PRIVATE DEVELOPMENT OF ARTIFICIAL REEFS

A Thesis

by

ARTHUR ALLEN BURNS, JR.

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

December 1978

Major Subject: Management

PRIVATE DEVELOPMENT OF ARTIFICIAL REEFS

A Thesis

by

ARTHUR ALLEN BURNS, JR.

Approved as to style and content by:

(Chairman of the Committee)

(Head of the Department)

(Member)

(Member)

December 1978

ABSTRACT

Private Development of Artificial Reefs.

(December 1978)

Arthur Allen Burns, Jr.

B.S., University of Mississippi

Chairman of the Advisory Committee:

John L. Seymour, LLM

This thesis is an examination of the feasibility of the private development of artificial reefs. Under this development scheme an entrepreneur would have the exclusive right to fish in the waters surrounding an artificial reef and would charge fishermen for the use of the reef.

The concerns of a potential investor addressed by this thesis are (1) the effects an artificial reef would have on the total productivity of coastal fishery resources, (2) the legal consideration associated with the private development of artificial reefs, and (3) the financial feasibility of the reef development. The geographic area addressed by this thesis is the coastal waters of Texas, Louisianna, Mississippi, Alabama, and northwestern Florida. The conclusions can, however, be applied to any temperate waters with high sedimentation and low wave energy.

Information and data for this thesis were obtained from personal and telephone interviews, from appropriate state and federal statutes and cases, and from secondary sources. The following conclusions are drawn:

(1) a properly constructed and located artificial reef will increase the productivity of coastal benthic environments, and will increase the total numbers of reef dwelling fishes;

(2) the private development of artificial reefs can be conducted in a manner consistent with state and federal law, and consistent with the public trust in which coastal waters and there associated fisheries are held; and

(3) the private development of artificial reefs is financially feasible, as evidenced by favorable calculations of return on equity and net present value.

Although the specific concern of this thesis is the private development of artificial reefs, the conclusion is made that a market economy would be the most efficient mechanism of allocating many common property resources.

DEDICATION

To my Parents,
whose love, encouragement
and assistance is unfailing,
this thesis is dedicated.

ACKNOWLEDGEMENTS

I would like to acknowledge Mr. John L. Seymour who served as chairman of my advisory committee and serves as the advisor for the Marine Resources Management program. Without John's guidance, support and patience my graduate studies would not have been possible. I would also like to acknowledge Dr. Clint Phillips and Dr. Rich Noble who served as members of my advisory committee. I am most grateful to them for their kind assistance.

Thanks to Priscilla Lee, Scott Davison, Bill Brah and other past and present members of the Marine Resources Management program at Texas A&M University; and thanks to Norman and Juana Gillis, Travis Roberts, Cherrie Felder and Victor Franckiewicz. I consider their support and encouragement invaluable and their friendship precious.

Finally, special thanks to Gary Cuevas for his help with the illustrations.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The development of artificial reefs in the coastal waters of the Gulf of Mexico has become commonplace. The greater part of this development has been conducted by state fish and wildlife departments or by sport fishing associations acting in concert with a state agency or a local municipality.[1] The effect of these reef developments has been to concentrate sport fishery resources for the angling public. The potential of these artificial reefs as exceptional fishing locations can be shown by the increase in numbers of fish caught in these locations and the relationship of angler hours fished over reef sites and nonreef sites. The catch over these new fishing reefs is usually more than ten-fold the catch over the areas surrounding these reefs.[2]

Although the development of artificial reefs by the public sector has benefited the public as a whole, it can be argued that the development of artificial reefs will not assure that sport fishery resources will be allocated in an optimum manner. Public agencies often have limited funds

---

The references in this thesis follow the style of the Coastal Zone Management Journal.

for such projects, and lack the profit incentive which motivates suppliers to meet demands for their resources.

It can also be argued that the development of artificial reefs by private parties would be the best means to achieve an optimum allocation of many sport fishery resources. Inplicit in this argument is a demand for fishery resources, as evidenced by the use of public reefs, and the desire for a developer to maximize his profits by locating artificial reefs in the areas of the greatest market demand. Thus, the market would be used to determine the wants of fisherman for artificial reefs but would provide for the optimal locations since there would be a market for fishery resources from reefs where the demand was high and no market where the demand was low.[3]

In order for a private development allocation process to operate properly, a potential developer would have to be assured of exclusive use of his reef development.[4] Exclusive use of a coastal fishery poses unique legal concerns, for coastal fisheries have developed historically as a common property resource. If it could be demonstrated that, as a result of an artificial reef development, the total number of reef dwellings fishes commonly sought by sport fishermen has increased, the exclusive use of an artificial reef and the superadjacent water column by a private developer might proceed in a manner consistent with the common property nature of coastal fisheries. Once a specific legal mechanism for the exclusive use of a reef could be formed, a developer would be free to perform the necessary analyses to determine if such a venture would be financially feasible.

Review of Literature

A wealth of Literature exists concerning the ecology of marine environments. The best introduction to this field is Hedgepeth's Treatise on Marine Ecology and Paleoecology.[5] This treatise contains information on submarine daylight and photosynthesis,[6] planktonic organisms,[7] disolved oxygen,[8] disolved carbon dioxide[9] and nutrient elements.[10] An understanding of these fundamental factors is necessary for an examination of the interaction of an artificial reef with its physical, chemical, and biological environments. Harvey[11] has examined the nature of primary and secondary production in the sea off Plymouth, England, and Odum and Odum[12] have conducted a similar study on a Pacific atoll. Stone[13] has employed many of the same techniques in his examination of the productivity of artificial reefs.

Literature also exists concerning the development of the public trust doctrine as that doctrine relates to coastal fisheries.[14] There is much case law which addresses and defines the public trust; the most famous American case is perhaps Illinois Central R.R. v. Illinois.[15] In addition, all states have enacted, to various degrees, legislation which defines and enhances their public trust responsibilities.

There is much literature concerning sport fishing activities as a whole,[16] but there is less available information concerning the profitability of specific sport fishing industries in the Gulf of Mexico. Two of the best works in this field are Schmeid's analysis of charter boat fishing[17] and Ditton's examination of charter fishing on the Texas coast.[18]

Objectives

The objectives of this thesis are: (1) to perform an analysis of the ecological, legal and financial considerations associated with the private development of artificial reefs; (2) to prove the feasibility of a new marine industry, i.e. the development of artificial reefs by private parties who have exclusive use of the reef and the superadjacent water column, and who in turn derive a profit from the fee use of an incidental charter boat operation.

These objectives necesitate the demonstrations that: (1) artificial reefs do, to at least a modest degree, increase the total numbers of those species of reef dwelling fishes existing in coastal waters of the Gulf of Mexico; (2) the private development and exclusive use of an artificial reef can be conducted in a manner consistent with the public trust in which coastal fisheries are held and consistent with state and federal law, and; (3) that the private development of artificial reefs in concert with a charter boat business is a financially feasible operation. For the purposes of this thesis the definition of "coastal waters" shall be that of the Coastal Zone Management Act of 1972,[19] those waters from the watermark of ordinary high tide to the extent of the three mile territorial sea.

Methodology

Information and data for this thesis were obtained from personal and telephone interviews, from appropriate state and federal statutes and cases, and from secondary sources. Scientific and technical literature and personal interviews with oceanographic and fisheries researchers were used in the analysis of the effects of natural and artificial reefs on marine productivity.

Law review articles and appropriate state and federal statutes and cases were used to develop a mechanism whereby the private development of artificial reefs could proceed in a manner consistent with the public trust in which coastal fisheries are held.

This legal mechanism was, in turn, used to generate operating assumptions for an artificial reef/charter boat business. Data from studies of the Texas charter boat industry were used with the operating assumptions to determine the financial feasibility of an artificial reef/charter boat business. The two financial analyses performed were a return on equity calculation and a net present value calculation.

CHAPTER II

ARTIFICIAL REEFS AND THE MARINE ENVIRONMENT

In order to demonstrate the useful role artificial reefs play in the marine environment, and understanding of the processes which create a thriving reef community, be it natural or artificial, is imperative. The concepts of primary production, the food chain, and the factors which limit production can be used to explain the intricacies of any living community of organisms, either terrestrial or marine.

Primary production is the process which transforms visible and invisible solar radiation into the high energy chemical bonding of phosphorus containing organic molecules. The energy of these phosphate bonds can, in turn, be used to create chemical bonding of a higher order; this is the mechanism by which an organism manufactures its food and builds its physical structure. Those organisms which synthesize their own food from inorganic matter in the presence of sunlight are known as autotrophic, i.e. self-nourishing. All green chlorophyll-containing plants are autotrops and are the primary producers of the biosphere. It can be more simply stated that autotrophic organisms or primary producers are those organisms which carry on the process of photosynthesis.

Solar radiation is the most fundamental factor in the marine environment. The degree of availability of this energy directly controls the amount of organic matter synthesized, for, no matter how favorable other factors may be, this amount will be limited by the relatively low efficiency of the photosynthetic process.[20] Light energy comes in discrete or quanta "packets" known as photons. The various wavelengths of sunlight which play a role in the photosynthetic process range from the infrared to the ultraviolet; when a photon of the appropriate wavelength strikes a chlorophyll molecule and is absorbed, its energy is apparently transferred in some manner to an electron of the chlorophyll. This electron is raised from its normal level to a higher energy level.[21] It is the unique capability of chlorophyll to absorb light energy and act as a donor of high energy electrons that is critical for photosynthesis.

In one of the photosynthetic processes, chlorophyll acts both as an electron donor and as the ultimate electron acceptor, donating an excited electron and eventually accepting the electron in a low energy state.[22] Because the same electrons can be carried round and round the system, and no outside source of electrons is needed, this method of synthesizing the high energy phospate bonded compound known as adenosine triphospate (ATP) is called cyclic photophosphorylation.

Noncyclic photophosphorylation is also intiated when light strikes the chlorophyll molecule and raises an electron to a high energy state, however, this electron is not returned to the chlorophyll molecule but is used to form hydrogen ions from water. The water molecules are split into hydrogen ions and free oxygen; it is in the formation of oxygen that an electron from the water molecule is returned to the chlorophyll molecule so the process can begin again. Noncyclic photophosphorylation is the process which forms oxygen and hydrogen ions. These hydrogen ions are in turn used to manufacture carbohydrates from atmospheric carbon dioxide.

The overall process of photosynthesis can be written as:

$$6CO_2 + 12H_2O + \text{light} \longrightarrow 6O_2 + C_6H_{12}O_6 + 6H_2O$$

(see Figure 1 for a more detailed diagram of the photosynthetic process).

The food chain represents the flow of energy through a living community. Plants are the primary sources of energy for all animals. Plants are eaten by herbivorous animals, which are eaten by carnivorous animals, which are eaten by other carnivores, and so on. Each step in the food chain is called a trophic level; the feeding relationships of organisms impart a trophic structure to the community through which energy flows in only one direction.[23] Most of the energy assimilated by a trophic level is dissipated as heat; it is not incorporated into growth and re-

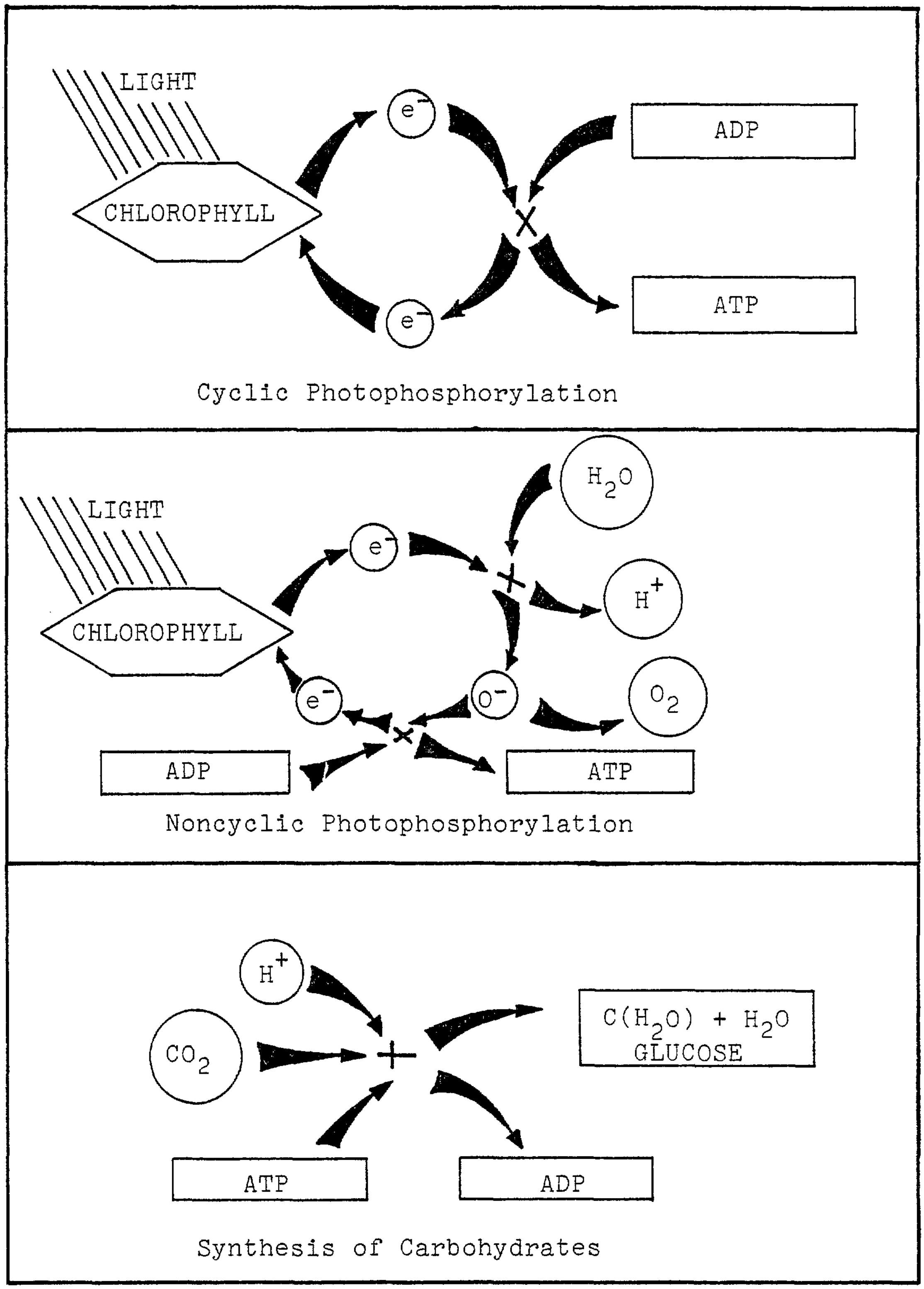


Figure 1 - The Photosynthetic Process

production, and is therefore not available to the next higher trophic level. One of the most useful generalizations in ecology, sometimes called "the 10 percent law," simply states that in nature some fraction of the energy entering any population is available for transfer to the populations that feed on it without serious disruptions of either. The actual amount of energy transferred probably varies widely. It seems fair to assume that in the grazing chain perhaps 10 to 20 percent of the energy fixed by the plant community can be transferred to herbivores, 10 to 20 percent of the energy entering the herbivore community can be transferred to the first level of carnivores, and so on. In this way what is called a mature community may support three or four levels of animal populations, each related to its food supply quantitatively on the basis of energy fixation.[24]

The relations between the producers and the consumers are clarified by two simple formulas. Consider the growth of a single green plant, an autotroph that is capable of fixing its own solar energy. Some of the energy it fixes is stored in organic matter that accumulates as new tissue. The amount of the new tissue, measured as dry weight, is the net production. This does not, however, represent all of the energy fixed. Some energy is required just to support the living tissues of the plant. This is energy used in respiration.[25]

The total energy fixed, then, is partitioned immediately within the plant according to the equation $GP - Rs_A = NP$. This is what happens as an ecosystem matures: consumer populations increase substantially, adding to the respiration of the plants the respiration of the heterotrophs (Rs_H), the organisms that obtain their energy from the photosynthesizing plants. For an ecosystem (the total biota of any unit of the earth's surface) NEP equals $GP - (Rs_A + Rs_H)$. NEP is the net ecosystem production, the net increase in energy stored within the system. $Rs_A + Rs_H$ is the total respiration of the ecosystem.[26] Clearly the amount of living tissue that can be supported in any ecosystem depends on the amount of net production. Net production, however, is coupled to both photosynthesis and respiration, both of which can be affected by many factors. Photosynthesis is sensitive to light intensity and duration, to the availability of water and mineral nutrients and to temperature. It is also sensitive to the concentration of carbon dioxide; on a worldwide basis the amount of carbon dioxide in the atmosphere may exert a major control over the rates of net production.[27]

The distribution of energy within a community can be represented by a pyramid, with the first trophic level (producers) at the base and the last consumer trophic level at the apex.[28] This pyramid of energy is a necessary consequence of physical law and is thus characteristic of all ecosystems. Other attributes of ecosystems sometimes fit a pyramid model because they are related to the flow of energy through the system. One example is the pyramid of biomass (see Figure 2). In general, the decrease of energy at each successive trophic level means that less biomass can be supported at each level.

The following are illustrative of pyramids of biomass. In 1950 Harvey made an attempt to measure total biomass in waters near Plymouth.[29] He estimated herbivore efficiency at 70 percent, as compared with an efficiency of 10 to 11 percent of carnivores. The yield per 100 g of vegetable matter assimilated was:

70 g of herbivorous short-lived zooplankton

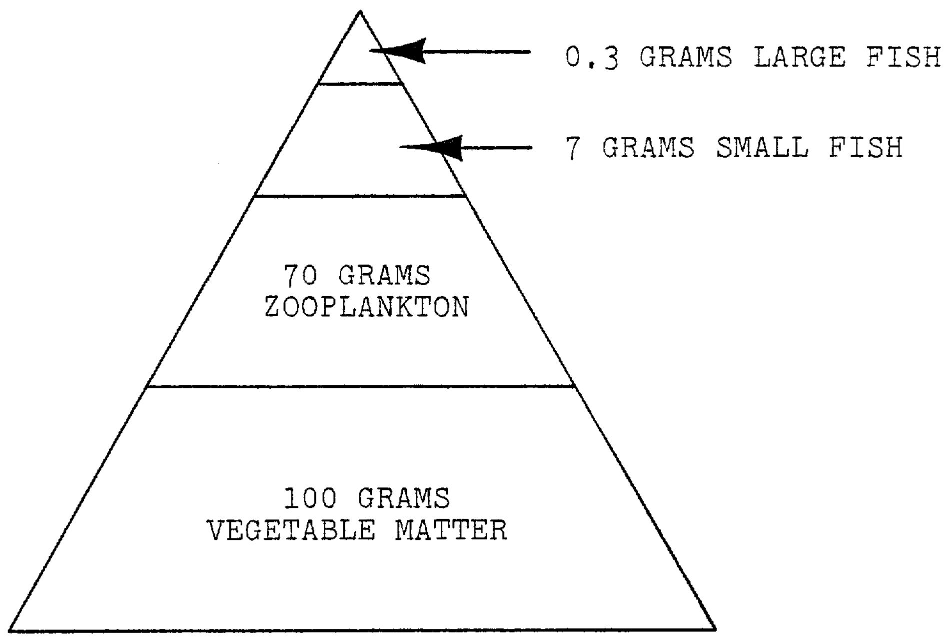
11 g of herbivorous well-grown long-lived bivalves or worms

4 to 7 g (6 to 7 percent of 70 g) of pelagic fish feeding on herbivorous zooplankton

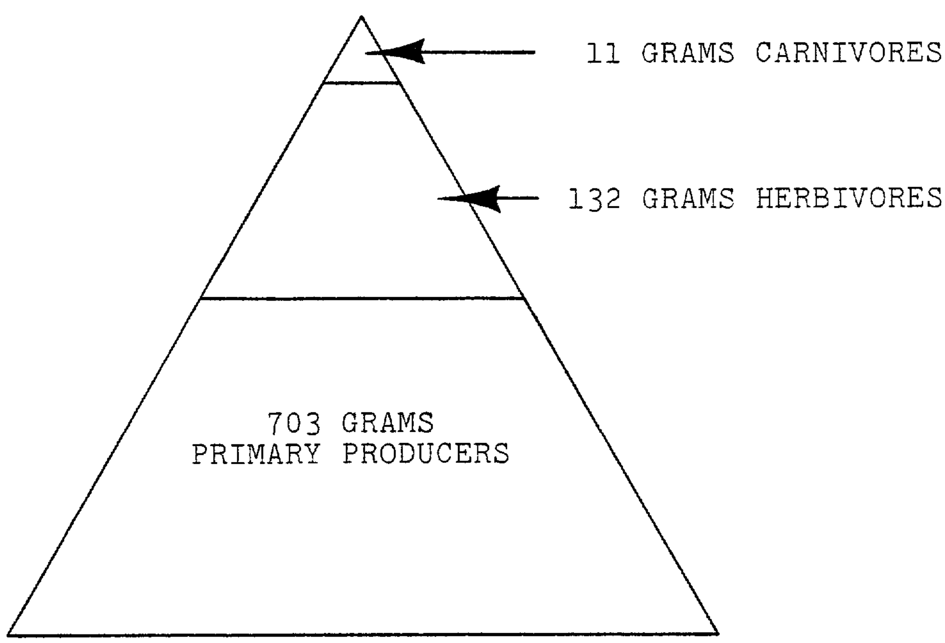
1 g (6 to 10 percent of 11 g) of demersal fish feeding on well-grown bivalves

0.3 g of carnivore feeding on carnivore, as fish on fish; or more if both are small and short lived

Odom and Odom[30] (1955) analysed the primary producers on a coral reef at Eniwetok Atoll and found zooxanthellae and filamentous algae in coral polyps and other animals, encrusting and bushy algae particularly on the dead parts of the reef, small filamentous algae in and on broken-off coral fragments, and a sometimes dense mat of filamentous



Marine Community off Plymouth, from Harvey (1950)



Pacific Coral Reef Community, from Odom and Odom (1955)

Figure 2 - Pyramids of Biomass

algae, particularly inside the coral skeletons. For each of their sample areas of 43.56 square meters they calculated the following:

703 g of primary producers

132 g (19 percent of producers) of herbivores

11 g (8 percent of herbivores) of carnivores

It can be seen from these studies that more energy can be obtained by feeding at lower trophic levels, or toward the base of the pyramid of biomass.

It has been mentioned that the attenuation of light in water limits photosynthesis in aquatic environments. The quantity of light that penetrates water decreases substantially with depth. For this reason, primary producers are restricted to a fairly narrow zone close to the surface of the water, its depth depending on the transparency of the water. The depth to which photosynthesis exceeds plant respiration delimits the euphotic zone.[31] The lower limit of the euphotic zone, where respiration and photosynthesis just balance each other, is referred to as the compensation point. In some exceptionally clear marine waters, the compensation point may be a hundred meters below the surface, but this is a relatively rare condition. In turbid natural waters, the euphotic zone may be as shallow as one meter; and in some polluted areas little light penetrates beyond a few centimeters.[32]

Because light is necessary for plant growth, the occurrence of large bentic (bottom-dwelling) algae is limited to areas near the edges of the continents where the depth of the water does not exceed a hundred meters at the most. In the vast open reaches of the ocean, as well as in the shallower coastal waters, the one-celled plants which make up the phytoplankton occur abundantly in the euphotic zone. The small animals (zooplankton) that prey upon the phytoplankton are also restricted primarily to this region where their food is found.[33]

There is abundant indirect evidence pointing to coastal waters as the greatest areas of greatest organic production. Conspicuous among such evidence is the yellow or brown color of coastal waters as contrasted to the blue of the open sea away from the influence of coastal currents, and the preponderance of benthic and pelagic animal life in coastal waters as compared with that of the open ocean or of abyssal depths.[34] This greater coastal production of phytoplankton and the resulting zooplankton is reflected in the richness of organic carbon in coastal marine sediments.

So, it is shown that factors other than the availability of light serve to limit the net production of marine ecosystems. In general, factors which limit production can be placed in two categories--limiting factors of a physical nature, and limiting factors of a chemical nature. Examples of physical limiting factors in the marine environment are as follows: the intensity and duration and character of solar radiation, the temperature of the ocean waters, and the amount of suitable hard substrate on which benthic organisms may attach. Examples of chemical limiting factors in the marine environment are as follows: oxygen, carbon dioxide, phosphorus, nitrogen, and silicon.

Photosynthesis is relatively insensitive to temperature at low light levels, but it increases by a factor of two to five times for each ten degree Celsius increase in temperature at moderate light intensity. Like most physiological functions, photosynthesis has an optimum temperature range, above which the rate of primary production decreases rapidly. As one would expect, the optimum temperature for photosynthesis varies with the environment, from about 16°C in some arctic species, to 30°C in many temperate species, and as high as 38°C in some tropical species.[35] Another physical factor which limits productivity in coastal waters is the absence of hard substrate within the euphotic zone. The absence of suitable substrate does not allow for the establishment of colonies of the larger marine plants such as the kelps, and the eel, turtle, and manatee grasses, which are amoung the most productive communities on Earth. The absence of suitable hard substrate does not, of course, limit the production of those marine plants that are suspended in the water column.

Of those limiting factors of a chemical nature, dissolved oxygen is the most basic. Both autotrophic and heterotrophic organisms require dissolved oxygen for cellular respiration. Oxygen can be added to the sea only in the upper layers, by absorption of air and in a layer strictly limited by the depth of light penetration, by photosynthesis. At the surface, oxygen can be lost from the sea by exchanges with the atmosphere, but at all depths it is consumed by the respriation of plants and animals, including the decomposition of organic material by bacteria. The respiratory processes of practically all organisms require the oxidation of organic compounds which are formed only in the upper layers, and so consumption of oxygen al all depths is limited by processes which have occurred in the upper euphotic zone. Since the rate of molecular diffusion through water is too small to be effective in carrying dissolved matter great distances, replenishment of oxygen to the deeper parts of the ocean can take place only by circulation with waters oxygenated at the surface layers.[36]

Very large quantities of calcium and carbon dioxide have passed through the ocean and the atmosphere and now exist in marine sediments. The partition of carbon among the geospheres depends on a complex mechanism. Among the variables are the temperature and chlorinity of the ocean, the solubility of calcium carbonate and carbon dioxide in sea water, the rate of production of carbon dioxide by volcanoes; the rate of passage of carbon dioxide across the air sea boundary; the rates of weathering of carbonate sediments and noncarbonate rocks; and the rate and character of the various organic processes, including photosynthesis, respiration, building of calcareous skeletons, decomposition of dead organic matter, man's consumption of fossil fuels, and his transformation of the land's surface.[37]

The annual consumption of atmospheric carbon dioxide by terrestrial plants is estimated at three precent, while the annual photosynthetic consumption, by marine plants, of carbon dioxide dissolved in ocean water, is estimated at only .036 percent.[38] It is apparent, that, under these conditions, carbon dioxide would never become a limiting factor in marine waters.

Phosphorus plays a very important role in the life processes of the marine environment. The original inorganic phosphorus is built up into a variety of organic phosphorus compounds. In almost all organic phosphorus compounds, the phosphorus is present as a phosphoric acid residue.[39] Although a rapid return of inorganic phosphorus to the upper waters of the sea may take place as a result of the decomposition of the simple excretory products of marine organisms, in general, autolytic or bacterial decomposition of organic debris is usually considered to be necessary for the return of most organic phosphorus.[40]

Early studies of lakes have shown that algal blooms, i.e. periods of great productivity, occur only when the concentration of phosphorus is greater than 0.01 milligrams per liter.[41] In the productive surface layers of marine waters the phosphorus content fluctuates seasonally; it may fall to nil in the summer but it reaches a maximum in late winter. The disappearance of phosphorus in summer is due to its combination in organic compounds.[42] Surface water which remains a long time without an intake of phosphate must gradually become impoverished, because any phosphate left tends to move downward. This kind of surface water is found, for example, in the Sargasso Sea, where the content of plankton is therefore always low.[43] This evidence suggests that phosphorus is the most common limiting factor in aquatic environments.

In general, the concentration of nitrate follows the concentration of phosphorus. Nitrate concentrations have been shown to decline rapidly during the algal blooms of the summer months. Bacterial action is considered necessary for both nitrogen and phosphorus regeneration; but since the regeneration of nitrogen occurs at a slower pace than that of phosphorus,[44] nitrogen is likely to be the factor that limits marine production in waters where phosphorus is not limiting.

Silica is also an important nutrient element in the marine environment. During algal blooms, diatoms incorporate great quantitites of silicon in their skeletal cases; but since the supply of silica is regenerated very quickly, silica is not usually considered a limiting factor.

With an understanding of the variety and nature of limiting factors, conclusions concerning the relative productivity of various naturally occuring communities can be made. Generally speaking, the ocean appears unproductive when compared with terestrial ecosystems. Recent studies at Woods Hole Oceanographic Institution emphasized that the oceans are far from an unlimited resource. The net production of the open ocean is about 50 grams of fixed carbon per square meter per year. Areas of very high productivity, including coastal areas and areas of upwelling where nutrients are abundant, do not average more than 300 grams of fixed carbon per square meter per year. The mean productivity of the oceans, according to this analysis would be about 55 grams of carbon per square meter per year, equivalent to between 120 and 150 grams of dry organic matter.[45]

The available evidence suggests that, in spite of the much larger area of the oceans, by far the greater amount of energy is fixed on land. The oceans, even if their productivity can be preserved do not represent a vast source of energy for support of larger human populations. They are currently being exploited at close to the maximum sustainable rate.[46]

Although the average productivity of the oceans does not compare favorably with the average productivity of the terrestrial environments, there are some marine communities which represent "hot spots" or areas of extremely high productivity. The following are examples of productive marine communities compared with terrestrial communities: (1) shallow coastal regions are about as productive as forests, moist grassland, land under ordinary cultivation, but are only 20 percent as productive as land under intensive cultivation;[47] (2) coral reefs are about four times as productive as forests, moist grasslands, land under ordinary cultivation, but only 80 percent as productive as land under intensive cultivation;[48] (3) estuaries can be five times as productive as forests, moist grasslands, land under ordinary cultivation, and equally productive as land under intensive cultivation;[49] and (4) man-made tropical reefs are three to eight times as productive as natural reefs. This implies that man-made tropical reefs are from 12 to 32 times as productive as land under normal cultivation and two to six times as productive as land under intensive cultivation.[50]

With this understanding of physical and chemical factors and how they become limiting factors in natural environments, the argument can be made that the artifical introduction of a physicial or chemical factor can increase the productivity of a natural system, provided, however, the introduced factor is the factor in shortest supply, i.e. the limiting factor. An example of an artificial introduction of a limiting factor precipitating an increase in the production is the introduction of phosphorus into lakes through sewage wastes and agricultural runoff. It has been demonstrated that the widespread use of home laundry detergents containing phosphates has been responsible for algal blooms.

A fundamental ecological concept relates the diversity of a natural system to the stability of the physical environment and the length of time that the physical environment has remained stable. Generally speaking, the more diverse a natural system is, diversity being defined as the number of species interrelating in a natural system, the more efficient and productive that system is. Ecological communities can be divided into two groups, those in which physical factors structure the composition of a community and those in which biological competition structures the community. In higher latitudes the abiotic factors will have a greater decimating action, whereas in warmer areas biological competition will be more effective.[51] An example of two extreme cases would be the structure and productivity of an arctic tundra and that of a tropical coral reef.

A study of artificial reefs in all oceanic environments would be much too broad a topic to address. This study will be limited generally to effects of artificial reefs in temperate waters and specifically to the waters off the coasts of Texas, Louisianna, Mississippi, and Alabama. This section of the Guld of Mexico can be characterized as a region of significant sedimentation due to the influence of major river systems draining the central portion of the North American continent; in addition the predominant coastal currents create a series of barrier islands which form sounds or lagoons between the coast line and the open gulf. This is an area which supports major commercial and sport fisheries, and is an area where artificial structures have enhanced already existing fisheries.

The continental shelf of the Gulf of Mexico is an expanse of shallow ocean bottom, and is the area inhabited by the majority of the commercially valuable reef fishes. Much of the shelf area, however, is relatively barren, consisting of a flat, sand, or mud bottom which slopes gently offshore, with little hard irregular substrate.[52] Areas of rough hard bottom are necessary for encrusting organisms such as barnacles, hydroids, corals, and mussels, vital organisms in the food chain, to settle and complete their life cycles and are used as protective areas, food sources, spawning grounds, and visual reference points for many fishes. It is well known by fishermen that coral reefs, rock ledges, wrecks, and other areas of relief on the continental shelf are productive fishing grounds.[53]

The evidence suggests that the lack of hard bottom substrate is the single factor which limits the benthic productivity in many of the coastal waters of the Gulf of Mexico.[54] It can also be demonstrated that once substrate is introduced in the form of artificial reefs, i.e. the limiting factor which is of a physical nature being now present, a highly productive biologically accomodative community can develop. This fact has been demonstrated time and time again by the rapid development of productive fisheries around new shipwrecks.

The Japanese have used artificial reefs in their coastal waters for almost 200 years.[55] The inhabitants of the Manzai and Toshi villages had, by the year 1795, become accustomed to unusally large catches of fishes when they set their nets close to a recently sunken ship. When the wooden ship deteriorated after seven or eight years and fish stopped thronging around the wreck, the villagers replaced the wreck with large wooded and bamboo frames weighted with sandbags. About 100 days later during the summer in the neighborhood of the new structures, the fishermen netted a far greater number of fish than they had been accustomed to catching around the sunken ship. In the ten year period that followed, the villagers sank several hundred more artificial structures.[56] In recent years the Japanese government has encouraged and assisted in the construction of artificial reefs, and by the year 1966 the number of artificial reefs off the Japanese coast totaled 721,065.[57]

The value of artificial reefs in the coastal waters off the Gulf of Mexico has been demonstrated by the accidental sinking of the V. A. Fogg which went down off Freeport, Texas, in 1972.[58] This wreck proved to be a productive fishery within a year. As a result of this and similar expericnces, the State of Texas has sunk 12 liberty ships in its coastal waters. Significant numbers of red snapper (Lutjanus campechanus), jewfish (Epinephelus itajava), and sand tigers (Odontapis taurus) have been taken on the new Texas reefs.[59]

From these examples it is demonstrated that in waters like the Gulf of Mexico where there is a high rate of sedimentation and sufficient inorganic nutrients, the absence of substrate is the factor which limits the productivity of the coastal waters. This fact is confirmed by the introduction of substrate artificially into waters with benthic environments of unconsolidated sediment. Without exception, fish will be feeding regularly in the new environment in a matter of months. This phenomenon is observable on a small scale even when the artificial reef is as insignificant as an accidentally discarded outboard motor or starter battery. On a large scale, such as the multitude of offshore drilling platforms paralleling the Texas and Louisiana coasts, very significant fisheries have resulted.[60]

Although significant fisheries develop around artificial reefs, it could be argued that these fisheries do not represent an actual increase in the total productivity of coastal waters. Many species of fishes exhibit a form of behavior known as thigmotropism. These fish will associate with solid objects as a visual reference or as a demarcation of territory. It has been stated that as a result of this behavioral tendency, artificial reefs serve only to concentrate fishery resources and do not increase the total productivity of the fishery, i.e. fishes vacate less desirable habitat in order to fulfill their instinctive drive to associate themselves with solid objects. While there is some evidence that this might occur as a short termed phenomenon, experimental evidence does not support this presumption. In 1973 and 1974 and experiment was conducted in Alantic waters off the Florida coast. An artificial reef made of discarded automobile tires was built adjacent to a natural coral patch reef. Both reefs were approximately the same size, and at the end of the experimental period, both reefs were poisoned out and the biomass was calculated. While the natural reef had a supported biomass which was normal for a reef its size, the adjacent artificial reef supported a biomass 2½ times as great as the natural reef.[61]

An analysis of the reefs showed more settled organisms, mostly algae and sponges, on the artificial reef.

This was undoubtedly the reason for the higher production of the artificial reef.[62]

This is clearly an example of a reef which increased the total numbers of benthic organisms and reef dwelling fishes. Since the population of the natural reef was normal after a year, the evidence demonstrates that any initial loss of migrants to the artificial reef was rapidly recovered from the overall increase in benthic productivity. It was demonstrated that each habitat will support populations proportional to the carrying capacity of that habitat; and since the introduction of a very productive habitat into an area of moderate or low natural production does not decrease the carrying capacity of adjacent areas of lower production, the populations or biomass of the adjacent areas are not reduced. The original productivity of a benthic environment with the additional production of an artificial reef results in a significant increase in the total productivity of the benthic environment.

The case can be restated that hard substrate is the needed factor in shortest supply in most benthic environments of the Gulf of Mexico and many other coastal waters; and when this factor is introduced in the form of artificial reefs, the productivity of coastal waters is directed in such a way that there is a net increase in the numbers of benthic organisms and reef dwelling fishers. This conclusion can be expanded to demonstrate that when substrate is introduced in the form of artificial reefs, it is no longer the limiting factor and the factor in shortest supply would probably be inorganic phosphorus or nitrate. If these essential nutrients were added to an established artificial reef environment, another significant increase in production might be expected. Production would be limited finally by the amount and quality of incident solar radiation and the efficiency of the photosynthetic process.

CHAPTER III

ARTIFICIAL REEFS AND THE LEGAL ENVIRONMENT

It has been demontrated that artificial reefs can increase the productivity of benthic environments, and as a result of this increase in productivity, artificial reefs can be used as a tool for the effective management of coastal fishery resources. Artificial reefs exist off the coasts of most of the United States of America and many foreign nations. For the most part, these reefs have been constructed by coastal states or public corporations for the benefit of the general public. Although these reefs have benefited the public as a whole, it is possible that the development of artificial reefs by private corporations or persons might prove to be the optimum method of obtaining a sustained yield sport fishery species from coastal waters. The private development of artificial reefs might also be conducted in a way in which the public trust nature of coastal fisheries would be preserved.

In order to understand the legal environment in which the private development of artificial reefs must operate, a survey of the development of the public trust doctrine, as it is applied today, is necessary. The rule that coastal fisheries are a public resource to be held in trust by the state is rooted in the law of the Romans.

Roman jurisprudence, developed in a society with heavy commerce, with important urban concentrarions, and with a legal heritage from the sea-dependent Greeks; held that by the most basic "natural law" the "air, running water, the sea, and consequently the seashore" were "common to all."[63] The following is a quotation from the Institutes Justinian:

> No one therefore is forbidden access to the seashore provided that he abstains from injury to improvements.... All rivers and harbours are public, so that all persons have a right to fish therein...everyone is entitled to bring his vessel to the bank of a river, and fasten cables to the trees growing there and use it as a resting place for cargo, as freely as he may navigate the river itself. But the owneship of the bank is in the owner of the adjoining land, and consequently so too is the ownership of the trees which grow upon it. Again, the public use of the seashore, as of the sea itself, is part of the law of nations; consequently everyone is free to build a cottage upon it for the purpose of retreat, as well as to dry his nets and haul them up from the sea. But they can not be said to belong to anyone as private property, but rather are subject to the same law as the sea itself, with the soil or sand which lies beneath it.

This imperial law is the original foundation from which the common law developed.[64]

As is well known, with the decline of the Roman Empire, Europe retrogressed in terms of commerce, navigation, and effective governmental administration. Public ownership of waterways and tidal areas frequently gave way to owneship by local powers and feudatories. Many continental princes, for example, came to claim that the right to fish was their personal right and required that all their fishermen be licensed for a fee. In the British Isles, then a thinly populated frontier, this process of decentralized control was far advanced by the time of William the Conqueror. The English King's jurisdictional and sovereign claims to tidal areas became confused with a personal private property claim. The King claimed a private interest in tidal and riverbed soil, and consequently the private right to whatever could be found on or under the soil. He also claimed the right to "several fishery" (an exclusive private right to fish) in these areas. Since private ownership always entails the right to alienate, and since the King could not easily enjoy these interests everywhere directly, Saxon grants, confirmed and extended by the Norman kings, vested the largest portion of the English foreshore in particular subjects. In theory, the crown had the exclusive right to certain types of fish, and it retained the right to take a net down many of the kingdom's rivers several times a year through all private fisheries. Between what the King claimed for himself and what the lords received by grant or took by prescription, the old common ownership in the public provided for in Roman law was seriously if unevenly eroded.[65]

This process of proliferating private ownership and control of tidal areas led to increasing public inconvenience. The Magna Carta, in part a reaction to these inconveniences, can be seen as a salient point at which the doctrinal trend began to shift back in the direction of protecting the public's interest, especially in the areas of navigation and fishery rights. The steps taken in this period, however, were insignificant when compared with those which have since been attribuited to it. In the process of developing ("interpreting") the contract made at Runnymede, the courts, while never abandoning the original Roman conception of a general common ownership in all the people, began to speak in terms of particular guaranteed rights. The resulting doctrinal ambiguity continues to this day.[66] Chapter 33 of the Magna Carta guarantees the public right of unimpeded navigation, and Chapter 47 guarantees public access to fisheries. The question remains, however, as to whether those common law rights not expressed in the Magna Carta have the same force of law as those rights guaranteed by the Magna Carta? As modern law developed, the King became the trustee for these public rights, guaranteed by the Magna Carta, but he could not appropriate these rights for his own use.

The public trust doctrine was later brought to the test by the development of _laissez-faire_ capitalism. Whereas both Roman law and the public trust doctrine called for the state to act as a trustee for the public interest, _laissez-faire_ theorists wished to do away with feudal encumbrances and to rely instead upon private ownership and the invisible hand. There was a greater perceived need for doing way with irrational feudal regulation and for widening assured access to tidal resources than for regulating the proposed multiple use. This historical movement, coming as it did at a period of especially rapid growth in the public trust doctrine, strongly reinforced the doctrine's existing tendency to develop in the framework of a series of public easements imposed on a largely private fee ownership system rather than that of public ownership through the state (a model subsequently followed in many socialist societies).[67]

By the subsequent development of democratic governments and the addition of public easements along with the reinterpretation of the extent of existing public easements, the common law became to resemble more and more the Roman concept of public ownership held in trust by the sovereign. Even though the law was often forced to recognize that the shore had been acquired by grant, prescription, or a combination of the two, both courts and academic writers continued to hold that ownership was prima facie in the crown. The crown's interest, moreover, was widely perceived to be the people's. In a close consideration of conflicting interests in the Brighton seashore, for example, Mr. Justice Baily held that to the extent that tidal areas are the King's they are held in trust for the public.[68] With the American Revolution, this sovereign representative proprietorship passed to the citizens of each state.

> For when the Revolution took place, the people of each state became themselves sovereign; and in that character hold the absolute right to all their navigable waters and the soils under them for their own common use, subject only to the rights since surrendered by the Constitution to the general government.[69]

In the United States the public trust doctrine has developed to the effect that "the state can no more abdicate its trust over property in which the whole people are interested...than it can abdicate its police power...."[70]

At least ten different categories of interest in tidal areas have been claimed at one time or another to be protected for the people under the public trust theory. They are: navigation; ports; free passage; commerce; fishing; sand and stones; seaweed and shells; bathing (recreation); conservation and aesthetics; and the "public interest." Public trust theory characterizes a given right as being fully protected or not protected at all.[71]

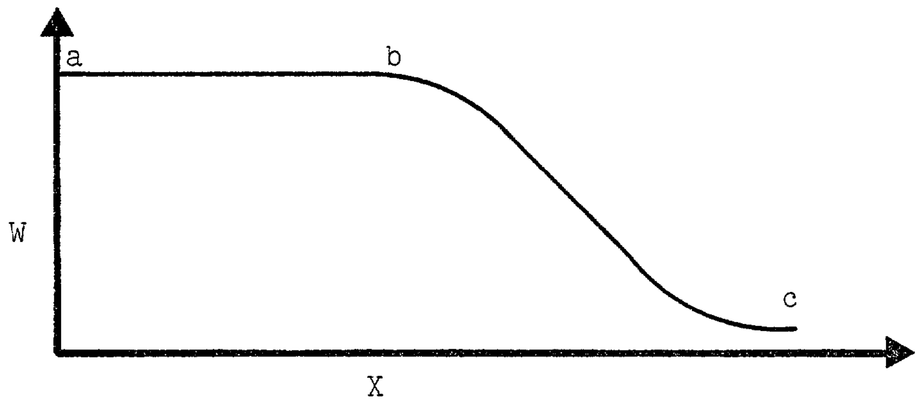
The right to fish is a public right subject to private invasion, primarily by prescription although initially in early England also in large degree by grant. In case of conflict with the right of navigation, the latter is paramount.[72]

The status of the right to fishery has long been one of the most uncertain areas of the public trust theory.

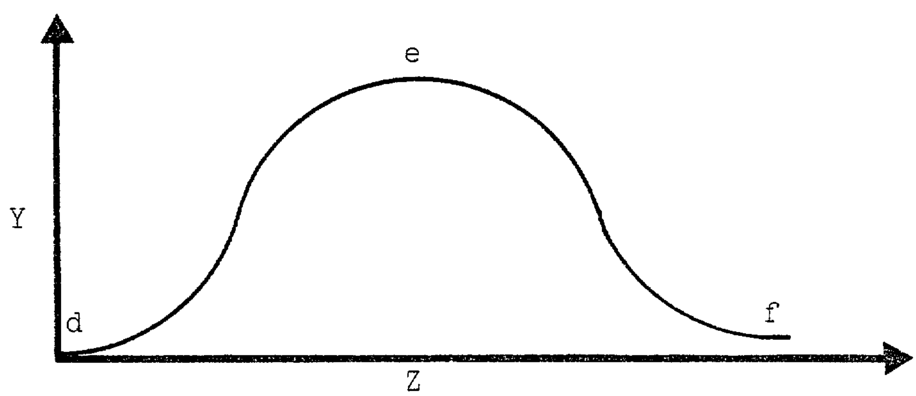
In large part this has been due to the ambiguity regarding the relationship between the right to fish and the ownership of the underwater soil. The questions are whether the right is an easement or a profit of the soil; or, whether the existence of the right does raise a presumption of the ownership of the soil and vice versa?[73]

These questions of ownership do not arise, however, when the right to fishery is limited to coastal waters. For fisheries which exist superadjacent to submerged lands held in trust by a state for the benefit of the public, the public right of fishery is recognized. Coastal states have recognized by statute the public trust nature of coastal fisheries, and have adopted management techniques by which they intend to maximize benefits accruing from coastal fisheries.

Achieving a maximum sustainable yield is one method used to maximize these benefits. Briefly stated, maximum sustainable yield is the highest level at which a fishery may be exploited on a perpetual basis. The population dynamics of a fishery can be described by four characteristics: recruitment, growth, natural mortality and catch.[74] If fishing effort is at a level above maximum sutainable yield, the natural productive capacity (the principal part of the recruitment factor) of the remaining population will not be sufficient to re-establish the fishery at is previous numbers. If carried to the extreme, an



"X" axis represents Total Catch in One Season
"W" axis represents Total Population the Following Season
"a" to "b" represents Under Exploitation
"b" represents Maximum Sustainable Yield
"b" to "c" represents Over Exploitation



"Y" axis represents Total Catch
"Z" axis represents Fishing Effort
"d" to "e" represents Under Exploitation
"e" represents Maximum Sustainable Yield
"e" to "f" represents Over Exploitation

Figure 3 - Dynamics of Fish Populations

effort at this level will result in the eventual collapse of the fishery (see figure 3). On the other hand, if fishing effort is at a level below maximum sustainable yield, growth and natural mortality will limit any increases in the population of the fishery. At an exploitation rate below maximum sustainable yield, part of the natural productive capacity of the fishery is, in effect, being wasted.

Traditionally the only method used by coastal states in limiting the exploitation of their fishery resources has been the limiting of catch by regulation. These regulations have taken one or more of the following forms:

(1) the seasonal opening and closing of fisheries;

(2) the limiting the number or weight of fish any one person or vessel can take or land, i.e. the establishing of quotas;

(3) the establishing of minimum or maximum size limitations on individuals of species which can be caught or kept; and

(4) the restricting of technology persons may employ in exploiting a fishery; e.g. mesh size of nets, type and size of vessels, etc.[75]

For the most part, the management of fishery resources by regulating catch has proven to be ineffective. Many states have not established a maximum sustainable yield due to a lack of basic biological data on which to base regulations and an inability to enforce these fishing regulations.[76] Those states which have established a maximum sustainable yield have done so only by diseconomic methods, as evidenced by the seasonal unemployment of persons engaged in fishing or in fishing support and processing industries, by the presence of unreasonably large fishing fleets, and by the presence of bizarre fishing vessels and equipment resulting from restrictions on technology.[77] The problem of effectively managing a fishery resource is compounded by the very nature of the resource; fish live in a fluid environment and are not respectors of political boundaries. If a state were to establish a biologically and economically sound fisheries management scheme, its efforts could be frustrated by the implementation of an equally well intentioned but incompatible management plan by one of its neighbors.[78]

It is paradoxical that the management of coastal fisheries as a common property resource has come into conflict with the public trust which was established to protect the common property nature of coastal fisheries. For destruction of a coastal fishery, or the exploitation of a fishery in a manner which results in grave social and economic costs, is clearly not in accord with the public interest.

The error which created a doctrine with conflicting method and purpose was the perception of fisheries as an unlimited or infinite resource. Coastal fisheries are a living and thus a renewable resource; and when a renewable resource is taken at a rate in which reproduction and growth re-establishes that portion of the resource which has been taken, i.e. the resource is being exploited at a rate below maximum sustainable yield, the resource does indeed behave as if it were unlimited. The common property nature of coastal fisheries developed as a legal doctrine during the Imperial Roman, feudal, and *laissez-faire* periods of world history. These are periods in which competition for coastal fishery resources did not result in the exploitation of coastal fisheries at a level beyond maximum sustainable yield. It has only been in the last century and a half that technological innovations, increasing human population, and the resulting increased competition for coastal fishery resources has demonstrated that coastal fisheries can be overexploited; and the collapse of many coastal fisheries in modern times attest to the fact that coastal fisheries do not represent an infinite resource.[79]

It is proposed that the public trust would be better served by methods other than the management of coastal fisheries as a common property resource to which everyone has unlimited access. All states recognize that it is sometimes in the public interest to lease public resources to private persons or corporations for the economic and social benefit of its citizens, and several states have statutes authorizing the leasing of both living and non-living coastal resources.

In its 1968 Session, the Mississippi Legislature extended the powers of the Mississippi Mineral Lease Commission by authorizing the Commission to employ competent engineering personnel to survey the territorial waters of the State of Mississippi in the Mississippi Sound and in the Gulf of Mexico and to prepare a map or plat of such territorial waters divided into blocks of not more than 6,000 acres each. The Mineral Lease Commission was authorized to adopt such survey, plat, or map for leasing of submerged lands for mineral development.[80] The authority of the Director of Conservation of Alabama is in general terms. He is merely directed to lease submerged lands in the Gulf of Mexico upon such terms as he may approve.[81] The Louisiana State Mineral Board is a body corporate, with its domicile at the state capitol, possessing, in addition to the powers conferred on it by statute, all power to sue and be sued. The courts have recognized, however, that despite its corporate entity, it is nevertheless an agency or arm of the State of Louisiana, for the purpose of granting and supervising mineral leases. Lands under the jurisdiction of the Board and capable of being leased by it are defined as any lands belonging to the state, or the title to which is in the public, including road beds, water bottoms, and lands adjudicated to the state at tax sales.[82]

The Mississippi Mineral Lease Commission is given wide discretion in setting the terms and conditions of the lease, the statute merely specifying that the commission shall lease for such consideration and upon such terms and conditions as said commission shall deem just and proper. Its only restriction is that the working interest shall not be for more than 7/8 and the royalty to the state shall be at least 1/8. Primary term, delay rentals and bonus are all left to the discretion of the Commission. No restriction is placed on acreage that may be leased.[83]

The Alabama statutes are also silent on the specific terms of the lease, the only provision being that no tract of land containing more than 5,200 acres shall be leased or advertised for lease. It has been held by the Supreme Court of Alabama, however, that the State Director of Conservation, in appraising the respective values of royalty proposals contained in bids for oil and gas leases, is authorized to use his best judgement; and that the consideration for a sale of oil and gas leases on state lands to the highest bidder is threefold: (1) the so-called bonus, which is the amount of cash presently paid; (2) the so-called annual rental; and (3) the royalty, each of which forms an integral part of the consideration or price of the rights sold.[84]

The Louisiana statutes fix certain minimum requirements which limit the State Mineral Board in accepting bids. For example, the maximum area that may be included in a single lease is 5,000 acres. The statutes fix the minimum royalty at 1/8 on oil and gas, but the policy of the Board is not to consider a 1/8 royalty bid on oil and gas except on rank wildcat areas and in extraordinary circumstances. The statutes require that if a bonus is stipulated, the annual rent must not be for less than one-half the amount of the bonus. The statutes do not fix a primary period for the lease. Nevertheless, the policy of the Board has been to grant leases for a term of five years on offshore leases.[85]

An oil and gas lease issued by the Secretary of the Interior pursuant to the Outer Continental Shelf Lands Act is limited to an area not exceeding 5,760 acres, and shall be for a period of five years and as long thereafter as oil and gas may be produced from the area in paying quantities, or drilling or well reworking operations, as approved by the Secretary, are conducted thereon. An annual rental shall be paid and royalty is fixed at not less than 12½% in the amount removed, or sold from the lease. Either the royalty or the bonus is fixed by the Secretary, if the bonus is fixed the bidding is on the royalty and if the royalty is fixed the bidding is on the bonus.[86]

From these statutes, it is shown that it is indeed in the public interest to lease publicly owned submerged lands to private parties for the purpose of oil and gas development, if these leases are issued on a competitive bid basis and provided that the governmental entity which is acting in the role of a public trustee received reasonable compensation in one or more of the following forms: (1) a royalty of at least 12½%; (2) an annual rent; and (3) a bonus. These principles which guide the leasing of nonliving public resources can be applied to the leasing of publicly owned living resources. In fact, many states have statutes which provide for the leasing of public trust living resources.

The Board of Trustees of the Florida Internal Improvement Trust Fund may, to the extent it is not contrary to the public interest, lease submerged lands to which it has title for the conduct of aquaculture activities and may grant exclusive use of the bottom and water column to the extent required by such activities.[87] The maximum initial term of the lease shall be ten years.[88] The lease terms shall also fix a rental to be paid throughout the term of the lease which will be supplemented with royalties after the productivity of the aquaculture enterprise has been established.[89] The lease is to be marked and fenced in a manner not to interfere with navigation and other traditional uses of the surface, and the lessee is to provide reasonable ingress and egress to the public for the capture of those species of marine organisms not being cultivated under the terms of the lease contract.[90]

The Commissioner of Wildlife and Fisheries of the State of Louisiana may lease bedding grounds for the cultivation and propagation of oysters within any waters within the territorial jurisdiction of the state.[91] The Commissioner shall require the bottoms of water areas leased to be as compact as possible and shall fix an annual rental of not less than one dollar or more than five dollars per acre leased.[92] Lessees enjoy the exclusive use of the water bottoms leased and of all oysters, shells, and cultch grown or placed thereon.[93] Leases are for a term of 15 years and are renewable for a period of not more than 10 years,[94] and no one person may lease more than 1,000 acres of waterbottoms.[95]

The Mississippi Marine Conservation Commission has the authority to lease submerged waterbottoms for the purpose of cultivating oysters.[96] No individual, corporation or partnership may lease less than five acres or more than 100 acres.[97] The Commission shall issue leases on a competitive bid basis, and the lease shall be for a term of one year, renewable up to 25 years.[98]

The Commission shall fix a ground rental of not less than one dollar per acre.[99]

It can be seen from these statutes that coastal states have indeed recognized that it can be within the public trust to lease publicly owned living resources to private parties if certain conditions are met. Artificial reefs increase the productivity of coastal waters, and the private development of artificial reefs on leased public trust submerged waterbottoms does not represent the leasing of publicly owned living resources, but rather the leasing of the potential, but presently wasted, productivity of publicly owned submerged water-bottoms and their superadjacent waters. However, the conditions in which the leasing of submerged water-bottoms and a water column for the private development of artificial reefs would be in accord with the public trust in which these resources are held, would be very similar to the conditions applied to the leasing of publicly owned living resources.

It is proposed that the leasing of submerged water-bottoms and their superadjacent water columns would be in accord with the public trust in which coastal resources are held, if the following conditions are met:

(1) no one person or corporation could lease more than 500 acres of submerged waterbottoms and their superadjacent water columns;

(2) the initial lease period would be 15 years renewable for an additional 10 years for a total lease period no greater than 25 years;

(3) there would be a $5.00 per acre annual rent;

(4) there would be a royalty on the income derived from the lease to be determined after the reef had established its productivity;

(5) the reef would be built on naturally unproductive submerged waterbottoms;

(6) leases would be issued on a competitive bid basis, the bid being based on a cash bonus; and

(7) the reef would be constructed in such a way as to not represent a hazard or a hinderance to navigation.

In return for these considerations the lessee would receive exclusive use of the submerged waterbottoms and all uses of the water column which would not interfere with navigation.

A person or corporation wishing to develop an artificial reef in coastal waters would, in addition to making application to the state agency or agencies responsible for the leasing of living resources and public lands, be required to obtain a number of federal permits. The agencies which would be most directly involved are the U.S. Army Corps of Engineers, the U.S. Coast Guard, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration.[100]

The National Environmental Policy Act requires the preparation of environmental impact statements from federal agencies permitting or licensing any activity likely to have a significant impact on the environment. Where the Corps of Engineers is permitting construction in navigable waters, they will determine whether a statement is required. Environmental impact statements may need to address such questions as whether these reefs will lead to increased numbers of those species the presence of which might upset the natural balance. Reefs to be built near the shore would require an assessment of the reefs impact on the shoreline and possible changes in the shoreline resulting from alteration of circulation patterns, the littoral transport of sediments, the refraction or reflection of wave energy, and the effects any of these coastal processes might have on the erosion or accretion of coastal lands.[101]

The protection of fisheries resources has been given greater attention since the passage of the Fish and Wildlife Coordination Act. Numerous activities which affect fish in navigable waters are being scrutinized to determine whether there will be any adverse consequences to them. Permits from federal agencies may be denied where the federal or state authorities have reviewed applications and decided that there would be detrimental effects. Therefore, permit applications for building reefs may be denied where the proposed reef would affect the ecology of nearby marine communities, e.g. natural reefs, grass beds, or certain rock outcroppings.[102]

Two provisions of the Marine Protection, Research, and Sanctuaries Act concern the construction of artificial reefs. Section 3(f) clearly states that ocean dumping, which is prohibited under the Act, "does not mean the construction of any fixed structure or artificial island nor the intentional placement of any device in ocean waters or on or in the submerged land beneath such waters, for a purpose other than disposal.[103] In describing the materials which are prohibited from being dumped in the ocean without a permit from the Environmental Protection Agency, nearly every material which is used for the construction of artificial reefs is specifically mentioned.[104]

The section on sanctuaries in the Marine Protection, Research, and Sanctuaries Act might also concern artificial reefs. The National Oceanic and Atmospheric Administration administers this portion of the Act, and is responsible for designating marine sanctuaries in coastal waters out to the edge of the continental shelf.[105] That agency is also responsible for issuing regulations concerning activities within the sanctuary. It can be assumed that NOAA will carefully scrutinize activities which would affect these marine preserves. Restoration of areas as well as preservation is one of the purposes of this Act. Thus, the placing of artificially created reefs within sanctuaries may be a method used to restore those areas for conservation and recreational purposes.[106]

When installing and operating an artificial reef, care should be taken to comply with all state and federal water quality legislation. Section 318 of the Federal Water Pollution Control Act[107] may have a significant impact on the operation of a reef if attempts are made to increase the production of the reef by introducting foods or chemicals to the artificial reef site. This section entitled "Aquaculture", is to authorize controlled discharges into navigable waters which would otherwise be prohibited by the Act.[108] This section does not mention artificial reefs, per se, as being within the operation of the Act; however, reef construction may be interpreted by the Environmental Protection Agency to be included.[109]

When planning to build an aritificial reef, one should first request a permit from the U.S. Army Corps of Engineers. A permit from the Corps will be required for construction of an artificial reef under requirements of Section 10 of the River and Harbors Act of 1899[110] and Section 4(f) of the Outer Continental Shelf Lands Act of 1953.[111]

The River and Harbors Act prohibits any unauthorized activities or construction in navigable waters of the United States which would be an obstruction or an alteration in those waters. Only those plans for construction in navigable waters recommended by the Chief of Engineers and authorized by the Secretary of the Army are allowed to be undertaken.[112] This same authority is extended to artificial islands and fixed structures to be built on outer continental shelf lands.[113]

The Corps of Engineers has apparently developed some general (albeit unofficial) criteria which it uses to determine whether or not an artificial reef will interfere with navigation. Those criteria include:

> (1) that no artificial reefs should be constructed in navigational channels or fairways; that
>
> (2) artificial reefs should be placed in depths of water to allow 50 feet between the top of the reef and the waters surface where the depth in the water generally exceed this depth; that
>
> (3) if an artificial reef is to be located near a large shoal, then the depth of the water over the reef should not be less than the least depth of the shoal; that
>
> (4) heavy, nonfloatable materials are to be used in construction of a reef; and that
>
> (5) reefs are to be marked as required by the U.S. Coast Guard.

With the exception of the last one, these criteria are only unofficial guidelines and are not necessarily hard and fast rules. It should be pointed out, however, that compliance with these criteria should enhance the probabilities of success in obtaining a permit. It can be assumed, for instance, that a reef in a recognized shipping lane will simply not be approved. The 50 feet minimum clearance criterion does not necessarily exclude the possibilities of placing reefs in areas where the water depths are generally shallow.[114]

Where fixed and floating aids to navigation are to accompany the construction of a reef in navigable waters, they must also be permitted by the Corps of Engineers in accordance with the River and Harbors Act. Any permits granted for the building of a reef will include a condition that the person seeking the permit will comply with Coast Guard requirements for marking and lighting these aids.[115]

The work accomplished under the terms of a lease should be completed with precision under the provisions of the permits. At least one case has been reported to the Environmental Protection Agency that the construction material for an artificial reef was dumped five miles from the location specified in the permit. This could present a hidden navigation hazard, and liability to the permitee may attach should an accident occur.[116]

Marking artificial reefs with buoys or other devices is desirable for easy location. Protection of other interests such as navigation may also require that reefs be properly marked. No aids to navigation may be established, erected, or maintained without U.S. Coast Guard permission. That agency is also responsible for prescribing regulations for lights and signals in order to maintain a uniform system for navigation. Proper marking of any sunken material or other obstruction to navigation is the responsibility of the owner. It is necessary for the owner to properly maintain a marker, including making sure that lighted markers have the lights working, and to make sure that markers remain in the proper location. After Coast Guard permission has been granted, private aids to navigation are installed and maintained at the owners expense. The type of marker and the number of buoys and other aids will depend on many factors considered by the Coast Guard. No single set of aids have been established for the marking of artificial reefs.[117]

In addtion to the public trust and regulatory environments in which a person or corporation wishing to develop an aritificial reef in coastal waters must operate, there are other legal considerations. The questions of liability arising from the construction or operation of a reef will generally follow the legal doctrines of tort and admiralty. Some novel questions may be the subject of litigation arising out of accidents. Such a venture where the private reef builder and operator rents scuba diving equipment for use in diving at the reef site would naturally require special care to avoid liability from harm to the divers. While contributory negligence or assumption of the risk might be a defense to a negligence action, it would be wise for an operator to obtain full written releases of liability from the divers.[118]

The law of admiralty will apply for navigational accidents occurring as a result of the reefs placement. When ships are sunk with the intention that they be used as artificial reefs, it is assumed that these sunken vessels would not be susceptible to general salvage. Where shipwrecks have occurred within numerous state's boundaries, the state is the owner and is entitled to the vessels.[119]

Numerous state and federal laws will apply to the operation of an artificial reef. If the facility is within a state's boundaries, then the state may apply its criminal and civil jurisdiction over it. If it is within county or city jurisdiction, the county or the city can exercise their police powers as that authority related to events associated with the reefs.[120]

It has been shown that the private development of artificial reefs in coastal waters can proceed in a manner consistent with the public trust in which coastal waters and submerged waterbottoms are held. Although the legal and regulatory issues which relate to the development of aritificial reefs are complex, a private developer should, by no means, find them insurmountable. Indeed, it is in the interests of coastal states to expedite the construction of artificial reefs by the most biologically and economically sound methods. The development of artificial reefs by private persons or corporations will avoid the "tragedy of the commons", for private ownership will encourage that these fishery resources will be managed at an optimum sustainable yield. The leasing of these coastal resources to private parties will increase to total productivity of coastal benthic environments and their associated fisheries and combine the virtues of the equity achieved by some modern socialist systems and the incentives inherent in traditional market economies.

CHAPTER IV

THE FINANCIAL FEASIBLITY OF ARTIFICIAL REEFS

In 1970, according to the U.S. Department of the Interior, there existed 9,460,000 habitual salt water anglers.[121] This salt water fishing generated 1.2 billion dollars of related business, or 129 dollars per angler for the 1970 year.[122] These salt water anglers spent a total of 114 million man days on the water.[123] A very large charter boat industry has developed to accomodate this tremendous demand, and it is the purpose of this chapter to examine the financial feasibility of the development of private artificial reefs by charter boat operators.

The development of an artificial reef by a charter boat operator would create an exclusive fishing zone for the operator, would enable the operator to manage his exclusive zone at an optimum level, and would increase the fishing success and thus the satisfaction of his clients.

Solid articles of all types have been used in the construction of artificial reefs. It has long been known that the areas around old shipwrecks provide good fishing prospects. Oil platforms have also become known as productive areas for sport fishing. Everything from sinking ships to deposits of building rubble has been used in the construction of artificial reefs. Included as items used have been junk cars, old streetcars, worn tires, bathroom fixtures, concrete drainpipes, stoves, refrigerators, quarry rock, and prefabricated concrete shelters built expressly to be used as part of an artificial reef.[124]

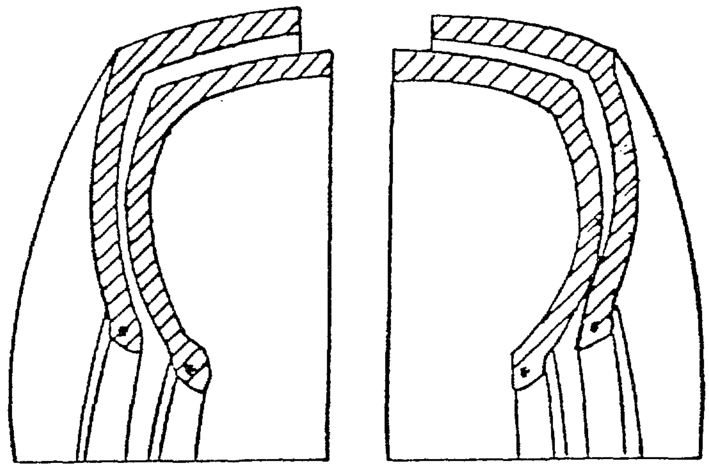
Some of these materials have been found to be quite satisfactory while others have proven to be less than ideal. Abandoned or junk automobiles for instance were used to build reefs in the late 1950's and early 1960's. It appeared at that time that this might prove to be a solution to the problem of disposing of old cars. It was not long until it was discovered that car bodies corrode and disintegrate after a few years with the consequent loss of their usefulness as a reef.[125]

Ships and watercraft of various types have been successfully employed as artificial reefs. The federal government initiated a program in 1972, whereby surplus Liberty ships were obtained by the states for use as artificial reefs.[126]

The most essential characteristic of artificial reef building material is that it resist deterioration. For this reason, scrap automobile tires have proven to be a good construction material. The relatively inert chemical nature of tires, which makes tires a serious solid waste disposal problem, enables tire reefs to resist the destructive effects of sea water. Indeed, a developer wishing to construct a tire reef might well make a profit collecting his reef material. In Houston, Texas, individuals are paid 25 cents a piece to haul away and dispose of scrap automobile tires.[127] It is possible that the profit made from disposing of old tires might cover the cost of transportation to the reef site, for a truck load of 800 tires will bring a reef developer a collection fee of 200 dollars.[128]

One of the biggest problems in using tires as building material for artificial reefs is that tires will trap air and float. This problem can be overcome in two ways; the tires may be punched with venting holes or the tires may be slit circumferentially (see figure 4). Of the two methods, the circumferential slitting of tires is superior, for slit tires are easier to handle, transport, store and package for sinking.[129]

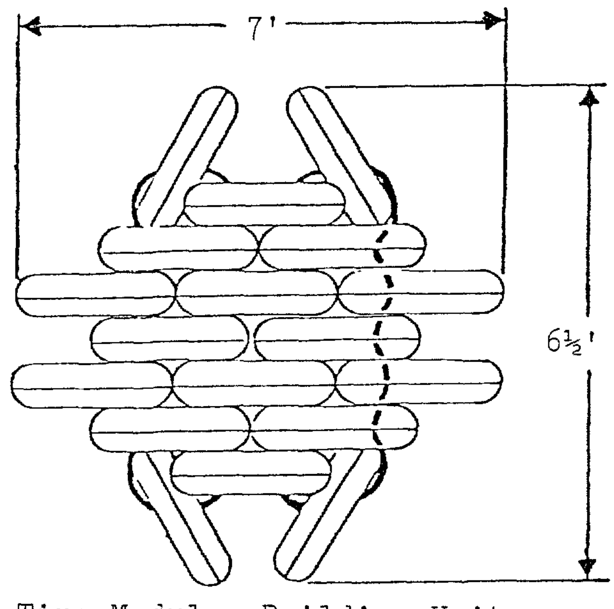
Scrap tires are presently being slit for use in rubber reclaim plants and landfill operations. Slit tires cost about 17 cents per tire, as compared to about 12 cents per tire for whole scrap tires, delivered to the site. Therefore, the additional cost of using slit tires would amount to about five cents per tire. This would amount to about a three percent increase in the total materials cost of a scrap tire reef. This additional slight



section view,

Circumferentially Slit and Doubled Tires,

from Candle and Fisher (1977)



36 Tire Modular Building Unit,

from Candle and Fisher (1977)

Figure 4 - Modular Tire Reef Building

increase in cost could easily be compensated for by the elimination of the existing venting process.[130] The following is an exact cost break-down of a 6700 slit tire modular artificial reef:

(1) 6700 slit scrap tires, cost $1005;

(2) 10,320 feet ½ inch open link special chain, cost $8,050;

(3) 14 handmade 500 pound concrete anchors, cost $420;

(4) 14 handmade 250 pound concrete anchors, cost $210;

(5) 2,800 feet mooring chain ½ inch open link, cost $2,184; and

(6) 688 man hours labor to bundle, build and install the reef, cost $3,784.[131]

The total cost for such a reef would be $15,658.[132] It has been estimated that 500 to 1,000 tires would be the minimum size reef necessary to support one charter or party boat, so it can be seen that a charter or party boat operator could supplement his existing investment with a modest cash outlay.[133]

For the operator to judge the attractiveness of this additional investment he would need to consider three elements; the investment, the operating benefits, and the time period over which these benefits are expected to prevail.[134] Two standard financial analysis techniques can be used to address these considerations; they are the calculation of return on equity and the determination of the projects present value.[135] The return on equity ratio is used to measure the relationship of net profit to investment at the end of the first year of operation, and net present value analysis is used to evaluate the trade-off between investment outlays and future benefits, in terms of time adjusted present value of dollars.[136]

Characteristically, charter boats range from 18 feet to 32 feet in length. They are powered by two 871 General Motors diesel engines which have a fuel consumption of 12 to 15 gallons per hour; fuel costs range from 41 cents to 50 cents per gallon. Charters usually stay out overnight and fish from 30 to 40 miles offshore. Charter boats carry six persons; four fishermen, the captain, and one crewman. Fishermen pay $75 to $100 each for an overnight charter.[137] Gulf charter boat captains indicate that the most sought after (and caught) species of fish are red snapper (Lutjanus campechanus), king mackerel (Scomberomorus cavalla), spanish mackerel (Scomberomorus maculatus), ling (Rachycentron canadum), shark (Charcharhinus, Carcharodon, Sphyrna, and Odontaspis species), barracuda (Sphyraena barracuda), spade (Chaetodipteus faber), dolphin (Coryphaena hippurus), warsaw (Epinephelus nigritus), and groupers (Epinephelus species).[138]

It has been estimated that the average charter boat operator in Texas had a gross income of $70,666 for the year 1974.[139] The average operator realized a net profit of $18,891, or approximately 26.73 percent of his gross income revenue.[140] Out of this profit the owner must pay all notes and interest on his bank loan and/or mortgages which were obtained to finance investments (averaging $114,076 per business).[141] The average operator is left with a final net income of approximately $10,000 per year.[142] Charter operators in other states do not fare as well as the Texas operators; Lake Michigan operators receive an average annual net income of $4,500 and Florida charter boat operators receive an annual net income of $8,500.[143]

The cost of capital or the opportunity cost for a charter boat operator is calculated to be an 8.8 percent annual return on an investment. It should be mentioned that there is a social factor or an "externality" which plays an important role in charter boat industry. If charter boat operators valued their business only in terms of the return on their investment most operators would leave the industry. However, Texas operators and other operators explain that they receive additional incentives and benefits from being able to be their own boss, and most importantly, for being paid to do what they enjoy the most, i.e. to fish.[144]

The feasibility of the private development of artificial reefs by charter boat operators will be determined by the comparison of the return on equity and the net present value of a charter operation with an exclusive artificial reef and fishing zone, with the return on equity and the net present value of a charter operation without an artificial reef. For the purpose of the calculations the following assumptions have been made:

(1) the operator has leased 25 acres of submerged water bottoms and the superadjacent water column for an annual rental of five dollars per acre;

(2) the investor has spent $1,169 to construct and put in place a 500 tire modular artificial reef;

(3) the cost of the reef is being depreciated on a line basis over the lease period of 15 years;

(4) the operator is paying a royalty of 12.5 percent of his gross income;

(5) the operator has located the artificial reef 1/3 closer to his base than the naturally occurring fishing "hot spots", and as a result of the reef's location has reduced his fuel expenses by 66 percent on a per trip basis;

(6) the artificial reef has increased the productivity of the exclusive fishing zone by a factor of four, and the operator is managing the reef zone at maximum sustainable yield; and

(7) the operator is making two charter trips a day and charges the same fee as a full day charter to a fishing area without an exclusive artificial reef;

(8) the satisfaction of the clients of the operator with an artificial reef has increased because, as a result of the increased productivity, they are catching twice as many fish on an average per trip basis, and because less time is spent in transit to the fishing area and the actual time spent fishing is 60 percent to 70 percent of the actual fishing time of

a full day charter to a more distant site.

The return on equity analysis is indicative of the relationship of annual net profit to the owners investment.[145] The following data were collected for a return on investment analysis for a charter boat operator without an exclusive fishing zone and artificial reef.[146]

Income	$14,251.46
Expenses	
Insurance	757.32
Advertising	148.21
Dock Fees	547.21
Office Rent	98.21
Local Taxes	14.82
Depreciation	1,240.86
Repairs	1,439.43
Fuel	2,055.32
Wages	2,366.00
Bait	515.39
Tackle	384.39
Ice	113.39
Other Variables	278.57
Total Expenses	$9,986.37

If one takes this income and subtracts the total expenses this leaves a figure of $4,265.09. This figure divided by the boat investment of $25,554.00 gives a return on equity of 16.7 percent.

The following data were generated for a charter boat operator with an exclusive artificial reef and fishing zone; they are based on the previous data, but factored in are the artificial reef operation assumptions.

Income	$28,502.92
Expenses	
Insurance	757.32

Advertising	148.21
Dock Fees	574.21
Office Rent	98.21
Local Taxes	14.82
Depreciation	1,318.76
Lease Rent	125.00
Royalties	3,562.87
Repairs	2,878.86
Fuel	1,370.21
Wages	4,732.00
Bait	2,061.56
Tackle	769.28
Ice	226.78
Other Variable	557.14
Total Expenses	$19,195.23

If one takes this income and subtracts the total expenses this leaves a figure of $9,307.69. This figure divided by the investment of the boat and the artificial reef of $26,723.00 gives a return on equity of 34.8 percent. This calculation clearly indicates that the development of an artificial reef by a charter or a party boat operator could increase the operator's net profits more than two fold and this increase represents a return on equity nearly double that of an operation without an artificial reef.

While the return on equity analysis measures the relationship of net profit to equity for a past or a current period, the net present value concept considers the investment over a future period of time.[147] The present value method discounts future cash flows back to the present to reflect the time-adjusted present value of money.[148] This enables one to measure the excess of discounted net cash inflow over cash outflow and determine the net present value of the investment.[149] There are four general steps entailed in the calculation of net present value.[150]

1) An appropriate discount rate must be ascertained. The discount rate should reflect the rate of return one might expect to derive from an alternative investment of equal risk.[151]

2) Once the discount rate has been determined, one must compute the present value of the expected net inflows resulting from the investment. The present value of the net inflows determines the amount a person can invest without incurring a financial loss.[152]

3) In addition, the present value of the cash outflows must be calculated. Generally, however, most capital outlays associated with investments are incurred initially. In this case, the present value of a current outflow is the same as the amount of outflowing cash.[153]

4) Finally, the present value of outlay of cash is subtracted from the present value of net income. The difference is the net present value of the project for the considered time period. To determine the total value of the investment, estimate the expected life of the facility and sum the net present value of the net cash flows. The resulting figures represent the actual worth of the investment in terms of present dollars.

Using the data for a gulf charter boat operator without an artificial reef and exclusive fishing zone, and an eight percent discount rate (this represents a present value of an ordinary annuity of one dollar discounted over a period of 15 years of 8.559), the net present value can be calculated. The operator's boat is valued at $25,554.00. The net cash flow is $5,505.95. The calculation is preformed before interest and taxes.

$$\text{Net Present Value} = (\$5{,}505.95 \times 8.559) - \$25{,}554.00$$
$$= \$21{,}571.43$$

Since the net present value is a positive amount, this indicates that charter boat operating is a good investment.

Using the data generated for a gulf charter boat operator with an artificial reef and an exclusive fishing zone, and an eight percent discount rate, and using the reef operation assumptions, the net present value can be calculated. The operator's boat is valued at $25,554.00 and the artificial reef is valued at $1,169.00. The net cash flow is $9,887.54. The calculation is preformed before interest and taxes.

$$\text{Net Present Value} = (\$9{,}887.54 \times 8.559) - \$26{,}723.00$$
$$= \$57{,}904.45$$

Since this figure is more than twice the figure calculated for an operation without an artificial reef, and since it only represents an investment of an additional $1,169, the charter operation with an artificial reef is a much more attractive investment than a similar operation without an artificial reef. These calculations demonstrate that it is financially feasible for private persons or corporations to develop artificial reefs.

CHAPTER V

CONCLUSION

The private development of artificial reefs has been examined in the light of the ecological, legal, and economic factors which concern such a development. In order for an artificial reef development to prove feasible, each one of these factors must prove to be feasible in itself.

The most basic factor concerns the physical, chemical, and biological processes which establish a reef community. It has been shown that naturally occurring coral reefs are one of the most productive communities in the marine environment, it has also been shown that artificial reefs located in coastal waters can be as productive or more productive than natural reefs. An artificial reef located in the coastal waters of the northern or the northwestern Gulf of Mexico could be expected to increase benthic biological productivity, and could be expected to increase the production of reef dwelling fishes by 400 percent. Although the question of whether an artificial reef can increase the biological productivity of an entire ocean system remains unanswered, it has been demonstrated that a properly constructed and located artificial reef will increase the total numbers of reef dwelling fishes available for fishermen.

The primary legal consideration is the public trust doctrine as this doctrine concerns coastal resources. Since it has been shown that the private development of artificial reefs increases the total number of fishes available for sportsmen, the exclusive use of a reef development does not represent an appropriation of a common property resource but rather an enhancement of a coastal resource. This development is, in fact, very similar to the private development of other coastal resources, e.g. offshore oil & gas, oysters, mariculture, etc. A mechanism has been proposed, involving leasing and royalties, which would allow the private development of artificial reefs to proceed in a manner consistent with the public trust in which coastal fisheries are held.

Other legal considerations concern the regulatory environment in which a developer would operate. Any potential developer of artificial reefs must be conscious of federal and state agencies' responsibilities concerning navigation, safety, pollution, wetlands protection, etc. Although an artificial reef development might require a wealth of state and federal permits, the regulatory processes are not so complex as to become a serious impediment to the development of these reefs.

Since biological and legal considerations do not prevent the development of artificial reefs. A potential developer can make a feasibility determination by the use of financial calculations. Using the assumptions of increased productivity, exclusive use, lower operating costs and market demand for exclusive fishing developments, calculations were used to compare the profitability of a charter boat operation with and without an associated exclusive artificial reef development. It was shown that a modest investment of $1,169.00 for an artificial reef could nearly double the profitability of a charter boat operation (from a 16.7% return on investment to a 34.8% return on investment). It was also shown that the net present value of a charter boat operation would be increased by the addition of an artificial reef (from $21,571.43 to $57,904.45). The return on equity and net present value calculations show the private development of artificial reefs to be not only feasible but highly desirable.

Coastal states can take advantage of this incentive of private developers to maximize their profits to achieve an optimum allocation of sport fisheries resources. The lease/private development scheme has been used to develop offshore oil and gas fields and to develop mariculture operations. Indeed, any comprehensive plan for the management of coastal resources should consider the private development of artificial reefs as an effective management tool.

REFERENCES

[1] Robert B. Ditton, John L. Seymour, and Gerald C. Swanson, Coastal Resources Management (Lexington, Massachusetts: D. C. Health and Company, 1977), p. 56.

[2] Ibid.

[3] Ibid.

[4] Ibid. p. 57.

[5] J. W. Hedgepeth, ed., Treatise on Marine Ecology and Paleoecology, Vol. 1: Ecology (Boulder, Colorado: The Geological Society of America Memoir 67, 1957), pp. 109, 186, 241, 304, 445.

[6] Robert W. Holmes, "Solar Radiation, Submarine Daylight and Photosynthesis," in Treatise on Marine Ecology, p. 109.

[7] Martin W. Johnson, "Plankton," in Treatise on Marine Ecology, p. 445.

[8] F. A. Richards, "Oxygen in the Ocean," in Treatise on Marine Ecology, p. 186.

[9] Roger Revell, and Rhodes Fairbridge, "Carbonates and Carbon Dioxide," in Treatise on Marine Ecology, p. 241.

[10] H. Barnes, "Nutrient Elements," in Treatise on Marine Ecology, p. 304.

[11] H. W. Harvey, "On the Production of Living Matter in the Sea off Plymouth," Journal of the Marine Biology Association (Vol. 29, 1950), p. 97.

[12] Howard T. Odum, and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," Ecological Monographs (July, 1955), p. 269.

13 Richard B. Stone, Chester C. Buchanan, and Frank W. Steimle, Jr., Scrap Tires as Artificial Reefs, (Washington, D.C.: Environmental Protection Agency Publication SW-119, 1974).

[14] For example see, "The Public Trust in Tidal Areas: A Sometime Submerged Traditional Doctrine," The Yale Law Journal (Vol. 79, 1970), pp. 763-770.

[15] Illinois Central R. R. v. Illinois, 146 U.S. 387.

[16] For example see, Harold F. Larson, "Economic Impediments and Incentives-the Role of Government," (Committee Print, the Committee on Commerce, United States Senate, 1973), pp. 138-139.

[17] Ronald L. Schmeid, "An Emploratory Analysis of the Texas Charter and Party Boat Fishing Industry," (Professional paper, Department of Recreation and Parks, Texas A&M University, 1977), pp 24-27.

[18] Robert B. Ditton, Richard N. Jarman, Thomas J. Mertens, Martin P. Schwartz, and Steve A. Woods, "Charter Fishing on the Texas Gulf Coast," Manuscript submitted to the Center for Marine Resources, College Station, Texas.

[19] Coastal Zone Management Act of 1972, P.L. 92-583.

[20] Holmes, "Solar Radiation, Submarine Daylight and Photosynthesis," p. 109.

[21] William T. Keeton, Elements of Biological Science (New York: W. W. Norton and Company, Inc., 1969), p. 74.

[22] Ibid., p. 82

[23] Robert E. Ricklefs, Ecology (Portland, Oregon: Chiron Press, 1973), p. 643.

[24] George M. Woodwell, "The Energy Cycle of the Biosphere," in The Biosphere (San Francisco: W. H. Freeman and Company, 1970), p. 29.

[25] Ibid., p. 31.

[26] Ibid.

[27] Ibid., p. 34.

[28] Keeton, Elements of Biological Science, p. 402.

[29] Harvey, "On the Production of Living Matter in the Sea off Plymouth," p. 97.

[30] Odum and Odum, "Trophic Structure and Productivity of a Windward Coral Reef," p. 269.

[31] Ricklefs, Ecology, p. 101.

[32] Ibid.

[33] Ibid.

[34] Johnson, "Plankton," p. 445.

[35] Ricklefs, Ecology, p. 633.

[36] Richards, "Oxygen in the Ocean," p. 186.

[37] Revelle and Fairbridge, "Carbonates and Carbon Dioxide," p. 241.

[38] Ibid., p. 242.

[39] Barnes, "Nutrient Elements," p. 304.

[40] Ibid.

[41] Ricklefs, Ecology, p. 691.

[42] Herman Friedrick, Marine Biology, trans. Gwynne Vevers (Seattle: The University of Washington Press, 1969), p. 87.

[43] Ibid., p. 88.

[44] Barnes, "Nutrient Elements," p. 313.

[45] Woodwell, "The Energy Cycle of the Biosphere," p. 33.

[46] Ibid.

[47] Peter P. Prantis, Jr. and G. H. McKay, "The Prantis Reef System," promotional brochure, Houston, Texas, October, 1975, p. 2.

[48] Ibid.

[49] Ibid.

[50] Ibid.

[51] Friedrick, Marine Biology, p. 375.

[52] Stone, et al., Scrap Tires as Artificial Reefs, p. 1.

[53] Ibid.

[54] Willis E. Pequegnat, interview held Department of Oceanography, Texas A&M University, College Station, Texas, 5 April 1976.

[55] Takaski Ino, "Historical Review of Artificial Reef Activities in Japan," in Proceedings of an International Conference on Artificial Reefs, ed. Laura Colunga, and Richard Stone (College Station, Texas: Texas A&M University, Sea Grant Publication 74-103, 1974), p. 21.

[56] Ibid.

[57] Ibid.

[58] Edward L. Bechman, "The V. A. Fogg--An Unplanned Artificial Reef," in Proceedings of an International Conference on Artificial Reefs, p. 118.

[59] Howard Lee, interview held Texas Council on Marine Related Affairs, Austin, Texas, 4 May 1976.

[60] Eugene A. Shinn, "Oil Structures as Artificial Reefs," in Proceedings of an International Conference on Artificial Reefs, p. 91.

[61] Richard Stone, interview by telephone, National Oceanic and Atmospheric Administration, Washington, D. C., 8 July 1977.

[62] Ibid.

[63] "The Public Trust in Tidal Areas: A Sometime Submerged Traditional Doctrine," p. 763.

[64] Ibid., p. 764.

[65] Ibid., p. 765.

[66] Ibid., p. 766.

[67] Ibid., p. 770.

[68] Dickens v. Shaw, K. B. 1822.

[69] Martin v. Waddel, 41 U. S. 367.

[70] Illinois Central R. R. v. Illinois, 146 U. S. 387.

[71] "The Public Trust in Tidal Areas: A Sometime Submerged Traditional Doctrine," p. 778.

[72] Ibid., p. 783.

[73] Ibid., p. 784.

[74] Lee G. Anderson, The Economics of Fisheries Management (Baltimore: The Johns Hopkins University Press, 1977), p. 23.

[75] Ibid., pp. 154, 156, 166, 169.

[76] Ibid., p. 183.

[77] Ibid., p. 151.

[78] Ibid., p. 185.

[79] For example, the redfish in Texas, Georges Bank Haddock, many oyster reefs in the Gulf of Mexico and the Atlantic, etc.

[80] Jean R. Richey, "A Comparison of Oil and Gas Leasing Authorities in the Gulf of Mexico (States of Alabama, Mississippi, and Louisiana, and the Federal Governement), and the Jurisdictional Conflict Over the Boundry Between State and Federal Authority in the Gulf of Mexico," Mississippi Law Journal (Vol. 40, 1969), p. 358.

[81] Ibid.

[82] Ibid., p. 359.

[83] Ibid., p. 361.

[84] Ibid., p. 362.

[85] Ibid., p. 363.

[86] Ibid., p. 366.

[87] Title 17, Chapter 253, Sec. 253.68, Florida Code.

[88] Ibid., Sec. 253.71.

[89] Ibid.

[90] Ibid., Sec. 253.72.

[91] Chapter 1, Title 56, Sec. 422, Louisiana Revised Statutes.

92 *Ibid.*, Sec. 425.

93 *Ibid.*

94 *Ibid.*, Sec. 426.

95 Ibid., Sec. 427.

96 Title 49, Chapter 15, Sec. 27, *Mississippi Code of 1972*.

97 *Ibid.*

98 *Ibid.*

99 *Ibid.*

100 John L. Seymour, "Preliminary Legal Considerations in Developing Artificial Reefs," *Coastal Zone Management Journal* (Vol. 2, 1975), p. 156.

101 *Ibid.*

102 *Ibid.*

103 *Marine Protection, Research, and Santuaries Act of 1972*, 16 USC 1402(f).

104 Seymour, "Artificial Reefs," p. 157.

105 16 USC 1432.

106 Seymour, "Artificial Reefs," p. 157.

107 *Federal Water Pollution Control Act*, 33 USC 1328.

108 *Ibid.*

109 Seymour, "Artificial Reefs," p. 157.

110 *Rivers and Harbors Act of 1899*, 33 USC 403.

111 *Outer Continental Shelf Lands Act of 1953*, 43 USC 1333.

112 33 USC 403.

113 43 USC 1333.

114 Seymour, "Artificial Reefs," p. 158.

[115] *Ibid*.

[116] *Ibid*.

[117] *Ibid*., pp. 158-159.

[118] *Ibid*., p. 154.

[119] *Ibid*.

[120] *Ibid*., p. 155.

[121] Larson, "Economic Impediments and Incentives," pp. 138-139.

[122] *Ibid*.

[123] *Ibid*.

[124] Seymour, "Artificial Reefs," p. 150.

[125] *Ibid*.

[126] 46 USC 1220.

[127] Caroline White, interview held Omega Salvage Co., Houston, Texas, 17 June, 1977.

[128] *Ibid*.

[129] Richard D. Candel and William J. Fisher, "Scrap Tire Shore Protection Structures," The Goodyear Tire and Rubber Co., Akron, Ohio 44316, 21 March, 1977, p. 34.

[130] *Ibid*., p. 35.

[131] Ibid., p. 17.

[132] *Ibid*.

[133] Stone, interview.

[134] Frank J. Lawlor III, "A Preliminary Technology Assessment of Alternative Uses for Offshore Petruleum Platforms," (Masters Thesis, Texas A&M University, 1976). p. 77.

[135] Robert J. Williams, "Economic Feasibility of Commercial Shrimp Farming in Texas," (Masters Thesis, Texas A&M University, 1973), p. 7.

[136] *Ibid*.

137 Gary Grahm, interview held Marine Extension Service, Angleton, Texas, 12 July, 1977.

138 Schmeid, "Texas Charter and Party Boat Fishing," p. 24.

139 Ibid., p. 25.

140 Ibid.

141 Ibid.

142 Ibid.

143 Ibid., p. 27.

144 Ibid.

145 Williams, "Economic Feasibility," p. 23.

146 Ditton, et al., "Charter Fishing on the Texas Gulf Coast,"

147 Williams, "Economic Feasibility," p. 23.

148 Ibid., p. 28.

149 Ibid.

150 Ibid.

151 Ibid.

152 Ibid.

153 Ibid., p. 29.

VITA

ARTHUR ALLEN BURNS, JR.

Date of Birth: November 18, 1952

Place of Birth: Jackson, Mississippi

Permanent Address: 4293 Berlin Dr., Jackson, MS 39211

Parents: Brig. Gen. & Mrs. Arthur A. Burns

Martial Status: Single

Height: 5'10

Weight: 158 lbs.

B.S., University of Mississippi, Biology, 1974

Deputy Director, Governor's Office of Natural Resources and Technology, Jackson, Mississippi, 1977-1978.

Professional Consultant, Mississippi Marine Resources Council, Long Beach, Mississippi, 1978.

The typist for this thesis was Mrs. Larry Wiginton.