 | Export market price of frozen fish | Dollars/ton |
| PFAC | Price of by-catch | Pesos/ton |
| PFTM(t) | Net profits of modern vessels in time t | Pesos/year |
| PFTT(t) | Net profits of traditional vessels in time t | Pesos/year |
| PM1 | Local market price for adult fish | Pesos/ton |
| PM2 | Price of red grouper for processing (adults) | Pesos/ton |
| PT1 | Coastal market price | Pesos/ton |
| PT2 | Price of red grouper for processing (juveniles) | Pesos/ton |
| R1(t) | Random variable of catch equation in time t (traditional vessels) | Kg/day |
| R2(t) | Random variable of catch equation in time t (modern vessels) | Kg/day |
| R3(t) | Random variable of total trip equation (traditional vessels) | # of trips/ year |
| R4(t) | Random variable of total trip equation (modern vessels) | # of trips/ year |
| SEAFC(t) | Seafood availability in coastal communities in time t | Tons/year |

| Symbol | Description | Unit of Measurement |
|---|---|---|
| SRi(t) | Survival rate of red grouper of age i in time t | %/year |
| SM1 | Proportion of fish catch for local market (modern) | % |
| SM2 | Proportion of fish catch for processing (modern) | % |
| ST1 | Proportion of fish catch for subsistence consumption | % |
| ST2 | Proportion of fish catch for local market (traditional) | % |
| ST3 | Proportion of fish catch for processing (traditional) | % |
| SS | Spawning success factor | % |
| TCM(t) | Total costs of modern vessels in time t | Pesos/year |
| TCT(t) | Total costs of traditional vessels in time t | Pesos/year |
| TFB(t) | Total fish biomass in time t | tons |
| TFP(t) | Total fish population in time t | # of fish |
| TFV(t) | Number of traditional fishing vessels in time t | # of vessels |
| TRIPM | Number of trips of modern vessels per year | # of trips |
| TRIPT | Number of trips of traditional vessels per year | # of trips |
| TRM(t) | Total revenues of modern vessels in time t | Pesos/year |
| TRT(t) | Total revenues of traditional vessels in time t | Pesos/year |
| TPFTM(t) | Accumulated net profits of modern vessels in time t | Pesos |

| Symbol | Description | Unit of Measurement |
|---|---|---|
| TPFTT(t) | Accumulated net profits of traditional vessels in time t | Pesos |
| VAR1 | Variance of catch equation (traditional vessels) | Kg |
| VAR2 | Variance of catch equation (modern vessels) | Kg |
| Wi | Average weight of fish at age i | Kg |

The specific relationships shown in the block diagram of Figure 10 are presented in a set of equations that conform to the model structure.

## Mathematical Model

The mathematical model for the red grouper fishery is discussed in this section by major system components.

Population Dynamics of the Red Grouper. The dynamics of this biotic resource were modeled applying the main concepts of the "cohort survival method" (Nisbet and Gurnet, 1982; Clark, 1985; Gulland, 1977,1983; Ricker, 1975) to develop a general equation for the population structure using Euler numerical integration. The method is based on the dynamic accounting of inflows and outflows of each age cohort of the population structure. The number of organisms in cohort i in time t+DT, $FP_i(t+DT)$, is obtained by integrating the survival rate of cohort i-1 in time t, $SR_{i-1}(t)FP_{i-1}(t)$, minus the death rate of cohort i in time t, $DR_i(t)FP_i(t)$, minus the rate at which organisms of age cohort i grow into cohort i+1 in time t, $SR_i(t)FP_i(t)$.

This can be expressed as follows:

$$\frac{dFP_i}{dt} = SR_{i-1}(t)FP_{i-1}(t)-(DR_i(t)+SR_i(t))FP_i(t) \qquad (8)$$

By definition $DR_i(t)+SR_i(t) = 1$, hence equation (8) can be represented as:

$$\frac{dFP_i}{dt} = SR_{i-1}(t)FP_{i-1}(t)-FP_i(t) \qquad (9)$$

Integrating equation (9) over the interval (t,t+DT), we obtain:

$$\int_t^{t+DT} FP_i(\tau)d\tau = \int_t^{t+DT} [SR_{i-1}(\tau)FP_{i-1}(\tau)-FP_i(\tau)]d\tau \qquad (10)$$

Using Euler numerical integration (Cheney and Kincaid, 1985) the number of red groupers of age i in time t+DT is obtained by equation (11):

$$FP_i(t+DT) = FP_i(t)+DT(SR_{i-1}(t)FP_{i-1}(t)-FP_i(t)) \qquad (11)$$

Summing up overall age groups we obtain the total red grouper population in time t.

$$TFP\ (t) = \sum_{i=1}^{20} FP_i\ (t) \qquad (12)$$

To estimate the population of new born groupers, the following equations were developed:

$$\frac{dNBORN}{dt} = FP_j(t)*EGG_j*SS \qquad (13)$$

Where: $3 < j < 20$

Integrating equation (13) we have:

$$\int_{t}^{t+DT} NBORN(\tau)d\tau = \int_{t}^{t+DT} [FP_j(\tau)*EGG_j*SS]d\tau \qquad (14)$$

Using Euler integration we obtain:

$$NBORN(t+DT) = NBORN(t)+DT*(FP_j(T)*EGG_j*SS) \qquad (15)$$

Where:

$FP_j(t)$ = Spawning stock in time t.

The spawning success parameter was estimated by determining the number of eggs required to survive given the estimated number of recruits and the spawned stock. It should be mentioned that recruitment to the fishery takes place at age one, while biological recruitment to the stock of adults begins at age 3.

Both males and females were considered as spawners because red groupers are protozinous hermaphrodites. Also, they are expected to spawn once a year (Moe, 1969; Doi, Mendizabal and Contreras, 1981). Nevertheless, it would have been desirable to express spawning per adult as a function of their age. But because of a lack of data, an average number of eggs provided by the above mentioned authors was used ($1.5 \times 10^6$).

For the red grouper, recruitment to the fishery takes place at age 1, given that:

(i) fishing effort of traditional fishermen occurs between 3 and 15 fathoms where most of the juvenile population is found.

(ii) a non-discriminatory fishing gear is used.

As a result, catch data are available from age 1 and up. This unfortunate situation from a biological viewpoint, facilitates the following population structure analysis.

To estimate population biomass, the number of organisms in each age group was multiplied by their corresponding weight and then summarized over all ages.

$$TFB\ (t) = \sum_{i=1}^{20} FP_i\ (t)\ W_i \qquad (16)$$

<u>Fishing Effort and Catch</u>. Fish catch equations were developed for both traditional and modern fishermen. It was assumed that the Cuban fleet fishing in Yucatan's Continental Shelf (within Mexico's EEZ) was catching the average 5000 tons/year reported by Doi et al. (1981). Using data collected from the survey, a catch function was estimated for different types of vessel j, fitting a Cobb-Douglas production function (Anderson, 1981; Hanneson, 1983). The independent variables are: effective fishing time, an exponentially autocorrelated random variable, and biomass availability over time. Catch per trip equations were developed for both traditional and modern vessels.

$$CAT(t) = (\alpha_1\, HF^{\beta_1}) + R1(t))*BAF(t) \qquad (17)$$

$$CAM(t) = (\alpha_2\, DF^{\beta_2}) + R2(t))*BAF(t) \qquad (18)$$

Where R1(t) and R2(t) are exponentially autocorrelated random variables, of catch per trip equations of traditional and modern vessels, with variances VAR1 and VAR2, and correlation coeficient XLMDA.

Multiplying equations (17) and (18) by TTRIPT(t) and TTRIPM(t) respectively we obtain total annual catch of both traditional and modern vessels.

$$CATCHT(t) = CAT(t)*TTRIPT(t) \tag{19}$$

$$CATCHM(t) = CAM(t)*TTRIPM(t) \tag{20}$$

Variables BAF(t), TTRIPT(t) and TTRIPM(t) are determined as follows:

$$BAF(t) = TFB(t)/TFB(0) \text{ (Laevastu et al., 1981)} \tag{21}$$

$$TTRIPT(t) = TFV(t)*(TRIPT + R3(t)) \tag{22}$$

$$TTRIPM(t) = MFV(t)*(TRIPM + R4(t)) \tag{23}$$

Where R3(t) and R4(t) are random variables representing uncertainty concerning the number of fishing trips per year, and TRIPT and TRIPM are the average number of trips per type of vessel/year.

TTRIPT(t) = Total number of fishing trips per year of traditional vessels having red grouper as target species.

TTRIPM(t) = Total number of fishing trips per year of modern vessels having red grouper as target species.

The rate at which fishing vessels entry or exit the red grouper fishery over time is determined by equations (24) and (25).

$$\frac{dTFV}{dt} = ACTFV(t) \tag{24}$$

$$\frac{dMFV}{dt} = ACMFV(t) \tag{25}$$

Integrating equations (24) and (25) we obtain the accumulated number of both types of vessels in time t.

$$\int_{t}^{t+DT} ACTFV(\tau)d\tau \qquad (26)$$

$$\int_{t}^{t+DT} ACMFV(\tau)d\tau \qquad (27)$$

Using Euler numerical approximation we obtain:

$$TFV(t+DT) = TFV(t) + DT*(ACTFV(t)) \qquad (28)$$

$$MFV(t+DT) = MFV(t) + DT*(ACMFV(t)) \qquad (29)$$

Where ACTFV(t) and ACMFV(t) represent the entry (or exit) of both traditional and modern vessels to the red grouper fishery over time.

There are time delays inherent in the processes of entering or leaving the fishery from the moment a fishermen faces economic rent or negative net revenues to the moment in which entry or exit takes place. Some of the most important time lags occur in:

(i) the decision-making process of entering or leaving the fishery,

(ii) the time required to obtain public financing to buy vessels and gears, and

(iii) The time it takes to receive a vessel after it has been ordered.

The number of vessels entering or leaving the fishery were obtained by the application of the distributed delay model (Manetsch, 1976, 1977; Roberts et al., 1983).

A Kth order distributed delay is defined by the following first-order differential equations.

$$\frac{dr_1}{dt} = \frac{k}{DEL} (x(t) - r_1(t)) \qquad (30)$$

$$\frac{dr_2}{dt} = \frac{k}{DEL} (r_1(t) - r_2(t)) \qquad (31)$$

$$\begin{matrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{matrix}$$

$$\frac{dr_k}{dt} = \frac{k}{DEL} (r_{k-1}(t) - r_k(t)) \qquad (32)$$

Where:

$x(t)$ = input to the delay process

$r\ (t) = y(t)$ is the output of the delay

$r\ (t)$, $r\ (t)$,..., $rk(t)$ are the intermediate rates

DEL = Expected value of the transit time of an individual entity through the given process

k = order of the delay

The parameter k specifies a member of the Erlang family of density functions which describes the transit times of individual entities as they pass through the delay process.

It should be mentioned that the model includes delays with different values for the parameter DEL (DEL1=1.5 and DEL2=2., for traditional and modern vessels, respectively). These average delay parameters were determined through interviews with fishermen who have experienced entry and/or exit to the fishery.

The outputs of the distributed delays are ACTFV(t) and ACMFV(t).

Costs and Revenues Analysis. Accumulated net profits are estimated by equations (33) and (34) as follows:

$$TPFTT(t+DT) = TPFTT(t) + \int_{t}^{t+DT} TRT(\tau) - TCT(\tau)d\tau \qquad (33)$$

$$TPFTM(t+DT) = TPFTM(t) + \int_{t}^{t+DT} TRM(\tau) - TCM(\tau)d\tau \qquad (34)$$

Total revenues are estimated from equations (35) and (36).

$$TRT(t) = PT_1*FMT(t) + PT_2*FPT(t) \qquad (35)$$

$$TRM(t) = PM_1*FMM(t) + PM_2*FMM(t) + PFAC*FAC(t) \qquad (36)$$

Even though fishermen are assumed to be price takers, in the study region they are paid different prices, $PT_1$, $PT_2$, $PM_1$ and $PM_2$ mainly for two reasons: first, there are different prices according to the size of the fish and second, there are different prices according to destination of the fish. The latter results from different prices paid for red grouper in the local market and by those who buy it for further processing.

Concerning the price of the bycatch, PFAC, this involves usually a lower price than that paid for red grouper as target species.

Interviews with both traditional and modern fishermen provided estimates of costs of operating a vessel in the red grouper fishery for a year. These costs are presented in Tables 2 and 3.

From Table 2 it can be observed that annual total costs per traditional vessel represent $ 3,167,560.0 Pesos. An average traditional vessel undertakes 210 effective fishing days from which approximately 85 days or 40% of the fishing effort is oriented towards the red grouper fishery. Hence, annual total cost of having red grouper as the target species is proportionately estimated as being $ 1,267,024.0 per year per boat. Concerning modern vessels, it is estimated that 62% of the fishing effort per year is allocated to red grouper, the remaining 38% has octopus (*Octopus maya* and *Octopus vulgaris*) as target species. Consequently, from the estimated total cost per modern vessel, $ 24,191,000.0 per year, $ 14,998,420.0 corresponds to the red grouper catch (Table 3). Total costs were estimated considering operating costs, fixed costs, and opportunity costs of labor and capital.

Depreciation was based upon 10% of the boat value, 20% of the engine value, and 10% of value of fishing gear and other equipment.

Table 2. Costs Analysis of Traditional Vessels (Pesos).

| COSTS | AMOUNT | TOTAL |
|---|---|---|
| Operating Costs | | 272,560.0 |
| . Bait | 27,360.0 | |
| . Fuel | 82,080.0 | |
| . Maintenance | 40,000.0 | |
| . Ice | 0.0 | |
| . Gear Replacement | 54,720.0 | |
| . Food and Beverages | 68,400.0 | |
| Fixed Costs | | 575,000.0 |
| . Depreciation | 175,000.0 | |
| . Interest | 400,000.0 | |
| Opportunity Cost of Capital and Labor | | 2,320,000.0 |
| . Labor | 1,620,000.0 | |
| . Capital | 700,000.0 | |
| Total Costs | | 3,167,560.0 |

Note: Estimates are based on prices of June, 1985.

Table 3. Costs Analysis of Modern Vessels (Pesos).

| COSTS | AMOUNT | TOTAL |
|---|---|---|
| Operating Costs | | 4,241,000. |
| . Bait | 65,000.0 | |
| . Fuel | 1,936,000.0 | |
| . Maintenance | 300,000.0 | |
| . Ice | 325,000.0 | |
| . Gear Replacement | 250,000.0 | |
| . Food and Beverages | 1,365,000.0 | |
| Fixed Costs | | 6,100,000.0 |
| . Depreciation | 1,300,000.0 | |
| . Interest | 4,800,000.0 | |
| Opportunity Cost of Capital and Labor | | 13,850,000.0 |
| . Labor | 5,450,000.0 | |
| . Capital | 8,400,000.0 | |
| Total Costs | | 24,191,000.0 |

Note: Estimates are based on prices of June, 1985.

Making total costs a function of effective fishing time, results in equations (37) and (38).

$$TCT(t) = \gamma_1 * HF \tag{37}$$

$$TCM(t) = \gamma_2 * DF \tag{38}$$

Where:

HF(t) = Effective fishing time of traditional vessels in time t

DF(t) = Effective fishing time of modern vessels in time t

To estimate marginal costs, MC1(t) and MC2(t), catch equations (17) and (18) are used to substitute fishing effort or effective fishing time by yield in total cost equations. This was done in order to find the first derivative of the total cost function with respect to a change in yield.

This procedure is presented in the following set of equations:

From catch equations (17) and (18) we have that:

$$HF = \left[ \frac{1}{\alpha_1} \quad \frac{CAT(t)}{BAF(t)} - R1(t) \right]^{1/\beta_1} \tag{39}$$

$$DF = \left[ \frac{1}{\alpha_2} \quad \frac{CAM(t)}{BAF(t)} - R2(t) \right]^{1/\beta} \tag{40}$$

Substituting HF and DF in equations (37) and (38) we have that:

$$TCT(t) = \gamma_1 \left[ \left\{ \frac{1}{\alpha_1} \right\} \left\{ \frac{CAT(t)}{BAF(t)} - R1(t) \right\} \right]^{1/\beta_1} \tag{41}$$

$$TCM(t) = \gamma_2 \left[ \left\{ \frac{1}{\alpha_2} \right\} \left\{ \frac{CAM(t)}{BAF(t)} - R2(t) \right\} \right]^{1/\beta_2} \tag{42}$$

Making $x = CAT(t)$ (43)

$$u = \left[ \left\{ \frac{1}{\alpha_1} \right\} \left\{ \frac{CAT(t)}{BAF(t)} - R1(t) \right\} \right]^{1/\beta_1} \tag{44}$$

$$c = \gamma_1 \quad \text{(constant)} \tag{45}$$

We have that:

$$\frac{d\,cu^n}{dx} = cnu^{n-1} \frac{du}{dx} \tag{46}$$

Given that:

$$\frac{dTCT}{dCAT} = MC_1(t) \tag{47}$$

Then, marginal cost of traditional vessels can be estimated from the following equation:

$$MC_1(t) = \left[ \left\{ \frac{\gamma_1}{\alpha_1 * \beta_1 * BAF(t)} \right\} \left\{ \frac{1}{\alpha_1} \right\} \left\{ \frac{CAT(t)}{BAF(t)} - R1(t) \right\}^{(n-1)} \right] \tag{48}$$

Where:

$$n = \frac{1}{\beta_1}$$

Analogously, a marginal cost equation was derived for modern vessels.

Finally, direct employment, seafood availability in rural coastal communities and export earning are represented by EMP(t), SEAFC(t) and EERG(t) respectively and estimated by equations (49), (50) and (51).

$$EMP(t) = \gamma_3\ TFV(t) + \gamma_4\ MFV(t) \tag{49}$$

Where $\gamma_3$ and $\gamma_4$ are the average number of fishermen per traditional and modern vessels, respectively.

$$SEAFC(t+DT) = SEAFC(t) + \int_t^{t+DT} FST(\tau)d\tau \tag{50}$$

Where FST(t) is the component of traditional fishermen catch that is kept in the coastal community for subsistence purposes.

$$EERG(t+DT) = EERG(t) + \int_t^{t+DT} [CATCHM(\tau)(E_1 PE1(\tau) + E_2 PE2(\tau))]d\tau \tag{51}$$

Where PE1 and PE2 are the export prices of fillet and frozen red grouper, and $E_1$, $E_2$ are the proportion of modern vessels catch that goes to the export market.

Model Assumptions. Some of the most important assumptions involved in this model are the following.

a. It was assumed that effective fishing time per trip by type of vessel, biomass availability, and an exponentially autocorrelated random variable which accounts for uncertainty, determine catch per unit of effort over time.

b. Age composition of the catch was assumed constant.

c. It was assumed that the average time delays involved in entry and exit of vessels to the fishery were 1.5 years and 2.0 years for traditional and modern vessels respectively.

d. Because of the sedentary nature and territorial behavior of red groupers (*E. morio*), net migration was assumed equal to zero.

e. Concerning demand of fish, price-taking behavior was assumed for red groupers at dockside. This seems to be a reasonable assumption, given that there are numerous harvesters and buyers within the study region. Price-taking behavior was also assumed in the fishery inputs market.

The values used for model parameters and for initializing state variables in the computer model are presented in Appendix B.

## Computer Model

A computer model was developed to simulate the state of the fishery over time. This important step in the modeling process was done on an IBM-PC using the MICROSOFT FORTRAN 77 compiler.

The general structure of the computer model involved two major phases: initialization and execution (Manetsch, 1982a).

<u>Initialization Phase</u>

a. Values were assigned to model parameters.

b. State and rate variables were initialized.

c. Time was initialized: T=0.

d. Run characteristics were specified: length, number, output, etc.

<u>Execution Phase</u>

e. Time updated: T=T+DT.

f. State variables were computed.

g. Rate variables were computed for time T.

h. State and rate variables were printed.

i. Returned to (e) if simulation run was not completed.

A listing of the computer program and its corresponding flow diagram are presented in Appendices C and D. It should be mentioned that to obtain meaningful results from the above structure, the stability of the model needs to be considered.

<u>Model Stability</u>. In order to have a stable computer model an appropriate value for DT (time increment) was determined. This value was required for stable simulation of differential equations included in the model, such as distributed delays.

Given that Euler numerical integration was used to solve the differential equations, the necessary condition for stable simulation of this model is that DT be selected such that: (Manetsch, 1982a)

$$2 \text{ MIN } [Dj] > DT > 0 \qquad (52)$$

Where $Dj = \frac{DEL}{K}$ and MIN [Dj] is the smallest delay constant in the model.

The smallest delay constant involved in the red grouper model is for DEL = 1.5 and K = 3. Therefore, the upper bound for DT in this model is 1.

In addition, given that this simulation model involves feedback in the population dynamics component, for stable simulation (using Euler integration) we must ensure that:

$$\frac{1}{c} > DT > 0 \qquad \text{Where: } c = \frac{1}{D_i} \qquad (53)$$

Therefore, the value of DT in this model must be in the interval given by:

$$1 > DT > 0 \qquad (54)$$

In order to reduce the numerical integration error to an acceptable level, below 5 %, DT was reduced till the maximum error condition was satisfied.

General Model Characteristics. The characteristics of the red grouper simulation model concerning time frame, level of aggregation, functional form of the equations and uncertainty are presented as follows:

a. Time Frame. Given the characteristics of the red grouper population dynamics and the planning horizon of decision-makers in the Ministry of Fisheries, this dynamic model has a time horizon of 20 years. The time interval (simulated time) which is thought to satisfy needs for information and analysis is yearly information.

b. Level of Aggregation. This modeling effort involves a macroscopic view of the world given that an attempt was made to model the real world grouper fishery in terms of aggregates of fundamental entities. It involves a continuous flow process.

c. Functional Form of the Equation. Given the inherent characteristics of the system, the equations that describe the fishery system are non-linear.

d. Uncertainty. Elements of uncertainty enter the analysis of ocean fisheries in three ways (Lewis, 1982).

(i) Uncertainties may exist about the current size of the resource, mainly because of difficulties in observing the stock.

(ii) Unpredictable changes in the environment may perturb the natural rate of growth or deterioration of the resource, as well as the effective fishing effort.

(iii) The market value of the red grouper and the cost of catching it may be random owing to fluctuations in economic conditions.

To deal with uncertainties involved in the red grouper fishery, random variables are included in the catch functions of traditional and modern vessels. It is assumed that random variables for the red grouper fishery at one point in time are not independent of previous values.

Today's catch is dependent to a certain extent on yesterday's catch. Selection of fishing site is usually dependent to a certain extent on previously selected site. Environmental factors that affect resource availability (and consequently fish catch) such as temperature, currents, winds, etc. tend also to be dependent to a degree on previous values.

Therefore, to deal with the above situation exponentially autocorrelated random variables, $R_1(t)$ and $R_2(t)$, were generated using a subroutine called EXACOR (Manetsch, 1982). It should be mentioned that the "inverse transformation method" (Gottfried, 1984) can be used to generate random variables with a desired probability density function. Random variables $R_3(t)$ and $R_4(t)$ were set to zero during similation runs because of lack of data. In order to use this subroutine values were provided for the autocorrelation parameter, XLMDA, and for the catch variance of both traditional and modern vessels, VAR1 and VAR2.

This subroutine EXACOR transforms a uniformly distributed random number, generated by Function UNIF (Thesen, 1985) in an exponentially autocorrelated random variable. A listing of this subroutine is included in Appendix C.

## Monte Carlo Analysis

It is important to consider randomness in the values of system parameters which vary from run to run, because there is often error in estimating the values of such parameters.

Monte Carlo analysis is "a set of statistics which gives an estimate of the uncertainty in system performance due to within-run random variables and errors in estimating system parameters" (Manetsch and Park, 1982).

The Monte Carlo method is concerned with estimating the unknown numerical value of certain parameter of some distribution. The general principles of the Monte Carlo Method (Cheney and Kincaid, 1985; Hammersley and Handscomb, 1965) can be summarized as follows:

If $x_1, x_2, \ldots\ldots, x_n$ are independent random numbers (uniformly distributed between 0 and 1), then the quantities

$$f_i = f(x_i) \tag{55}$$

are independent random variates with expectation $\theta$. Therefore,

$$\bar{f} = \frac{1}{n} \sum_{i=1}^{n} f_i \tag{56}$$

is an unbiased estimator of $\theta$, and its variance is

$$\frac{1}{n} \int_0^1 (f(x) - \theta)^2 \, dx = \sigma^2/n \tag{57}$$

The standard error of f is thus:

$$\sigma_{\bar{f}} = \sigma/\sqrt{n} \tag{58}$$

Given that in practice the standard error is not known, it can be estimated from the formula

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (f_i - \bar{f})^2 \tag{59}$$

From the above formula we have an estimate of s for $\sigma$ and finally obtain $s/\sqrt{n-1}$.

Given that the sample size is large, a normal approximation for the distribution of the sample mean $\bar{f}$ is appropriate. When the sample size is large, the population $\sigma$ is unknown, and the significance level is $\alpha$ = .05, a 100(1-$\alpha$) confidence interval for $\theta$ is given by : (Bhattacharyya and Johnson, 1977)

$$\theta = \bar{f} \pm Z_{\alpha/2} \; s/\sqrt{n-1} \tag{60}$$

Where: $Z\alpha_{/2}$ = 1.96

According to Manetsch et al.(1975), the Monte Carlo process, operationally, involves the following set of steps:

a. Values are assigned to random model parameters.

b. The simulation model is run over the desired time horizon.

c. Variables are computed over the time horizon which measures the system performance.

d. Values are stored at the end of each simulation run.

e. Steps (a) through (d) are repeated a number of times (usually 100 or more) to generate data from which significant statistics can be computed.

f. Statistics are computed for each performance variable.

Monte Carlo analysis was conducted in this study to obtain estimates of the uncertainty in system performance, using the random variables generated by the subroutine EXACOR. A listing of the computer program in

Monte Carlo mode is included in Appendix E.

## Model Validation and Sensitivity Analysis

### Model Validation

A model is validated by providing a correct representation of the real system. Validation requires that the model exhibit behavior characteristics of the system itself. There are four major approaches suggested in the literature to validate a simulation model (Payne, 1982; Graybeal and Pooch, 1980):

(i) Compare simulated results with results historically produced by the real system operating under the same conditions.

(ii) Compare model behavior with that established by accepted theories. Model validity is based upon the assumptions and theories used, which determined the structural form of the equations and values assigned to parameters.

(iii) Validate the model with expert opinion concerning behavior of the real system.

(iv) Use the simulator to predict results. The predictions are then compared with the results produced by the real system during some future period time.

The first three approaches were used to validate the red grouper simulation model. Results were compared with historical data, mainly catch data. Model behavior was checked with major theories dealing with ocean fisheries.

Finally, results, equations and parameters were presented in a seminar to experts on the red grouper fishery of Yucatan's continental shelf, among them, biologists Martin Contreras, Manuel Solis and Victor Moreno.

The output of this validation process is presented in the results chapter.

Sensitivity Analysis

In most simulation models, some data used to develop the model is subject to error, and often the model is used to explore situations where operating conditions differ from those for which data were observed. Therefore, in order to establish confidence in model validity, it is necessary to determine that reasonable changes in the model parameters or operating conditions do not lead to unreasonable changes in model conditions. A major approach to testing this aspect of model behavior is by the use of sensitivity analysis. The basic technique is to vary an input to the model by using incremental changes, and then observe output behavior. Sensitivity analysis provides a basis for identifying decision variables (design parameters and controllable inputs) most important to the decision-making process.

Sensitivity analysis was conducted in the red grouper simulation model through: (1) changes in parameters of both the biologic and economic subsystem and (2) changes in controllable inputs in the economic and institutional subsystems.

## Simulation of Management Strategies

Resource management strategies were simulated to observe the behavior of performance variables over time. Performance variables observed over time included: fish biomass, yield and net revenues of traditional and modern fishermen, direct employment, available seafood in coastal communities and export earnings.

Management alternatives considered in different simulation runs included:

- Fish quota to Cuban fishing fleet
- Vessel quotas (limited entry to domestic vessels)
- Minimum fish size restrictions
- Fostering exports through increased fish production. This management strategy involves maintaining the status quo of a domestic open access regime.

The results of simulating these management strategies are presented in the next chapter.

CHAPTER IV

# RESEARCH RESULTS

The purpose of this chapter is to present the major research findings obtained in this study. Results are discussed in the following sections: (1) study region survey results, (2) stability analysis, (3) model validation, (4) sensitivity analysis, (5) Monte Carlo analysis, (6) simulation results, and (7) resource management strategies.[7]

## Survey Results

### Information obtained from Primary and Secondary Sources

After data were collected from both primary and secondary sources, they were analyzed and prepared in a set of tables which are presented in the following subsections.

**Fishing Fleet.** The fishing fleet involved in catching red grouper as the target species was estimated to be about 1210 vessels. As shown in Table 4, 80.16% of these vessels are small boats of 20 to 30 feet of length. The remaining 19.84% are vessels of 40 to 75 feet. These vessels belong to "traditional" and "modern" fishermen, respectively, as defined at the beginning of Chapter III.

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[7]Readers interested in acquiring a copy of computer runs for stability analysis, sensitivity analysis, model validation and Monte carlo analysis, please contact the author at Centro de Investigacion Pesquera Yucalpeten, Apartado Postal 73. Progreso, Yucatan, C.P. 97320 Mexico.

Table 4. Red Grouper Fishery: Fishing Fleet.

| VESSEL SIZE | QUANTITY (#) | PERCENTAGE (%) |
|---|---|---|
| 20 to 30 feet[a] | 970 | 80.16 |
| 40 to 75 feet[b] | 240 | 19.84 |
| TOTAL | 1210 | 100.00 |

Source: [a]Survey conducted as part of this study.
[b]Centro de Investigaciones Pesqueras Yucalpeten.

<u>Fishing Effort</u>. There are substantial fishing effort differences among these two types of fishing vessels. Table 5 shows that the effective fishing time of Type I vessel involves an average of 5.46 hours per day and a total of 873 hours per year per vessel. This last figure is obtained by multiplying the number of fishing trips/year by the number of days/trip and finally by the number of effective fishing hours per day. On the other hand, Type II vessels have an average of 10 hours/day of effective fishing and a total of 1367 hours per year per vessel. It can also be observed from Table 5 that the number of fishing days per trip is 1 for the traditional small vessels and an average of 10.52 days for the modern vessels. It should be mentioned that the figure for days/trip refers to effective fishing days. The total trip duration of Type II vessel is between 15 and 18 days but because of transfer time and weather conditions

the effective fishing time is reduced to an average of 10.52 days/trip.

Table 5. Effective Fishing Time per Year.

| VESSEL TYPE | FISHING TRIPS/ YEAR | DAYS/TRIP | HOURS/DAY | TOTAL HOURS |
|---|---|---|---|---|
| Type I (20'to 30') | 160[a] | 1.0 | 5.46 | 837 |
| Type II (40' to 75') | 13 | 10.52 | 10.0 | 1367 |

a. This figure includes an average of 85 trips to fish for red grouper and 75 trips having octopus as the target species.
Source: Survey conducted as part of this study.

The differences between this two types of vessels are more significant when analyzing catch per vessel figures.

Fish Catch. Because of different technology, the fish catch of the two types of vessels differ substantially. It can be observed from Table 6 that the average catch of traditional vessels was estimated to be 7.1 Kg/hour or 38.7 Kg/day; while the modern vessel obtains an average catch of 27.7 Kg/hour or 277 Kg/day.

Table 6. Catch Per Unit of Effort (Kg/day)

| VARIABLE | VESSEL TYPE I[a] (20 to 30 feet) | VESSEL TYPE II[b] (40 to 75 feet) |
|---|---|---|
| Average Catch/hour | 7.1 Kg/hour | 27.7 Kg/hour |
| Average Catch/man | 2.36 Kg/hour | 3.95 Kg/hour |
| Average Catch/Day | 38.7 Kg/day | 277.00 Kg/day |

Source: [a]Survey conducted as part of this study.
[b]Centro de Investigaciones Pesqueras Yucalpeten.

It should be mentioned that the average number of fishermen involved in the fishing effort of traditional vessel is 3, while modern vessels include 7 fishermen per trip.

This above described information was an input to the modeling process for both model parameters and estimation of fishing effort functions.

## Stability Analysis

As mentioned during the research methods chapter, in order to have a stable computer model, an appropriate value for the time increment, DT, was selected. Determination of DT also involved using a very small time increment in order to reduce numerical integration errors to acceptable limits. The analysis was conducted for all state variables using DT=.005 as the convergence time increment. To run the model without numerical integration errors involves a high trade-off in computing time. Therefore, for this modeling effort, the process of reducing DT was stopped when the integration error was smaller than 5%.

Results of this analysis are presented in Tables 7 and 8. Some of the state variables exhibited substantially larger integration errors than others for each value of DT. Errors in state variables for different time increments, DT, were estimated with respect to their values obtained using DT=.005 as the convergence time increment.

Table 7. Percentage Errors in State Variables for DT =.5

| T | BIOMASS(t) | TPFTM(t) | MFV(t) |
|---|---|---|---|
| 1 | 0.07 | -0.21 | -1.07 |
| 2 | 0.32 | -0.24 | -1.55 |
| 3 | 0.58 | 0.06 | -1.00 |
| 4 | 0.77 | 0.48 | -0.96 |
| 5 | 0.91 | 0.97 | -0.92 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 15 | 2.95 | 5.19 | 1.32 |
| 16 | 3.26 | 6.10 | -1.28 |
| 17 | 3.61 | 7.20 | -1.23 |
| 18 | 3.98 | 8.53 | -0.89 |
| 19 | 4.22 | 10.10 | 2.37 |
| 20 | 4.01 | 11.76 | 7.31 |

Table 8. Error Analysis Expressed in % for DT=.05

| T | BIOMASS(t) | TPFTM(t) | MFV(t) |
|---|---|---|---|
| 1 | 0.01 | 0.02 | 0.00 |
| 2 | 0.03 | -0.02 | 0.00 |
| 3 | 0.05 | -0.01 | -0.52 |
| 4 | 0.07 | 0.02 | -0.49 |
| 5 | 0.08 | 0.06 | 0.00 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 15 | 0.27 | 0.51 | 0.00 |
| 16 | 0.30 | 0.59 | 0.00 |
| 17 | 0.33 | 0.70 | 0.00 |
| 18 | 0.36 | 0.83 | 0.00 |
| 19 | 0.35 | 0.96 | 0.59 |
| 20 | 0.30 | 1.08 | 0.91 |

It can be observed from table 7 that state variables such as TPFTM(t) involve more numerical integration error than BIOMASS(t) or MFV(t). With DT=.5, the error exceeded 5 % (Table 7).

Nevertheless, when DT was reduced from .5 to .05, numerical errors for all variables were substantially reduced. To achieve error levels below 5 % for all state variables, the time increment selected was DT=.05 (Table 8). With this value of DT, both stability and numerical error conditions are satisfied (Appendix F).

## Model Validation

In order to validate the model, three major approaches were used: (1) comparison of actual and simulated catch, (2) verification of consistency with accepted theory, and (3) discussion of simulation results with resource experts and decision-makers.

Comparison of Actual and Simulated Catch.

Red grouper catch data, historically produced by the real system, were compared with simulated catch for the same time period, 1976-1985. This comparisson is presented in Figure 11 where simulated and actual catch are graphed together. In this figure, the simulated catch begins in 1976 given that the needed initial values for the number individuals of age i in the study region, FPi(0), were estimated from an available publication on red grouper population (Doi et al., 1981) which included data on age composition of the population up to that year.

The most noticeable differences between simulated and actual catch take place in years 1977 and 1979 due to the stochastic nature of the model. Simulated catch exhibits a satisfactory close pattern to actual catch taking into account that fishing effort equations include a random variable.

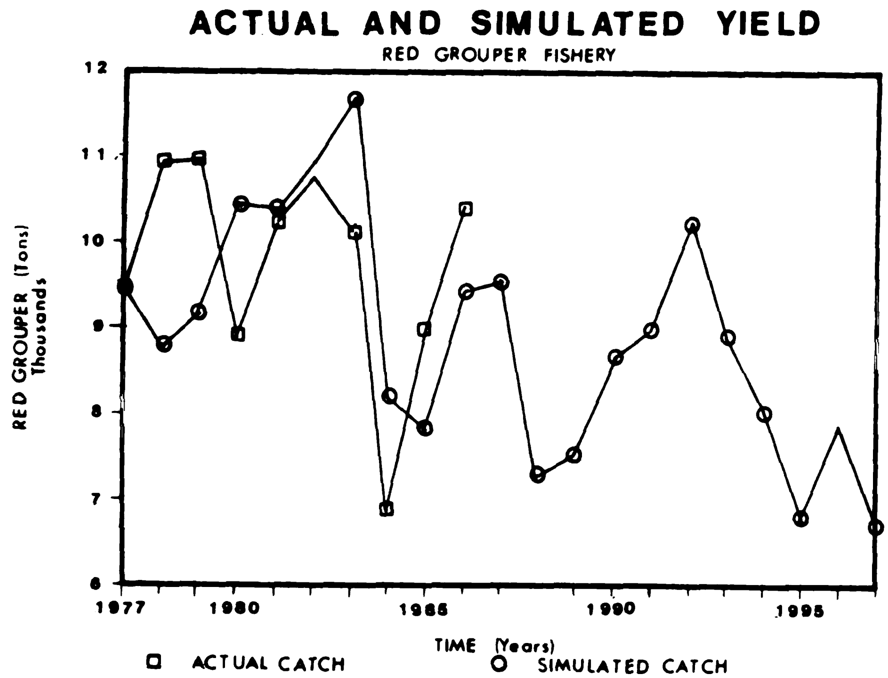



Figure 11. Model Validation: Comparison of Simulated and Actual Catch.

The red grouper catch was a basis for validation given that it is one of the performance variables available from published information.

It should also be mentioned that the simulated changes in fishing effort, in terms of number of fishing vessels, are consistent with figures published by the Ministry of Fisheries.

The simulation run generated, through the exit and entry process built in the model, 241 modern vessels and 962 traditional boats which exercise their fishing power on the red grouper fishery in 1984. The published figure, adjusted for those vessels fishing for other species as main targets and, substracting those vessels which have not operated in the last three years, results in 230 modern vessels and 970 traditional ones (Secretaria de Pesca, 1986).

It should be mentioned that one change was made to the model initial conditions in order to take in to account that since T=7, which corresponds to 1982, most of the modern fleet are allocating their fishing effort to the octupus fishery (Octopus maya) from September to December. This was done by including an IF statement that specified a reduction in the number of fishing trips per year from 13 to 9.

Consistency with Accepted Theory.

As discussed in the fisheries bioeconomic theory, a point is reached after which additional units of fishing effort result in decreasing catch per unit of effort, CPUE (Anderson,1977; Bell, 1982; Crutchfield) . This diminishing marginal productivity of the resource with increasing fishing effort, is present in the simulation results for CPUE1 after T=11 and, for CPUE2 after T=6 (Figures 12 and 13).

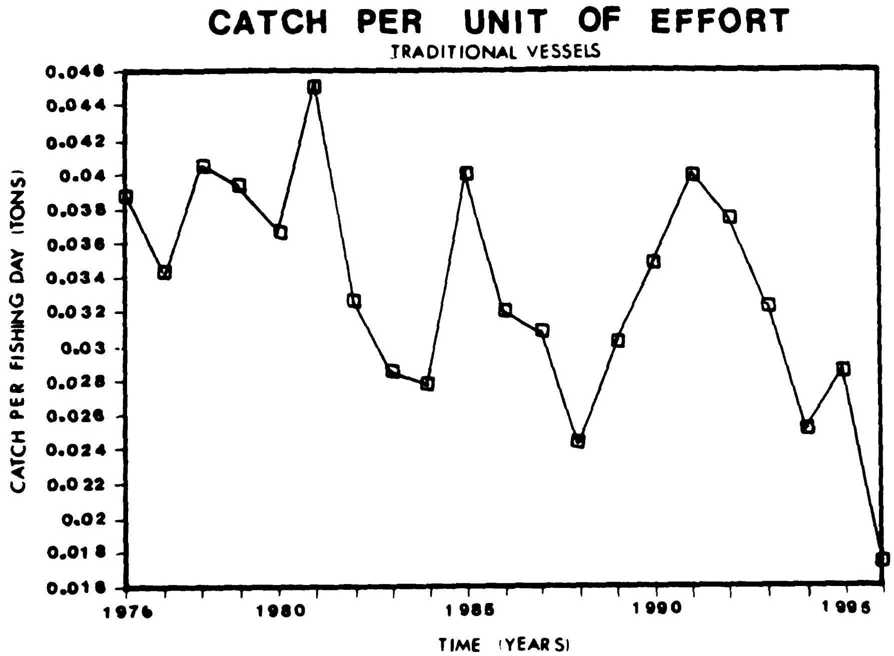



Figure 12. Model Validation: Catch per Unit of Effort of Traditional Vessels, CPUE1.

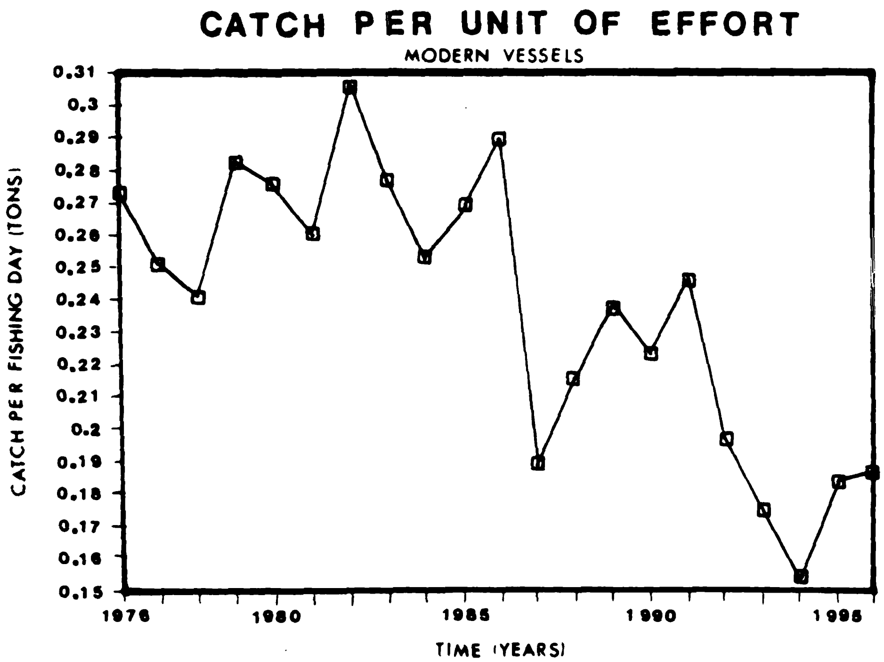



Figure 13. Model Validation: Catch per Unit of Effort of Modern Vessels, CPUE2.

Concerning total costs and total revenues, the decreasing fishery yield with increasing effort results in:

$$TC > TR \quad \text{for} \quad T > 16.$$

which can also be expressed as net profits below zero:

$$PFTM < 0. \text{ for } \quad T > 16.$$

As a result, the number of modern vessels aiming at red grouper stops growing and even start declining because of the entry and exit processes taking place with the appropriate time DELAY. The simulated evolution of number of vessels for both, traditional and modern sectors, is presented in Appendix H. In the case of modern vessels for instance, exit takes place a year after (assumed time lag) of having PFTM < 0. This fishermen economic behavior is presented in figure 14.

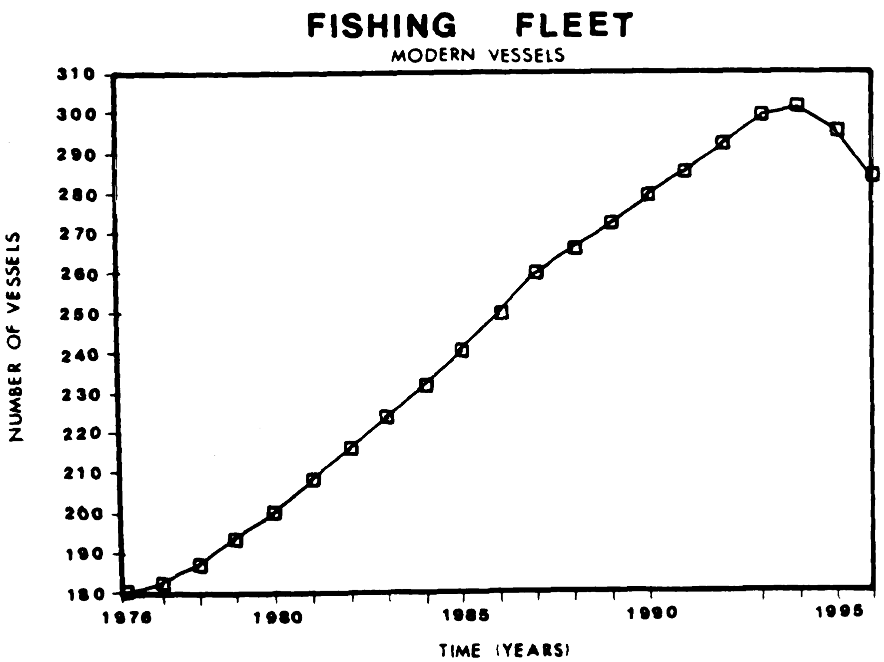



Figure 14. Simulation of Modern Fleet Size.

From the point of view of fish population and biomass by age group, these variables were graphed after 10 years of simulation to observe whether the shape of the curves corresponded to the theoretically accepted one (Figures 15 and 16). Both curves exhibit a shape that is usually presented in the fish population dynamics literature (Everhart and Youngs, 1981; Gulland, 1983; Pitcher and Hart, 1982).

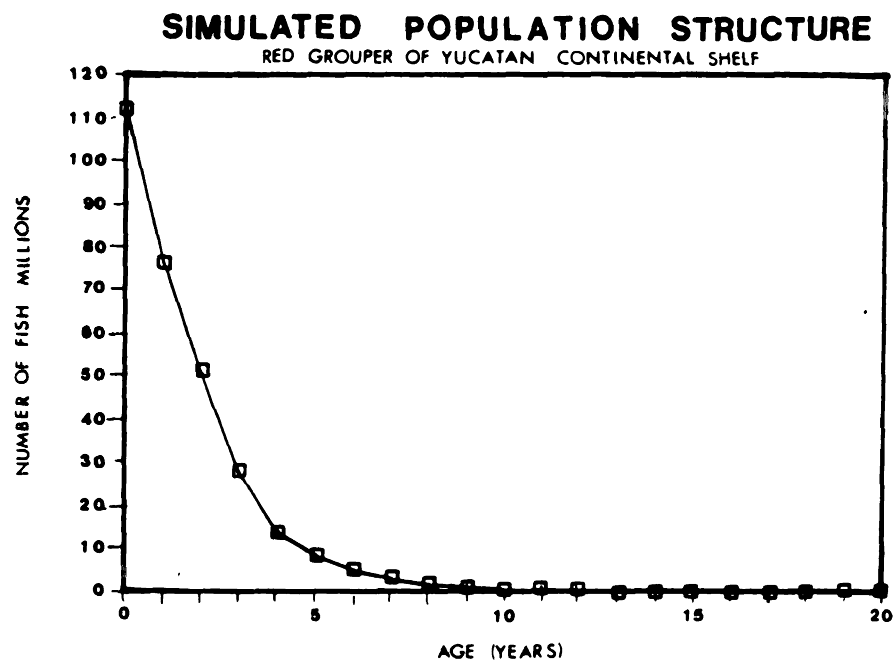



Figure 15. Model Validation: Simulated Population Structure

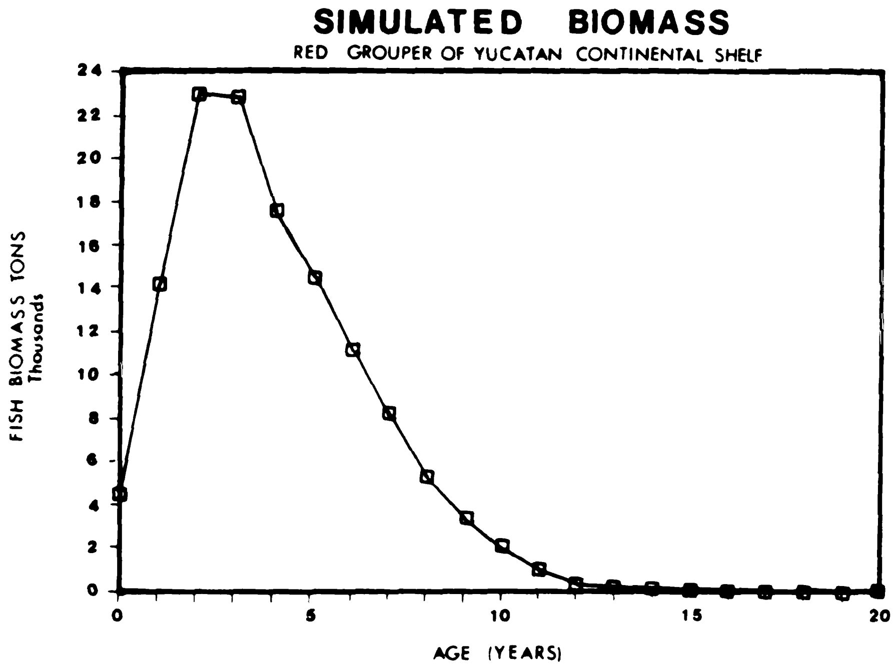



Figure 16. Model Validation: Simulated Biomass by Age Group

## Discussion of the Simulation Model and Results with Resource Experts and Decision Makers

A seminar was presented to researchers and decision makers of the Ministry of Fisheries on January 9th, 1986. During this seminar, the model, its assumptions and the corresponding results were discussed. Participants in the seminar found the results quite reasonable and made suggestions concerning the assumption of constant natural mortality rate. Given that there is no published information on natural mortality rates by age group (at least to the knowledge of the author), it was agreed during the seminar that further research needed to be conducted in order to relax this assumption.

It was also mentioned during the meeting that research was being initiated concerning age specific fecundity. In this modeling effort, the number of eggs produced by all spawners was considered constant for all age groups in the spawning population given that the secondary data sources dealing with fecundity of red grouper only sampled 14 gonads from which an average of 1.5 million eggs per gonad was estimated (Moe, 1969). It will definitely be more appropriate to have average fecundity per age group of the spawning population.

In general, model structure and its behavioral equations were considered to reflect important fishery processes which are often overlooked by the fisheries science literature.

## Sensitivity Analysis

Concerning sensitivity analysis, model inputs and design parameters were changed marginally in order to observe whether reasonable changes in them generated reasonable changes in model behavior. Initial fish biomass, spawning success and, natural mortality among others, were increased and decreased by 10%. Changes in controllable inputs, such as fishing effort of domestic as well as foreign fleet, were also entered as inputs to sensitivity analysis and results are being reported in the section dealing with resource management strategies.

Simulation runs involving changes in initial biomass resulted in reasonable changes in state variables as well as important rate variables such as fish catch. Simulation runs were conducted with values of initial red grouper biomass, TFB(0), within the interval [124000,151000] Tons. This interval is the result of decreasing and increasing by 10 % an average of 138000. Tons of red grouper biomass reported by Doi (et al.).

Effects of these changes are illustrated with state and rate variables such as accumulated net revenues, TPFTM(t), total red grouper biomass, TFB(t) and, fishery yield, CATCH(t) ( Tables 9 and 10 ). To observe the effects caused by changes in inputs or design parameters, the model was run in deterministic mode. System performance in stochastic mode (including random variables with the appropriate probability density function) is discussed in the next section.

Table 9. Sensitivity Analysis: Effect of 10 % Decrement in Initial Biomass, TFB(0), Expressed in %.

| T | TFB(t) | CATCH(t) | TPFTM(t) |
|---|---|---|---|
| 0 | -10.00 | 00.00 | 00.00 |
| 1 | -10.57 | -10.58 | -17.17 |
| 2 | -11.06 | -11.06 | -25.04 |
| 3 | -11.68 | -11.53 | -29.35 |
| 4 | -12.01 | -12.01 | -32.28 |
| 5 | -12.49 | -12.50 | -34.85 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 15 | -18.50 | -23.60 | -58.15 |
| 16 | -18.58 | -28.14 | -61.55 |
| 17 | -18.11 | -38.08 | -65.08 |
| 18 | -16.96 | -37.38 | -68.63 |
| 19 | -15.16 | -40.08 | -72.12 |
| 20 | -12.91 | -41.01 | -75.69 |

Table 10. Sensitivity Analysis: Effect of 10 % Increment in Initial Biomass, TFB(0), Expressed in %.

| T | TFB(t) | CATCH(t) | TPFTM(t) |
|---|---|---|---|
| 0 | 10.00 | 00.00 | 00.00 |
| 1 | 10.40 | 10.40 | 17.51 |
| 2 | 10.93 | 10.93 | 24.73 |
| 3 | 11.44 | 11.44 | 28.29 |
| 4 | 11.94 | 11.94 | 31.89 |
| 5 | 12.44 | 12.44 | 34.42 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 15 | 18.95 | 18.95 | 58.07 |
| 16 | 19.87 | 19.87 | 62.10 |
| 17 | 20.89 | 21.45 | 66.90 |
| 18 | 22.00 | 22.26 | 72.75 |
| 19 | 23.09 | 25.88 | 79.95 |
| 20 | 23.80 | 32.44 | 88.62 |

The rate of spawning success, SS, an important parameter of the system feedback component, was also changed within the interval [$1.10 \times 10^{-6}$,$1.34 \times 10^{-6}$]. This interval is obtained from decreasing and increasing by 10% the estimated $1.22 \times 10^{-6}$ spawning success parameter. Shifting of this parameter resulted in changes in the correct direction involving reasonable magnitudes.

It should be mentioned that model performance variables exhibited greatest changes when average natural mortality, MR = .33 , was increased and decreased by 10 %. Simulation runs were conducted for values of this parameter within the interval [.29,.36].

The effects of changes in other inputs (controllable) and design parameters are discussed in the section dealing with simulation of management strategies.

## Monte Carlo Analysis

As discussed in the reaserch methods chapter the model was set into Monte Carlo mode in order to estimate confidence intervals, $\theta \pm Z_{\alpha/2} \cdot s/\sqrt{n}$, for model inputs as well as important performance variables.

Monte Carlo experiments were conducted <u>within</u> a simulation run to estimate the expected value and confidence intervals for a randomly generated series of 100 traditional and modern vessels catch.

Table 11 presents estimators and confidence intervals for mean catch of both traditional and modern vessels, respectively.

Table 11. Monte Carlo Analysis of Fishery Yield by type of vessel, CATCHT(t) and CATCHM(t)

| Statistic | CATCHT(t) (Tons/year) | CATCHM(t) (Tons/year) |
|---|---|---|
| Average | 2949 | 6456 |
| Standard Deviation | 417 | 908 |
| Standard Error | 42 | 91 |
| 95% Confidence Interval. | $2867 < \theta_1 < 3031$ | $6278 < \theta_2 < 6634$ |

By the Central Limit Theorem, it is expected that the distribution is approximately normal. therefore, it can be said that a 95% confidence interval for $\theta_1$ and $\theta_2$ is given by:

$\theta_1 \pm 82$ for traditional vessels, and

$\theta_2 \pm 178$ for modern vessels

In addition an experiment was conducted by implementing 50 simulation runs to estimate the statistics of important performance variables such as PFTT(t), PFTM(t), and TFB(t). The results of this experiment are presented in Table 12 and Table 13.

With 95 % confidence, the intervals for the means, $\theta_3$, $\theta_4$, $\theta_5$ of the above mentioned variables are the following:

$\theta_3 \pm 82$

$\theta_4 \pm 272$

$\theta_5 \pm 2767$

Table 12. Monte Carlo Analysis of Net Revenues by Type of Vessel, PFTT(20) and PFTM(20).
(Millions of Pesos)

| Statistic | PFTT(t) | PFTM(t) |
|---|---|---|
| Average | 295 | 633 |
| Standard Deviation | 293 | 973 |
| Standard Error | 42 | 139 |
| 95 % Confidence Interval. | $213 < \theta_3 < 377$ | $361 < \theta_4 < 905$ |

Table 13. Monte Carlo Analysis of Red Grouper Biomass, TFB(10) and TFB(20).

| Statistic | TFB(10) (Tons) | TFB(20) (Tons) |
|---|---|---|
| Average | 148834. | 112769. |
| Standard Deviation | 6757. | 9887. |
| Standard Error | 965. | 1412. |
| 95 % Confidence Interval | $146943 < \theta_6 < 150725$ | $110000 < \theta_5 < 115537$ |

In order to have an estimate of red grouper biomass in 1986, a Monte Carlo experiment was conducted with run length of 10 years. This experiment provided the following confidence interval for mean red grouper biomass:

$$\theta_6 \pm 1891$$

This biomass estimate which resulted from 50 independent simulation runs, provides an indication of the current status of the red grouper population of Yucatan Continental Shelf.

## Simulation Results

After implementing the comprehensive simulation model developed in Chapter III for the red grouper fishery, the main results (Appendix F) concerning rate as well as state variables are discussed as follows (Chappelle, 1985; Sassaman et al., 1969):

### Red Grouper Biomass

Total red grouper biomass over time, TFB(t), is presented in Figure 17. It can be observed that fish biomass (summing up age specific biomass), begins to decline after year 3 (1979). This downward sloping section of the curve shows a small inflection in year 7 (1983). This is caused by a reduction in fishing effort of the modern fleet resulting from the allocation of an average 5 trips per year to the octopus fishery (*Octopus maya* and *Octopus vulgaris*).

This change in fishing effort takes place from September to December. It should be mentioned that during the octopus season the fishing gear discriminates other demersal species like grouper, snappers and, grunts. Concerning traditional fishermen, they had been incorporated to the octopus fishery for a number of years before T=0, therefore there was no need to include changesin their fishing effort.

Total biomass declines to a level of 95000 Tons in year T=20. This is basically the result of the existing open access regime for this species. This overexploitation effect indicates the need for government intervention to prevent resource exhaustion.

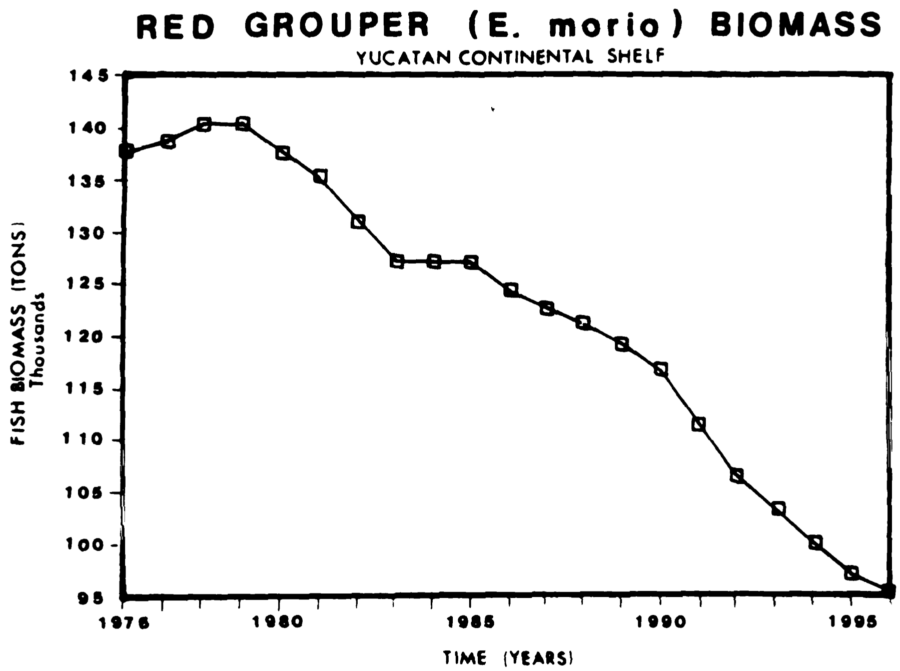



Figure 17. Red Grouper Biomass Over Time

## Fishery Yield

Red grouper simulated catch of both traditional and modern vessels is presented in Figures 18 and 19. Annual catch of traditional vessels is sustained, with fluctuations due to uncertainty, up to year T=15 (1991). After that point in time, CATCHT(t) decreases to its lowest level of 1646 Tons in year T=20 (1996). Annual yield of modern fishermen shows a decreasing trend after T=5 (1981).

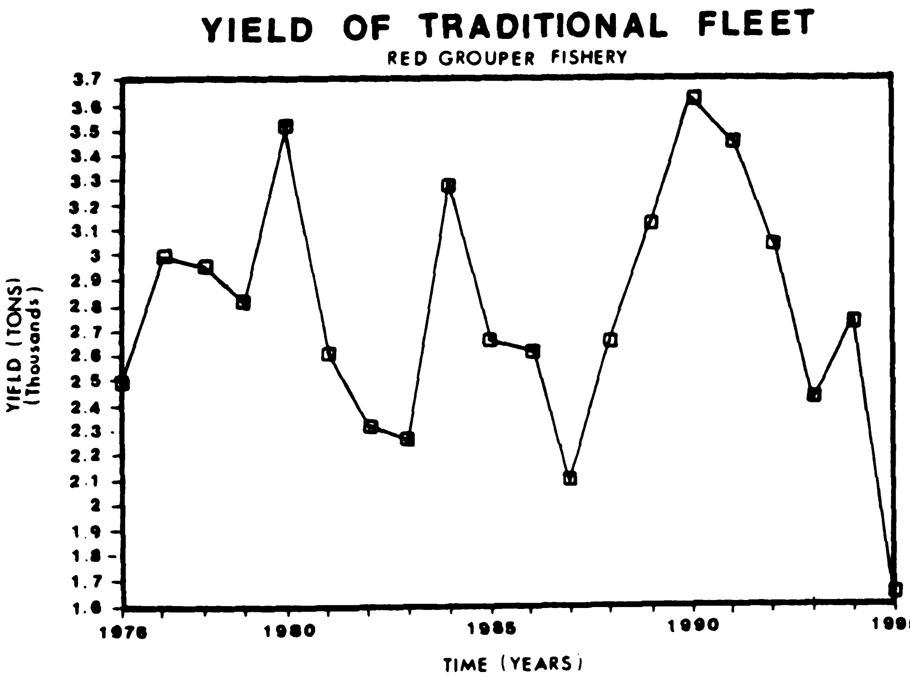



Figure 18. Yield of the Traditional Fleet: Red Grouper Fishery

It should be mentioned that, given the continuing entry of new vessels to the fishery up to T=17, it would be more realistic to analize the status of the fishery by observing annual catch per unit of effort, CPUE1(t) and CPUE2(t), which shows the actual status of the fishery over time This can be observed from Figures 12 and 13 discussed in the Model Validation section.

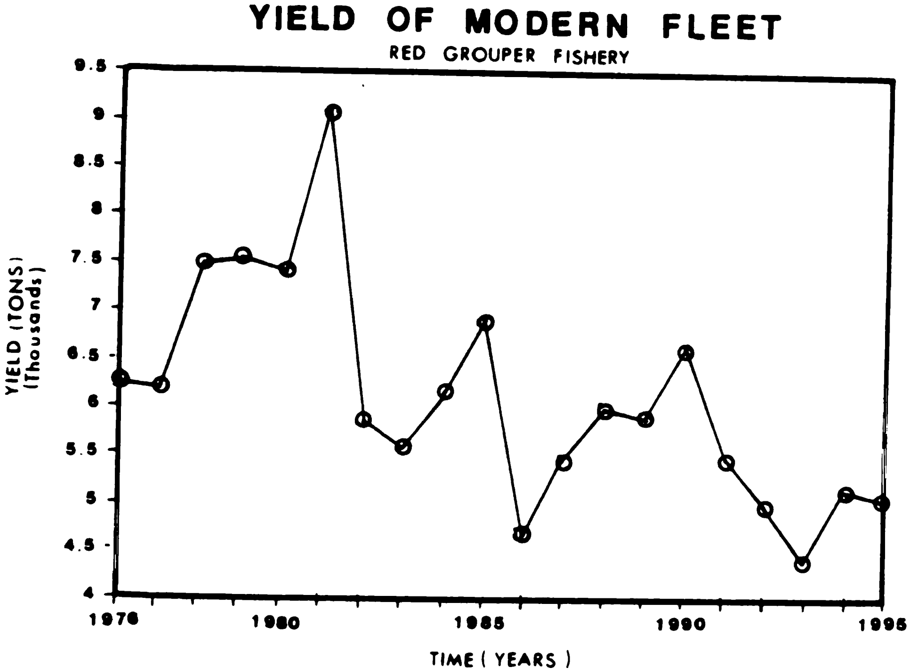



Figure 19. Yield of Modern Fleet: Red Grouper Fishery.

The random variables generated for the catch equations to incorporate uncertainty in the analysis are graphed in Figure 20 and 21. This random yield component of CATCHT(t) and CATCHM(t) is generated by subroutine EXACOR using variances VAR1 and VAR2 and correlation coeficient XLMDA, estimated from monthly catch and effort data for 1984 (Burgos and Lope, 1985).

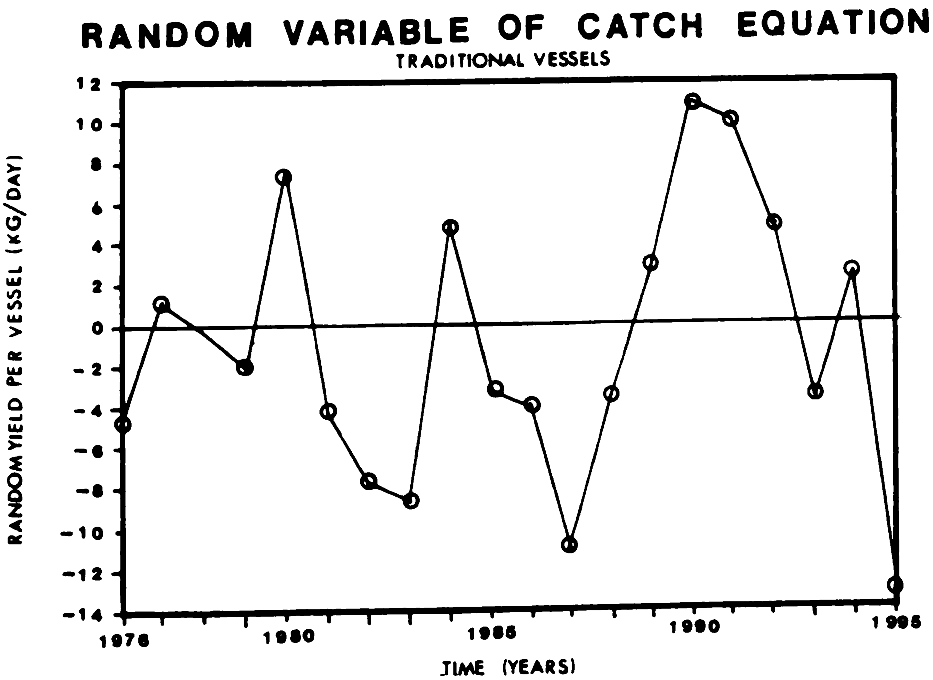



Figure 20. Random Variable of Catch Equation of Traditional Vessels.

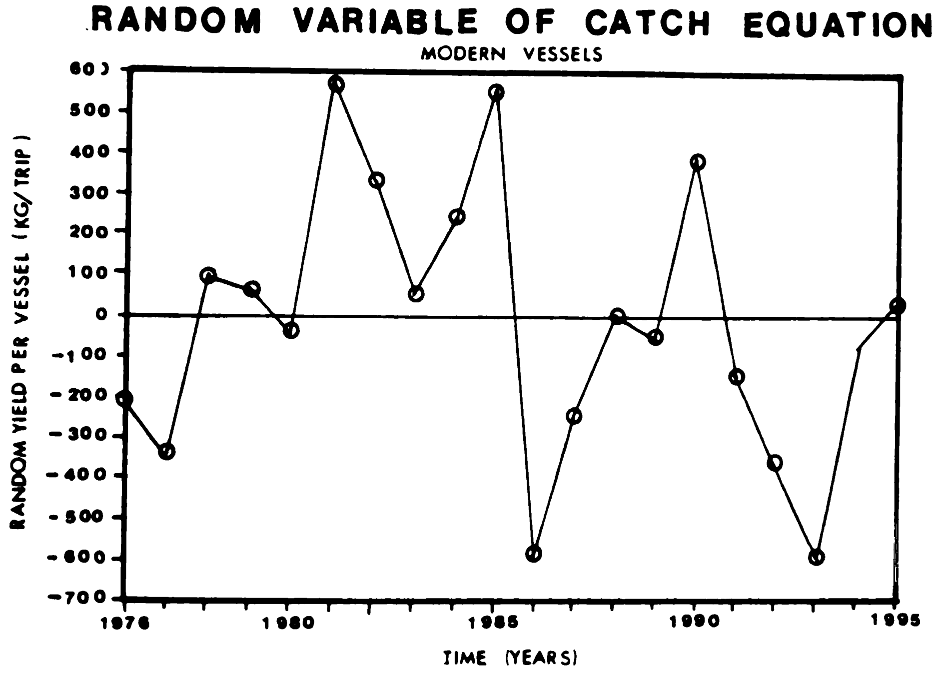



Figure 21. Random Variable of Catch Equation: Modern Vessels.

## Costs and Returns

Annual net revenues obtained by fishermen involved in the red grouper fishery are illustrated in Figure 22 where net profits of modern fishermen are presented in bar diagram format. It can be observed that total costs are greater than total revenues in T=11 (1987) and T > 16 (1992). The first occurrence of losses are related to uncertainty given that the random variable $R_2$ = -.595 (tons/vessel/trip) in T=11.

On the other hand, economic rent (difference between fish resource dockside price and harvesting average cost multiplied by total yield) is dissipated after T > 16 because catch per unit of effort, CPUE2, decreases to a level at which average costs are greater than average revenues. As a result, "exit" of modern vessels takes place with its corresponding time lag.

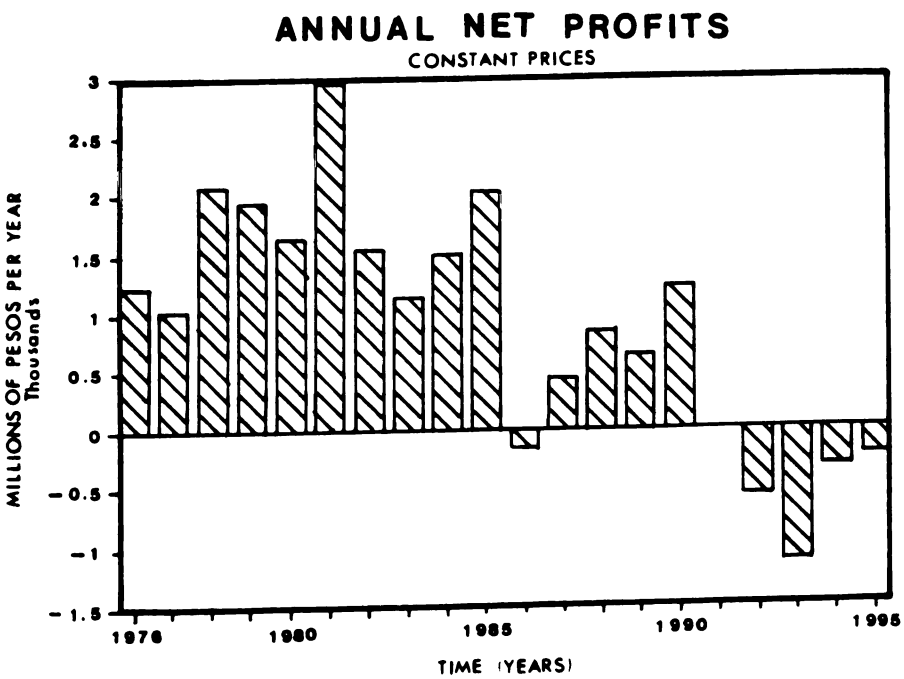



Figure 22. Annual Net Revenues of Modern Vessels Targeting at Red Grouper.

Average and marginal costs and average revenues per type of fishing vessel are presented in Tables 13 and 14. Bioeconomic equilibrium occurs whenever average revenue equals average cost, and consequently there is no stimuli for entry or exit to the fishery.

As shown in Tables 13 and 14, the number of fishing vessels increases over time up to the point at which economic rent is dissipated. Economic rent is understood as a payment in excess of what is needed to bring a factor into production. It should be pointed out that open access equilibrium is approximately observed, when TFV(t) = 1110 and MFV(t) = 292. As a result, entry of modern vessels to the red grouper fishery stops at T = 16 (1992), when $AC_2 = AR_2$, and exit begins when T > 18 (1994). Concerning traditional vessels, entry stops after T = 17 (1993) and exit takes place when T > 18.(Tables 13 and 14)

Maximum economic yield, MEY, takes place when marginal costs equal willingness to pay for the resource (average revenue). Given the assumption of price taking behavior, in the case of the red grouper fishery average revenue equals marginal revenue. Therefore, MEY occurs at T = 16 for traditional fishermen, the point at which $MC_1 = AR_1$. It is observed when TFV(t) = 1082.

Table 13. Costs and Revenues of Traditional Fishermen.

| T | Year | Vessel TFV(t) | Ave. Cost AC1(t) | Ave. Revenue AR1(t) | Marginal Cost MC1(t) |
|---|---|---|---|---|---|
| 1 | 1977 | 856 | 435 | 577 | 445 |
| 2 | 1978 | 869 | 367 | 577 | 439 |
| 3 | 1979 | 884 | 378 | 577 | 440 |
| 4 | 1980 | 901 | 405 | 577 | 448 |
| 5 | 1981 | 919 | 329 | 577 | 456 |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| 15 | 1991 | 1062 | 372 | 577 | 555 |
| 16 | 1992 | 1082 | 397 | 577 | 579 |
| 17 | 1993 | 1103 | 459 | 577 | 598 |
| 18 | 1994 | 1117 | 588 | 577 | 616 |
| 19 | 1995 | 1116 | 516 | 577 | 636 |
| 20 | 1996 | 1104 | 849 | 577 | 649 |

Note: Costs and revenues are expressed in thousands of pesos per ton.

Table 14. Costs and Revenues of Modern Fishermen.

| T | Year | Vessel MFV(t) | Ave Cost AC2(t) | Ave. Revenue AR2(t) | Marginal Cost MC2(t) |
|---|---|---|---|---|---|
| 1 | 1977 | 183 | 711 | 906 | 1164 |
| 2 | 1978 | 187 | 739 | 906 | 1149 |
| 3 | 1979 | 193 | 628 | 906 | 1150 |
| 4 | 1980 | 200 | 647 | 906 | 1172 |
| 5 | 1981 | 208 | 684 | 906 | 1194 |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| 15 | 1991 | 285 | 722 | 906 | 1451 |
| 16 | 1992 | 292 | 904 | 906 | 1514 |
| 17 | 1993 | 299 | 1018 | 906 | 1563 |
| 18 | 1994 | 301 | 1161 | 906 | 1611 |
| 19 | 1995 | 295 | 969 | 906 | 1664 |
| 20 | 1996 | 283 | 951 | 906 | 1698 |

Note: Costs and revenues are expressed in thousands of pesos per ton

In the case of modern vessels, marginal costs have been greater than marginal revenue, $MC_2 > AR_2$, since the simulation run was initialized. This means that there have been overinvestment in the case of modern vessels, at least from the point of view of the red grouper fishery. When the marginal cost of catching an additional unit of the resource is higher than marginal benefits derived from it, a loss in welfare to society occurs. This loss is equal to the opportunity costs of capital, labor and management used to harvest the additional unit.

## Fish for Coastal Zone Consumption

A component of the red grouper catch is allocated for local consumption in the Yucatan coastal area. It is basically composed of: (1) the proportion of red grouper and by-catch that fishermen take to their home for subsistence purposes and, (2) the proportion of fish catch that is sold in coastal markets of The Yucatan Peninsula.

The simulation run provided an estimate of the amount of seafood generated by this fishery in coastal areas over time, SEAFC(t). Estimates are presented in Figure 23.

According to the simulation results presented in Figure 23 and Appendix H, the red grouper fishery might be contributing at present time approximately 1000 tons of protein rich seafood per year. From Figure 23 it can be observed that SEAFC(20) may decrease to 500 tons per year under the current open access regime.

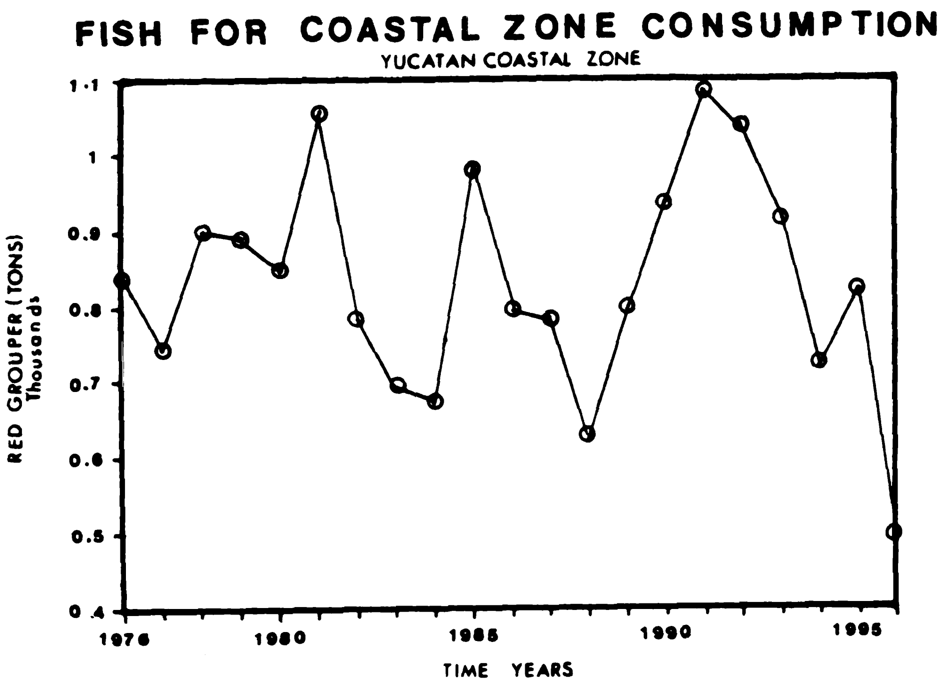



Figure 23. Red Grouper for Coastal Zone Consumption.

## Fishery Direct Employment

Given the average number of fishermen per type of fishing vessel, direct employment generated by red grouper harvesting is basically determined by the entry and exit of vessels to the fishery. Figure 24 shows the evolution of accumulated direct employment for this fishery. Because of the assumption of constant crew size, the shape of the curve is very similar to the one that estimates the number of vessels over time

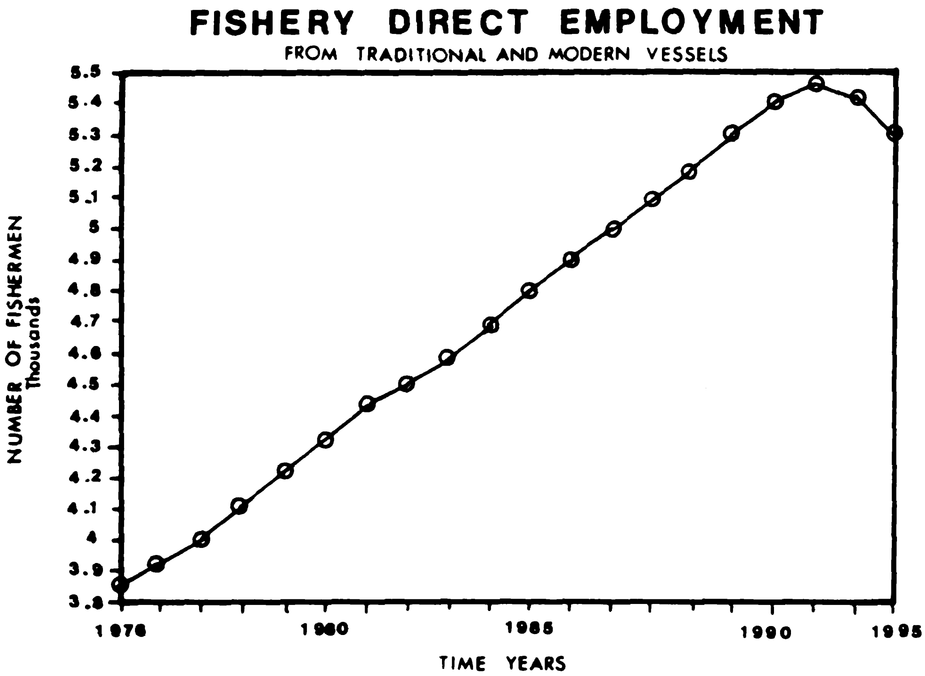



Figure 24. Direct Employment Generated by Harvesting of Red Grouper

Figure 24 shows that, under the current unlimited entry regime, the number of fishermen employed at the present time (1985), is in the order of 4600. The estimated number of fishermen that could be harvesting this resource at T=20, may represent 5300 individuals. It can also be observed in Figure 24, that when vessel exit to the fishery takes place, the number of fishermen is consequently decreased.

## Resource Management Strategies

Simulation of management strategies of this tropical demersal fishery involved a set of regulations affecting both age composition of the catch and size of the catch. It also included allocation of property rights to a group of resource users. Specifically, four management strategies were simulated to observe the effect on system performance variables: (1) allocation of exclusive property rights to domestic fishermen, (2) Limited entry to the fishery, (3) minimum size restrictions and, (4) price controls. Each of these strategies was implemented for T > 10 .

### Allocation of Exclusive Property Rights

As discussed in the in Chapter I, The Law of the Sea establishes that coastal States must determine the portion of the exploitable biomass that could be harvested domestically and make available surpluses (if any) to foreign fishing fleets through yearly quotas.

Overexploitation is present in the red grouper fishery, given that catch per unit of effort has been decreasing since 1972 (Chavez, 1983; Doi et al., 1981). This trend was also observed and discussed in the simulation results section. Therefore, before limiting domestic fishing effort, an alternative strategy is to provide exlusive property rights to domestic fishermen by excluding foreign fishing in the red grouper fishery. This was done in the computer model with the following FORTRAN statement: IF(T.GE.10) CCUB=0.

Limited Entry to the Fishery

An alternative strategy to mitigate overfishing involves a limited entry policy that could be implemented to regulate domestic fishing effort. This involves not allowing entry of new traditional and modern vessels to the fishery, except for boat replacement purposes. This strategy is implemented by the following statements:

```
IF(TFV.GE.975.) TFV=975.
IF(MFV.GE.250.) MFV=250.
```

Minimum Size Regulation

This management strategy involves requiring harvested fish to be adults. Consequently red grouper cohorts of ages 1 and 2 will not experience fishing mortality. This is done by specifying age composition of the catch, $ACT_i$ and $ACM_i$, with the above mentioned constraints for $T > 10$.

Price Controls

A policy instrument usually employed by Mexican planners dealing with food products is concerned with price ceilings. This management strategy is implemented in the computer program by reducing red grouper and by-catch dockside real prices by 20 %.

Other resource management strategies such as closed seasons, fish quotas and taxes were not simulated given that: (1) there is an "spontaneous closed season" resulting from fishing effort being diverted to the octopus fishery from August to December, (2) There are substantial constraints in the fisheries information system that will make non-operational a regulatory scheme involving fish quotas, which requires real time data, and (3) imposing taxes to increase total costs and consequently decrease fishing effort may foster severe catch information distortions that would generate underestimation of fishing mortality.

These management strategies can be identified in the following Figures as:

Policy 1: cancel foreign fish quota

Policy 2: limited entry to domestic vessels

Policy 3: enforce minimum size restrictions

Policy 4: price controls on red grouper and by-catch

The effects and trade-offs of the above mentioned set of resource management strategies, are discussed in terms of important system performance variables. These performance variables are compared according to the values they attain at the end of the simulation run. Combinations of management strategies were also made to observe system performance and results and summarized at the end of the chapter.

## Red Grouper Biomass

The impact on the amount of red grouper biomass over time is is presented in Figure 25 and Table 15. Policies 1 and 3 generate the highest increments, 62 % and 59 % respectively. Policy 2 and Policy 4 also improve the level of biomass with increments of 13 % and 15 %. These increments, expressed as percentages, are estimated with respect to the base run, which reflects the open access regime currently operable in the fishery.

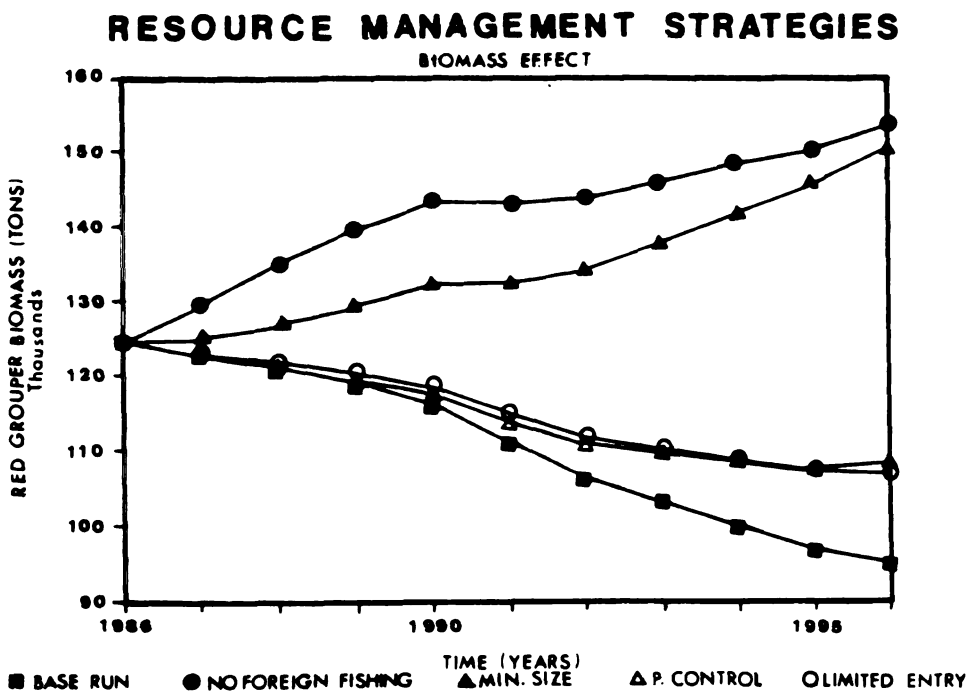



Figure 25. Resource Management Strategies: Biomass Effect

Table 15. Impact of Alternative Resource Management Strategies.

| Performance Variable | Policy 1 % | Policy 2 % | Policy 3 % | Policy 4 % |
|---|---|---|---|---|
| Biomass | 62 | 13 | 59 | 14 |
| Fishery yield | 94 | -4 | 86 | -16 |
| Net Revenues (Traditional) | 73 | 9 | 54 | -34 |
| Net Revenues (Modern) | 55 | 5 | 42 | -33 |
| Employment | 13 | -13 | 12 | -19 |
| Seafood Availability | 14 | -2 | 11 | -1 |
| Fish Exports | 15 | -3 | 11 | -5 |

## Fishery Yield

The effect on domestic fishery yield with policies 1 and 3 involve substantial improvements: 94 % and 87 % respectively (Table 15 and Figure 26). With these management strategies the red grouper catch will approximate the maximum sustainable yield reached in 1972. On the other hand, imposing either limited entry restrictions or price controls, generate reductions in annual fish catch with respect to the base run (Table 15).

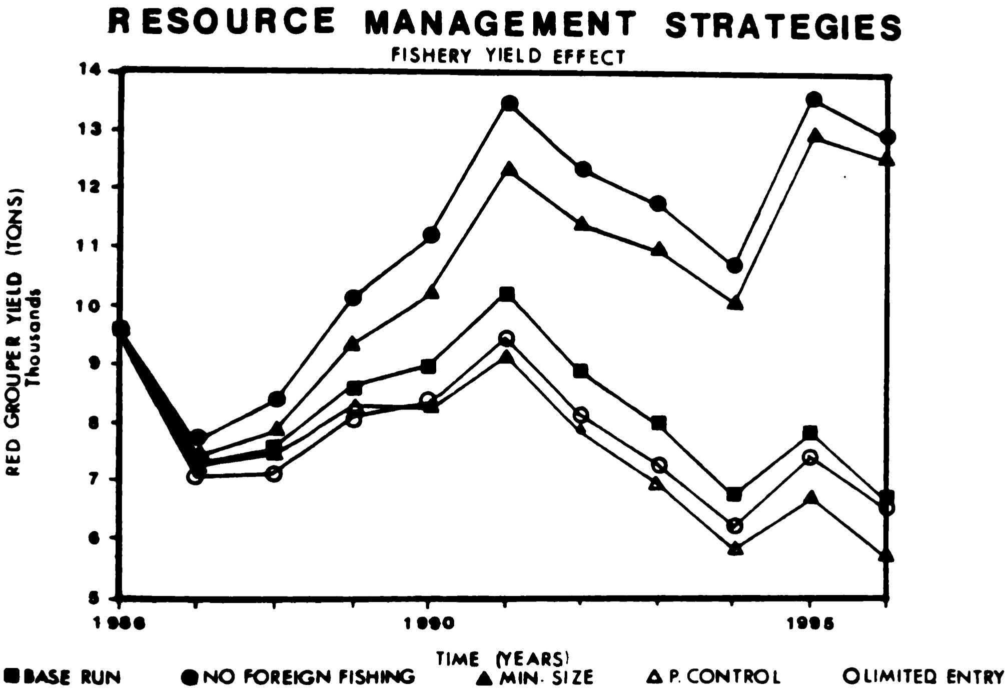



Figure 26. Resource Management Strategies: Fishery Yield Effect.

## Net Revenues

To observe the effect on net revenues of both, traditional and modern fishermen, note that Table 15 show that accumulated net revenues increase with Policies 1, 2 and 3 and decrease with price control policies (Figure 27)

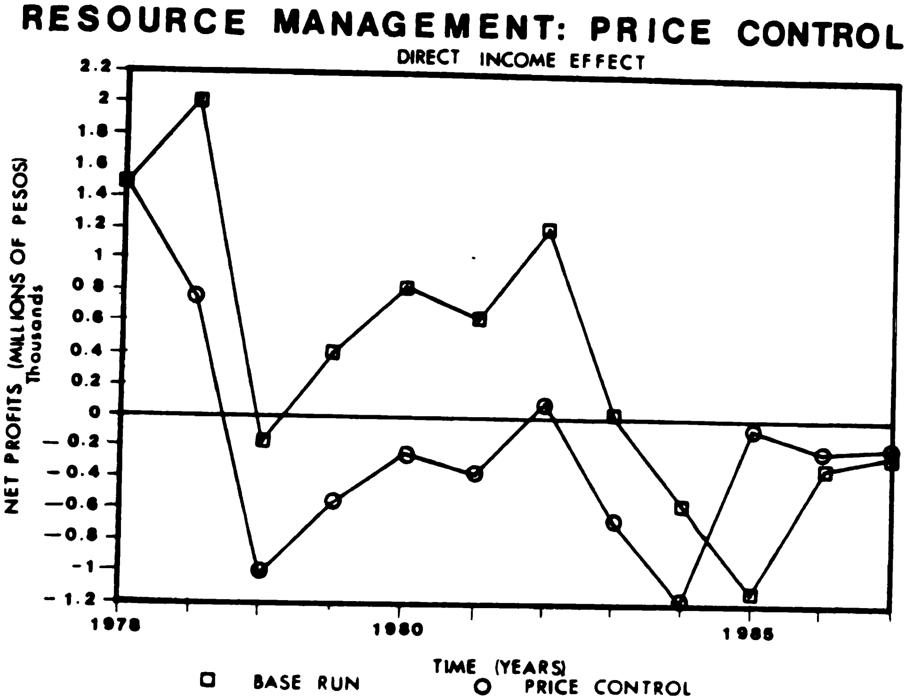



Figure 27. Price Controls Policy: Effect on Net Revenues.

## Direct Employment

The resulting impact on direct employment is presented on Figure 28. With limited entry, direct employment becomes a constant that involves lower employment levels when compared to the base run. With policy 1 and 3, employment of fishermen increases 13 % and 12 % respectively.

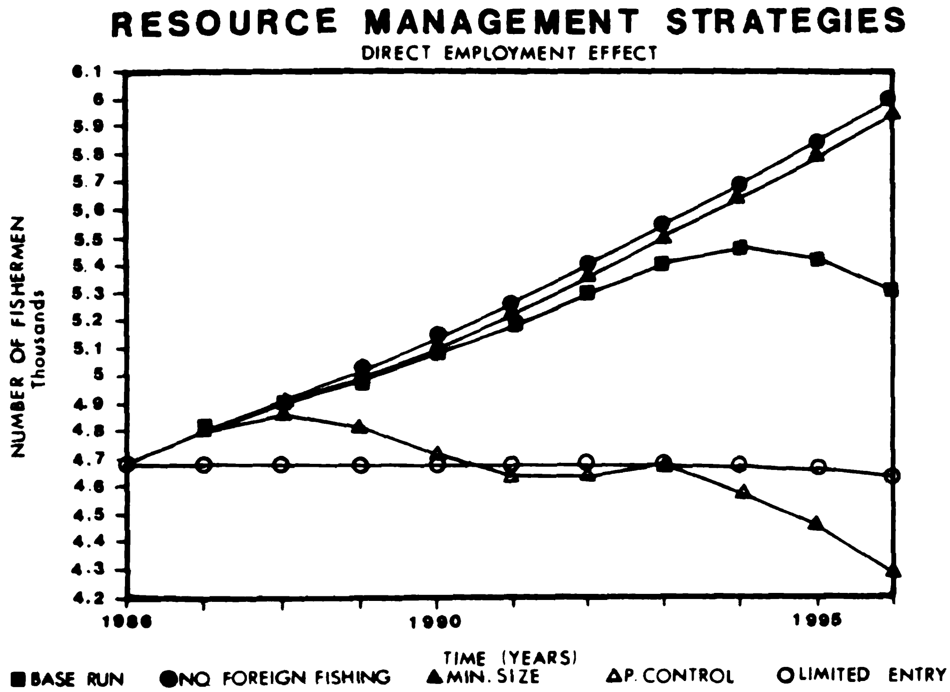



Figure 28. Resource Management Strategies: Effect on Direct Employment.

## Seafood Availability and Export Earnings

Finally, it can be observed from Table 15, that Policy 1 and 3 result in higher levels of seafood availability in coastal communities. Also export earnings experience increments in the order of 15 % when compared to the open access simulation run.

On the other hand, Policies 2 and 4, both generate small decrements with respect to the base run.

When more than one resource management starategies were included in the same simulation run, policies 1 and 3 combined yielded highest system desired output.

Discussion of the results described in this Chapter and analysis of trade-offs of alternative management regimes, are presented in Chapter V, which deals with Conclusions and Recommendations.

# CHAPTER V

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this final Chapter the following sections are presented: (1) a summary of the research, (2) a discussion of the major conclusions derived from this research effort, (3) study implications, (4) study limitations, and (5) recommendations for further research.

## Summary

Management of renewable resources such as tropical fisheries, is a complex process that requires an understanding of the resource biology and ecology, as well as the economic and institutional factors that affect behavior of fishermen as resource users. Inherent characteristics of this common property resource are also important. These include: high exclusion costs, free rider problems, and high transactions costs, mainly enforcement and information costs.

It should be pointed out that fisheries resource managers require information concerning dynamics of fish populations and factors that determine their spatial and temporal distribution. Management of ocean fisheries also demands information about linkages between resource management strategies and fishery system performance.

Different approaches have been used to aid the decision-making process through modelling efforts. These are discussed in the fisheries science literature as the surplus yield approach, the bio-economic approach and the dynamic pool approach. It is also recognized in the literature, that "...few general descriptions of the complete management system have been given. It is therefore not surprising that models of the complete system do not exist" (Gulland, 1981:130). Rather, there are a number of fisheries models describing individual parts of the system, these can be grouped into (1) biological models describing fish populations and the ecosystem in which they live, (2) bio-economic models describing large scale interactions between fish stocks and fishing effort by a set of equilibrium conditions, and (3) models describing actual operations of individual elements of the fishing industry.

Therefore, the major objective of this dissertation was to develop a comprehensive model integrating biological, economic and institutional factors using the systems simulation approach.

The systems simulation approach is a problem-solving process of designing a model of a real system such as an ocean fishery, and conducting experiments with this model for the purpose of either understanding the system or of evaluating various strategies for the operation of the system. This involves obtaining solutions over time of a mathematical model based on specific assumptions regarding model inputs and values assigned to parameters.

The systems simulation methodology was applied to model a tropical demersal fishery: red grouper (*Epinephelus morio*) of the Yucatan continental shelf. To develop a comprehensive simulation model for this species, the following steps were taken:

(i) System Identification. A first step in this process involved linking the needs statement discussed above with a conceptual identification of the fishery system. This required a definition of exogenous and controllable inputs, design parameters, and desired and undesired outputs of this tropical demersal fishery.

(ii) Model Decomposition. The red grouper fishery system was decomposed into three interacting sub-systems: biological, economic and resource management. This model decomposition emphasize interface variables that link the sub-systems together.

(iii) Design of System Causal Diagram. This diagram was built to represent cause and effect relationships between relevant variables of each subsystem. This is a conceptual model of the fishery showing flows of fish, dollars and information.

(iv) Data Collection for Parameter Estimation

Data were collected from primary as well as secondary sources to generate production functions for traditional and modern vessels. In addition, these data were used to determine important design parameters.

(v) Mathematical Model

Implicit form equations were developed for performance and rate variables using the fishery causal diagram as a main reference. Then, a block diagram was constructed using a set of basic mathematical operations including:

. Arithmetic operations

. Generation of explicit functions

. Generation of non-explicit functions

. Distributed DELAY functions

. Differentiation

. Integration

The resulting mathematical model involved 44 linear and non-linear equations. It should be mentioned that uncertainty was included in the model through generation of random variables with an appropriate probability density function.

(vi) Computer Model

A computer simulation model (SIMERO) was developed in FORTRAN 77 and implemented in a IBM-PC microcomputer using a Microsoft FORTRAN Compiler. The resulting computer program has 349 lines (without including Comments). A second version of this program (SIMERO-1) was developed for Monte Carlo analysis purposes. SIMERO-1 has 376 lines without including comments.

(vii) Stability Analysis

In order to have a stable computer model an appropriate value for DT (time increment) was determined. This value was required for stable simulation of differential equations (converted to difference equations) included in the model such as distributed delays. Given that this simulation model involves feedback in the population dynamics component upper bounds were determined for values of DT. It should be pointed out that in order to reduce the numerical integration error (Euler numerical integration) to an acceptable level, below 5 %, DT was reduced to DT=.05

(viii) Model Validation

A model is validated by providing a correct representation of the real system. Validation of the model built for the red grouper fishery involved checking if it exhibited behavior characteristic of the fishery system itself. Model validation was conducted using three major approaches (or validation norms):

a. Comparison of actual and simulated catch.
b. Consistency with accepted theory.
c. Discussion of the simulation model and results with resource experts and decision-makers.

(ix) Sensitivity analysis

In order to establish confidence in model validity it was necessary to determine if reasonable changes (marginal) in model parameters or operating conditions lead or do not lead to reasonable changes in behavior. Initial fish biomass, spawning success, and the natural mortality rate, among others, were increased and decreased by 10 %. In general, the model exhibited reasonable behavior when marginal changes in parameters and controllable inputs were implemented. It should be pointed out that model performance variables exhibited greatest changes when average natural mortality (MR) was increased and decreased by 10 %. Simulation runs were conducted for values of this parameter within the interval [.29,.36].

(x) Monte Carlo Analysis

The simulation model was put into Monte Carlo mode in order to estimate confidence intervals for model inputs as well as important performance variables. Monte Carlo experiments were conducted within a simulation to estimate the expected catch value and confidence interval for a randomly generated series of 100 traditional and modern vessels. In addition, an experiment was conducted by implementing 50 simulation runs to estimate statistics of important performance variables such as net revenues by fishermen type and total red grouper biomass.

(xi) Analysis of Simulation Results

A next step in this process involved analyzing major simulation results. Red grouper biomass over time (TFB(t)) begins to decline after year 3. This downward sloping section of the curve showed a small inflection in year 7. This is caused by a reduction in fishing effort of the modern fleet resulting from allocating an average 5 trips per year to fishing for octopus. Total biomass (summing up over age specific biomass), declines to a level of 95000 tons in T = 20.

Fishery yield of traditional vessels exhibit sustainable levels up to T = 15. After that point CATCHT(t) decreases to its lowest level of 1646 tons in T = 20. On the other hand, considering catch per unit of effort over time for the two types of vessels (CPUE1(t) and CPUE2) show that fishery yield is decreasing per unit of effort. This performance is specially significant in modern vessels. This research result indicates that the red grouper fishery of the Yucatan continental shelf exhibits overexploitation. Dissipation of economic rent is another simulated performance of the current open access regime. Net revenues, contribution of seafood availability in coastal communities, direct employment, and export revenues all tend to decrease in the long run.

(xii) Simulation of Management Strategies

In order to guide management of this renewable resource, four management strategies were implemented to simulate impacts on performance variables:

- Policy 1: Allocation of exclusive property rights to domestic fishermen
- Policy 2: Limited entry of domestic vessels
- Policy 3: Enforcement of minimum size restrictions
- Policy 4: Price controls on red grouper and by-catch.

All four policies increased fish biomass as expected. However, they differ on the degree of impact on this important performance variable. Policies 1 and 3 had the greatest desired effect on the red grouper population. Policies 2 and 4 resulted in undesired performance of important variables such as fishery yield, employment, and seafood availability.

Choice of either policy 1 or 3 , involve important distributional impacts on different resource users. Policy 1 provides the highest benefits to domestic fishermen and to the regional economy. With policy 1 the trade-off involves not allowing a foreign fleet to harvest fish species within Mexico's EEZ. This may have economic as well political implications.

Decision-makers need to make a value judgement concerning whose interests count the most when regulating resource use and exploitation. Adopting Policy 3 imposes severe restrictions to traditional fishermen because their fishing vessel characteristics allow them to fish only in near shore ecosystems where juveniles are located. Therefore, in order to keep them fishing, the Mexican government would need to provide financing for acquiring larger vessels. The opportunity cost of financing traditional vessels is the highest economic alternative forgone.

## Conclusions

The conclusions derived from this research study are the following:

1. It was feasible to build a comprehensive simulation using the systems simulation approach. This dynamic model integrated biological, economic, and institutional factors that determine the performance of a tropical demersal fishery over time. The systems simulation approach proved to be a systematic and robust methodology for modelling the dynamics of renewable resources, given the comprehensive nature of ocean fisheries development and management. As a problem-solving methodology it allowed for conducting experiments dealing with impacts of alternative resource management strategies.

2. The model was shown to be useful as a tool for simulating alternative management strategies and for observing the impacts on the fishery performance variables.
3. Inclusion of the dualistic characteristics of tropical fisheries, which involve modern and traditional fishermen, allowed the possibility of estimating important important performance variables.
4. It is concluded that the spatial disaggregation of fishing effort in tropical fisheries is fundamental in order to conduct meaningful cohort survival analysis of fish populations. The rationale behind this statement is based on the fact that traditional vessels usually apply their fishing effort in near shore environments where most of the juvenile population is located. As a result, differences in age composition of the catch by type of vessel become substantial. Therefore, disaggregating fishing effort and catch over space results in more realistic fishing mortality rates by age cohort.
5. The stochastic nature of ocean fisheries was also incorporated in this simulation model. Random variables were generated to represent uncertainties that exist about the current size, and spatial and temporal distributions of the resource, mainly because of difficulties in observing the stock. These random variables were also an expression of

unpredictable changes in the natural environment, which may affect effective fishing effort.

6. Among domestic management strategies, if a minimum size regulation is enforceable, it provides the highest desired impacts on performance variables. It should be mentioned, however, that the trade-off of this policy involves substantial investment in safer and more efficient vessels and gear in order for traditional fishermen to apply their fishing effort in deeper waters where most of the adult fish population is located.

## IMPLICATIONS

Some of the most important study implications include the following:

1. The application of the distributed DELAY model (Manetsch, 1976), to represent the exit and entry processes of vessels to the fishery. Such processes involve time lags in:
   - the decision-making process of entering or leaving the fishery.
   - the time required to obtain public financing to buy vessels and fishing gears.
   - the time it takes to receive a vessel after it has been ordered.

2. Incorporation of random variables generated with an exponentially autocorrelated probability density function, to indicate that random variables for the red grouper fishery at one point in time are not independent of previous values. Today's catch is dependent to a certain extent on yesterday's catch. Selection of site is also dependent to certain degree on previously selected sites.

   Environmental factors that affect resource availability and fishing effort (and consequently fish catch), such as water temperature, currents and winds tend also to be dependent to a degree on previous values.
3. Dynamic marginal cost equations based on Cobb-Douglas production functions which have effective fishing time, biomass availability and a random variate as independent variables were developed. These marginal cost equations allow for the possibility of determining dynamic maximum economic yields.
4. A dynamic feedback mechanism was designed to estimate population structure and recruitment to the fishable stock as a function of a time varying spawning stock population, an average fecundity rate and a spawning success parameter. This population dynamics submodel could be applied to tropical as well as non-tropical fisheries with appropriate

inputs.

5. The fishing mortality rate was decomposed by type of vessel which resulted into time variants:
   - fishing mortality rate by age cohort i, $FR_i(t)$,
   - total mortality rate by age cohort, $DR_i(t)$, and
   - Cohort survival rates, $SR_i(t)$.
6. The model developed in this study could be used as a tool to aid the decision-making process used in managing tropical fisheries.
7. The simulation characteristics of the model, provides the possibility of conducting a number of resource management experiments to identify the effects and trade-offs involved in relevant performance variables.
8. In the case of the red grouper fishery of the Yucatan Continental Shelf, two resource management strategies exhibited overall higher desired performance: (i) Allocation of exclusive property rights to domestic fishermen and, (ii) enforcement of minimum size restrictions on this species.
9. Given that the computer model was developed and implemented on an IBM PC using a Microsoft FORTRAN compiler, the resulting software could easily be implemented in IBM-PC compatibles, the kind of microcomputers usually available in tropical coastal nations.

## Study Limitations

Some of the most important limitations involved in this research effort, are as follows:

1. Because of lack of information, it was not feasible to incorporate into the the model the high diversity of species usually present in tropical ecosystems. It would have been desirable to model the dynamics and interdependencies of tropical multispecies fisheries.
2. When running the computer model, the population dynamics component used the available average fecundity rate. It would have been more appropriate to include the average fecundity by age of spawners, as indicated in the mathematical model.
3. Natural mortality was assumed as an average rate, instead of being a function of age. This model assumption, might be relaxed in the near future, given that a group of marine biologists are conducting studies to estimate this rate by cohort.
4. Estimation of the fishing effort function of traditional fishermen was based on cross-section data collected as part of this study. It would have been more desirable to estimate production functions based on time series which incorporate seasonal variations in catch-effort relations.
5. The model would have been a more accurate representation of reality if information about the following system elements had been available and

included:

. Interdependencies of fish species in the tropical ecosystem.

. Community intertemporal preferences in the use of fish resources.

. Socio-cultural factors that affect behavior of fishermen as resource users.

. Preferences of resource managers dealing with intertemporal and distributional allocation of fisheries resources.

## Recommendations for Further Research

A number of future research efforts seem to be relevant to the fisheries resource development field with emphasis in resource modelling. In ranked order the following studies are needed:

(i) Development of comprehensive simulation models for other renewable resources and more specifically for other biotic resources of marine ecosystems.

(ii) Research efforts concerning the <u>human dimension</u> are needed to model decision-making mechanisms dealing with:

. intertemporal preferences in the use of resources,

. socio-cultural factors that affect fishermen as resource users,

. utility functions of resource managers.

(iii) Multiple-objective optimization functions, could be incorporated in a simulation model like the one developed in this dissertation, to optimize objective functions of different decision-makers (fishermen and resource managers), in order to model the human dimension of ocean fisheries.

(iv) Modelling efforts concerning recruitment of tropical demersal fisheries should include biotic as well as non-biotic factors in order to come up with adequate representation of this important and complex process. Also, time varying distributed delay functions could be applied to model time lags involved in recruitmnet processes.

(v) Parameters which are highly difficult to observe, such as spawning success, could be estimated by applying optimal control theory and dynamic optimization algorithms.

(vi) Application of Monte Carlo analysis to estimate confidence intervals of resource prices in order to account for uncertainty inherent in market fluctuations and government interventions.

(vii) Multivariate analysis of fisheries production functions to include variables such as:

. fishing skills

. type of gear

. vessel characteristics

. number of fishing vessels

. effective fishing time

. Environmental variables

. fishing site

(viii) Biological and technological interdependencies should be included in the analysis of tropical fisheries to deal with a high diversity of species and non-discriminating fishing gears.

(ix) Studies concerning age dependence of fecundity and natural mortality are needed to provide data for research efforts dealing with population dynamics of tropical fisheries.

# APPENDIX A

# APPENDIX A

## FISHERMEN SURVEY

### Questionnaire

Location ______________________

1. Are you involved full time in the fishing activity?

   Yes ( )      No ( )

2. If you are involved in harvesting fish species, please indicate the form of organization to which you belong (if any), to carry out your fishing activity:

   a. Fisheries cooperatives ( )

   b. Private firm ( )

   c. Productos Pesqueros Mexicanos S.A de C.V. ( )

   d. Harvest fish with someone who owns a boat ( )

   e. Harvest fish with your own boat ( )

   (If answer is d., proceed to interview the next fishermen)

3. Please indicate the capacity and length of the fishing vessel that you own:

| CAPACITY | LENGTH |
|---|---|
| 1 to 3 tons ( ) | 10 to 15 feet long ( ) |
| 5 to 10 tons ( ) | 16 to 25 feet long ( ) |
| 11 to 15 tons ( ) | 26 to 30 feet long ( ) |
| 16 to 20 tons ( ) | 31 to 35 feet long ( ) |
| 21 to 30 tons ( ) | 36 to 40 feet long ( ) |
| More than 30 tons ( ) | 41 to 75 feet long ( ) |

4. Please indicate the type of fishing gears that you use in your fishing boat.

   Hand lines ( )

   Longlines ( )

   Nets ( )   Please indicate the mesh size ___________

   Gill-nets ( )

5. How many fishing trips do you undertake per year?

   # of trips per year __________

6. What is the average duration of each of your fishing trips?

   # of days per fishing trip __________

7. How many hours, on the average, do you actually fish in each of your fishing trips?

   Hours fishing activity per trip __________

8. Do you always fish in the same fishing ground?

   Yes ( )   No ( )

9. What is the depth range in which you fish most of the time?

   3 to 5 fathoms ( )

   6 to 10 fathoms ( )

   11 to 15 fathoms ( )

   16 to 20 fathoms ( )

   21 to 25 fathoms ( )

   26 to 30 fathoms ( )

   31 to 40 fathoms ( )

   41 to 50 fathoms ( )

   More than 50 fathoms ( )   How many? __________

10. How many fishermen go in your vessel during each fishing trip?

    # of fishermen __________

11. On the average, how much do you spend on the following items per trip?

    Gasoline and oil __________

    Lines and hooks __________

    Bait __________

    Ice __________

12. On the average, how much do you pay per day to each of the fishermen that fish on your boat?

    $__________ per day per fisherman

13. How much do you think your vessel is approximately worth today including both the boat and the fishing equipment?

    Value of boat $__________

    Value of equipment $__________

    Total value of vessel $__________

14. Indicate the type of fish that you catch when you go fishing, and please indicate the approximate number of kilograms that you catch of each of them in an average trip.

| | | | L S |
|---|---|---|---|
| Red grouper | ( ) | # of Kg | __________ |
| Ocean perch | ( ) | # of Kg | __________ |
| Yellow snapper | ( ) | # of Kg | __________ |
| Red snapper | ( ) | # of Kg | __________ |
| White Grunt | ( ) | # of Kg | __________ |
| King Mackerel | ( ) | # of Kg | __________ |
| Spanish Mackerel | ( ) | # of Kg | __________ |

| | | |
|---|---|---|
| Barracuda | ( ) | # of Kg ________ |
| Octopus | ( ) | # of Kg ________ |
| Squid | ( ) | # of Kg ________ |
| Shark | ( ) | # of Kg ________ |

15. From the above species could you indicate which one of them you are mostly trying to catch as your major fish target and where do you sell it?

    Name of fish ____________________

    For local market ( )

    For processing plants ( )

16. In trying to catch the above indicated fish which are the most common fish species that you are also likely to catch? Please indicate them in order of most occurrence:

    Name of fish ____________________

    Name of fish ____________________

    Name of fish ____________________

17. Do you keep some of your catch for your family consumption?

    Yes ( ) No ( )

    If yes, how many kg/trip ________

18. If your answer was affirmative, what fish species do you keep for consumption?

    Species ____________________

19. If you are fishing for red grouper please indicate the month(s) of the year that you catch the most:

| | |
|---|---|
| January ___ | July ___ |
| February ___ | August ___ |

| | | | |
|---|---|---|---|
| March | ___ | September | ___ |
| April | ___ | October | ___ |
| May | ___ | November | ___ |
| June | ___ | December | ___ |

20. Have you or your organization received financial support from the Fisheries Bank?

    Yes ( )     No ( )

21. How many Kg. of fish would you be willing to accept today as an equivalent of 100 Kg. of fish a year from today?

    Kg. of fish today __________

22. For how many years would you like to keep fishing in the coastal areas of the Peninsula of Yucatan?

    # of years __________

23. If you were informed that one of the fish species that you are currently catching is being depleted, would you be willing to reduce fishing effort to protect the species for future generations?

    Yes ( )     No ( )

    Why?______________________________________________________

Thank you very much!

APPENDIX B

# APPENDIX B

## CONSTANTS, PARAMETERS AND STATE VARIABLES

Table B.1 Model Constants and Parameters.

| Constant and parameter | Value | Unit of Measurement |
|---|---|---|
| ACM(1) | .01 | % |
| ACM(2) | .19 | % |
| ACM(3) | .32 | % |
| ACM(4) | .09 | % |
| ACM(5) | .08 | % |
| ACM(6) | .06 | % |
| ACM(7) | .08 | % |
| ACM(8) | .06 | % |
| ACM(9) | .04 | % |
| ACM(10) | .04 | % |
| ACM(11) | .03 | % |
| $\alpha_1$ | .009016 | % |
| $\alpha_2$ | .74995 | % |
| ACT(1) | .05 | % |
| ACT(2) | .30 | % |
| ACT(3) | .25 | % |
| ACT(4) | .20 | % |
| ACT(5) | .10 | % |
| ACT(6) | .06 | % |
| ACT(7) | .04 | % |
| $\beta_1$ | .859 | % |
| $\beta_2$ | .565 | % |
| C1 | 2.7301 | Thousand Pesos/Hour |
| C2 | 178.2130 | Thousand Pesos/Day |

| Constant and parameter | Value | Unit of Measurement |
|---|---|---|
| CCUB | 5000.0 | Tons/Year |
| DELM | 2.0 | Years |
| DELT | 1.5 | Years |
| DF | 10.52 | Days |
| EGG | 1.5 $(10^6)$ | # of Eggs/Gonad |
| EM1 | .016 | % |
| EM2 | .043 | % |
| ENTRYM | .04 | % |
| ENTRYT | .02 | % |
| EXITM | .05 | % |
| EXITT | .05 | % |
| HF | 5.46 | Hours |
| K | 3. | - |
| MR | .33 | |
| PE1 | 2000.0 | Dollars/Ton |
| PE2 | 6500.0 | Dollars/Ton |
| PFAC | 625.0 | Thousand Pesos/Ton |
| PM1 | 750.0 | Thousand Pesos/Ton |
| PM2 | 750.0 | Thousand Pesos/Ton |
| PT1 | 700.0 | Thousand Pesos/Ton |
| PT2 | 625.0 | Thousand Pesos/Ton |
| SS | 1.22 $(10^{-6})$ | % |
| SM1 | .2 | % |
| SM2 | .8 | % |

| Constant and parameter | Value | Unit of Measurement |
|---|---|---|
| ST1 | .1 | % |
| ST2 | .2 | % |
| ST3 | .7 | % |
| TRIPM | 13.0 | Fishing Trips/Year |
| TRIPT | 85.0 | Fishing Trips/Year |

Table B.2 Initial Values of State Variables.

| State Variable | Initial Value | Unit of Measurement |
|---|---|---|
| FP(1) | 94276000. | # |
| FP(2) | 63817000. | # |
| FP(3) | 32056000. | # |
| FP(4) | 13300000. | # |
| FP(5) | 7543000. | # |
| FP(6) | 4787000. | # |
| FP(7) | 3025000. | # |
| FP(8) | 1709000. | # |
| FP(9) | 1039000. | # |
| FP(10) | 566000. | # |
| FP(11) | 253000. | # |
| FP(12) | 169000. | # |
| FP(13) | 113000. | # |
| FP(14) | 74000. | # |
| FP(15) | 44000. | # |
| FP(16) | 38000. | # |
| FP(17) | 27000. | # |
| FP(18) | 18000. | # |
| FP(19) | 9000. | # |
| FP(20) | 9000. | # |
| TFB(0) | 138000. | Tons |
| CATCH(0) | 9496. | Tons/year |
| CATCHM(0) | 6703. | Tons/year |
| CATCHT(0) | 2793. | Tons/year |

| State Variable | Initial Value | Unit of Measurement |
|---|---|---|
| MFV(0) | 180 | # |
| TFV(0) | 850 | # |
| TPFTM(0) | 1688 | Millions of Pesos |
| TPFTT(0) | 536 | Millions of pesos |
| EMP(0) | 3810 | Individuals |
| SEAFC(0) | 279 | Tons |
| EERG(0) | 2088 | Thousands of Dlls. |

# APPENDIX C

APPENDIX C

COMPUTER PROGRAM SIMERO

```
C       COMPREHENSIVE SIMULATION MODEL OF THE RED GROUPER
C       FISHERY OF YUCATAN'S CONTINENTAL SHELF.
C       JUAN CARLOS SEIJO.
        PROGRAM SIMERO
C       DEFINITION OF VARIABLES AND PARAMETERS.
C       POPULATION AND BIOMASS BY AGE GROUP J: FP(J) AND FB(J).
C       COMPOSITION OF THE CATCH BY FLEET: ACT(J) AND ACM(J)
C       TOTAL, NATURAL AND FISHING MORTALITY BY AGE: DR(J),MR,FR(J).
C       FISHING MORTALITY BY AGE BY TYPE OF VESSEL: CT(J),CM(J),CC(J).
C       LENGTH AND WEIGHT OF FISH AGED J: L(J) AND W(J).
C       MATURING AND ADULT POPULATION AND BIOMASS: MFP,MFB,AFP,AFB.
C       NEW BORN POPULATION: NBORN.
C       TOTAL,TRADITIONAL AND MODERN VESSEL YIELD: CATCH,CATCHT,CATCHM.
C       CATCH PER UNIT EFFORT BY TYPE OF VESSEL: CPUE1 AND CPUE2.
C       TOTAL NUMBER OF TRADITIONAL AND MODERN VESSELS: TFV AND MFV.
C       ANNUAL FISHING TRIPS BY TYPE OF VESSEL: TRIPT,TRIPM.
C       BIOMASS AVAILABILITY FACTOR: BAF.
C       RANDOM VARIABLES OF YIELD EQUATIONS: R1,R2.
C       DIRECT EMPLOYMENT: EMP
C       SEAFOOD AVAILABILITY IN COASTAL AREAS: SEAFC.
C       EXPORT EARNINGS FROM RED GROUPER PRODUCTS: EERG.
C       NET REVENUES OF TRADITIONAL AND MODERN VESSELS: PFTT,PFTM.
C       ACCUMULATED NET REVENUES: TPFTT,TPFTM.
C       TOTAL COSTS PER TYPE OF VESSEL: TCT,TCM.
C       TOTAL REVENUES PER TYPE OF VESSEL: TRT,TRM.
C       MARGINAL AND AVERAGE COSTS PER TYPE OF VESSEL: MC1,MC2,AC1,AC2.
C       DISTRIBUTED DELAY PARAMETERS: DEL,K.
C       DISTRIBUTED DELAY INTERMEDIATE RATES: RT(3),RM(3).
C       VARIANCE OF CATCH EQUATIONS: VAR1,VAR2.
        REAL TFV,MFV,THF,TDF,BAF,PFTT,PFTM,TPFTT,TPFTM,AC1,AC2
        REAL TFVE,MFVE,TTRIPT,CATCHT,CATCHM,FBE,DR,FR,FP,FB,U1,U2
        REAL NBORN,R1,R2,CPUE1,CPUE2,SR,CT,CM,MR,CC,L,W,TTRIPM,CAT
        REAL CAM,MFP,MFB,AFP,AFB,TRIPT,TRIPM,HF,DF,MC1,MC2,AR1,AR2
        EXTERNAL UNIF
        DIMENSION RT(3),RM(3),ACT(20),ACM(20),DR(20),SR(20),L(20)
        DIMENSION FP(20),FB(20),W(20),FR(20),CT(20),CM(20),CC(20)
        DIMENSION SR1(20),SR2(20),SCACHT(20),SCACHM(20),SAC1(20)
        DIMENSION SAC2(20),SPFTT(20),SPFTM(20),STRT(20),STCT(20)
        DIMENSION STRM(20),STCM(20),SEMP(20),SSEAFC(20),SEERG(20)
        DIMENSION STFV(20),SMFV(20),STPFTT(20),STPFTM(20)
        DIMENSION SMC1(20),SMC2(20),SAR1(20),SAR2(20)
        WRITE (*,10)
  10    FORMAT(24X,'SIMULATION MODEL OF THE RED GROUPER FISHERY')
        WRITE (*,20)
  20    FORMAT (31X,'YUCATAN CONTINENTAL SHELF')
C       MODEL CONSTANTS AND PARAMETERS
        DATA K/3/,DELT/1.5/,DELM/2.0/,ST1/.1/,ST2/.2/,ST3/.7/
```

```
      DATA SM1/.2/,SM2/.8/,EM1/.016/,EM2/.043/,PT1/700./
      DATA PT2/625./,PM1/750./,PM2/750./,PFAC/625./
      DATA PE1/2000./,PE2/6500./,HF/5.46/,DF/10.52/,TRIPT/85./
      DATA TRIPM/13./,ENTRYT/.02/,ENTRYM/.04/,EXITT/.05/
      DATA EXITM/.05/,CCUB/5000./,MR/.33/,ALPHA1/.009016/
      DATA ALPHA2/.74995/,BETA1/.859/,BETA2/.565/,C1/2.7301/
      DATA C2/178.213/,SS/1.22E-6/,EGG/1.50E6/
      DATA ACT(1)/.05/,ACT(2)/.30/,ACT(3)/.25/,ACT(4)/.20/
      DATA ACT(5)/.10/,ACT(6)/.06/,ACT(7)/.04/,ACM(1)/.01/
      DATA ACM(2)/.19/,ACM(3)/.32/,ACM(4)/.09/,ACM(5)/.08/
      DATA ACM(6)/.06/,ACM(7)/.08/,ACM(8)/.06/,ACM(9)/.04/
      DATA ACM(10)/.04/,ACM(11)/.03/
C     INITIAL VALUES PHASE
      RT(1)=6.
      RT(2)=6.
      RT(3)=6.
      RM(1)=3.
      RM(2)=3.
      RM(3)=3.
      CATCHT=2793.
      CATCHM=6703.
      CATCH=CATCHT+CATCHM
      FP(1)=94276000.
      FP(2)=63817000.
      FP(3)=32056000.
      FP(4)=13300000.
      FP(5)=7543000.
      FP(6)=4787000.
      FP(7)=3025000.
      FP(8)=1709000.
      FP(9)=1039000.
      FP(10)=566000.
      FP(11)=253000.
      FP(12)=169000.
      FP(13)=113000.
      FP(14)=74000.
      FP(15)=44000.
      FP(16)=38000.
      FP(17)=27000.
      FP(18)=18000.
      FP(19)=9000.
      FP(20)=9000.
      DO 1  J=1,20
      L(J)=80.2*(1.-EXP(-0.159*(J+1.21)))
      W(J)=.0000138*(L(J)**3.)
      FB(J)=FP(J)*W(J)/1000.
1     CONTINUE
      MFP=FP(1)+FP(2)
      AFP=FP(3)+FP(4)+FP(5)+FP(6)+FP(7)+FP(8)+FP(9)+FP(10)+FP(11)+
     + FP(12)+FP(13)+FP(14)+FP(15)+FP(16)+FP(17)+FP(18)+FP(19)+FP(20)
      TFP=MFP+AFP
      MFB=FB(1)+FB(2)
      AFB=FB(3)+FB(4)+FB(5)+FB(6)+FB(7)+FB(8)+FB(9)+FB(10)+FB(11)+
```

```
     +  FB(12)+FB(13)+FB(14)+FB(15)+FB(16)+FB(17)+FB(18)+FB(19)+FB(20)
        TFB=MFB+AFB
        DO 2   J=1,20
        CT(J)=ACT(J)*CATCHT/FB(J)
        CM(J)=ACM(J)*CATCHM/FB(J)
        CC(J)=ACM(J)*CCUB/FB(J)
        FR(J)=CT(J)+CM(J)+CC(J)
        DR(J)=FR(J)+MR
        SR(J)=1.-DR(J)
 2      CONTINUE
        CPUE1=.0388
        CPUE2=.2723
        MFV=180.
        TFV=850.
        TTRIPT=TFV*TRIPT
        TTRIPM=MFV*TRIPM
        FBE=138.E3
        EMP=TFV*3.+MFV*7.
        SEAFC=CATCHT*(ST1+ST2)
        EERG=CATCHM*(PE1*EM1+PE2*EM2)
        ACTFV=0.
        ACMFV=0.
        TFVE=0.
        MFVE=0.
        FST=ST1*CATCHT
        FMT=ST2*CATCHT
        FPT=ST3*CATCHT
        FMM=SM1*CATCHM
        FPM=SM2*CATCHM
        FAC=CATCHM*.25
        TRT=PT1*FMT+PT2*FPT
        TRM=PM1*FMM+PM2*FPM+PFAC*FAC
        THF=HF*TRIPT*TFV
        TDF=DF*TRIPM*MFV
        TCT=C1*THF
        TCM=C2*TDF
        AC1=TCT/CATCHT
        AC2=TCM/CATCHM
        PFTT=TRT-TCT
        PFTM=TRM-TCM
        TPFTT=PFTT
        TPFTM=PFTM
        EGGS=EGG*SS
        NBORN=EGGS*AFP
        WRITE (*,30)
30      FORMAT ('0',12X,'T',11X,'CPUE1',10X,'CPUE2',10X,
     +          'CATCH',8X,'BIOMASS')
        WRITE (*,40) T,CPUE1,CPUE2,CATCH,TFB
40      FORMAT (F15.1,2F15.4,2F15.1)
        I=0.
        XLMDA=.3
        VAR1=65E-6
        VAR2=124256E-6
```

```
      R1=0.
      R2=0.
      T=0.
C     SPECIFICATIONS OF SIMULATION RUN.
      DT=.05
      RLGTH=20.
      NIPP=1./DT+.0001
      NIT=RLGTH/DT+.0001
      NIOL=NIT/NIPP
C     EXECUTION PHASE
      DO 3  I1=1,NIOL
      DO 4  I2=1,NIPP
      T=T+DT
C     COMPUTE STATE VARIABLES.
      DO 5   J=20,2,-1
      FP(J)=FP(J)+DT*(SR(J-1)*FP(J-1)-FP(J))
 5    CONTINUE
      FP(1)=FP(1)+DT*((1.-MR)*NBORN-FP(1))
      MFP=FP(1)+FP(2)
      AFP=FP(3)+FP(4)+FP(5)+FP(6)+FP(7)+FP(8)+FP(9)+FP(10)+FP(11)+
     + FP(12)+FP(13)+FP(14)+FP(15)+FP(16)+FP(17)+FP(18)+FP(19)+FP(20)
      TFP=MFP+AFP
      NBORN=EGGS*AFP
      DO 6  J=1,20
      FB(J)=FP(J)*W(J)/1000.
 6    CONTINUE
      MFB=FB(1)+FB(2)
      AFB=FB(3)+FB(4)+FB(5)+FB(6)+FB(7)+FB(8)+FB(9)+FB(10)+FB(11)+
     + FB(12)+FB(13)+FB(14)+FB(15)+FB(16)+FB(17)+FB(18)+FB(19)+FB(20)
      TFB=MFB+AFB
      TPFTT=TPFTT+DT*(TRT-TCT)
      TPFTM=TPFTM+DT*(TRM-TCM)
      IF(TFV.LT.850) ENTRYT=.05
      IF(TFV.GE.850) ENTRYT=.02
      IF(MFV.LT.180) ENTRYM=.05
      IF(MFV.GE.180) ENTRYM=.04
      IF(PFTT.LT.0.) TFVE=TFV*(-EXITT)
      IF(PFTT.GT.0.) TFVE=TFV*ENTRYT
      IF(PFTT.EQ.0.) TFVE=0.
      IF(PFTM.LT.0.) MFVE=MFV*(-EXITM)
      IF(PFTM.GT.0.) MFVE=MFV*ENTRYM
      IF(PFTM.EQ.0.) MFVE=0.
      TFV=TFV+DT*(ACTFV)
      MFV=MFV+DT*(ACMFV)
      EMP=TFV*3.+MFV*7.
      SEAFC=SEAFC+DT*(FST+FMT)
      EERG=EERG+DT*(CATCHM*(PE1*EM1+PE2*EM2))
      CALL DELAY(TFVE,ACTFV,RT,DELT,DT,K)
      CALL DELAY(MFVE,ACMFV,RM,DELM,DT,K)
C     GENERATE RANDOM VARIABLES.
      CALL EXACOR(XLMDA,VAR1,DT,I,R1)
      CALL EXACOR(XLMDA,VAR2,DT,I,R2)
C     COMPUTE RATE VARIABLES.
```

```
      BAF=TFB/FBE
      IF(T.GE.7.) TRIPM=9.
      TTRIPT=TRIPT*TFV
      TTRIPM=TRIPM*MFV
      CATCHT=(ALPHA1*(HF**BETA1)+R1)*BAF*TTRIPT
      CATCHM=(ALPHA2*(DF**BETA2)+R2)*BAF*TTRIPM
      CATCH=CATCHT+CATCHM
      CPUE1=CATCHT/(TFV*TRIPT)
      CPUE2=CATCHM/(MFV*TRIPM*DF)
      DO 7  J=1,20
      CT(J)=ACT(J)*CATCHT/FB(J)
      CM(J)=ACM(J)*CATCHM/FB(J)
      CC(J)=ACM(J)*CCUB/FB(J)
      FR(J)=CT(J)+CM(J)+CC(J)
      DR(J)=FR(J)+MR
      SR(J)=1.-DR(J)
7     CONTINUE
      FST=ST1*CATCHT
      FMT=ST2*CATCHT
      FPT=ST3*CATCHT
      FMM=SM1*CATCHM
      FPM=SM2*CATCHM
      FAC=CATCHM*.25
      TRT=PT1*FMT+PT2*FPT
      TRM=PM1*FMM+PM2*FPM+PFAC*FAC
      AR1=TRT/CATCHT
      AR2=TRM/CATCHM
      THF=HF*TRIPT*TFV
      TDF=DF*TRIPM*MFV
      TCT=C1*THF
      TCM=C2*TDF
      CAT=CATCHT/TTRIPT
      CAM=CATCHM/TTRIPM
      U1=((1./ALPHA1)*((CAT/BAF)-R1))**((1/BETA1)-1)
      U2=((1./ALPHA2)*((CAM/BAF)-R2))**((1/BETA2)-1)
      MC1=(C1/(ALPHA1*BETA1*BAF))*U1
      MC2=(C2/(ALPHA2*BETA2*BAF))*U2
      AC1=TCT/CATCHT
      AC2=TCM/CATCHM
      PFTT=TRT-TCT
      PFTM=TRM-TCM
4     CONTINUE
      SR1(I1)=R1
      SR2(I1)=R2
      SCACHT(I1)=CATCHT
      SCACHM(I1)=CATCHM
      SAC1(I1)=AC1
      SAC2(I1)=AC2
      SMC1(I1)=MC1
      SMC2(I1)=MC2
      SAR1(I1)=AR1
      SAR2(I1)=AR2
      SPFTT(I1)=PFTT
```

```
      SPFTM(I1)=PFTM
      STRT(I1)=TRT
      STCT(I1)=TCT
      STRM(I1)=TRM
      STCM(I1)=TCM
      SEMP(I1)=EMP
      SSEAFC(I1)=SEAFC
      SEERG(I1)=EERG
      STFV(I1)=TFV
      SMFV(I1)=MFV
      STPFTT(I1)=TPFTT
      STPFTM(I1)=TPFTM
      WRITE (*,50) T,CPUE1,CPUE2,CATCH,TFB
50    FORMAT (F15.1,2F15.4,2F15.1)
 3    CONTINUE
      WRITE (*,60)
60    FORMAT ('1',12X,'T',9X,'RANVAR1',8X,'RANVAR2',
   +         9X,'CATCHT',9X,'CATCHM')
      DO 8  I1=1,NIOL
      WRITE (*,70) I1,SR1(I1),SR2(I1),SCACHT(I1),SCACHM(I1)
70    FORMAT (I15,2F15.6,2F15.1)
 8    CONTINUE
      WRITE (*,80)
80    FORMAT ('1',12X,'T',11X,'ACTV',11X,'ACMV',11X,'PFTT',
   +         11X,'PFTM')
      DO 9  I1=1,NIOL
      WRITE (*,90) I1,SAC1(I1),SAC2(I1),SPFTT(I1),SPFTM(I1)
90    FORMAT (I15,4F15.1)
 9    CONTINUE
      WRITE (*,100)
100   FORMAT ('1',12X,'T',12X,'TRT',12X,'TCT',12X,'TRM',12X,'TCM')
      DO 11  I1=1,NIOL
      WRITE (*,110) I1,STRT(I1),STCT(I1),STRM(I1),STCM(I1)
110   FORMAT (I15,4F15.1)
 11    CONTINUE
      WRITE (*,120)
120   FORMAT ('1',12X,'T',12X,'EMP',10X,'SEAFC',11X,'EERG')
      DO 12  I1=1,NIOL
      WRITE (*,130) I1,SEMP(I1),SSEAFC(I1),SEERG(I1)
130   FORMAT (I15,4F15.1)
 12   CONTINUE
      WRITE (*,140)
140   FORMAT ('1',12X,'T',12X,'TFV',12X,'MFV',10X,'TPFTT',
   +         10X,'TPFTM')
      DO 13  I1=1,NIOL
      WRITE (*,150) I1,STFV(I1),SMFV(I1),STPFTT(I1),STPFTM(I1)
150   FORMAT (I15,4F15.1)
 13   CONTINUE
      WRITE (*,160)
160   FORMAT ('1',12X,'T',12X,'MC1',12X,'MC2',12X,'MR1',12X,'MR2')
      DO 14  I1=1,NIOL
      WRITE (*,170) I1,SMC1(I1),SMC2(I1),SAR1(I1),SAR2(I1)
170   FORMAT (I15,4F15.1)
```

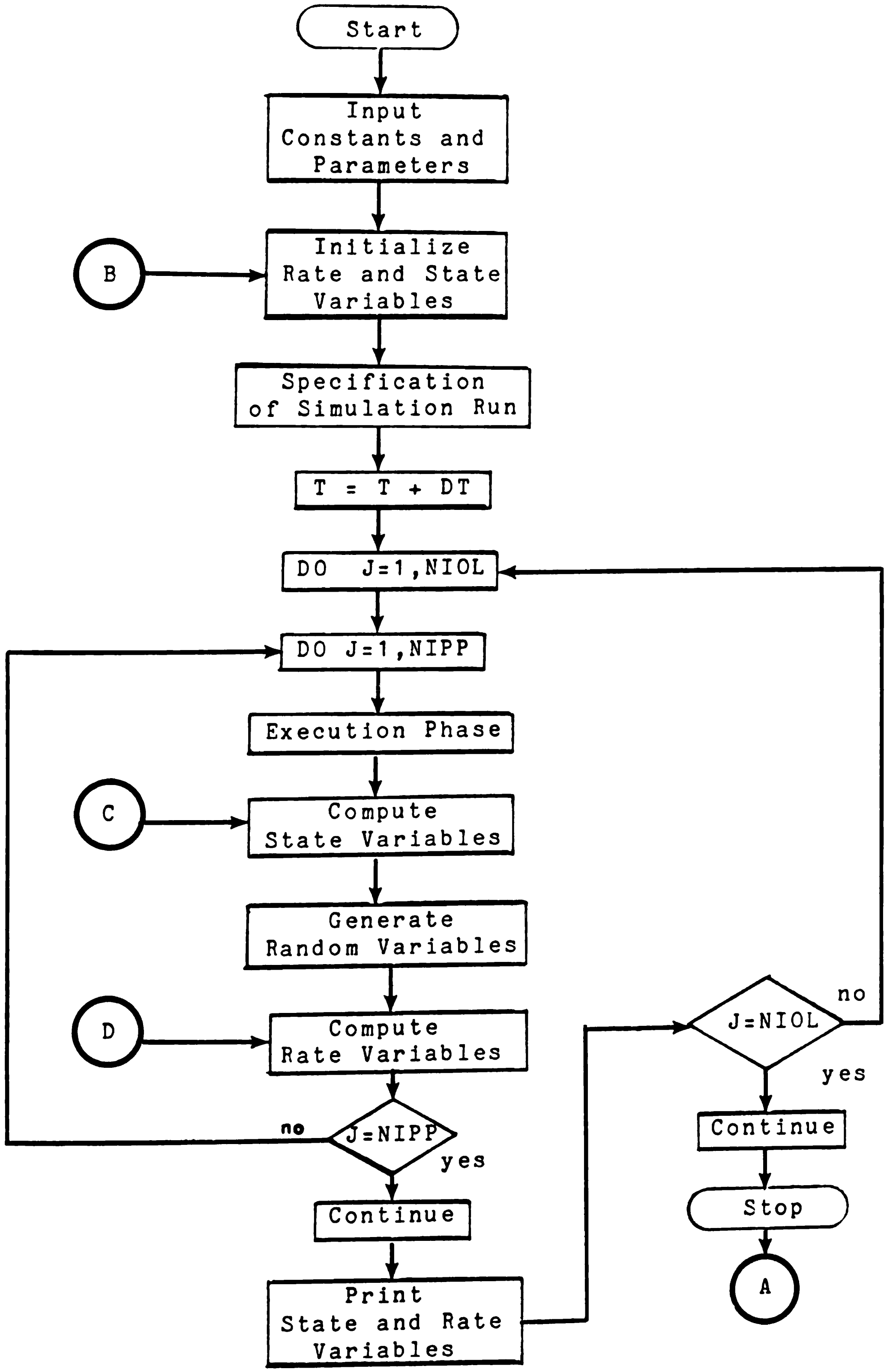
```
   14   CONTINUE
        WRITE (*,180)
180     FORMAT ('1',12X,'AGE',6X,'POPULATION',10X,'BIOMASS')
        DO 15  J=1,20
        WRITE (*,190) J,FP(J),FB(J)
190     FORMAT (I15,2F17.1)
   15   CONTINUE
        END
        SUBROUTINE EXACOR(XLMDA,VAR,DT,I,U)
        IF(I.NE.0) GO TO 1
        U=0.
        B=XLMDA**DT
        A=(1.+B)/(1.-B)
  1     R=UNIF(ISEED,JSEED)
        XK=(A*12.*VAR)**.5
        XN=XK*(R-.5)
        U=B*U-(1.-B)*XN
        I=I+1
        RETURN
        END
        SUBROUTINE DELAY(RINR,ROUTR,CROUTR,DEL,DT,K)
        DIMENSION CROUTR(1)
        DEL1=DEL/(FLOAT(K)*DT)
        RIN=RINR
        DO 3   I=1,K
        ABC=CROUTR(I)
        CROUTR(I)=ABC+(RIN-ABC)/DEL1
   3    RIN=ABC
        ROUTR=CROUTR(K)
        RETURN
        END
        SUBROUTINE RANDOM(I,B)
        INTEGER*2 ISEED,I
        CHARACTER BYTE(2),B
        EQUIVALENCE (ISEED,BYTE(1))
        ISEED=I
        ISEED=ISEED*2837+1
        B=BYTE(2)
        IF(ISEED.LT.0) ISEED=ISEED+32767+1
        I=ISEED
        RETURN
        END
        FUNCTION UNIF(ISEED,JSEED)
        INTEGER*2 ISEED,JSEED,IEXPO
        CHARACTER*1 B(4),RBYTE
        EQUIVALENCE (X,B(1))
        CALL RANDOM(ISEED,B(2))
        CALL RANDOM(ISEED,B(3))
        CALL RANDOM(ISEED,B(1))
        IEXPO=63
        IF (B(3).LT.128) GOTO 1030
        IEXPO=66
 1010   CALL RANDOM(JSEED,RBYTE)
```

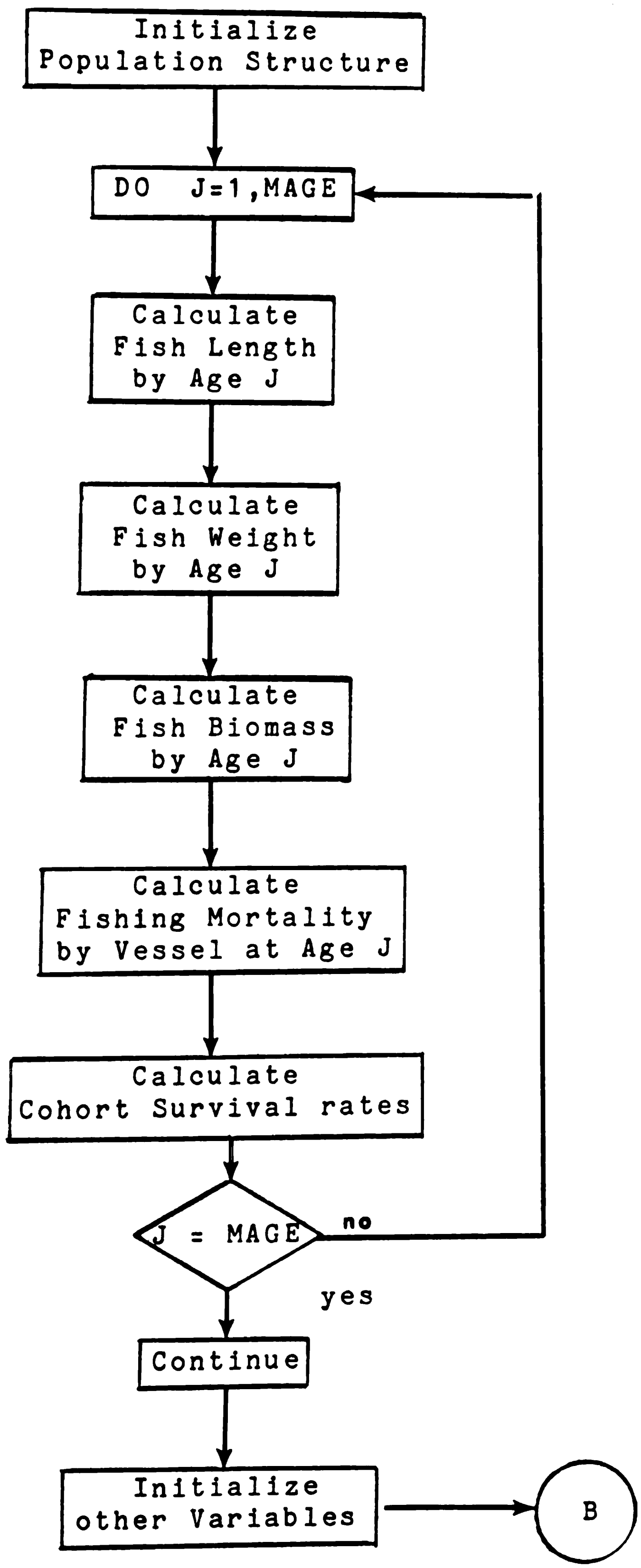
```
      IEXPO=IEXPO-4
      IF (RBYTE.EQ.0) GOTO 1010
      IF (RBYTE.GT.127) GOTO 1030
      IF (RBYTE.GT.63) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.31) GOTO 1030
      IF (RBYTE.GT.15) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.7) GOTO 1030
      IF (RBYTE.GT.3) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.1) GOTO 1030
1020  B(3)=CHAR(ICHAR(B(3))-128)
1030  B(4)=CHAR(IEXPO)
      UNIF=X
      RETURN
      END
```

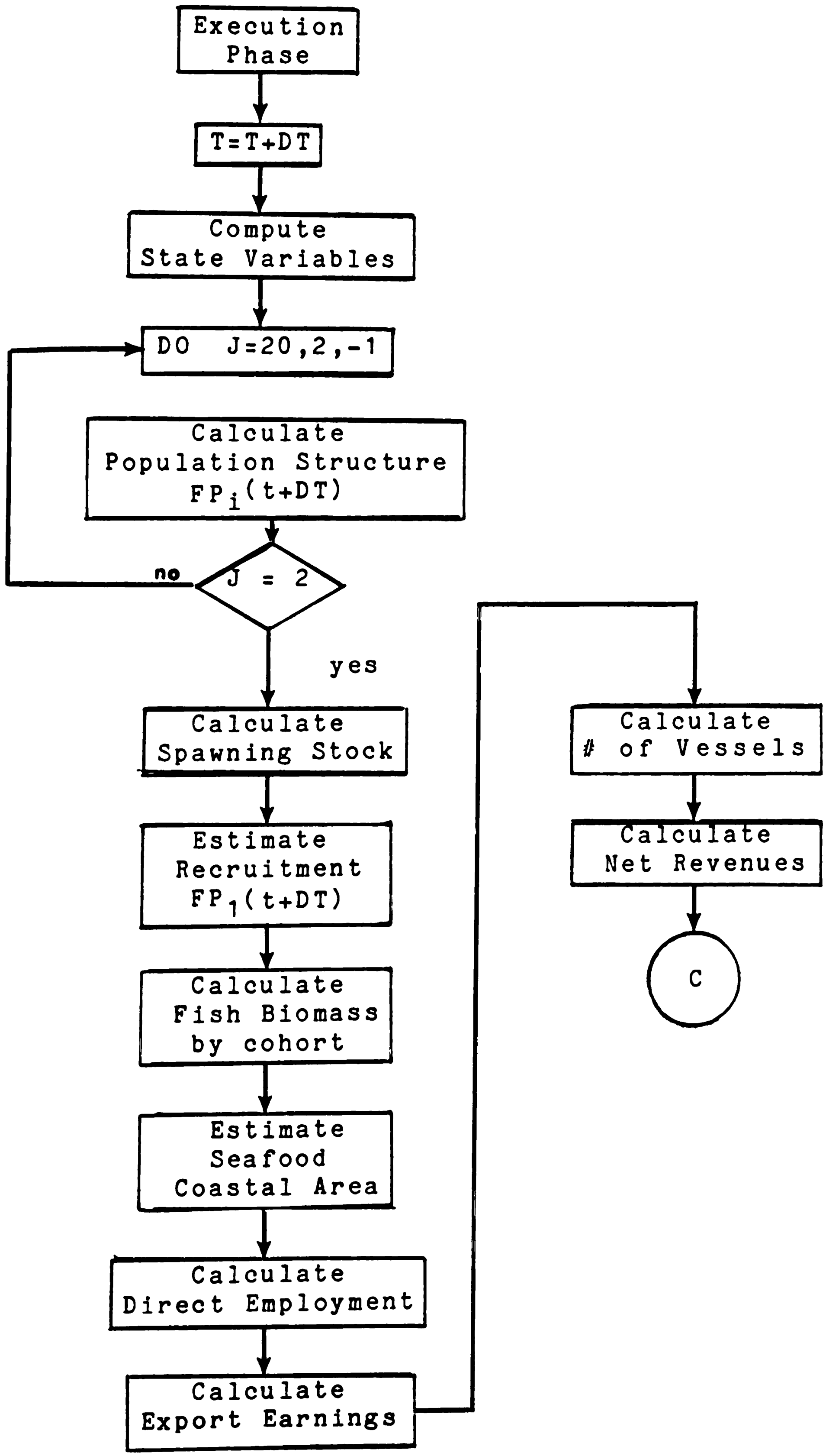
APENNDIX D

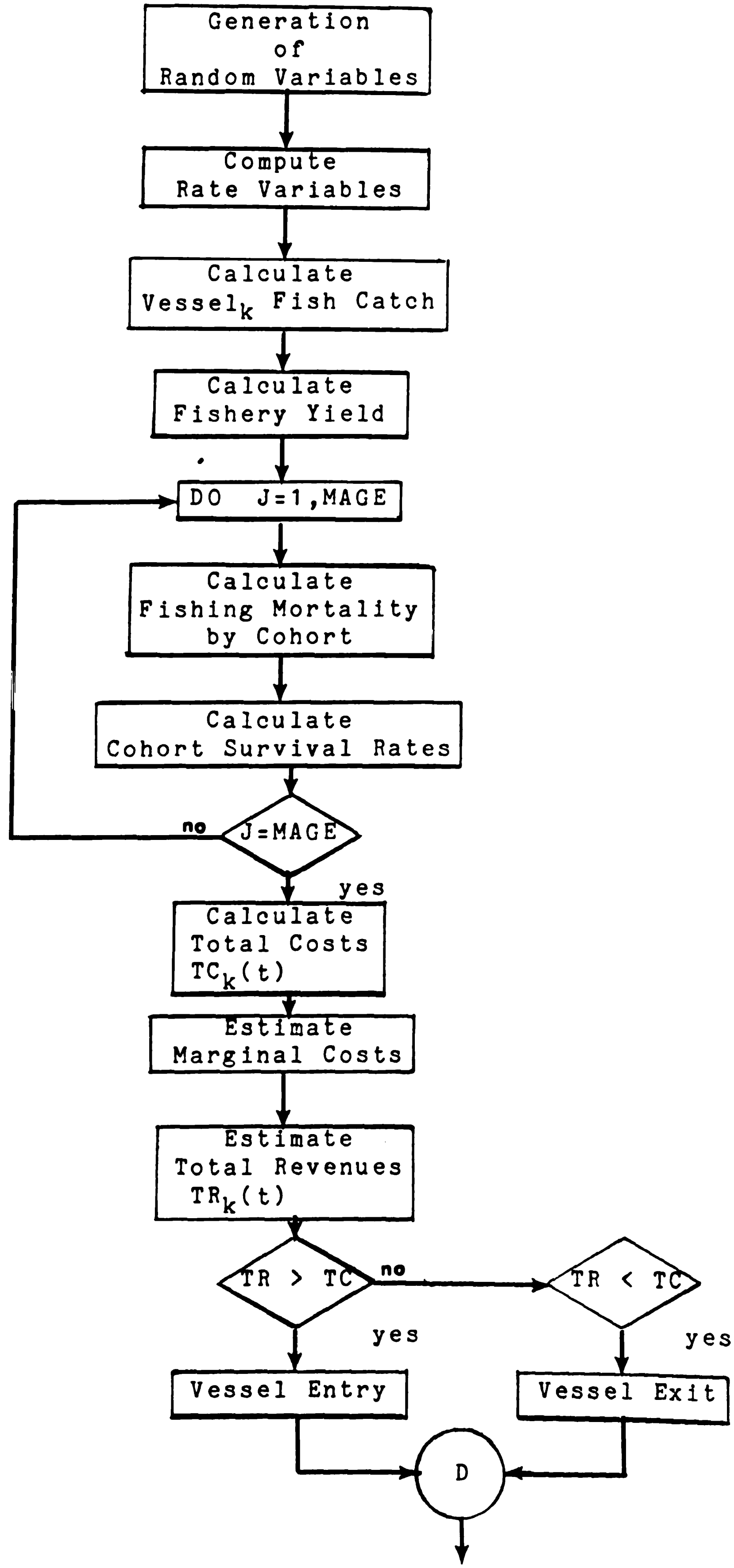
# APPENDIX D

## FLOW DIAGRAM OF COMPUTER MODEL




Initialize
Population Structure
DO J=1,MAGE
Calculate
Fish Length
by Age J
Calculate
Fish Weight
by Age J
Calculate
Fish Biomass
by Age J
Calculate
Fishing Mortality
by Vessel at Age J
Calculate
Cohort Survival rates
J = MAGE
no
yes
Continue
Initialize
other Variables
B


Execution Phase
T=T+DT
Compute State Variables
DO J=20,2,-1
Calculate Population Structure FPi(t+DT)
J = 2
no
yes
Calculate Spawning Stock
Estimate Recruitment FP1(t+DT)
Calculate Fish Biomass by cohort
Estimate Seafood Coastal Area
Calculate Direct Employment
Calculate Export Earnings
Calculate # of Vessels
Calculate Net Revenues
C



Generation of Random Variables
Compute Rate Variables
Calculate Vessel$_k$ Fish Catch
Calculate Fishery Yield
DO J=1,MAGE
Calculate Fishing Mortality by Cohort
Calculate Cohort Survival Rates
J=MAGE
no
yes
Calculate Total Costs $TC_k(t)$
Estimate Marginal Costs
Estimate Total Revenues $TR_k(t)$
TR > TC
no
TR < TC
yes
yes
Vessel Entry
Vessel Exit
D

# APPENDIX E

## APPENDIX E

## MONTE CARLO MODE OF PROGRAM SIMERO

```
C       MONTE CARLO ANALYSIS OF A TROPICAL DEMERSAL FISHERY
C       RED GROUPER (E. morio) OF YUCATAN CONTINENTAL SHELF.
C       MONTE CARLO EXPERIMENTS TO ESTIMATE CONFIDENCE INTERVALS
C       FOR IMPORTANT PARAMETERS AND PERFORMANCE VARIABLES.
C       JUAN CARLOS SEIJO.
        PROGRAM SIMERO
C       MONTE CARLO MODE.
        REAL TFV,MFV,THF,TDF,BAF,PFTT,PFTM,TPFTT,TPFTM,AC1,AC2
        REAL TFVE,MFVE,TTRIPT,CATCHT,CATCHM,FBE,DR,FR,FP,FB,U1,U2
        REAL NBORN,R1,R2,CPUE1,CPUE2,SR,CT,CM,MR,CC,L,W,TTRIPM
        REAL MFP,MFB,AFP,AFB,TRIPT,TRIPM,HF,DF,MC1,MC2,AR1,AR2
        REAL BIOM,TBIOM,TCATT,TCATM,SUMCT,SUMCM,XMEANT,XMEANM,SSUMT
        REAL SSUMM,S1,S2,SS1,SS2,STDT,STDM,RV1,RV2,RN,S3,SS3,STDB
        REAL PROFTT,PROFTM,XMEANB,XMPFTT,XMPFTM,SUMB,TTPFTT,TTPFTM
        REAL S4,S5,SS4,SS5,SUMPT,SUMPM,STDPT,STDPM
        EXTERNAL UNIF
        DIMENSION RT(3),RM(3),ACT(20),ACM(20),DR(20),SR(20),L(20)
        DIMENSION FP(20),FB(20),W(20),FR(20),CT(20),CM(20),CC(20)
        DIMENSION RV1(100),RV2(100),TCATT(100),TCATM(100),BIOM(50)
        DIMENSION PROFTT(50),PROFTM(50)
        WRITE (*,10)
  10    FORMAT(20X,'SIMULATION MODEL OF THE RED GROUPER FISHERY')
        WRITE (*,20)
  20    FORMAT (30X,'MONTE CARLO ANALYSIS')
C       MODEL CONSTANTS AND PARAMETERS
        DATA K/3/,DELT/1.5/,DELM/2.0/,ST1/.1/,ST2/.2/,ST3/.7/
        DATA SM1/.2/,SM2/.8/,EM1/.016/,EM2/.043/,PT1/700000./
        DATA PT2/625000./,PM1/750000./,PM2/750000./,PFAC/625000./
        DATA PE1/2000./,PE2/6500./,HF/5.46/,DF/10.52/,TRIPT/85./
        DATA TRIPM/13./,ENTRYT/.02/,ENTRYM/.04/,EXITT/.05/
        DATA EXITM/.05/,CCUB/5000./,MR/.33/,ALPHA1/9.016/
        DATA ALPHA2/749.95/,BETA1/.859/,BETA2/.565/,C1/2730.1/
        DATA C2/178213./,SS/1.22E-6/,EGG/1.50E6/
        ACT(1)=.05
        ACT(2)=.30
        ACT(3)=.25
        ACT(4)=.20
        ACT(5)=.10
        ACT(6)=.06
        ACT(7)=.04
        ACM(1)=.01
        ACM(2)=.19
        ACM(3)=.32
        ACM(4)=.09
        ACM(5)=.08
        ACM(6)=.06
        ACM(7)=.08
```

```
      ACM(8)=.06
      ACM(9)=.04
      ACM(10)=.04
      ACM(11)=.03
C     MONTE CARLO EXPERIMENT 1: ANALYSIS OF 50 SIMULATION RUNS.
      NR=50.
      TBIOM=0.
      SUMB=0.
      TTPFTT=0.
      TTPFTM=0.
      SUMPT=0.
      SUMPM=0.
      DO 9  M=1,NR
C     INITIAL VALUES PHASE
      RT(1)=6.
      RT(2)=6.
      RT(3)=6.
      RM(1)=3.
      RM(2)=3.
      RM(3)=3.
      CATCHT=2793.
      CATCHM=6703.
      CATCH=CATCHT+CATCHM
      FP(1)=94276000.
      FP(2)=63817000.
      FP(3)=32056000.
      FP(4)=13300000.
      FP(5)=7543000.
      FP(6)=4787000.
      FP(7)=3025000.
      FP(8)=1709000.
      FP(9)=1039000.
      FP(10)=566000.
      FP(11)=253000.
      FP(12)=169000.
      FP(13)=113000.
      FP(14)=74000.
      FP(15)=44000.
      FP(16)=38000.
      FP(17)=27000.
      FP(18)=18000.
      FP(19)=9000.
      FP(20)=9000.
      DO 1  J=1,20
      L(J)=80.2*(1.-EXP(-0.159*(J+1.21)))
      W(J)=.0000138*(L(J)**3.)
      FB(J)=FP(J)*W(J)/1000.
 1    CONTINUE
      MFP=FP(1)+FP(2)
      AFP=FP(3)+FP(4)+FP(5)+FP(6)+FP(7)+FP(8)+FP(9)+FP(10)+FP(11)+
     + FP(12)+FP(13)+FP(14)+FP(15)+FP(16)+FP(17)+FP(18)+FP(19)+FP(20)
      TFP=MFP+AFP
      MFB=FB(1)+FB(2)
```

```
      AFB=FB(3)+FB(4)+FB(5)+FB(6)+FB(7)+FB(8)+FB(9)+FB(10)+FB(11)+
     +FB(12)+FB(13)+FB(14)+FB(15)+FB(16)+FB(17)+FB(18)+FB(19)+FB(20)
      TFB=MFB+AFB
      DO 2   J=1,20
      CT(J)=ACT(J)*CATCHT/FB(J)
      CM(J)=ACM(J)*CATCHM/FB(J)
      CC(J)=ACM(J)*CCUB/FB(J)
      FR(J)=CT(J)+CM(J)+CC(J)
      DR(J)=FR(J)+MR
      SR(J)=1.-DR(J)
2     CONTINUE
      CPUE1=.0388
      CPUE2=.2723
      MFV=180.
      TFV=850.
      TTRIPT=TFV*TRIPT
      TTRIPM=MFV*TRIPM
      FBE=138.E3
      EMP=TFV*3.+MFV*7.
      SEAFC=ST1*CATCHT
      EERG=CATCHM*(PE1*EM1+PE2*EM2)
      ACTFV=0.
      ACMFV=0.
      TFVE=0.
      MFVE=0.
      FST=ST1*CATCHT
      FMT=ST2*CATCHT
      FPT=ST3*CATCHT
      FMM=SM1*CATCHM
      FPM=SM2*CATCHM
      FAC=CATCHM*.25
      TRT=PT1*FMT+PT2*FPT
      TRM=PM1*FMM+PM2*FPM+PFAC*FAC
      THF=HF*TRIPT*TFV
      TDF=DF*TRIPM*MFV
      TCT=C1*THF
      TCM=C2*TDF
      AC1=TCT/CATCHT
      AC2=TCM/CATCHM
      PFTT=TRT-TCT
      PFTM=TRM-TCM
      TPFTT=PFTT
      TPFTM=PFTM
      EGGS=EGG*SS
      NBORN=EGGS*AFP
      SUMCT=0.
      SUMCM=0.
      SSUMT=0.
      SSUMM=0.
      I=0.
      XLMDA=.3
      VAR1=65.
      VAR2=124256.
```

```
      R1=0.
      R2=0.
      T=0.
C     SPECIFICATIONS OF SIMULATION RUN.
      DT=.2
      RLGTH=20.
      NIPP=1./DT+.0001
      NIT=RLGTH/DT+.0001
      NIOL=NIT/NIPP
C     EXECUTION PHASE
      DO 3  I1=1,NIT
      T=T+DT
C     COMPUTE STATE VARIABLES.
      DO 5   J=20,2,-1
      FP(J)=FP(J)+DT*(SR(J-1)*FP(J-1)-FP(J))
  5   CONTINUE
      FP(1)=FP(1)+DT*((1.-MR)*NBORN-FP(1))
      MFP=FP(1)+FP(2)
      AFP=FP(3)+FP(4)+FP(5)+FP(6)+FP(7)+FP(8)+FP(9)+FP(10)+FP(11)+
     + FP(12)+FP(13)+FP(14)+FP(15)+FP(16)+FP(17)+FP(18)+FP(19)+FP(20)
      TFP=MFP+AFP
      NBORN=EGGS*AFP
      DO 6  J=1,20
      FB(J)=FP(J)*W(J)/1000.
  6   CONTINUE
      MFB=FB(1)+FB(2)
      AFB=FB(3)+FB(4)+FB(5)+FB(6)+FB(7)+FB(8)+FB(9)+FB(10)+FB(11)+
     + FB(12)+FB(13)+FB(14)+FB(15)+FB(16)+FB(17)+FB(18)+FB(19)+FB(20)
      TFB=MFB+AFB
      TPFTT=TPFTT+DT*(TRT-TCT)
      TPFTM=TPFTM+DT*(TRM-TCM)
      IF(TFV.LT.850) ENTRYT=.05
      IF(TFV.GE.850) ENTRYT=.02
      IF(MFV.LT.180) ENTRYM=.05
      IF(MFV.GE.180) ENTRYM=.04
      IF(PFTT.LT.0.) TFVE=TFV*(-EXITT)
      IF(PFTT.GT.0.) TFVE=TFV*ENTRYT
      IF(PFTT.EQ.0.) TFVE=0.
      IF(PFTM.LT.0.) MFVE=MFV*(-EXITM)
      IF(PFTM.GT.0.) MFVE=MFV*ENTRYM
      IF(PFTM.EQ.0.) MFVE=0.
      TFV=TFV+DT*(ACTFV)
      MFV=MFV+DT*(ACMFV)
      EMP=TFV*3.+MFV*7.
      SEAFC=SEAFC+DT*(FST+FMT)
      EERG=EERG+DT*(CATCHM*(PE1*EM1+PE2*EM2))
      CALL DELAY(TFVE,ACTFV,RT,DELT,DT,K)
      CALL DELAY(MFVE,ACMFV,RM,DELM,DT,K)
C     COMPUTE RATE VARIABLES.
      BAF=TFB/FBE
      IF(T.GE.7.) TRIPM=9.
      TTRIPT=TRIPT*TFV
      TTRIPM=TRIPM*MFV
```

```
      CALL EXACOR(XLMDA,VAR1,DT,I,R1)
      CATCHT=(ALPHA1*(HF**BETA1)+R1)*BAF*TTRIPT/1000.
      CALL EXACOR(XLMDA,VAR2,DT,I,R2)
      CATCHM=(ALPHA2*(DF**BETA2)+R2)*BAF*TTRIPM/1000.
      CATCH=CATCHT+CATCHM
      CPUE1=CATCHT/(TFV*TRIPT)
      CPUE2=CATCHM/(MFV*TRIPM*DF)
      DO 7  J=1,20
      CT(J)=ACT(J)*CATCHT/FB(J)
      CM(J)=ACM(J)*CATCHM/FB(J)
      CC(J)=ACM(J)*CCUB/FB(J)
      FR(J)=CT(J)+CM(J)+CC(J)
      DR(J)=FR(J)+MR
      SR(J)=1.-DR(J)
 7    CONTINUE
      FST=ST1*CATCHT
      FMT=ST2*CATCHT
      FPT=ST3*CATCHT
      FMM=SM1*CATCHM
      FPM=SM2*CATCHM
      FAC=CATCHM*.25
      TRT=PT1*FMT+PT2*FPT
      TRM=PM1*FMM+PM2*FPM+PFAC*FAC
      AR1=TRT/CATCHT
      AR2=TRM/CATCHM
      THF=HF*TRIPT*TFV
      TDF=DF*TRIPM*MFV
      TCT=C1*THF
      TCM=C2*TDF
      U1=((CATCHT*1000./(TTRIPT*BAF))-R1/1000.)**((1/BETA1)-1)
      U2=((CATCHM*1000./(TTRIPM*BAF))-R2/1000.)**((1/BETA2)-1)
      MC1=(C1*1000./((ALPHA1**(1./BETA1))*BETA1*BAF))*U1
      MC2=(C2*1000./((ALPHA2**(1./BETA2))*BETA2*BAF))*U2
      AC1=TCT/CATCHT
      AC2=TCM/CATCHM
      PFTT=TRT-TCT
      PFTM=TRM-TCM
C     MONTE CARLO EXPERIMENT 2: WITHIN RUN ANALYSIS.
      IF(M.GT.1) GOTO 3
      SUMCT=SUMCT+CPUE1
      SUMCM=SUMCM+CPUE2
      TCATT(I1)=CATCHT
      TCATM(I1)=CATCHM
      XMEANT=SUMCT/NIT
      XMEANM=SUMCM/NIT
      RV1(I1)=R1
      RV2(I1)=R2
 3    CONTINUE
      DO 8  I1=1,100
      S1=(ABS(TCATT(I1)-XMEANT))**2.
      S2=(ABS(TCATM(I1)-XMEANM))**2.
      SSUMT=SSUMT+S1
      SSUMM=SSUMM+S2
```

```
  8     CONTINUE
C       STORE RUN DATA FOR STATISTICS.
        BIOM(M)=TFB
        TBIOM=TBIOM+TFB
        PROFTT(M)=PFTT
        TTPFTT=TTPFTT+PFTT
        PROFTM(M)=PFTM
        TTPFTM=TTPFTM+PFTM
        SS1=SSUMT/(NIT-1)
        SS2=SSUMM/(NIT-1)
        STDT=SQRT(SS1)
        STDM=SQRT(SS2)
  9     CONTINUE
C       COMPUTE MEANS AND STANDARD DEVIATIONS.
        XMPFTT=TTPFTT/NR
        XMPFTM=TTPFTM/NR
        XMEANB=TBIOM/NR
        DO 11  M=1,NR
        S3=(ABS(BIOM(M)-XMEANB))**2.
        S4=(ABS(PROFTT(M)-XMPFTT))**2.
        S5=(ABS(PROFTM(M)-XMPFTM))**2.
        SUMB=SUMB+S3
        SUMPT=SUMPT+S4
        SUMPM=SUMPM+S5
 11     CONTINUE
        SS3=SUMB/(NR-1)
        SS4=SUMPT/(NR-1)
        SS5=SUMPM/(NR-1)
        STDB=SQRT(SS3)
        STDPT=SQRT(SS4)
        STDPM=SQRT(SS5)
        WRITE (*,30)
 30     FORMAT ('0',15X,'N',15X,'CATCHT',12X,'CATCHM')
        DO 12  I1=1,NIT
        WRITE (*,40) I1,TCATT(I1),TCATM(I1)
 40     FORMAT (11X,I6,4X,2F17.1)
 12     CONTINUE
        WRITE (*,50) XMEANT,XMEANM,STDT,STDM
 50     FORMAT ('0','XMEANT=',F6.1,3X,'XMEANM=',F6.1,3X,
     +  'STDT=',F6.1,3X,'STDM=',F6.1)
        WRITE (*,60)
 60     FORMAT ('1',15X,'N',11X,'RV1',11X,'RV2')
        DO 13  I1=1,NIT
        WRITE (*,70) I1,RV1(I1),RV2(I1)
 70     FORMAT (11X,I6,4X,F10.3,4X,F10.3)
 13     CONTINUE
        WRITE (*,80)
 80     FORMAT ('1',14X,'RUN',10X,'BIOMASS',10X,'PROFTT',
     +  10X,'PROFTM')
        DO 14  M=1,NR
        WRITE (*,90) M,BIOM(M),PROFTT(M),PROFTM(M)
 90     FORMAT (12X,I6,3F17.1)
 14     CONTINUE
```

```
      WRITE (*,100) XMEANB,STDB
100   FORMAT('0',12X,'XMEANB=',F8.1,10X,'STDB=',F8.1)
      WRITE (*,110) XMPFTT,STDPT
110   FORMAT ('0',12X,'XMPFTT=',F12.1,6X,'STDPT=',F12.1)
      WRITE (*,120) XMPFTM,STDPM
120   FORMAT ('0',12X,'XMPFTM=',F12.1,6X,'STDPM=',F12.1)
      END
      SUBROUTINE EXACOR(XLMDA,VAR,DT,I,U)
      IF(I.NE.0) GO TO 1
      U=0.
      B=XLMDA**DT
      A=(1.+B)/(1.-B)
1     R=UNIF(ISEED,JSEED)
      XK=(A*12.*VAR)**.5
      XN=XK*(R-.5)
      U=B*U-(1.-B)*XN
      I=I+1
      RETURN
      END
      SUBROUTINE DELAY(RINR,ROUTR,CROUTR,DEL,DT,K)
      DIMENSION CROUTR(1)
      DEL1=DEL/(FLOAT(K)*DT)
      RIN=RINR
      DO 3   I=1,K
      ABC=CROUTR(I)
      CROUTR(I)=ABC+(RIN-ABC)/DEL1
 3    RIN=ABC
      ROUTR=CROUTR(K)
      RETURN
      END
      SUBROUTINE RANDOM(I,B)
      INTEGER*2 ISEED,I
      CHARACTER BYTE(2),B
      EQUIVALENCE (ISEED,BYTE(1))
      ISEED=I
      ISEED=ISEED*2837+1
      B=BYTE(2)
      IF(ISEED.LT.0) ISEED=ISEED+32767+1
      I=ISEED
      RETURN
      END
      FUNCTION UNIF(ISEED,JSEED)
      INTEGER*2 ISEED,JSEED,IEXPO
      CHARACTER*1 B(4),RBYTE
      EQUIVALENCE (X,B(1))
      CALL RANDOM(ISEED,B(2))
      CALL RANDOM(ISEED,B(3))
      CALL RANDOM(ISEED,B(1))
      IEXPO=63
      IF (B(3).LT.128) GOTO 1030
      IEXPO=66
1010  CALL RANDOM(JSEED,RBYTE)
      IEXPO=IEXPO-4
```

```
      IF (RBYTE.EQ.0) GOTO 1010
      IF (RBYTE.GT.127) GOTO 1030
      IF (RBYTE.GT.63) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.31) GOTO 1030
      IF (RBYTE.GT.15) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.7) GOTO 1030
      IF (RBYTE.GT.3) GOTO 1020
      IEXPO=IEXPO-1
      IF (RBYTE.GT.1) GOTO 1030
1020  B(3)=CHAR(ICHAR(B(3))-128)
1030  B(4)=CHAR(IEXPO)
      UNIF=X
      RETURN
      END
```

# APPENDIX F

APPENDIX F

SIMULATION RESULTS

SIMULATION MODEL OF THE RED GROUPER FISHERY
YUCATAN CONTINENTAL SHELF

| T | CPUE1 | CPUE2 | CATCH | BIOMASS |
|---|---|---|---|---|
| .0 | .0388 | .2723 | 9496.0 | 137783.3 |
| 1.0 | .0342 | .2504 | 8761.9 | 138725.1 |
| 2.0 | .0406 | .2410 | 9181.1 | 140491.3 |
| 3.0 | .0393 | .2835 | 10474.5 | 140414.7 |
| 4.0 | .0367 | .2754 | 10378.0 | 137792.9 |
| 5.0 | .0453 | .2602 | 10955.4 | 135259.9 |
| 6.0 | .0327 | .3071 | 11681.8 | 130849.7 |
| 7.0 | .0286 | .2771 | 8201.7 | 127140.7 |
| 8.0 | .0278 | .2534 | 7843.5 | 127357.3 |
| 9.0 | .0402 | .2688 | 9435.0 | 126943.6 |
| 10.0 | .0320 | .2905 | 9548.6 | 124331.2 |
| 11.0 | .0309 | .1892 | 7268.2 | 122661.4 |
| 12.0 | .0243 | .2154 | 7527.9 | 121177.7 |
| 13.0 | .0303 | .2327 | 8644.7 | 119192.5 |
| 14.0 | .0351 | .2229 | 9007.3 | 116718.9 |
| 15.0 | .0400 | .2465 | 10269.9 | 111318.5 |
| 16.0 | .0375 | .1971 | 8914.0 | 106641.2 |
| 17.0 | .0324 | .1751 | 8004.2 | 103315.7 |
| 18.0 | .0253 | .1534 | 6780.5 | 100265.8 |
| 19.0 | .0288 | .1838 | 7874.6 | 97073.3 |
| 20.0 | .0175 | .1874 | 6681.5 | 95130.2 |

| T | RANVAR1 | RANVAR2 | CATCHT | CATCHM |
|---|---|---|---|---|
| 1 | -.004700 | -.213885 | 2492.6 | 6269.3 |
| 2 | .001089 | -.344297 | 2995.7 | 6185.4 |
| 3 | -.000080 | .097101 | 2959.1 | 7515.4 |
| 4 | -.001968 | .066637 | 2815.5 | 7562.5 |
| 5 | .007471 | -.041350 | 3540.8 | 7414.5 |
| 6 | -.004312 | .572591 | 2602.2 | 9079.6 |
| 7 | -.007742 | .329322 | 2315.7 | 5886.1 |
| 8 | -.008675 | .054458 | 2255.9 | 5587.5 |
| 9 | .004903 | .240089 | 3283.5 | 6151.5 |
| 10 | -.003275 | .558007 | 2649.2 | 6899.4 |
| 11 | -.003996 | -.595116 | 2606.6 | 4661.7 |
| 12 | -.011104 | -.253756 | 2087.9 | 5440.0 |
| 13 | -.003647 | -.000627 | 2651.3 | 5993.4 |
| 14 | .002731 | -.061732 | 3113.1 | 5894.3 |
| 15 | .010846 | .380420 | 3612.9 | 6657.1 |
| 16 | .009816 | -.151064 | 3454.1 | 5459.9 |
| 17 | .004589 | -.374663 | 3043.1 | 4961.1 |
| 18 | -.003891 | -.613079 | 2404.9 | 4375.6 |
| 19 | .002245 | -.085024 | 2736.7 | 5137.9 |
| 20 | -.013307 | .025220 | 1646.1 | 5035.3 |

| T | ACTV | ACMV | PFTT | PFTM |
|---|---|---|---|---|
| 1 | 435.5 | 711.7 | 353935.1 | 1219844.0 |
| 2 | 367.5 | 739.5 | 628973.3 | 1031229.0 |
| 3 | 378.9 | 628.5 | 587812.8 | 2087216.0 |
| 4 | 405.9 | 647.2 | 483195.6 | 1959010.0 |
| 5 | 329.0 | 684.8 | 879750.8 | 1641802.0 |
| 6 | 456.5 | 580.3 | 314828.9 | 2959136.0 |
| 7 | 521.8 | 643.2 | 128993.1 | 1548366.0 |
| 8 | 537.1 | 703.2 | 91198.6 | 1134592.0 |
| 9 | 371.2 | 662.9 | 677318.8 | 1497032.0 |
| 10 | 466.4 | 613.4 | 294317.0 | 2020550.0 |
| 11 | 482.6 | 941.9 | 247466.1 | -166185.5 |
| 12 | 614.1 | 827.3 | -76331.3 | 429392.0 |
| 13 | 491.7 | 766.0 | 227579.8 | 840775.0 |
| 14 | 424.9 | 799.4 | 475103.6 | 629578.5 |
| 15 | 372.6 | 722.9 | 740282.3 | 1220318.0 |
| 16 | 397.2 | 904.1 | 622819.0 | 11657.5 |
| 17 | 459.4 | 1018.0 | 359311.5 | -554636.5 |
| 18 | 588.6 | 1161.6 | -26605.9 | -1117311.0 |
| 19 | 516.9 | 969.4 | 165762.9 | -324307.0 |
| 20 | 849.9 | 951.0 | -448429.3 | -225519.5 |

| T | TRT | TCT | TRM | TCM |
|---|---|---|---|---|
| 1 | 1439469.0 | 1085534.0 | 5681521.0 | 4461677.0 |
| 2 | 1730020.0 | 1101047.0 | 5605522.0 | 4574294.0 |
| 3 | 1708880.0 | 1121068.0 | 6810812.0 | 4723596.0 |
| 4 | 1625928.0 | 1142732.0 | 6853543.0 | 4894533.0 |
| 5 | 2044837.0 | 1165087.0 | 6719414.0 | 5077613.0 |
| 6 | 1502754.0 | 1187925.0 | 8228381.0 | 5269246.0 |
| 7 | 1337298.0 | 1208305.0 | 5334260.0 | 3785893.0 |
| 8 | 1302805.0 | 1211606.0 | 5063708.0 | 3929117.0 |
| 9 | 1896225.0 | 1218906.0 | 5574796.0 | 4077763.0 |
| 10 | 1529903.0 | 1235586.0 | 6252583.0 | 4232033.0 |
| 11 | 1505283.0 | 1257817.0 | 4224641.0 | 4390826.0 |
| 12 | 1205737.0 | 1282068.0 | 4930019.0 | 4500627.0 |
| 13 | 1531129.0 | 1303550.0 | 5431535.0 | 4590760.0 |
| 14 | 1797793.0 | 1322690.0 | 5341693.0 | 4712114.0 |
| 15 | 2086425.0 | 1346143.0 | 6032974.0 | 4812656.0 |
| 16 | 1994761.0 | 1371942.0 | 4948040.0 | 4936383.0 |
| 17 | 1757401.0 | 1398089.0 | 4496020.0 | 5050656.0 |
| 18 | 1388828.0 | 1415434.0 | 3965375.0 | 5082686.0 |
| 19 | 1580434.0 | 1414671.0 | 4656240.0 | 4980547.0 |
| 20 | 950632.6 | 1399062.0 | 4563275.0 | 4788794.0 |

| T | EMP | SEAFC | EERG |
|---|---|---|---|
| 1 | 3851.7 | 1695.7 | 4123091.0 |
| 2 | 3920.8 | 2547.9 | 5947948.0 |
| 3 | 4011.0 | 3439.5 | 8057350.0 |
| 4 | 4111.4 | 4254.6 | 10701960.0 |
| 5 | 4216.9 | 5140.4 | 13148600.0 |
| 6 | 4326.1 | 6004.1 | 15906910.0 |
| 7 | 4431.5 | 6654.5 | 18649940.0 |
| 8 | 4498.8 | 7413.6 | 20352570.0 |
| 9 | 4577.7 | 8253.9 | 22044580.0 |
| 10 | 4681.2 | 9292.8 | 23896740.0 |
| 11 | 4799.7 | 10279.2 | 25516060.0 |
| 12 | 4902.7 | 11108.4 | 27206640.0 |
| 13 | 4991.0 | 11910.9 | 28982030.0 |
| 14 | 5086.6 | 12834.2 | 30655520.0 |
| 15 | 5183.9 | 13891.6 | 32709450.0 |
| 16 | 5296.3 | 14936.1 | 34495940.0 |
| 17 | 5405.6 | 15745.0 | 36153630.0 |
| 18 | 5460.0 | 16563.4 | 37653400.0 |
| 19 | 5415.8 | 17329.1 | 39154090.0 |
| 20 | 5299.3 | 17884.1 | 40541400.0 |

| T | TFV | MFV | TPFTT | TPFTM |
|---|---|---|---|---|
| 1 | 856.7 | 183.1 | 1106799.0 | 3189056.0 |
| 2 | 869.0 | 187.7 | 1654808.0 | 3986516.0 |
| 3 | 884.8 | 193.8 | 2260911.0 | 5480608.0 |
| 4 | 901.9 | 200.8 | 2698563.0 | 8371086.0 |
| 5 | 919.5 | 208.3 | 3250440.0 | 10508450.0 |
| 6 | 937.6 | 216.2 | 3737149.0 | 13365240.0 |
| 7 | 953.6 | 224.4 | 3790598.0 | 15982290.0 |
| 8 | 956.3 | 232.9 | 4041518.0 | 17082280.0 |
| 9 | 962.0 | 241.7 | 4444828.0 | 18005590.0 |
| 10 | 975.2 | 250.8 | 5218456.0 | 19243530.0 |
| 11 | 992.7 | 260.2 | 5871494.0 | 19647140.0 |
| 12 | 1011.9 | 266.7 | 6198512.0 | 20116170.0 |
| 13 | 1028.8 | 272.1 | 6450166.0 | 20740370.0 |
| 14 | 1043.9 | 279.3 | 6915323.0 | 20961090.0 |
| 15 | 1062.4 | 285.2 | 7617293.0 | 22176270.0 |
| 16 | 1082.8 | 292.6 | 8269621.0 | 22505380.0 |
| 17 | 1103.4 | 299.3 | 8442161.0 | 22333470.0 |
| 18 | 1117.1 | 301.2 | 8610855.0 | 21620170.0 |
| 19 | 1116.5 | 295.2 | 8667441.0 | 20941910.0 |
| 20 | 1104.2 | 283.8 | 8327390.0 | 20083630.0 |

| T | MC1 | MC2 | MR1 | MR2 |
|---|---|---|---|---|
| 1 | 445.5 | 1164.6 | 577.5 | 906.3 |
| 2 | 439.9 | 1149.9 | 577.5 | 906.3 |
| 3 | 440.1 | 1150.5 | 577.5 | 906.3 |
| 4 | 448.5 | 1172.4 | 577.5 | 906.3 |
| 5 | 456.9 | 1194.4 | 577.5 | 906.3 |
| 6 | 472.3 | 1234.6 | 577.5 | 906.3 |
| 7 | 486.1 | 1270.7 | 577.5 | 906.3 |
| 8 | 485.3 | 1268.5 | 577.5 | 906.3 |
| 9 | 486.8 | 1272.6 | 577.5 | 906.3 |
| 10 | 497.1 | 1299.4 | 577.5 | 906.3 |
| 11 | 503.8 | 1317.1 | 577.5 | 906.3 |
| 12 | 510.0 | 1333.2 | 577.5 | 906.3 |
| 13 | 518.5 | 1355.4 | 577.5 | 906.3 |
| 14 | 529.5 | 1384.1 | 577.5 | 906.3 |
| 15 | 555.2 | 1451.3 | 577.5 | 906.3 |
| 16 | 579.5 | 1514.9 | 577.5 | 906.3 |
| 17 | 598.2 | 1563.7 | 577.5 | 906.3 |
| 18 | 616.4 | 1611.2 | 577.5 | 906.3 |
| 19 | 636.6 | 1664.2 | 577.5 | 906.3 |
| 20 | 649.6 | 1698.2 | 577.5 | 906.3 |

| AGE | POPULATION | BIOMASS |
|---|---|---|
| 1 | 58986310.0 | 10922.1 |
| 2 | 39530140.0 | 17974.6 |
| 3 | 21860560.0 | 18082.9 |
| 4 | 10617480.0 | 13505.9 |
| 5 | 6235509.0 | 10965.2 |
| 6 | 3683768.0 | 8326.5 |
| 7 | 2201208.0 | 6069.1 |
| 8 | 1199125.0 | 3878.6 |
| 9 | 649983.1 | 2393.8 |
| 10 | 350952.4 | 1437.6 |
| 11 | 154861.7 | 692.7 |
| 12 | 47172.1 | 227.0 |
| 13 | 35596.7 | 182.0 |
| 14 | 26173.4 | 140.8 |
| 15 | 18997.2 | 106.7 |
| 16 | 13608.9 | 79.2 |
| 17 | 9599.8 | 57.6 |
| 18 | 6634.2 | 40.9 |
| 19 | 4471.7 | 28.1 |
| 20 | 2937.8 | 18.8 |

# LIST OF REFERENCES

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Agnello, R.J.; Donnelley. 1976. Externalities and Property Rights in the Fisheries. Land Economics. 52(4):518-529.

Allen, P.M.; J.M. McGlade. 1986. Dynamics of Discovery and Exploitation: The Case of the Scotian Shelf Groundfish Fisheries. Can. J. Fish. Aquat. Sci. 43:1187-1200.

Anderson, L.G. 1977. The Economics of Fisheries Management. The Johns Hopkins University Press, New York. 214 p.

___________. 1983. A Preliminary Theory of Fisheries Regulation Development. Paper presented at the Canadian Regional Science Association Seventh Annual Meeting, Vancouver, British Columbia, June 5-6, 1983.

___________. 1984. Uncertainty in the Fisheries Management Process. Journal of Marine Resource Economics 1(1):77-87.

Banco Nacional de Comercio Exterior. 1981. Fisheries: Plenty of Sea and Little Fishing... Yet. Comercio Exterior de Mexico. 27(10):417-421.

Bardach, J.E. 1958. On the Movements of Certain Bermuda Reef Fishes. Ecology. 39(1):139-146.

Beddington, J.; R.M. May. 1977. Harvesting Populations in a Randomly Fluctuating Environment. Science. 197:463-465.

Bell, F.W. 1977. Food from the Sea: The Economics and Politics of Ocean Fisheries. Westview Press, Boulder, Colorado

Bell, F.W. 1980. Fisheries Economics. In: R.T. Lackey and L.A. Nielsen (editor) 1980. Fisheries Management. Blackwell Scientific Publications, Boston Massachusetts. pp. 197-217.

Beverton, R.J.H.; S.J. Holt. 1956. The Theory of Fishing. In: M. Graham (editor).Sea Fisheries: Their Investigation in the United Kindom. Arnold, London. pp. 372-441.

-----------. 1957. On the Dynamics of Exploited Fish Populations. Fish. Invest. London. Ser. II. 19:1-533.

Burgos, R.; R.Lope. 1984. Coeficientes de Captura de la Flota Mayor de Yucatan. Centro Regional de Investigacion Pesquera Yucalpeten, Progreso, Yucatan. 62 p.

Burke, W.T. 1983. Extended Fisheries Jurisdiction and the New Law of Sea. In: B. J. Rothschild (editor). 1983. Global Fisheries: Perspectives for The 1980s. Springer-Verlag, New York. 289 p.

Bhattacharyya, G.K.; R.A. Johnson. 1977. Statistical Concepts and Methods. John Wiley and Sons, New York. 639 p.

Carranza, J. 1959. Pesca y Recursos Pesqueros. In Beltran E. (editor). 1959. Los Recursos Naturales del Sureste y su Aprovechamiento. Inst. Mexicano Rec. Nat. Renov., Mexico. 3(5):151-238.

Chappelle, D.E. 1985. Presentation of Research Results. (Class notes) Department of Resource Development, Michigan State University: East Lansing, Michigan.

Chavez, E.; F. Arreguin.1986. Un Metodo Alternativo para la Evaluacion de Poblaciones Pesqueras. Paper Presented at the Workshop on Recruitment in Tropical Coastal Demersal Communities. IOC/FAO. Ciudad del Carmen, Campeche.

Chavez, E. 1983. La Pesca de Arrastre de Yucatan. Un Conflicto de Intereses o una Alternativa del Desarrollo?. Centro de Investigaciones y de Estudios Avanzados del IPN - Unidad Merida, Yucatan.

Cheney, W.; D. Kincaid. 1985. Numerical Mathematics and Computing. Brooks Cole Publishing Company, Monterey, California. 562 p.

Clark, C.W. 1976. Mathematical Bioeconomics. John Wiley and Sons, New York. 352 p.

----------. 1980. Towards a Predictive Model for the Economic Regulation of Commercial Fisheries. Can. J. Fish. Aquat. Sci. 37:1111-1129.

----------. 1982. Models of Fishery Regulation. In: Mirman, L.J. and D.F. Spulber, Editors. Essays in the Economics of Renewable Resources. North Holland Publishing Company, New york. 287 p.

----------. 1985. Bioeconomic Modelling of Fisheries Management. John Wiley and Sons, New York. 291 p.

Clayden, A.D. 1972. Simulation of the Changes in Abundance of the Cod, Gadus morhua L., and the Distribution of Fishing in the North Atlantic. Fish. Invest. London. Ser. II. 27:1-57.

Cruz, R.; Lesser, H. 1986. Caracol Strombus gigas: Informe de Actividades. X Reunion MEXUS Golfo. National Marine Fisheries Service, NOAA; Instituto Nacional de la Pesca, Houston, Texas. 39-42 pp.

Comision de Pesca para el Atlantico Centro Occidental (COPACO). 1981. Informe de la Segunda Reunion Conjunta sobre Evaluacion de Recursos Pesqueros, y del Grupo de Trabajo sobre Evaluacion de los Recursos Camaron y Langosta. Ciudad de Mexico, 26-29 de Noviembre de 1979. FAO, Inf. Pesca. (235):43p.

Comision Nacional de Alimentacion. 1983. Programa Nacional de Alimentacion 1983-1988. Secretaria de Programacion y Presupuesto, Mexico D.F.

Crutchfield, J.A.; G. Pontecorvo. 1969. The Pacific Salmon Fisheries. Johns Hopkins University Press, Baltimore. 220 p.

Crutchfield, J.A. 1979. Economic and Social Implications of the Main Policy Alternatives for Controlling Fishing. J. Fish. Res. Board Can. 36:742-752.

Cushing, D.H. 1983. Key Papers on Fish Populations. IRL, Press, Oxford. 405 p.

Cushing, D.H. 1968. Fisheries Biology: A Study in Population Dynamics. University of Wisconsin Press, Madison. 200 p.

Cuyvers, L. 1984. Ocean Uses and Their Regulation. Wiley Interscience, New York. 179 p.

Departamento de Pesca. 1977. Plan Nacional de Desarrallo Pesquero: 1977-1982. Mexico: Secretaria de Programacion y Presupuesto.

Doi, T.; D. Mendizabal; M. Contreras. 1981. Analisis Preliminar del Estado de la Poblacion del Mero Epinephelus morio (Valenciennes), frente al Banco de Campeche. Ciencia Pesquera. Inst. Nal. Pesca. Depto. Pesca. Mexico. 1(1):1-15.

Eckert, R. 1979. The Enclosure of Ocean Resources. Hoover Institution Press, Stanford Californaia. 390 p.

Ervik, L.K. et al. 1981. Comprehensive Modelling of Fisheries: Comments and Case Study. In: Haley, K.B., (editor). Applied Operations Research in Fishing. Plenum Press, New York. pp. 3-21.

Everhart, W.H.; Youngs, W.D. 1981. Principles of Fishery Science. 2nd ed. Cornell University Press, Ithaca. 349 p.

F.A.O. 1981. Yearbook of Fisheries. Food and Agriculture Organisation, Rome. pp. 41.

Fox, W.W. 1970. An Exponential Surplus Yield Model for Optimizing by Exploited Fish Populations. Trans. Amer. Fish. Soc. 99:80-88.

Frost, H. 1984. Fisheries Management and Uncertainty Within the EEZ. Journal of Marine Resource Economics. Vol. 1(1):97-103.

Fuentes, D.; Aguilar, C.; Ramos, R. 1986. Estado del Conocimiento Biologico-Pesquero de la Langosta, Panulirus argus, (Latreille, 1804), en el Caribe Mexicano. Instituto Nacional de la Pesca, Yucalpeten, Yucatan. 44 p. Unpublished Manuscript.

Garcia, C.; L. Miranda. 1975. Fondos, Zona Oriental del Banco de Campeche (Contoy). Informe Tecnico no Publicado. La Havana, Cuba.

Garrod, D.J.; B.W. Jones. 1974. Stock and Recruitment Relationship in the N.E. Atlantic Cod Stock and the Implications for Management of the Stock. J. Cons. Int. Explor. Mer. 36:36-41.

Gislalon, G.S.; J.A. Macmillan; J.W. Craven. 1982. The Manitoba Commercial Fishery. The University of Manitoba Press, Canada. 311 p.

Gobierno del Estado de Yucatan. 1983. Monografia del Estado de Yucatan. Merida, Yucatan, Mexico.

Gordon, H.S. 1954. The Economic Theory of a Common-Property Resource: The Fishery. Journal of Political Economy. 62:124-142.

Gottfried, B.S. 1984. Elements of Stochastic Process Simulation. Prentice-Hall, Inc, Englewood Cliffs. 300 p.

Graham, M. 1935. Modern theory of Exploiting a Fishery and Application to North Sea Trawling. J. Cons. Int. Explor. Mer. 10:264-74.

Grant, W.E.; Griffin, W.L.; J.P. Warren. 1981. A Management Model of the Northwest Cephalopod Fishery. Marine Fisheries Review. 43(11):1-10.

Graybeal, W.J.; W.W. Pooch. 1980. Simulation Principles and Methods. Winthrop Publishers, Inc, Cambridge, Mass. 249 p.

Gulland, J.A. 1983. Fish Stock Assessment. John Wiley and Sons, New York. 223 p.

Gulland, J.A. 1981. An Overview of Applications of Operations Research in Fishing. In: Haley B., Editor. Applied Operations Research in Fishing. Plenum Press, New York. pp. 125-135.

________________. 1977. Analysis of Data and Development of Models. In: Gulland, J.A. Editor. Fish Population Dynamics, Wiley, London. pp. 67-95

Hammersley, J.M.; D.C. Handscomb. 1964. Monte Carlo Methods. Barnes and Noble, Inc., New York. 178 p.

Hannesson, R. 1978. Fisheries Economics. Columbia University Press, New York. 156 p.

________________. 1983. Bioeconomic Production Function in Fisheries: Theoretical and Empirical Analysis. Can. J. Aquat. Sci. 40:968-982.

Hardin, G. 1973. The Tragedy of the Commons. In: Enthoven, A.C. and Freeman III, A.M.,(editors). Pollution, Resources and the Environment. W.W. Norton and Co., New York. pp. 1-13.

Hilborn, R. 1979. Comparison of Fisheries Control Systems that Utilize Catch and Effort Data. J. Fish. Res. Board Can. Vol. 36:1477-1489.

Howe, C.W. 1979. Natural Resource Economics, Issues, Analysis and Policy. John Wiley and Sons, New York. 350 p.

Jarvis, N.D. 1935. Fishery for Red Snappers and Groupers in the Gulf of Mexico. Invest. Rep. U.S. Fish., No. 26, 29 p.

Jensen, A.L. 1973. Relation Between Simple Dynamic Pool and Surplus Production Models for Yield from a Fishery. J. Fish. Res. Board Can. 30:998-1002.

Johnston, D.A. 1981. The Environmental Law of The Sea. International Union for Conservation of Nature and Natural Resources, Gland Switzerland.

Klima, E.F. 1976. Snapper and Grouper Resources of the Western Central Atlantic Ocean. In: H.R. Bullis, Jr. and A.C. Jones (editors), Proceedings: Colloquium on Snapper-Grouper Fishery Resources of the Western Central Atlantic Ocean, Florida Sea Grant Report No. 17, pp. 5-40.

Kuester, J.L.; J.H. Mize. 1973. Optimization Techniques with Fortran. McGraw-Hill Book Company, New York. 500 p.

Laevastu, T.; H.A. Larkins. 1981. Marine Fisheries Ecosystem. Its Quantitative Evaluation and Management. Fishing News Books, Ltd, England. 162p.

Lewis, T.R. 1982. Stochastic Modeling of Ocean Fisheries Resource Management. University of Washington Press, Seattle. 109 p.

Manetsch, T.J.; G.L. Park. 1982. System Analysis and Simulation With Applications to Economic and Social Systems. Fourth Edition. Michigan State University, East Lansing, Michigan.

Manetsch, T.J. 1975. General Principles of System Modeling with Case Study. (Class Notes). Department of System Science and Electrical Engineering, Michigan State University, East Lansing, Michigan.

---------------. 1976. Time Varying Distributed Delays and their Use in Aggregate Models of Large Systems. IEEE Transactions on Systems, Man and Cybernetics. SMC-6, No. 8:547-553.

---------------. 1977. On the Role of Systems Analysis in Aiding Countries Facing Acute Food Shortages. IEEE Transactions on Systems, Man, and Cybernetics, 7(4):264-273.

---------------. 1982b. A Collection of Notes and Readings for Advance Systems Science and Simulation." (Class notes). Department of System Science and Electrical Engineering. Michigan State University, East Lansing, Michigan.

Moe, M.A. 1969. Biology of the Red Grouper Epinephelus morio (Valenciennes) from the Eastern Gulf of Mexico." Florida: Dept. Nat. Res., Prof. Papers Ser., No. 10, 95 p.

Moyle, P.; J.J Cech.1982. Fishes: An Introduction to Ichthyology. Prentice Hall, Inglewoods Cliff, N.J. 593 p.

Moreno, V. 1980. La Pesqueria del Mero (Epinephelus morio) en el Estado de Yucatan. Memoria. Cuernavaca, Morelos. Universidad Autonoma del Estado de Morelos. 41 p.

Muhlia, A.F.M. 1976. Aspectos Biologico-Pesqueros de Epninephelus morio (Val.); Mero. Mem Primer Simp. Nal. sobre rec. pesq masivos de Mexico. INP/SIC pp. 223-264.

Mohn, R.K. 1980. Bias and Error Propagation in Logistic Production Models. Can. J. Fish. Aquat. Sci. 37:1276-1283.

Munro, G.R. 1981. The Economics of Fishing: An Introduction. In: Butlin, J.A. (editor). The Economics of Environmental and Natural Resource Policy. West View Press, Boulder, Colorado. 206 p.

Nisbet, R.M.; W.S.C. Gurney. 1982. Modelling Fluctuating Populations. John Wiley and Sons, New York. 379 p.

Pauly, D. 1979. Theory and Management of Tropical Multispecies Stocks: A review, with Emphasis on the South East Asia Demersal Fisheries. ICLARM Stud. Rev. 1, 35 p.

___________. 1986. Towards Appropriate Concepts and Methodologies for the Study of Recruitment in Tropical Demersal Communities. Paper Presented at the Workshop on Recruitment in Tropical Demersal Communities, Ciudad de Carmen, Campeche

Payne, A.J. 1982. Introduction to Simulation. McGraw-Hill Book Company, New york. 324 p.

Pearse, P.H. 1980. Regulation of Fishing Effort. Rome: FAO. Fish. Tech. Pap. (197):82 p.

Pella, J.J.; Tomlinson, P.K. 1969. A Generalized Stock Production Model. Bull. Inter-Amer. Trop. Tuna Comm. (13):421-496.

Pitcher, T.J.; P.J.B. Hart. 1982. Fisheries Ecology. AVI Publishing Company, Great Brittain. 414 p.

Pope, J.G. 1972. An Investigation of the Accuracy of Virtual Population Analysis. ICNAF Research Bulletin. (9):65-74.

Randall, A. 1981. Resource Economics: An Economoic Approach to Natural Resources and Environmental Policy. Grid Publishing Inc. Columbus, Ohio. 415 p.

Rettig, R.B.; J.J.C. Ginter. 1978. Limited Entry as a Fishery Management Tool. University of Washington Press, Seattle. 463 p.

Richards, W.J. 1984. Larval Distribution and Abundance of Engraulidae, Carangidae, Clupeidae, Lutjanidae, Serranidae, Coryphaenidae, Istiophoridae, Xiphiidae, and Scombridae in The Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFC-144.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Board Can. 191. 382 p.

Rivas, L.R. 1968. Fishermen's Atlas of Monthly Sea Surface Temperatures for the Gulf of Mexico. U.S. Fish. Wildl. Serv. Circ. 300, 33 pp.

-----------. 1970. The Red Grouper of the Gulf of Mexico. Commercial Fisheries Review, Vol. 32(10).

Roberts, N.; D. Andersen; R. Deal; M. Garet; W. Shaffer. 1983. Introduction to Systems Simulation: A Systems Dynamics Modelling Approach. Addison-Wesley Publishing Company, Reading, Mass. 562 p.

Ross, D.A. 1982. Introduction to Oceanography. Prentice Hall Inc., Englewood Cliffs, N.J.

Rothschild, B.J. 1983. Global Fisheries. Perspectives for the 1980's. Springer-Verlag, New York. 289 p.

________________. 1967. Competition for Gear in a Multispecies Fishery. J. Cons. Int. Explor. Mer. 31(1):102-110.

Russell, E.S. 1931. Some Theoretical Consideration on the Overfishing Problem. J. Cons. Int. Explor. Mer. 6:3-20.

Sassaman, R.W.; Chappelle, D.E.; Fritchman, K. 1969. Users Manual for SORAC Computer Program. Portland, Oregon: U.S. Department of Agriculture.

Schaefer, M.B. 1954. Some Aspects of the Dynamics of Populations Important to the Management of Commercial Marine Fisheries. Bull. Inter-Amer. Trop. Tuna Commission. 1:27-56.

Schelling, T.C. 1978. Micromotives and Macrobehavior. W.W. Norton and Company, New York. pp. 11-43.

Schmid, A.A. 1978. Property, Power and Public Choice. Praeger, New York. 316 p.

Schnutte, J. 1977. Improved Estimates from the Schaefer Production Model: Theoretical Considerations. J. Fish. Res. Board. Can. 34:583-603.

Scott, A.D. 1979. Development of Economic Theory on Fisheries Regulation. J. Fish. Res. Board. Can., 36(7): 725-741.

Secretaria de Pesca. 1985. Anuario Estadistico 1984. Secretaria de Pesca, Mexico, D.F.

Secretaria de Pesca. 1986. Mosaico Pesquero, Abril 1986. Direccion General de Comunicacion Social, Mexico, D.F.

Secretaria de Programacion y Presupuesto. 1980. Plan Global de Desarrollo: 1980-1982. Secretaria de Programacion y Presupuesto, Mexico, D.F.

Secretaria de Programacion y Presupuesto. 1982. Censo de Poblacion y Vivienda 1980. Secretaria de Programacion y Presupuesto, Mexico, D.F.

Secretaria de Programacion y Presupuesto. 1983. Plan Nacional de Desarrollo 1983-1988. Secretaria de Programacion y Presupuesto, Mexico, D.F.

Shannon, R.E. 1975. System Simulation: The Art and Science. Prentice Hall, Englewood Cliffs, N.J.

Smith, C.L. 1961. Synopsis of Biological Data on Groupers (Epinephelus and Allied Genera) of the Western North Atlantic. FAO Fisheries Biology Synopsis. 23(1):1-62.

Smith, C.L.; J.M. Stander; A.V. Tyler. 1982. Human Behavior Incorporation into Ecological Computer Simulations. Environmental Management. 6(3):251-260.

Solis, R.M. 1969. The Red Grouper Fishery of Yucatan Peninsula, Mexico. Gulf and Caribbean Fisheries Institute, pp. 122-129.

Swartzman, G.L.; W.M. Getz; R.C. Francis; R.T. Haar; K. Rose. 1983. A Management Analysis of the Pacific Whiting (Merluccius productus) Fishery using an Age Structured Stochastic Model. Can. J. Aquat. Sci. 40:524-539.

Thesen, A. 1985. An Efficient Generator of Uniformly Distributed Random Variates Between Zero and One. Simulation. 44(1):17-22.

Tyler, A.V.; V.F. Galucci. 1980. Dynamics of Fish Stocks. In: Lackey, R.T and L.A. Nielsen (editors). Fisheries Management. Blackwell Scientific Publications, Boston. pp. 111-148.

Uhler, R.S. 1980. Least Squares Regression Estimates of the Schaefer Production Model: Some Monte Carlo Results. Can. J. Fish. Aquat. Sci. 37:1284-1294.

Valdez, E.; G. Padron. 1980. Pesquerias de Palangre. Rev. Cub. Inv. Pesq. 5(2).Cuba.

Walter, G.G. 1973. Delay-Differential Equation Models for Fisheries. J. Fish. Res. Board Can. 30:939-945.

______________. 1978. A Surplus Yield Model Incorporating Recruitment and Applied to a Stock of Atlantic Mackerel. J. Fish. Res. Board. Can. 35:229-234.

Walters, C.J. 1980. Systems Principles in Fisheries Management. In: Lackey, R.T. and L.A. Nielsen (editors) Fisheries Management. Blackwell Scientific Publications, Boston. pp. 167-183.

________________. 1969. A Generalized Simulation Model for Fish Population Studies. Trans. Amer. Fish. Soc., Vol. 98,505-512.

Wilson, J.A. 1982. The Economical Management of Multispecies Fisheries. Land Economics. 58:417-434.

Wilson, J.P.F. 1979. The Biology and Population Ecology of the Pollan, Coragenus autumnalis pollon Thompson, in Lough Neagh, Northern Ireland. Ph.D. thesis, New University of Ulster, Northern Ireland.

Yoho, J.G.; Chappelle, D.E.; Schweitzer, D.L. 1969. "The Economics of Converting Red Alder to Douglas Fir." Portland, Oregon: USDA Forest Service Research Paper PNW-88.

Young, O.R. 1981. Natural Resources and the State: the Political Economy of Resource Management. University of California Press, Berkeley. 227 p.

Zubey, J.R.; A.C. Johns. 1978. Everything You Always Wanted to Know About MSY and OY (but were afraid to ask).Paper Presented at a Meeting of the Gulf of Mexico Management Council, Mobile, Alabama. 29 p.

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