Criteria for Underwater Recreational Design

by

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Approved by:

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Abstract -

The report, "Criteria for Underwater Recreational Design," accomplished two major goals. The first proved that structures designed specifically for the diver and management of the ecosystem are more responsive to diver and ecosystem needs than present artificial reefs. The second established a comprehensive set of guidelines by which a diving reef should be designed. External management criteria, site selection criteria, and internal management criteria were all determined.

The research process consisted of seven major aspects. These included introduction, identification of diver and ecosystem needs, evaluation of existing natural diving environments, evaluation of present artificial reefs, synthesis of ecosystem and diver management considerations and design criteria, legal and economic considerations, and conclusion. Within the conclusion, artificial reefs were compared to designed diving reefs based on the established management considerations. The designed diving reef satisfied 85% of those considerations while the next best artificial reef satisfied only 50% of the needs.

AQUATIC
DIVER
ECOSYSTEM
ENVIRONMENT
REEF
SCUBA
UNDERWATER

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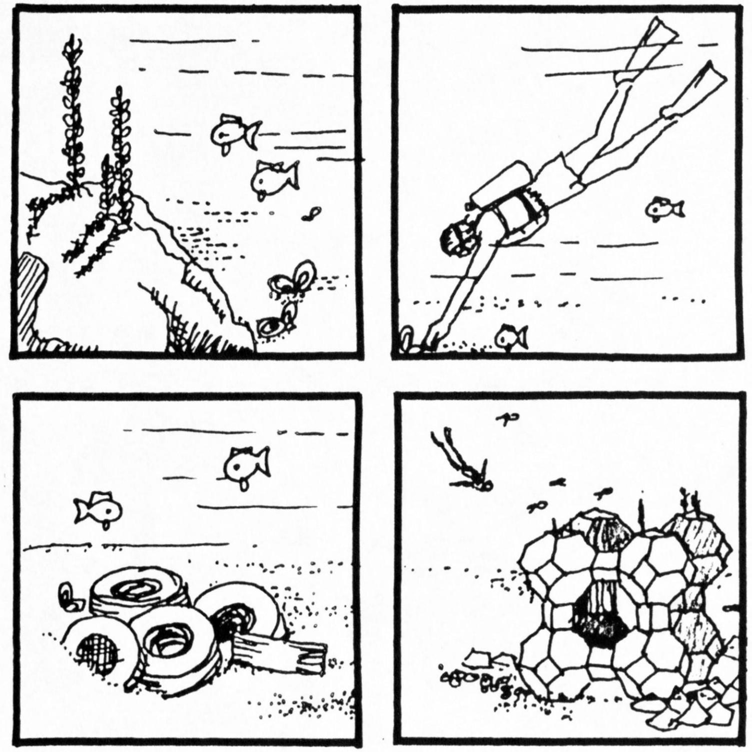


Preface-

In 1973, I developed an interest in skin diving (use of mask, fins, and snorkle). My major experiences centered around artificial reefs such as jetties and piers rather than natural reefs. The distinction between natural and artificial reef lies in the fact that artificial reefs are objects submerged by man that attract sea life. Natural reefs include communities like coral reefs and kelp beds. The jetties and piers which I viewed underwater were extremely successful in attracting a diversity and abundance of aquatic life.

When I obtained my certification for scuba diving (use of self-contained underwater breathing apparatus), I was able to extend my experiences in diving to artificial reefs such as deliberately sunken cars and ships. The artificial reefs supported much more aquatic life than similar areas without a reef.

Although I was fascinated by fish and invertebrates attracted to the reef, I was appalled at the lack of visual quality of many of these reefs. Rusting metal, old tires and debris appeared extraneous in the aquatic environment.

In April of 1981, an opportunity arose to research possible alternatives to the state-of-the-art of artificial reefs through the Undergraduate Fellow's Program at Texas A&M University. John Motloch, an assistant professor in Landscape Architecture, was chosen as the advisor for this research because of his expertise and interest in natural systems and research processes.

After accepting the opportunity, my first order of business was to develop a questionnaire to aquire an understanding of diver experience and views of present artificial reefs and possible alternatives (see Appendix I). As a control measure, demographic information was gathered to insure that populations groups were weighted in accordance to general diving population characteristics. Dr. Edward Gbur, professor of statistics, was consulted for methods of interpreting this data.

The questionnaire was administered in three general areas. These included Seaspace '81 (convention given by the Houston Underwater Club, Inc.), various dive shops and a meeting of the Texas A&M University Scuba Diving Club.

From these diverse areas, the survey sample acquired demographic characteristics similar to those in the scuba diving community.

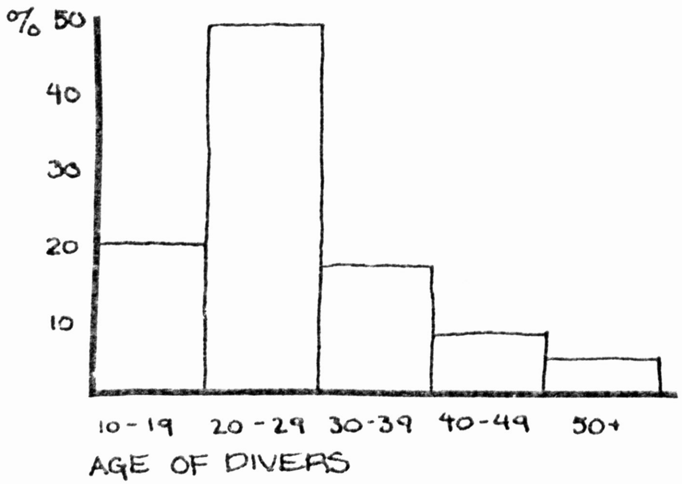


Figure P-1

Age Bracket of Divers within the Survey Sample

Out of 99 divers surveyed, 49% were between 20 and 29 years of age. The 10 to 19 and 30 to 39 age brackets accounted for 20% and 17% respectively. The 40 to 49 age group accounted for 8% of the survey while the 50 plus age bracket comprised 6%. Although demographic statistics on the community of divers were not available, observation indicates that these percentages roughly approximate the population of divers.

Whereas the aqualung was not introduced until 1943, P-1, the community of divers was quite small into the 1960's. However, since the mid-60's, the number of recreational divers has increased drastically. With only a decade and a half of diving as a popular sport, the median age of 26 within the survey sample approximates that within the diving community. Also, the recent addition of scuba courses and clubs to high schools and colleges adds to the high percentage (68%) of 15 to 30 year-old divers.

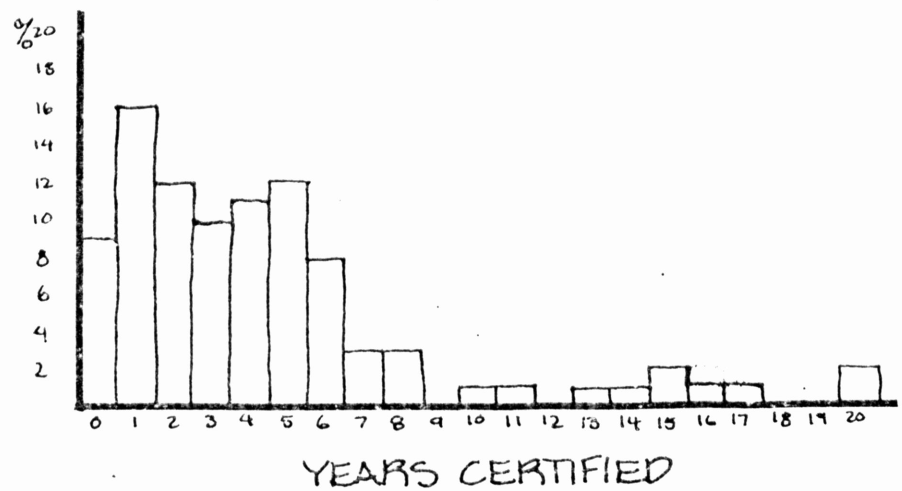


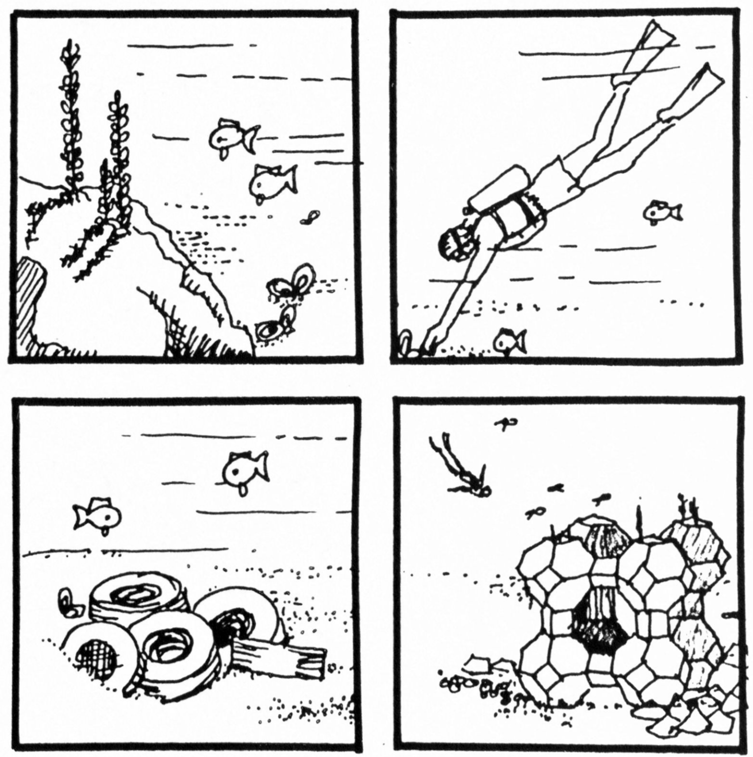
Figure P-2

Experience of Divers within the Sample Survey

As expected in a rapidly growing sport, an inverse relationship existed between the number of divers and number of years in which they were certified. The greatest number of divers had the least experience. Over 88% of the divers surveyed had been certified 6 years or less.

From the questionnaire results (supplemented with an extensive review of existing literature and personal communications), I was able to gain insight into the motivations for diving, experience with natural and artificial reefs and occurrence of stress leading to panic while diving. These factors must be considered when determining criteria for alternative artificial reef design.

Introduction



Chapter 1 - Introduction

Before 1960, recreational scuba divers "consisted of a mere handful of pioneering enthusiasts..."[1-1] Since then, scuba diving has grown rapidly.[1-2] Unfortunately, diving areas abundant with aquatic life are a limited resource. In an attempt to increase this resource, artificial reefs are submerged to attract invertebrates and fish. Although divers take advantage of this benefit provided by artificial reefs, these reefs are essentially designed for anglers. Tires, rubble, derelict cars and ships are submerged to attract aquatic life for the angling population which never views the reefs. For divers though, areas of disposed refuse leave something to be desired as a diving environment.

The purpose of this research is to prove that structures designed specifically for the diver and management of the ecosystem can be more responsive to diver and ecosystem needs than present artificial reefs. The research also develops criteria for designing "diving reefs". These criteria are responsive to the needs of the diver and the characteristics and needs of different diving environments and related ecosystems.

To organize and communicate the research methodology, a network (see Figure 1-1) was developed. The network delimits the research and identifies the research process.

The research process consists of seven major aspects. These include introduction, identification of diver and ecosystem needs, evaluation of existing natural diving environments, evaluation of present artificial reefs, synthesis of ecosystem and diver management considerations and design criteria, legal and economic considerations, and conclusion.

The introduction presents the need for research and the research hypothesis. It also explains, graphically and verbally, the methodology of research.

The identification of diver and ecosystem needs is complex and intricate. Thus, it involves a major breakdown to identify each point fully. Chapter II examines the underwater environment as a system. Biotic and abiotic factors are both considered to give a foundation upon which to base later conclusions. From this examination, ecosystem needs are defined and

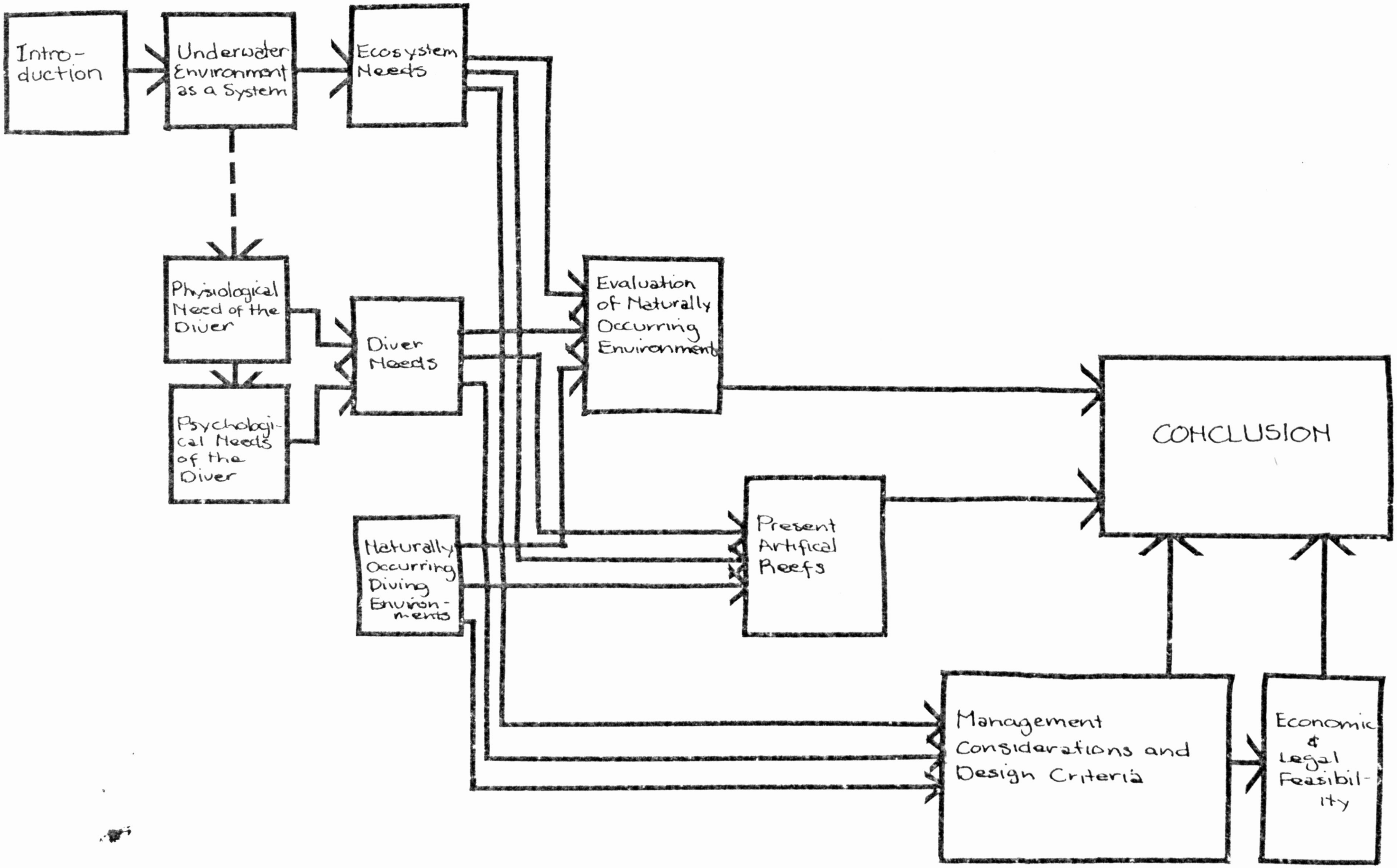


Figure 1-1

Network for Research Methodology

management considerations are developed in Chapter III. To examine diver needs, both physiological and psychological needs are regarded. In Chapter IV, the environmental affects upon the diver physiology is determined. Psychological factors are defined in Chapter V from the survey and from the review of existing literature. In Chapter VI, management considerations which respond to diver needs are determined from these preceding two chapters.

Existing natural diving environments are defined in Chapter VII. These general aquatic environments are characterized based on factors defined in Chapters II and III. In Chapter VIII, these environments are evaluated as to their quality as diving environments. The evaluation is based on management criteria determined in Chapter II (ecosystem needs) and Chapter VI (diver needs).

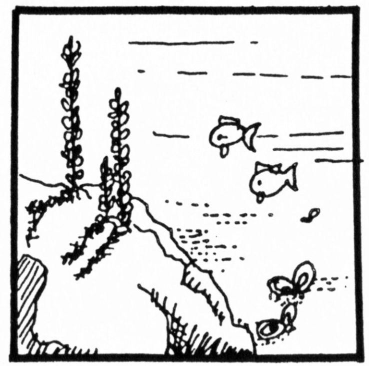
Through literature and previous research, the types of artificial reefs are identified in Chapter IX. These types are characterized and then correlated to the needs of the diver and ecosystem.

Management considerations of the aquatic ecosystem and diver are then inter-related in Chapter X. From this inter-relationship, site location selection and diving structure design criteria are determined.

Economic and legal considerations have historically been the largest constraint to designed artificial reefs. Chapter XI deals with these considerations briefly with a bibliography for further reading on legal factors.

The conclusion, Chapter XII, illustrates acceptance of designed diving reefs and contrasts present artificial "fishing" reefs to artificial diving reefs. It also discusses the extent to which the hypothesis is correct.

The Underwater Environment as a System



Chapter II - The Underwater Environment as a System

The underwater environment is an intricate network of processes. The whole system must be considered when developing an intelligent management strategy. "Any attempt to manage separately one of the many interdependent components of a complex ecosystem will very likely fail."[2-1]

Although this intricacy does exist, the ecosystem is composed of two fundamental classifications and relationships. The major areas are the biotic and abiotic factors.

BIOTIC FACTORS

The biotic factors are typically identified as the organisms and relationships between organisms in an environment. This inter-relationship of organisms defines the biotic community.

Energy Flow -

"Transfer of food energy from lower to higher life forms, known as the food chain or food web, is composed of a number of separate components."[2-2] Plants (autotrophs) continually bring energy into the chain. Thus, they are referred to as producers. Consumers are the smaller plankton and plant-feeding animals. They consist of zooplankton, benthic (bottom-dwelling), pleustonic (floating), and nektonic (free swimming) animals. The bentic animals include those capable of locomotion and sessile animals which attach to solid substrate. Those animals that prey on consumers are foragers which include nektonic and benthic animals. Predators consume foragers. "Finally, there are decomposers, bacteria (and other organisms) that reduce dead matter back into basic minerals."[2-3] Through this process, nutrients are cycled in the aquatic ecosystem.

Patterns of Growth -

The inter-relationship of species in the aquatic environment is typically very stable. Growth of new communities follows a regular procession. A typical series of changes "on a submerged microscope slide might be as follows: clean surface bacteria microscope algae various invertebrates (hydroids, coelenerates, barnicles and tunicates) blue mussels."[2-4]

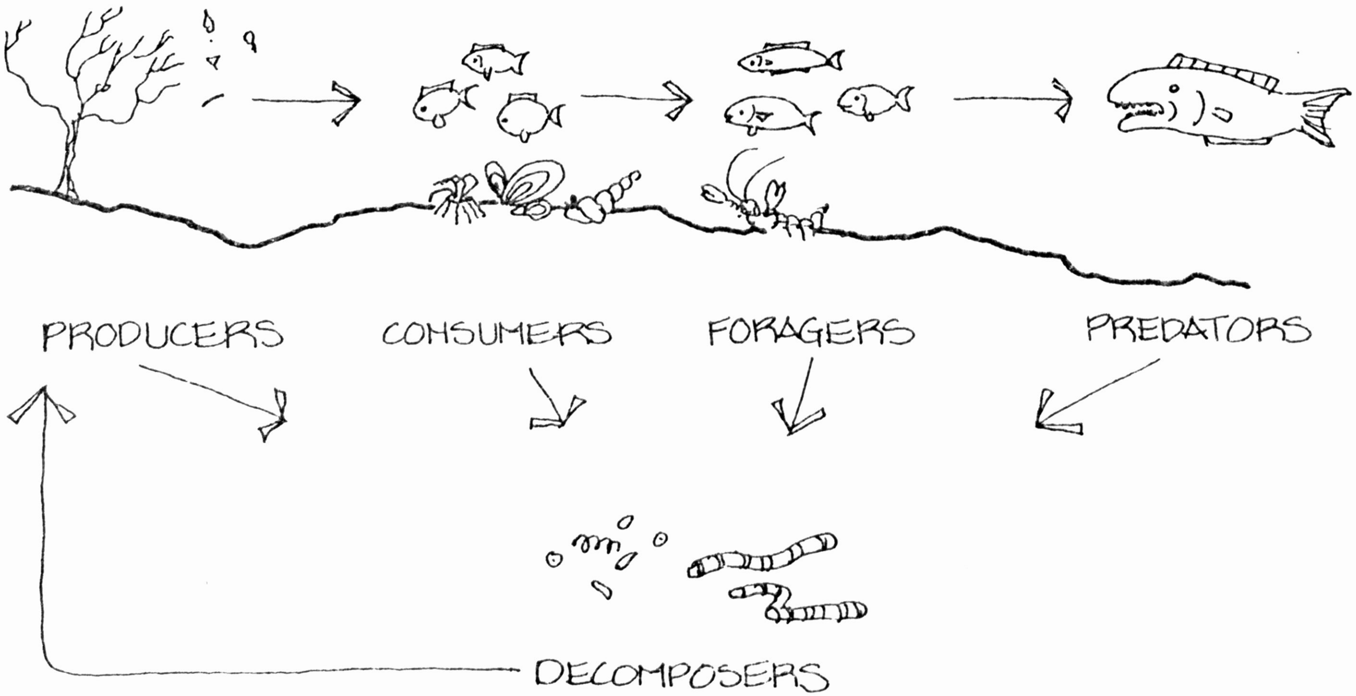


Figure 2-1
Food Chain of the Aquatic Environment

Foragers then appear which attracts predators. Thus, the components of a food chain exist and a biotic community is established.

"The series of successional changes described on glass slides takes approximately 4 weeks, while (on land) the successional sequence from field to pine forest may take 50 years to complete."[2-5] This indicates that management and recovery potential of the underwater environment exceeds that of the terrestrial environment in terms of time.

Growth of a particular species after introduction to an area increases at an expotential rate. A carrying capacity (number of individuals that an environment can hold) is typically exceeded for a short perid of time. Starvation or other natural regulators takes place and carrying capacity is established.

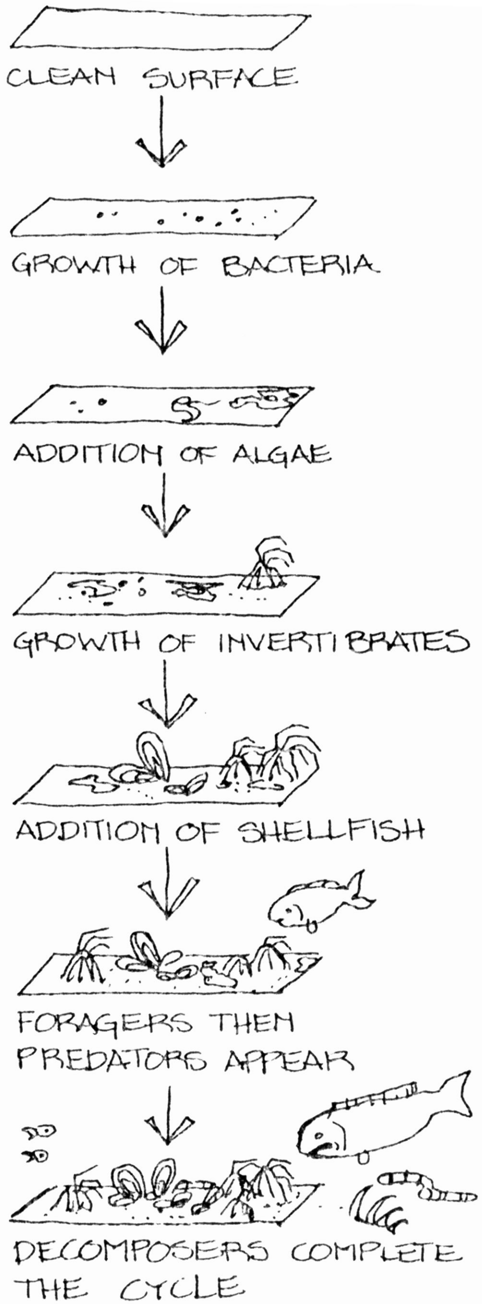


Figure 2-2

Growth of a New Underwater Community

Establishment time varies widely with the species, competition and limiting physical factors. The carrying capacity itself may rise or fall with changes in chemical and physical factors.[2-6]

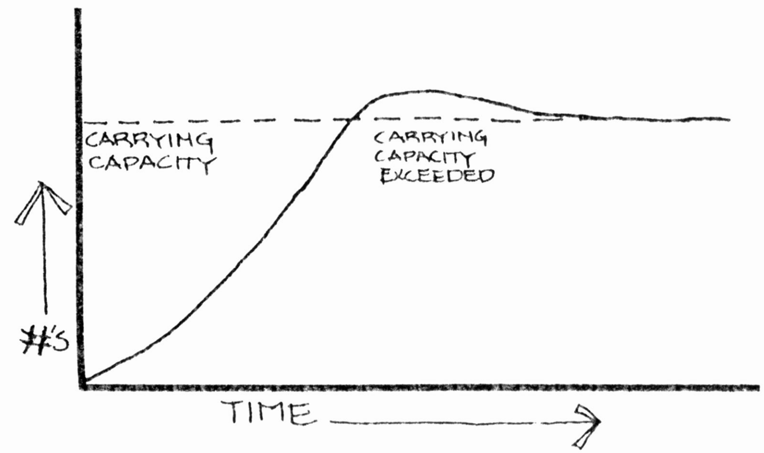


Figure 2-3

Population Growth

ABIOTIC FACTORS

The abiotic factors are typically identified as physical and chemical processes within the ecosystem. All of these processes may characterize any underwater environment.

Chemical Factors

Oxygen -

"Oxygen, necessary for respiratory decomposition of carbohydrates, is introduced into the upper layers of the ocean water and exhanged with the atmosphere at the sea surface or through the process of photosynthesis."[2-7] The photosynthetic introduction of oxygen occurs within the photic zone (area of light penetration) which is approximately 45 meters deep in coastal waters.

The atmosphere has much more oxygen than does the water. The soluability of oxygen in water varies inversely with temperature and salinity. The greater the warmth and/or the salinity, the less the soluability of oxygen.[2-8]

To organisms which consume energy rather than manufacture it (heterotophic), oxygen is an essential element in the synthesis of that energy. Since oxygen is continually expelled by plants, oxygen is not a limiting factor for heterotrophs in the photic zone.

Carbon -

"Carbon dioxide is produced in the respiration of both animals and plants. The buffering system of sea water is such that it is doubtful whether carbon dioxide ever becomes a limiting factor under natural conditions."[2-9] Carbon enters the biotic cycle through plant photosynthesis. Consumers (heterotrophs) acquire carbon by digesting plant material. Carbon is then supplied to decomposers through waste product or death or it is replaced to the atmosphere or water through respiration. Organic and inorganic carbon of sedimentation stores the carbon in rock formations for a long term only to be released by weathering, volcanic activity or consumption of fossil fuels.

Nitrogen -

Soluable compounds of nitrogen are vital to the existence of aquatic life and are often a limiting factor in the growth of plants. These compounds do not include N_2, which is plentiful in the atmosphere, because this atmospheric

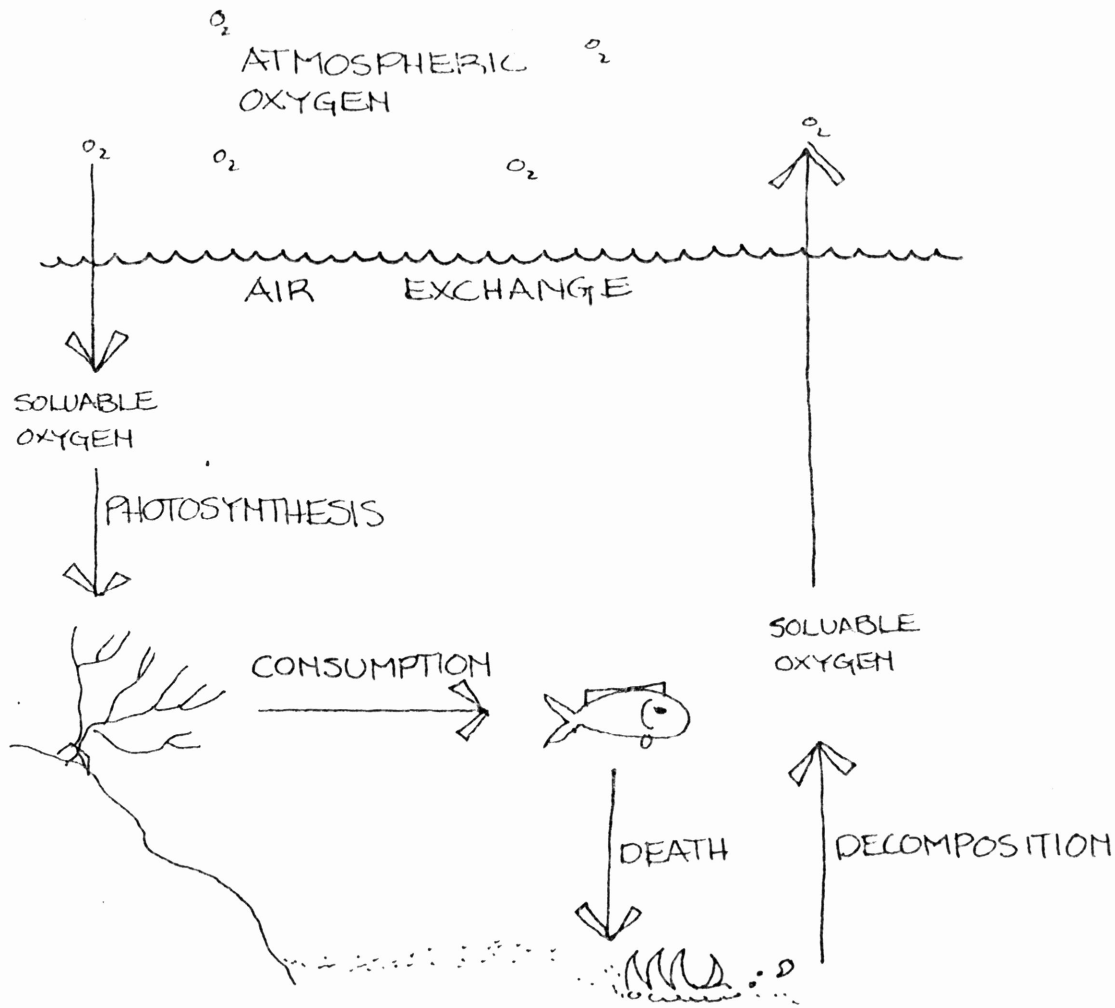


Figure 2-4

The Oxygen Cycle

Other Elements -

Phosphorous, sulfur, and other micronutrients also occur in compounds which influence natural aquatic processes.

Phosphorous, like nitrogen, can be a limiting factor in the growth of phytoplankton. The two elements stimulate phytoplankton blooms.[2-12] When over-growth occurs, the plankton limits light to the deeper plankton. Thus, the system is self-regulated.

"The sulfur cycle ... may be of importance in determining animal and plant distribution in marine sediment and overlying waters."[2-13] The greatest concentration of sulfur is in the form of hydrogen sulfide. This contributes to an environment that is necessary for the existence of certain types of organisms. Most marine organisms, however, perish when the hydrogen sulfide-rich bottom waters swell or when other mixing processes occur.

"Elemental mercury as well as some of its compounds can adversely affect" the internal functions of higher aquatic life.[2-14]

Other micronutrients, including iodine, calcium, sodium, and magnesium, are essential to the existence of underwater life.

Pollution -

Five types of pollution exist that impact water resources.

1. "Bacterial contamination associated with untreated human sewage" and city runoff. Many bacteria are associated with disease and death of many organisms.
2. "Discharges of decomposable organic materials from human sewage and some industrial waste which depletes dissolved oxygen resources."
3. Toxic materials from land runoff, pesticides, herbicides and chemical plant and industrial wastes. "These wates may kill directly or cause damage to reproduction capability."
4. "Materials which act as fertilizers and tend to stimulate growth of some life forms at the expense of others."
5. Inert materials (dredgings, etc.) which smother benthic forms.[2-15]

Management tools do exist to avoid these five types of pollution. After dumping of human sewage, decomposable organic material, toxic materials and fertilizers is curtailed, the underwater environment eventually reaches a natural equilibrium. Toxic materials unfortunately have a longer term effect than the others.

In areas where dredging and/or dumping inert materials has been managed, many benthic forms have not been able to re-establish on the soft sediment. Substrate can be added to aid the attachment of these forms.

Physical Factors

Waves -

A wave period is defined as "the time required for two wave crests to pass a fixed point."[2-16]

"As the lead wave passes forward, it sets particles of water in an orbital motion" which sets off decreased orbits beneath the top orbit.[2-17]

The orbits rotate at more than half the wave height. When the bottom material affects the orbits, the character of the wave changes. It grows steeper. "When the crest angle becomes less than 120 degrees, the wave loses its stability and the crest falls forward which dissipates energy."[2-18]

If wave action reaches the bottom material, organisms may be prevented from attaching. Sessile populations do occur however. Typically these forms have been "modified to withstand

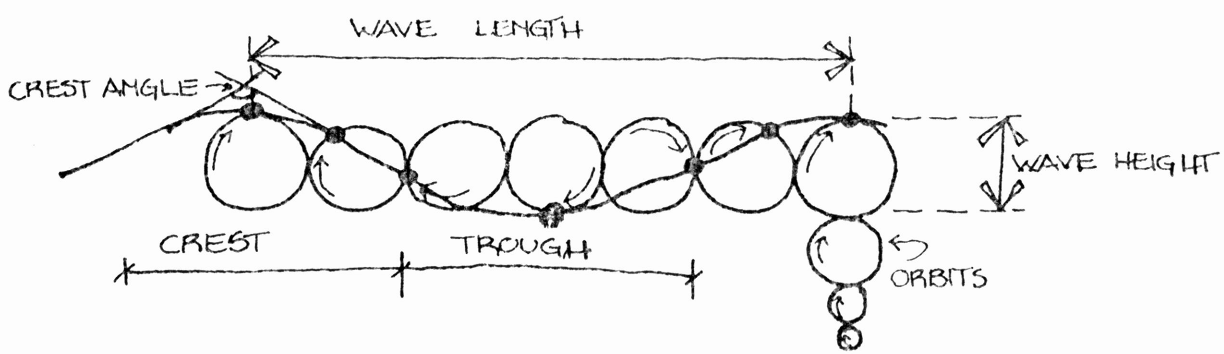


Figure 2-7
Diagram of a Wave

heavy wave action."[2-19] "Moderate wave action can be beneficial by facilitating ... (oxygenization) of surface waters and acting as an agent for mixing sediments containing organic matter, which are then available for filter feeders."[2-20]

Tides -

Tides are a "dominent force in water movement." Tide amplitude varies with season and the shape, size and type of objects (rocks, coral, tree branches, et cetera) and bottom material.

"Circulation forces tend to be greater and flushing better where tidal amplitudes are high."[2-21] Thus, nutrients are brought to sessile organisms unless the force prevents these organisms from attaching.

Currents -

Currents have both disadvantages and advantages when considering the underwater environment. Current lifts sediments which limits light (unlike waves which only diffuse light). The force from currents and abrasive qualities of suspended particles may damage tissues of

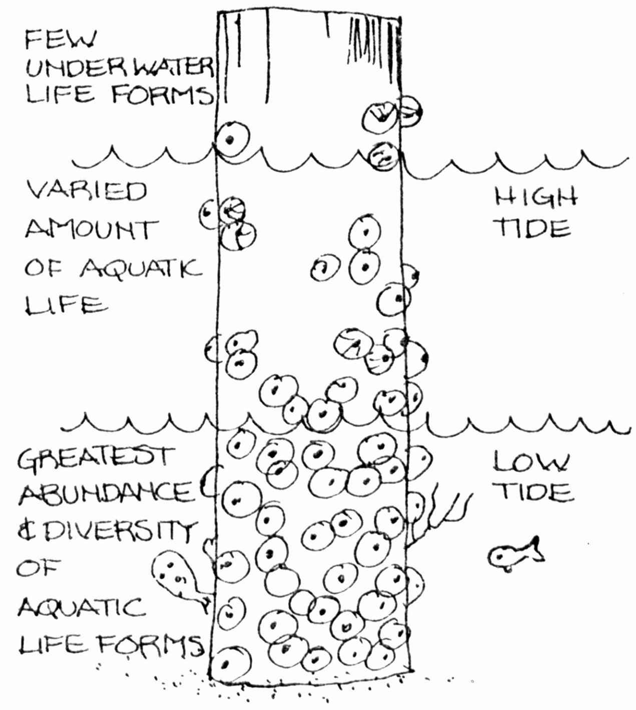


Figure 2-8
Tidal Zones

sessile organisms. "On soft bottoms, currents result in constant ... shifting of the sediments and may cause impoverishment of the flora and fauna."[2-22] The force from the current may disturb substratum which results in the death or departure of organisms the substrate has harbored.[2-23]

Currents, however, also contribute to the environment. Dispersion of eggs and larvae depends on currents. Sessile filter-feeders require this circulation to bring their microscopic food. Swift currents play an active role in the diversity and abundance of aquatic life.

Temperature -

Temperature is the most important physical variable in the aquatic environment. A rise in temperature tends to accelerate chemical reactions which in turn affect the diversity and concentration of biota.

Water temperature is more stable than air temperature because of the water's high specific heat (heat storage capacity), its low albedo (its great ability to absorb incoming solar radiation), and its great volume.[2-24] In lakes and shallower bays, temperature change takes place at an increased rate and applitude as the volume to surface area ratio of the water decreases

Temperature fluctuations determine when and at what rate organisms carry on certain life functions (spawning, migration, et cetera). It is a limiting factor as well. Ranges exist beyond which different species cannot survive.

These ranges are usually bordered in the aquatic environment by thermoclines. Thermoclines are distinct lines where water temperature changes drastically. This phenomenon occurs because cold water is denser and heavier than warmer water. Thus the water becomes stratified in terms of temperature. Thermoclines are more distinct in areas of little current or upwelling.

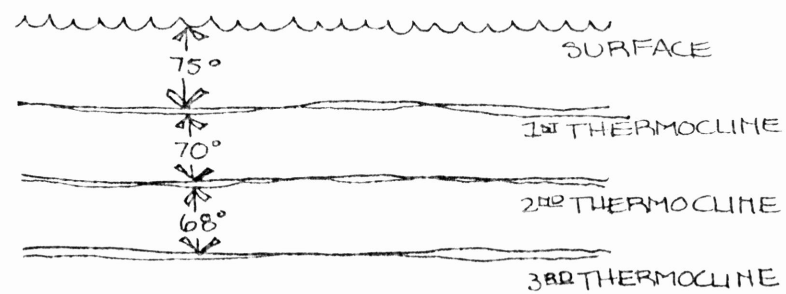


Figure 2-9

Thermoclines

Substrata -

For the purpose of this research, substrata is defined as any type of surface which organisms utilize for attachment and/or dwelling. This includes both bottom material and objects within the aquatic environment.

Two types of substrata exist. These include solid substrata (metal, rock, wood, shell, et cetera) and particulate substrata (sand, mud, et cetera). Suspended particulate matter increases with the amount of current and decreases with the increased size of particles of the substrate.

Sessile organisms require solid substrata for existence while others utilize solid substrate extending into the aquatic environment as protective hideouts. Mollusks and other burrowing animals (flounders, sting rays, et cetera) require particulate matter for protection.

Illumination -

"Light is of importance in marine ecology connection with a wide range of phenomenon including vision, photosynthesis, heating and actinic (solar radiation-induced) damage."[2-25]

The sediment load has a negative impact on the amount of light that penetrates through the water. Thus, water quality is higher with less sediment and turbidity.

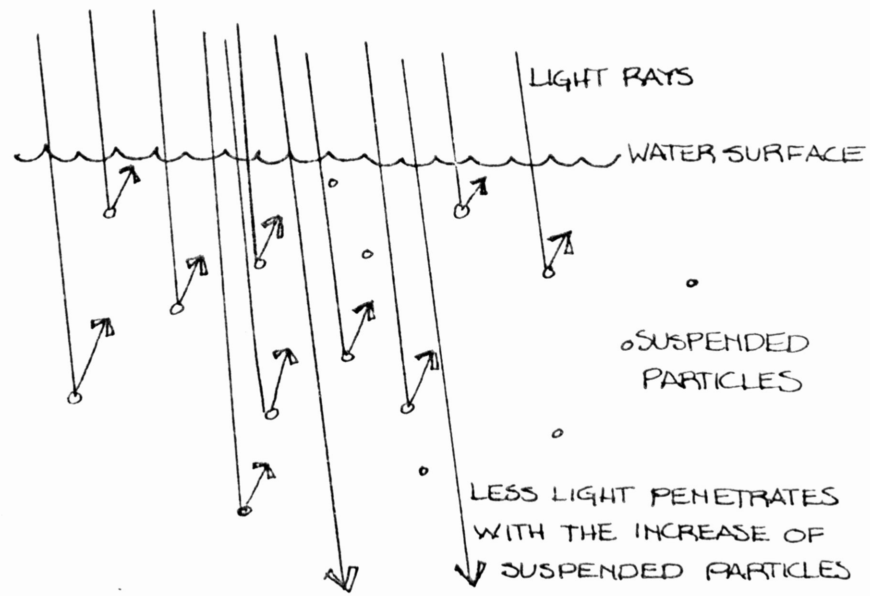


Figure 2-10
Light Penetration and Suspended Material

Water depth has a direct effect on light as well. The greater the depth the less light penetration. In addition, total water depth affects the total amount of suspended material. Theoretically, twice the depth contains twice the amount of suspended material.

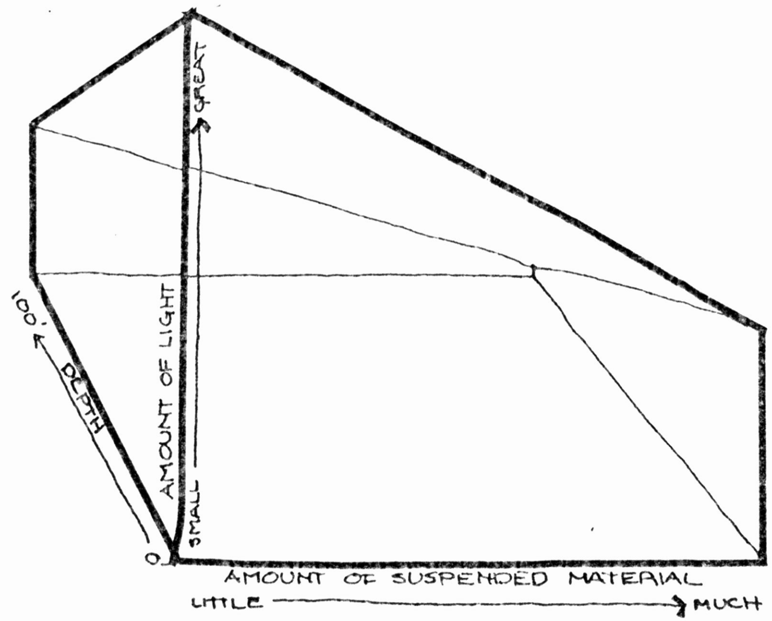


Figure 2-11
Relationship Between Light, Depth, and Amount of Suspended Material

Since photosynthesis is dependent on light, solar energy is needed by all organisms directly or indirectly. When phytoplankton grows, less light penetrates. When this occurs, the deeper individuals do not receive adequate light. Thus, phytoplankton are self-limiting.

Many predators rely on vision to capture prey. Light penetration is vital for these organisms. Conversely, many organisms are nocturnal or take refuge in dim areas to escape predators.[2-26]

Salinity -

Salinity is considered a physical rather than chemical factor because of the effect on "specific gravity control and variations in osmotic pressure" on organisms.[2-27] High water salinity decreases the organisms' relative specific gravity and osmotic pressure.

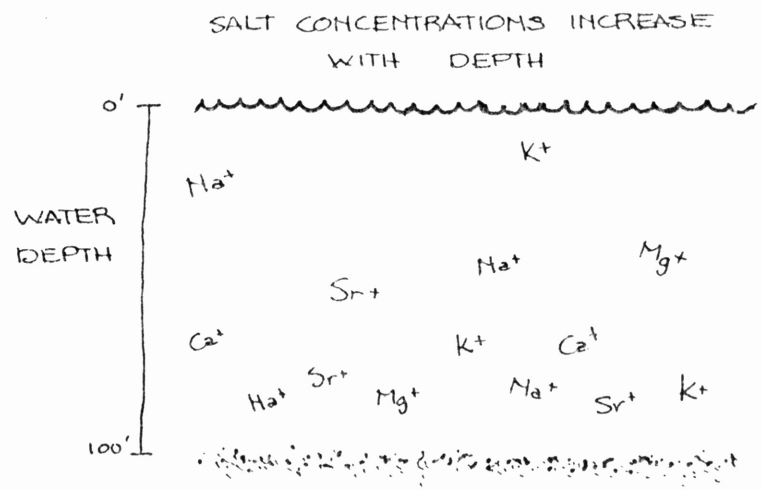


Figure 2-12
Salt Concentration with Depth

The salinity range is higher in bays and estuaries since the volume of freshwater runoff fluctuates greatly. In open ocean, the salinity range is more stable. "However, it appears possible that some deep sea forms may be particularly sensitive to differences in specific gravity."[2-28]

Salinity is extremely important to the forms that depend on water to support their bodies. As many of these forms go deeper, their relative specific gravity decreases with the greater concentration of salt found at lower levels. With this decrease, the organisms apply energy to go deeper. If they remain still, the imbalance in specific gravities will cause the organisms and that of the water reach a balance. Conversely, more dense organisms that dwell at deeper regions apply energy to rise.

Pressure -

"The pressure increases 1 atmosphere (14.7 lbs/in^2) for every 10 meters (33 feet) of water."[2-29]

With pressure, gases in semi-solid containers (such as balloons, air bladders and lungs) compress. Many nektonic organisms utilize this

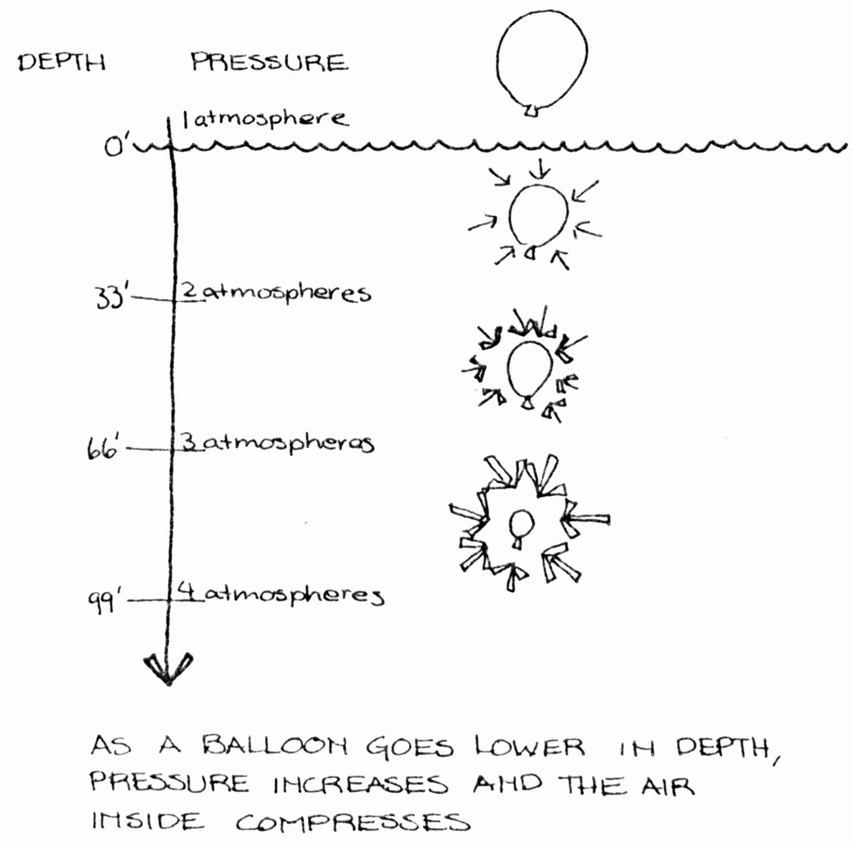
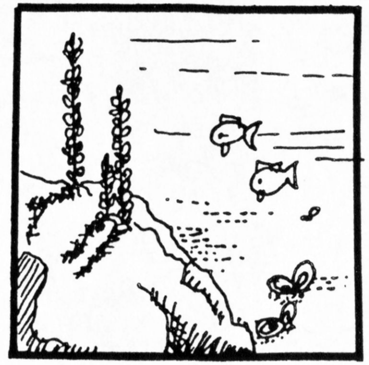


Figure 2-13
Pressure and Depth

principle. To combat relative higher specific gravities in more saline water at greater depth, an air bladder is utilized by certain organisms. As these organisms swim deeper, the bladder compresses and they gain a higher overall density. However, most organisms do not have such an air bladder and must therefore exist only at shallower depths and lower pressures.

Again, nitrogen and other gases become more soluable at greater pressures. The concentrations of these compounds affect the range beyond which many organisms cannot exist. For example, a high concentration of hydrogen sulfide is mandatory for the existence of certain organisms. Conversely, hydrogen sulfide-rich upwelling from the areas of higher pressures and greater depths, cause death to other organisms.

Ecosystem Needs/Management Considerations



Chapter III - Ecosystem Needs/Management Considerations

The network of existing species in any environment is determined by the characteristics of that environment. Thus, each species has an ecological niche and certain survival strategies. There is a high degree of overlap in these niches and strategies. Because of the subtle interplay of needs, management strategies have to be determined for the ecosystem.[3-1]

Management can occur in two modes. These are external and internal management. The former consists of off-site management. In this case, management on the land should be of benefit to the underwater ecosystem. For example, control of pollution on the land is a management tool that benefits the aquatic environment.

"Any significant discharge of suspended solids, nutrients or toxic chemicals is presumed adverse and is unacceptable."[3-2] This statement suggests that the control of pollution from the land is necessary for the maintenance of the aquatic environment. Suspended solids should be controlled by minimizing terrestrial erosion. Also, dredging which adds to the amount of suspended material should be minimized and then managed carefully. The introduction of excessive amounts of nutrients which stimulate growth of some life forms at the expense of others should be minimized. This necessitates the exclusion of fertilizers near the water's edge and the strict limiting of dumping of raw or processes sewage into the water or where it can readily leach into the water. The use of toxic materials such as herbicides and pesticides should also be managed carefully, particularly at the water's edge. In addition, industrial and chemical wastes should be strictly controlled.

Internal management constitutes those management techniques which can be employed on site. These include maximizing illumination, substrate diversity, circulation and optimal temperature while minimizing waves and high velocity currents and controlling salinity.

Incoming solar radiation which converts raw chemical compounds to necessary compounds through photosynthesis is the beginning of energy flow within the aquatic environment. Thus, the photic zone is the area of most abundant and diverse aquatic life. Ultimately, this zone is the most stable and should be maximized. This necessitates the maximization of water clarity which creates a deeper photic zone. Turbidity is an occurrance which decreases clarity while damaging fish and invertebrates with the increased water velocity. Thus, turbidity should be minimized.

Many organisms rely on particulate or solid substrata for protection (hiding or camoflage). Diversity of substrata should be maximized for greatest diversity of organisms. This substrata diversity should include sand, gravel and large, solid material. Solid substrata is also utilized by much aquatic life for a reference point.

Solid substrata should not interfere with circulation patterns. Sessile organisms rely on water movement to bring nutrients. Damaging currents, however, should be minimized by introducing solid substrata which limits high water velocities. Unfortunately, turbidity is increased when natural circulation patterns are disturbed. The increased turbidity is detrimental to both fish and invertebrate. When the current is constricted by solid substrata, however, an area of protection from high water velocity and turbidity is developed.

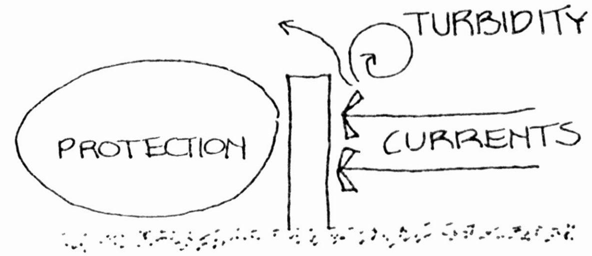


Figure 3-1
Application of Solid Substrate to
Limit Swift Currents

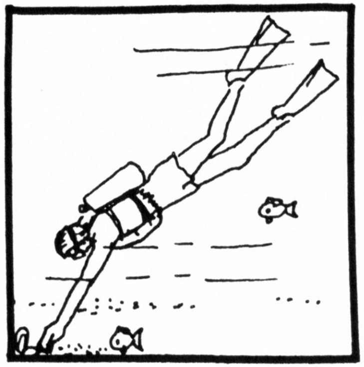
Increased temperature tends to increase diversity of organisms. Thus, organisms access to warm water should be maximized. This can be done by providing opportunities for food and protection within the higher thermoclines.

Waves, like turbidity, prevent sessile organisms from attaching and should therefore be minimized. Since waves are produced by surfaces (particulate or solid) that are close to the water surface, all substrate should remain at more than half the wave height at low tide.

High and excessively low salinity decreases the diversity of organisms which may survive. Thus, salinity should be kept at "normal" levels. Increased runoff of freshwater (external management) should be minimized in the marine environment. Also, opportunities for food and protection should be maximized at the upper levels where saline concentrations are not as extreme.

Chemically, high concentrations of oxygen and carbon dioxide are necessary. Nutrients such as nitrogen and phosphorous are required but can be lethal to certain organisms if occurring in excessive levels. If nutrient concentrations become elevated, this can stimulate growth of some life forms, resulting in elimination of others. Typically, the over stimulation occurs with the plankton to the exclusion of larger organisms. Therefore, the chemical constituents of the water must be managed to sustain the ecological niches of larger organisms as well as smaller organisms.

Physiological Needs of the Diver



Chapter IV - Physiological Needs of the Diver

As the diver enters the water, he/she becomes part of the aquatic ecosystem. The same physical factors which affect native organisms, impact human organisms as well. These factors include waves, currents, temperature, illumination, salinity, and pressure.

Waves -

"Surface travel to and from the site, mooring at the site, entry and exit can be made (uncomfortable), even dangerous, by wind and waves."[4-1] Waves may knock the diver's mask off or delay air intake which may panic the diver.

Currents and Tides

The diver's environmental knowledge should include cognition of regular water flows for diving areas.[4-2] Time of dive, entry and exit points, and location of dive are all decisions that should be planned around the direction and speed of currents. "A diver's horizontal speed generally averages less than one knot. Thus, trying to gain against a one knot current could be an exhausting and loosing battle."[4-3]

The time of the dive should be effected by tidal movement. Between the ebb and flow of tides is a period of little or no motion. In this period (usually about one hour), the safest and least exhausting diving occurs.[4-4]

The entry and exit points of the dive should be determined by the current direction. Swimming with the current, rather than against it, is usually desirable[4-4] (see Figure 4-1).

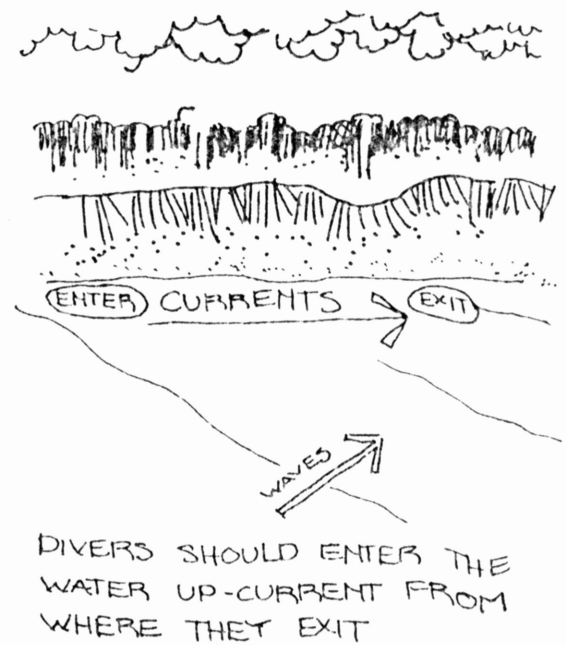


Figure 4-1
Entry and Exit Points
in Terms of Current

General location of the dive in terms of current should be planned. Undertow and rip currents are often causes of diver panic. Undertow, or backflow usually does not extend beyond the area of the waves.

Rip currents are an extremely dangerous situation. "This particular type of current is caused by water flowing seaward through a gap in a bar, (jetty,) or reef, wetting up a swirling action inshore leading into a strong current outward, which carries the unwary or inexperienced diver rapidly out to sea."4-5 Rip currents typically remain along the side of the bar, jetty or reef that is perpendicular to the shoreline. Then, the rip current dissipates and loses velocity. Finally, the current again becomes managable for the diver.

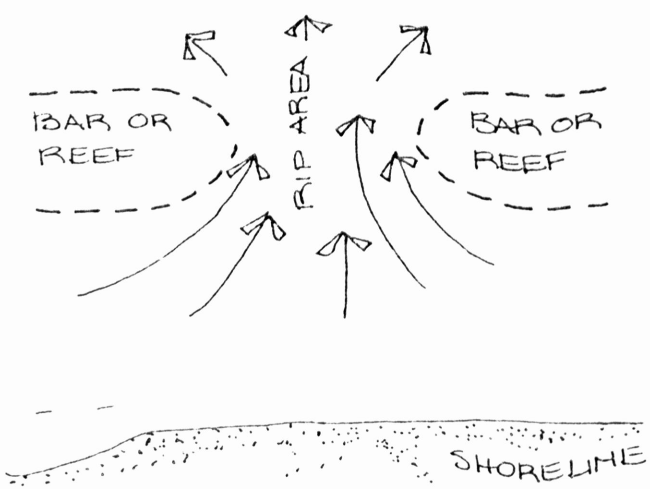


Figure 4-2
Rip Currents

Temperature -

Like most aquatic organisms, temperature is a limiting factor to humans. Certain protective gear is necessary in cold water or hypothermia

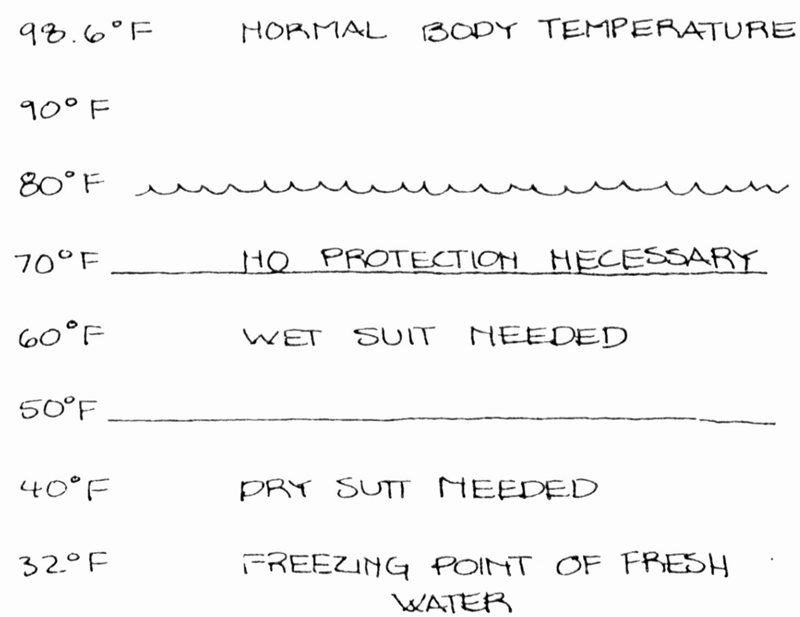


Figure 4-3
Temperature and Protective Gear

may occur. Hypothermia is an affliction whereby an individual loses internal body temperature. Since water has high heat absorption properties, the effect of cold water is more dramatic than that of cold air. In waters less than 70°F, a wet suit is needed. Below 50°F, a dry suit is necessary for a comfortable and safe dive.

Illumination -

As illumination decreases, so does the color range that is perceptable to the diver. When ample illumination exists, the complete color spectrum can be seen. As light decreases, red is absorbed. Orange is lost next, Then yellow, green, blue then indigo and finally vio-

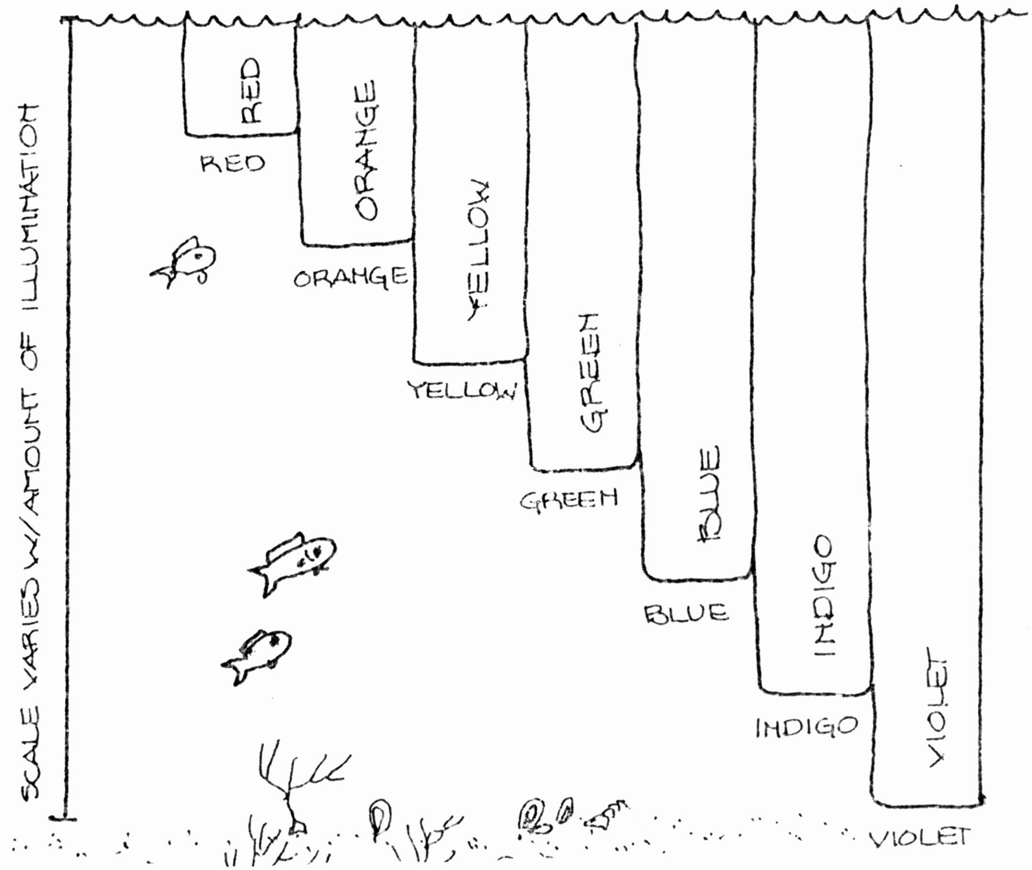


Figure 4-4

Color Absorbtion Properties

let are absorbed.

Areas "can become dangerously dark when currents stir up or carry in with them particles that reduce the penetration of light."[4-6] Poor visibility is a hazard that increases the likelihood of cutting skin and damaging equipment. Sharp edges, old pilings, rocks and sunken hulls are obstacles which may not be avoided when they cannot be seen.[4-7] Darkness and disorientation also contribute to diver stress and panic.

Divers are able to decrease the effects of poor illumination with waterproof lights to supplement natural illumination.

Salinity -

Skin and scuba divers are not affected by salinity to a great extent. Divers can be compared to fish with air bladders since they utilize bouyancy compensators. A bouyancy compensator is a device by which the diver adds or releases air to possess the correct specific gravity.

Pressure -

Increasing pressure affects the body in basically two ways. The effects can be direct, which are largely mechanical, or indirect, which are related to changes in gas volume from the addition or release of pressure.

The solid tissues of the body can "transmit pressure through itself without being compressed."[4-8] The soft tissue is affected greatly by increasing pressure. These areas include spaces associated with the ear, the sinuses, lungs and airways, gas pockets in the stomach and intestines, and any air space along the surface of the body.[4-9]

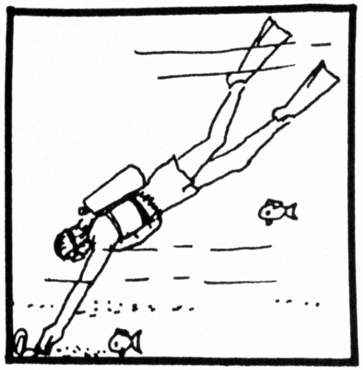
In these areas of the body, pressure differences build up and cause barotrauma (injury due to pressure). These injuries include over-inflating the lungs, and sinus/ear squeeze.[4-10] Over-inflating of the lungs occurs when compressed air is breathed from scuba takes under pressure. Then, the diver ascends without releasing the rapidly expanding air from the lungs. Sinus or ear squeeze occurs when the air within these cavities contracts under increased pressure. When additional air cannot be supplied, the result is damaged tissue.

Changes in gas volume has a drastic effect upon the body. Oxygen poisoning, nitrogen narcosis, decompression sickness and air embolism may occur due to increased soluability of gases at increased depths and pressures.[4-11]

Nitrogen narcosis is caused by an increase in the amount of nitrogen dissolved in the body. As depth is increased, the amount of dissolved increases. The main symptom of nitrogen narcosis is an extreme feeling of euphoria which will lead to death beyond 250 feet of depth or cause the diver to make a fatal mistake. As the diver ascends, the symptom vanishes. Decompression sickness occurs when the diver ascends too quickly and air bubbles form in the joints.[4-12]

Air embolism forms when gases which have dissolved in the blood stream re-emerge as gas when pressure is released. The gas then becomes trapped within the veins.[4-13]

Psychological Needs of the Diver



Chapter V - Psychological Needs of the Diver

The psychological needs of the diver can be divided into two categories. These include alleviation of stress and fulfillment of diver motivation.

Stress while diving can eventually lead to dangerous situations. Time pressures, excessive tasks, exertion, cold, buoyancy problems and disorientation all lead to stress. Effects of stress include the narrowing of mental abilities (including perception, response time, cognition or analytical reasoning), and increasing the chances of panic.[5-1] As a result, a host of diving techniques may not be observed and serious injury or death may come to the diver. For example, a panicked diver may not observe techniques of dealing with pressure and obtain air embolisms or decompression sickness.

Little research has been done to determine diver motivations. Even so, some insight has been gained by diving literature and by the survey presented in the introduction and Appendix I. Both mental and physical motivations appear to exist.

Fascination/excitement is the most often

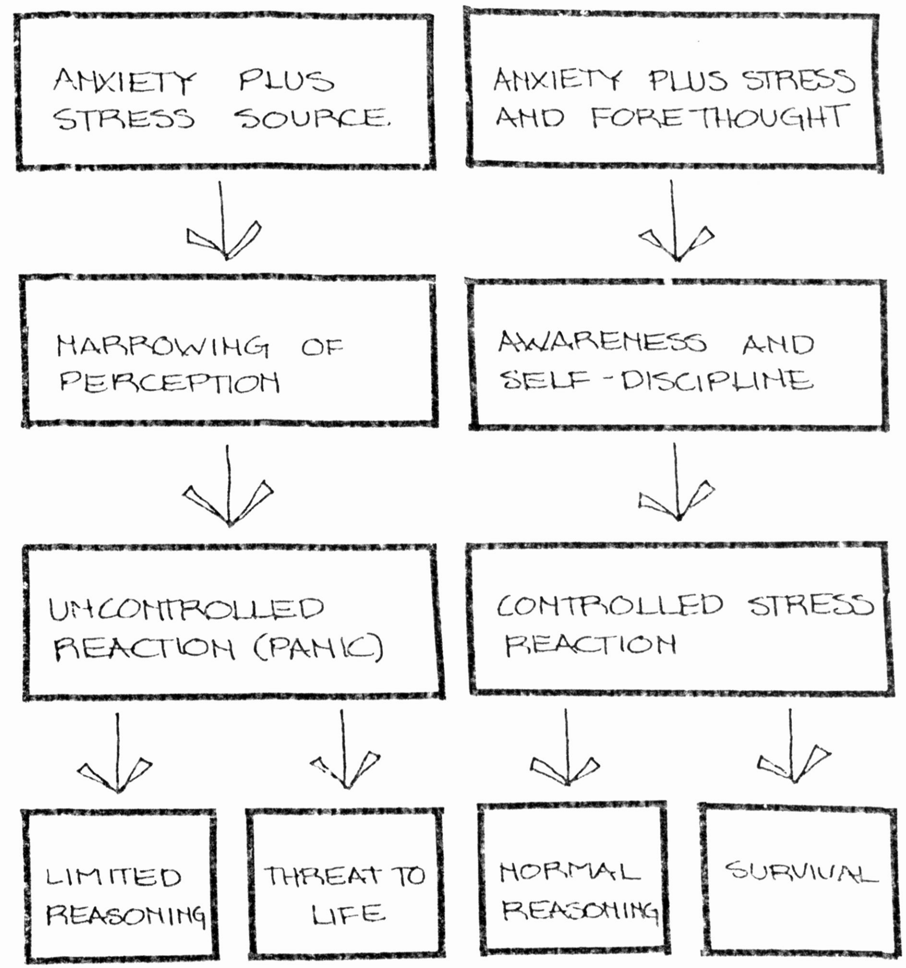


Figure 5-1

Flow Chart of Panic vs. Control

cited motivation for diving. Fascination can ultimately be tied to the senses of the diver and perception of color, form, texture and movement. Excitement (another often cited motivation) is an internal response to those sensations.

Exploration is the seond factor emphasized by divers. This indicates that people dive to satisfy a curiosity and gain an understanding.

Both fascination/excitement and exploration relate to the cited motivation of viewing the ecosystem. "Observing marine creatures at near touching range can be a never ending source of fascination and entertainment ... Perhaps it is the (excitement) of establishing a brief communication link with a totally wild animal."[5-2]

The third most quoted motivation is the freedom or flying sensation. The diver experiences the third dimension since he/she may go up or down at will. This promotes the sensation of freedom or flight. The intensity of this sensation can be increased or decreased with scale and frame-of-reference. Scale and frame-of-reference is affected by the depth of the water and the size and proximity of objects. Diving depth is optimum if the bottom can be seen but is well beneath the diver. Solid substrate at or near diver's elevation provides a frame-of-reference while the objects may define the edge of a space. Scale is influenced by the size of the space. Therefore, a variety of spaces with

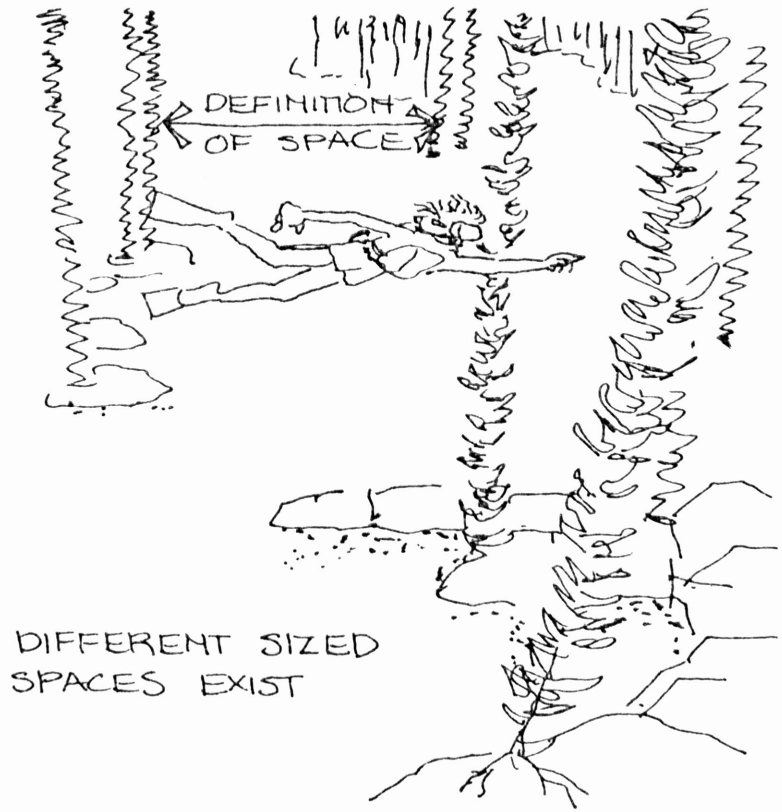


Figure 5-2
Elements which Promote the Sensation of Flight

areas to swim through, around, over, and under promotes varying scale and frame-of-reference in a diving environment.

Social interaction is considered a primary motivation for divers. It is generally accepted that divers should pair off for safety reasons. Social interaction grows out of this. After the divers return to the surface, they typically compare experiences of their dive. Many times the ego will enter into diving and social interaction. "It is no secret that some insecure people attempt to build or strengthen their ego as skydiving, mountain climbing, and scuba diving."[5-3]

Diving for sport and recreation was also commonly cited. Diving is a diversion that unites exercise with other motivations. The motivations include those mentioned previously as well as photography, spearfishing and viewing historically significant wrecks.

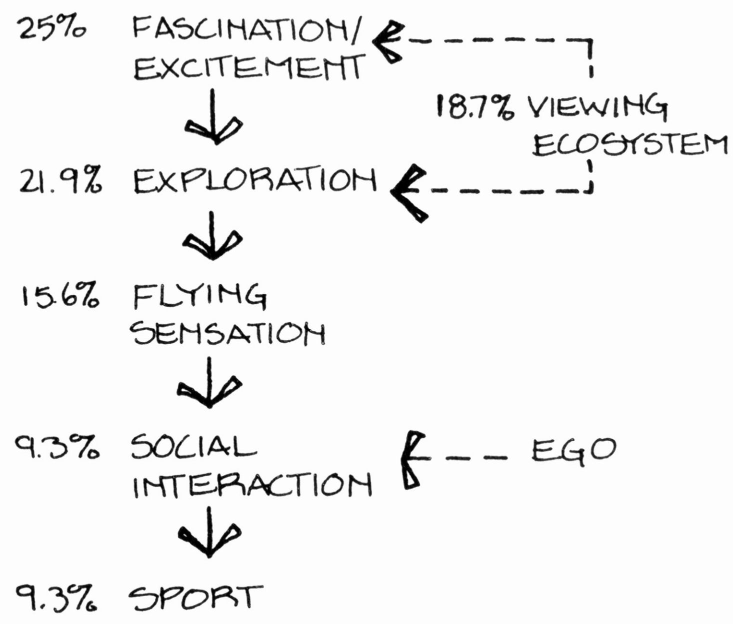
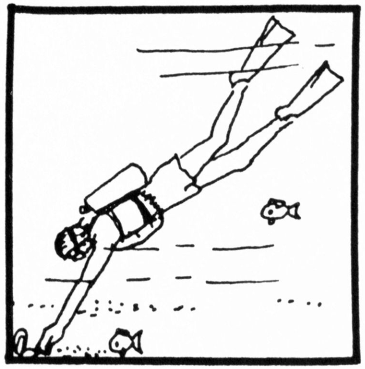


Figure 5-2

Hierachy of Diver Motivation

Diver Needs/Management Considerations



Chapter VI - Diver Needs/Management Considerations

The needs of the diver are a composite of both physiological and psychological aspects. The degree to which the needs are met is a function of the diver needs correlated with the ability of the ecosystem to satisfy these needs. The appropriate management strategy should respond to this correlation. By such management, diver stress should be minimized and motivation satisfaction maximized.

When entering the foreign aquatic environment, the diver experiences stress. This stress should be taken into account when managing the underwater environment. Waves, currents, turbidity, temperature and pressure physiologically affect the diver, and therefore should be managed.

Since waves and strong currents can be exhausting and dangerous, they should be minimized. Waves are minimized by removing solid substrate from near the surface of the water. Turbidity is minimized by allowing currents to flow freely. However, in areas of over one knot, currents may be blocked to gain an area of protection.

Unprotected divers experience less stress in water that is above 70°F. Since water temperature varies inversely with its depth, the best diving environments should be established in shallower water. The diving area should be above 70°F most of the year if possible. In regions that are warm throughout the year, diving areas may be established in deeper zones that are above 70°F.

Because of the vast physiological problems associated with pressure, diving areas should be established at shallower depths. Accounts of barotrauma occur less frequently above 33 feet of depth (1 atmosphere). Thus, the best opportunities to satisfy diver motivation occur above this point.

The major reasons people five are the psychological benefits involved. To maximize motivation satisfaction, water clairty, illumination, an abundant and diverse biotic communty, and a frame-of-reference must be present.

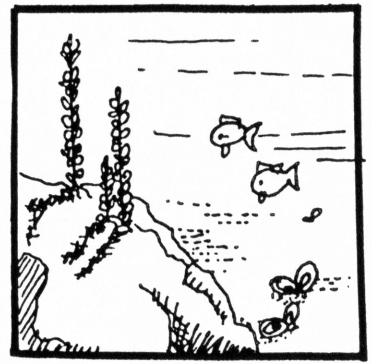
With water clarity; color, form, texture, and movement can be perceived. It is these elements that trigger fascination and excitement of the diver. Better water clarity and visibility is obtained by minimizing suspended sediments. Control of dredging and erosion can do much to lower sediment bad. Turbidity which suspends sediments must also be minimized to effect water clarity.

Illumination also benefits visibility. It aids the diver in the perception of the full color spectrum, form, texture, and movement. The limiting factors of aquatic illumination are suspendced sediment, depth, and shade. Suspended sediment filters the light. The amount of suspended sediment is closely tied to the depth of the water. With the increase of depth, the total amount of sediment from light source to diver increases. Shade from clouds, trees and other objects greatly decreases the amount of light. Thus, diving areas should not be established in areas where a great amount of shade exists.

Aquatic life adds variety in color, form, texture and movement. Thus it promotes fascination, excitement and exploration. An abundant and diverse biotic community is obtained by following the management strategies developed in Chapter III.

A frame-of-reference is necessary to maximize the diver's perception of the third dimension. Large, perceptable spaces should be created. The frame-of-reference should include varied scales of spaces (tight and expansive) within which the diver can swim.

Characteristics of Naturally-Occurring Aquatic Environments



Chapter VII - Characteristics of Naturally Occurring Aquatic Environments

Abiotic and biotic factors combine to give aquatic environments varying characteristics. However, underwater environments may be divided into two general categories. The categories, saltwater and freshwater, differ vastly in their abiotic and biotic variables.

Saltwater environments include oceans, gulfs, bays, and channels. These enviroments tend to have relatively high specific gravity and a amount of currents, turbidity, wave action and stable temperatures in comparison to freshwater. Thus, the biotic community is quite different between the two.

The saltwater environment is impacted greatly by the type of base material that exists. Rock-based substrata has the capability of promoting the establishment and growth of coral reefs and kelp beds. These two biotic communities represent extremely popular diving environments. Particulate-based saltwater is that which consists primarily of gravel to clay-sized particles. Once boulders are added, that area falls into the division of rock-based. It is the shifting particles of the particulate-based saltwater environment that makes it unique.

Freshwater environments are inland underwater environments which are either runoff or spring-fed. Of the freshwater environments, lakes are the best for diving. Although both particulate-based and rock-based lakes exist, the water source and the size of the lake determine the character of the lake.

Saltwater	Freshwater
Rock-based	*Lakes
*Coral Reefs	Spring-fed
*Kelp Beds	Runoff-fed
*Particulate-based	

Figure 7-1
Typical Diving Environments

Coral Reefs -

Coral reefs are well-known for their beauty and richness but are also biologically stable communities. "It is primarily through food web interactions that the coral reef(s) achieve (their) biological stability."[7-1]

Coral reefs are diverse and intricate ecosystems. It is the coral itself that supplies the substructure to suppor the biotic diversity.

Corals are animals that live in colonies and filter plankton for food. For protection, they produce a calcareous outer skeleton. When a coral polyp dies, another polyp grows over it. Over years, the colonies become substantial structures. At times, the older calcareous skeletons will dissolve into the water. Caves result with the dissolution of the coral structure.

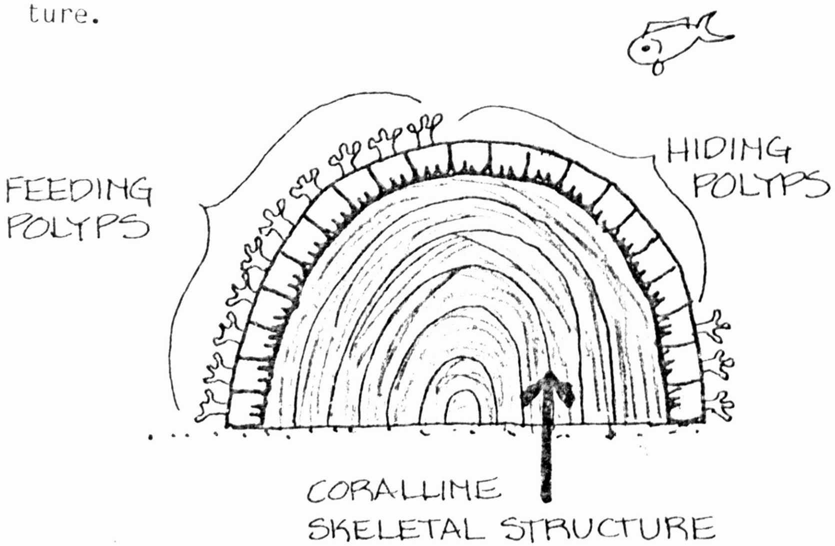


Figure 7-2
Physiology of A Coral Structure

Corals are classified by terms of form. These classifications include branching, brine, plate and encrusting corals.[7-2] In addition to the varying shapes, corals also consist of a wide range of colors.

With corals supplying the solid substructure, plants and animals find many protection, camoflage, and feeding opportunities. Many species of alga, tubeworms, shellfish, echinoderms and fish are included in the coral reef community. Thus, diversity of biota as well as color is high. Coral, sponges, shellfish, fish and alga combine to create a brightly colored environment.

Unfortunately for the diver, there are limitations for the existence of coral reefs. Temperature, light and sediment load are vital limiting factors.

"Distribution ... is restricted to areas where mean annual water temperature is (not less than) 70°F.[7-3] However, certain types of coral live in water below the 70°F average. The northwestern Atlantic harbors coral animals which do not build substantial reefs and attract stable biotic communities.

Corals require readily available plankton for nourishment. To obtain this environment, solar radiation must be readily attainable by the plankton. Thus, corals occur in shallow water with high visibility.

Precipitating sediment has a negative impact upon the coral. Normally, a colony can cleanse itself of sediment. In areas where excessive sediment has been added due to dredging and erosion, the coral is unable to adequately clense itself. Once sediment begins to accumulate, the coral cannot feed and dies. In such cases, the coral cannot re-establish since the solid substructure has been covered by particulate matter. This matter shifts with currents and turbidity. Thus, sessile organisms cannot attain the stability they require.

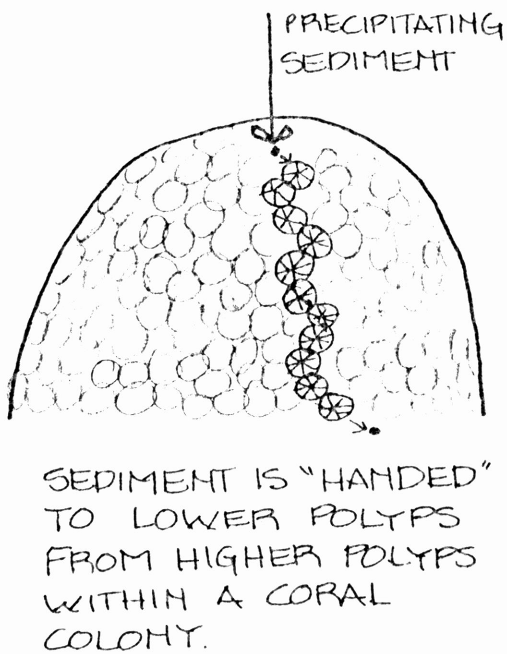


Figure 7-3

Coral Colonies and Sediment

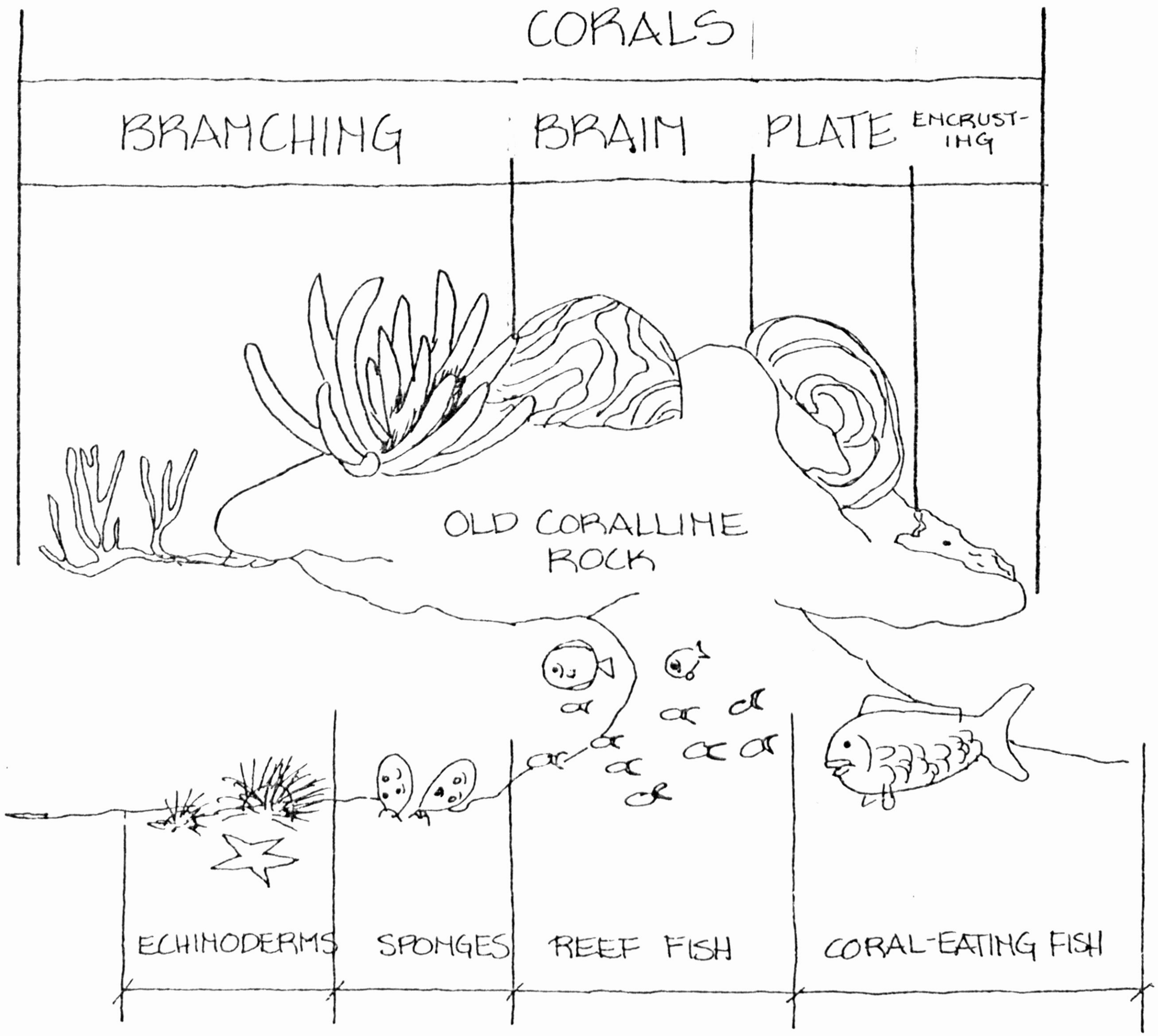


Figure 7-4
A Coral Community

Kelp Beds -

"Kelp beds are an important component of certain ecosystems, especially those of the ... Pacific Shores."[7-4] Kelp can be found in rocky, shallow depths (0-11 feet) where "water quality permits alga to survive."[7-5] Like coral, kelp requires solid substrate for stability. Without this substrate, currents would have the ability to remove the sessile hairs from the shifting particulate matter, thus destroying the plant.

Kelp affects both the abiotic and biotic factors within the aquatic environment. Abiotically, "kelp beds exert a breaking influence on wave surges and act as a stabilizing factor to retard erosion of the shoreline."[7-6] This factor decreases suspended sediment within the water, thereby, increasing visibility. Biotically, the kelp forests "offer refuge for fish which require this protection as a nursery ground for there young and as cover and escape from predators. Abalone, crabs, snails and sea urchins are the consumers of kelp. When conditions are favorable, they can literally destroy kelp forests.[7-7]

Kelp forests contain a diverse, yet quite uncolorful, biotic community. This environment includes extremely large flora and fauna. Kelp may grow to over 100 feet in length. Thus, a very dramatic environment is created. Sea mammals also are included in the kelp community. Sea otters are often observed by divers .

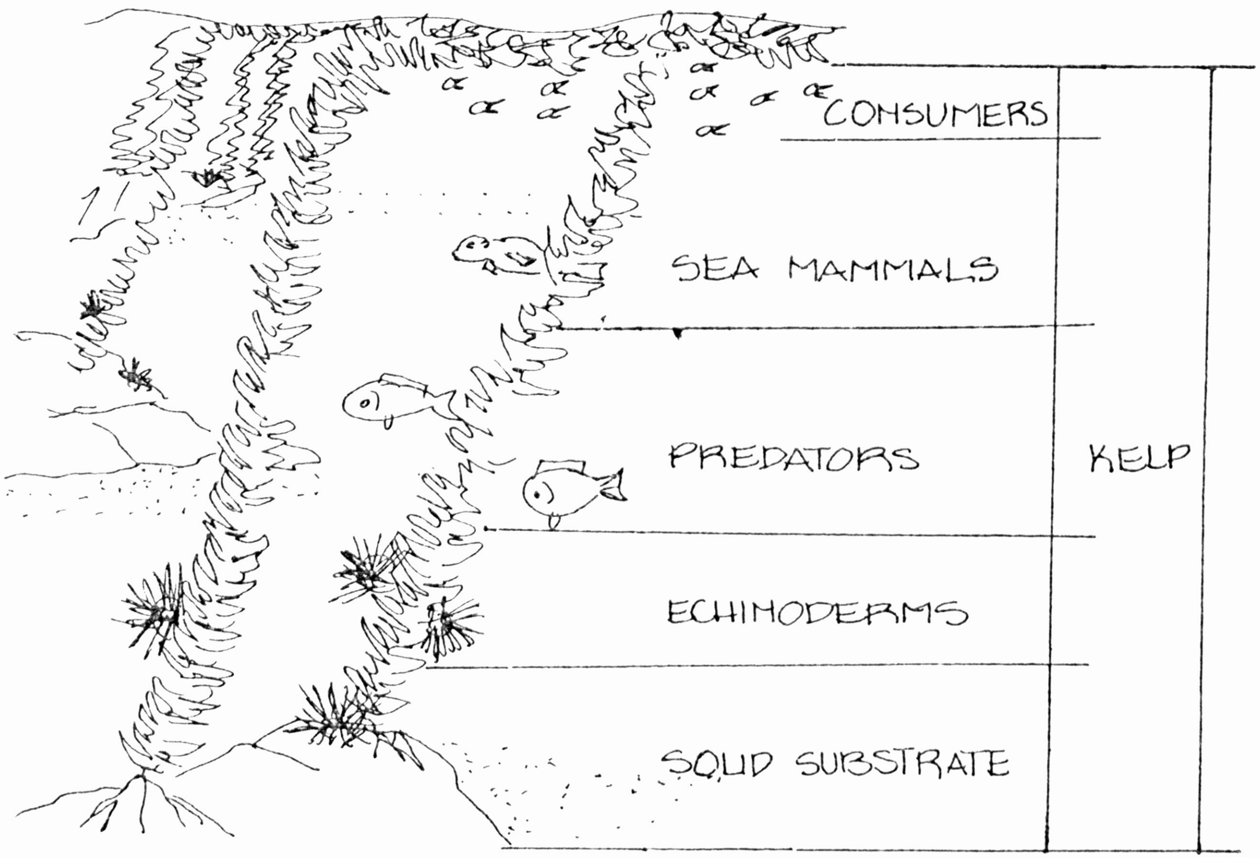


Figure 7-5
The Kelp Bed Community

Particulate-based Saltwater-

"In ecological terms, a (coral reef and) kelp bed may be 100 times more productinve than the adjacent sand bottom."[7-6] In terms of production, particulate-based areas are comparable to the terrestrial deserts.[7-8]

Special problems exist with particulate-based marine areas. With a relatively flat or gently sloping bottom, wave surges and currents are not hindered. Therefore, rapid erosion of the shoreline and high sediment load are common. However, visibility varies with the type

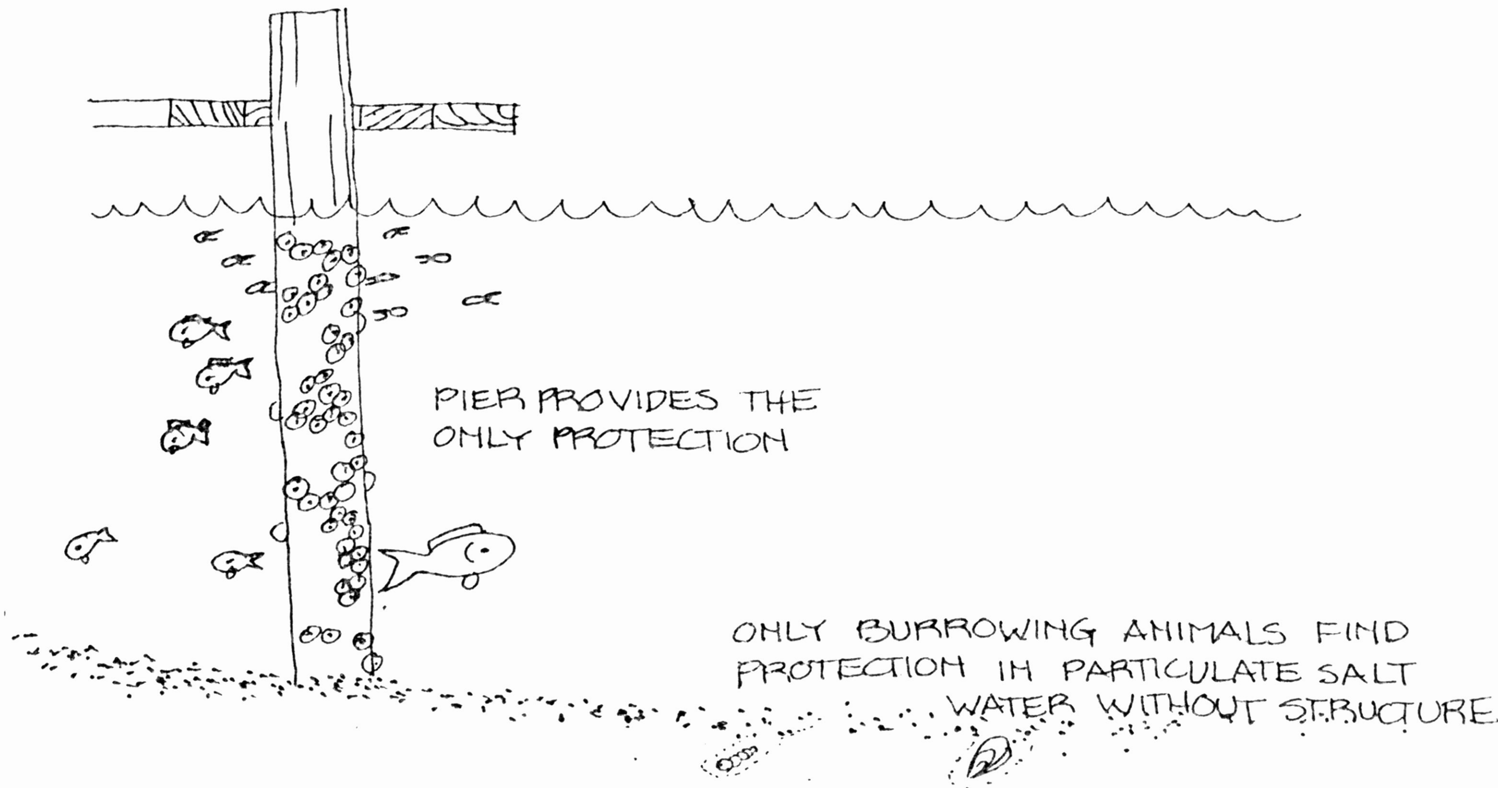


Figure 7
Character of Particulate-Based Saltwater

of sediment and amount of turbidity. If the sediment is predominately silt-sized, more is suspended than if it is sand-sized. By the same token, more is suspended if high turbidity exists.

Biotically, "hiding places are at ... a premium."[7-9] Thus, refuge from predators is not available and biotic diversity is low. Only when a rock outcrop, pier or other solid substrate exists, is there adequate abundance and diversity of sea life.

Although sessile organisms cannot attach to particulate matter, animals do burrow in it.[7-10] Unfortunately, divers are not able to easily view this type of biota.

Lakes -

"Lakes are bodies of slowly moving or standing water that occupy inland basins ..."[7-11] Characteristics of lakes vary more widely than do those of the ocean environment. Because of the smaller volume of lakes, they are more "likely to fill in or be drained, to evaporate or freeze solid ..."[7-12] Abiotic and biotic factors are greatly affected by the volume and transitory nature of lakes.

Lakes that are fed by runoff contain much of the suspended sediment that is carried by the streams.[7-13] "Current and wave action along the shoreline is responsible for additional erosion and sediment deposition."[7-14] For these reasons, runoff-fed lakes tend to have particulate bases and poor water clarity. Conversely, spring-fed lakes tend to have solid bases, good water clairty and lower temperatures.

Because of the lower volume of lakes (as compared to saltwater bodies), lakes have slower currents and circulation. In addition, annual water temperature fluctuations have a much greater range. Thermoclines are also more distinct.

Biotic diversity varies greatly between lakes. For example, lakes fed by sulphur-rich springs are greatly limited in biotic diversity while runoff-fed lakes with a fertile particulate base and ample water clarity have a high biotic diversity. Lakes that provide a complete habitat for aquatic plants tend to have high biotic diversity. The plant material provides food and shelter for fish, invertebrates and amphibians. Regions that have biotic diversity and water clarity provide color, movement, form, texture, as well as frame-of-reference to divers. Tree roots, branches and certain types of aquatic plants provide the spacial definition necessary for frame-of-reference. While lakes predominately are composed of greens and browns, certain types of biota provide other spectral colors to the diving environment.

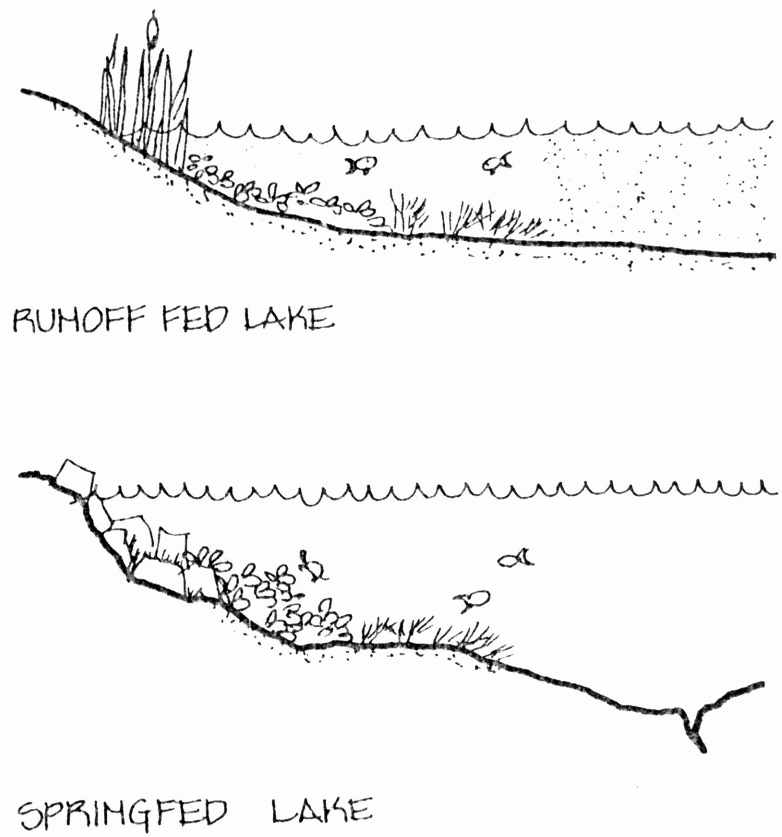
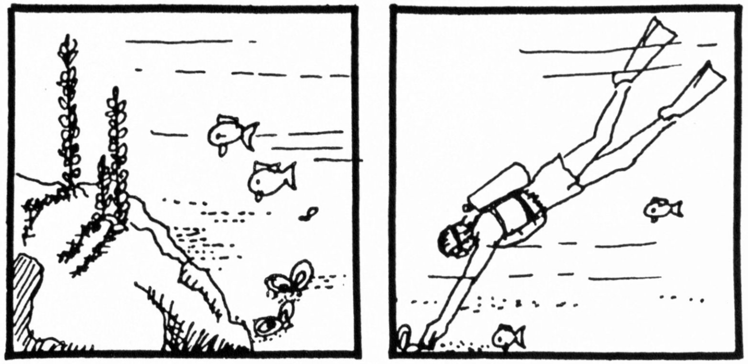


Figure 7-7
Character of Various Lakes

Evaluation of Naturally-Occurring Aquatic Environments



Chapter VIII - Evaluation of Existing Naturally-Occurring Environments

Not surprisingly, the ecosystem and diver needs tend to be highly correlated, although they occur for different reasons. For example, illumination and water clarity are necessary to allow autotrophs (self-feeding organisms) to bring energy into the system while divers desire them to view a diverse aquatic life. In addition, the biotic community requires protective solid substrate to provide greater abundance and diversity of biota while divers may gain an increased frame-of-reference from the substrate. However, the success of specific diving environments is determined by all of the management considerations established in Chapters III and VI.

Coral Reefs -

Mature coral reefs support many diver and ecosystem needs. The growing conditions for coral is an effect of certain ecosystem needs. Illumination, water clarity, circulation and average temperatures above 70°F are necessary

Ecosystem Needs	Diver Needs
Maximized Illumination	Maximized Illumination
Maximized Water Clarity	Maximized Water Clarity
Maximized Substrate Diversity	
Maximized Circulation	
Optimal Temperature (above 70°F)	Optimal Temperature (above 70°F)
Minimized Turbidity	Minimuzed Turbidity
Minimized Wave Action	Minimized Wave Action
Adequate Protection from Excessive Currents	Limited Current Velocity (below 1 knot)
Controlled Salinity	
	Minimized Pressure
	Minimized Jagged Edges
	Maximized Abundance and Diversity of Aquatic Life
	Adequate Frame-of-Reference
	Elements such as color, form, texture and movement

Figure 8-1

Synthesis of Management Considerations

for the existence of coral. Thus, the congruent diver needs are satisfied. Since coral requires adequate illumination, the colonies tend to grow in shallow water. This is advantageous for divers because pressure decreases as depth decreases. However, coral increases wave action when it exists too close to the water surface.

Many ecosystem and diver needs are satisfied directly by the coral. Many types of coral create frame-of-reference as well as variety of color, form, texture and movement. Coral attracts a diverse and abundant biotic community which also adds color, form, texture, and movement. Coral supplies the ecosystem with solid substrate as well as particulate substrate from weathering processes. This substrate diversity increases biotic diversity.

Unfortunately, coral produces sharp, irregular edges which may seriously cut the diver or damage equipment. In addition, coral may grow in currents of over 1 knot.

Kelp Beds -

Kelp beds satisfy many diver and ecosystem needs. Kelp affects many abiotic processes for the benefit of divers and the ecosystem. It slows currents without increasing turbidity. However, circulation is not decreased and waves are not increased. Kelp is also affected by abiotic conditions. It requires solid substrate for stability. The solid substrate is usually surrounded by particulate matter. Thus, substrate diversity is usually present. Kelp as an autotroph, requires ample illumination, and typically grows in extremely clear water (25-75 feet visibility).

Kelp grows as deep as 100 feet. However, pressure is not a problem since it grows vertically from the substrate to the water surface. Thus, the diver can descend to the desired depth and pressure. This verticality creates a frame-of-reference for the diver at a convenient diving depth. In addition, biota feeds at the necessary depth, pressure and illumination intensity. Although kelp has no jagged, sharp edges, the diver must beware of sea urchin spines which are part of the kelp community. The biotic community which is attracted by the kelp is fairly diverse and nominally abundant.

Kelp does not usually coexist with the satisfaction of the ecosystem and diver need for 70°F or above water. It requires 50°-60°F temperatures. Kelp beds do not provide a variety of color, form, texture and movement. Green color and vertical form is extremely dominant. In addition, a diver may become tangled in the kelp and become unable to ascend.

Particulate-Based Saltwater -

The low biotic abundance and diversity of particulate-based saltwater indicate that the needs of a rich and diverse biotic community remain unfulfilled. Since many diver needs are dependent upon ecosystem diversity and upon factors that contribute to ecosystem diversity, it follows that these needs also remain unfulfilled.

Although illumination may be adequate for autotrophs, the limited solid substrate prevents attachment and growth of both micro and megaflora. This, in turn, seriously reduces the amount of heterotrophs that the area is able to sustain. Strong currents are not hindered. However, turbidity and wave action is minimized by the lack of solid substrate which increases these factors.

Since biotic abundance and diversity is low and no solid objects exist, diversity of color, form, texture and movement is not present. In addition, frame-of-reference is not created.

Temperature varies in particulate-based saltwater depending upon latitude, depth, and current flows. Thus, the temperature might be optimal.

Fortunately, this environment has biotic potential. Once solid substrate and protection for biota is placed in this environment, abundance and diversity of sea life increases sharply.

Lakes -

Although lakes are extremely variable, certain typical characteristics can be identified. The water volume of lakes is much lower than that of marine environments. Thus, currents are much slower and wave action and turbidity are not a major force upon the biotic community. However, circulation is still present. The surface water temperature varies greatly throughout the year. Because of the drastic changes of surface water temperature and low currents with gentle mixing processes, thermoclines are well defined with extreme temperature differentiation.

Spring-fed lakes vary greatly from runoff-fed lakes. Spring-fed lakes typically have better illumination, water clarity and substrate diversity. They have solid substrate with some particulate sediment.

The lakes that supply the needs for megaflora typically have the most diverse and abundant biotic community. Megaflora also produces a frame-of-reference for the diver. Color, form, texture and movement is created by a diverse and abundant biotic community. Bright colors are not prevalent, but exist on a small scale. On occasion, branches produce sharp edges which may cut a diver or damage equipment.

Evaluation of Diving Environments -

When each diving environment is evaluated against the management considerations, a definite comparison between the environments may be made. Physiological and psychological satisfaction fulfilled by each environment may be viewed and evaluated.

Physiologically, rock-based saltwater satisfies 4 1/2 of the 14 management considerations. Particulate-based saltwater satisfied more needs with a 5 1/2 rating while lakes had the best rating at 6.

Psychologically, coral reefs fill most needs with a rating of 5. Kelp beds and springs were comparable at 3 while particulate-based saltwater and run-off lakes rated 1.

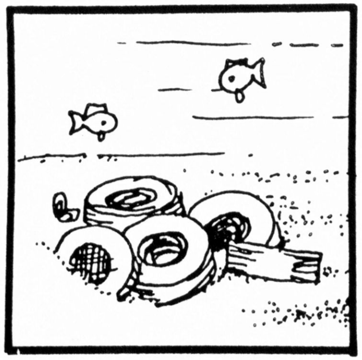
All of the management considerations weighted equally and totalled promoted a different evaluation rating. Diving environments characterized by coral reefs (11 1/2) satisfy most needs. They are followed by spring-fed lakes (10 1/2) and kelp bed diving areas (9 1/2). Run-off lakes (8) and particulate-based saltwater (7 1/2) fulfilled the least physiological and psychological needs.

These ratings correlate strongly with the diver survey. Respondents were asked in which aquatic environment they preferred to dive. Seventy-three percent preferred coral reefs. Coral reefs rated as having the best overall and psychological need satisfaction. Respondents cited spring-fed lakes and run-off fed lakes about equally at 2.6% and 3.9% respectively. The remaining 20% were less specific and simply cited "saltwater" as their preferred diving environment.

Evaluation of Naturally-Occurring Diving Environments

	Coral Reef	Kelp Bed	Particulate Saltwater	Springfed Lake	Run off Lake
PSYCHOLOGICAL					
Illumination	●	●	◐	●	○
Water Clarity	●	●	◐	●	○
Abundant & Diverse Aquatic Life	●	○	○	◐	◐
Substrate Diversity	●	●	○	◐	○
Circulation	●	●	●	●	●
Frame-of-Reference	●	●	○	◐	◐
Elements like Color, Form, Texture & Movement	●	○	○	○	○
	5	3	1	3	1
PHYSIOLOGICAL					
Optimal Temperature	●	○	◐	○	◐
Turbidity	◐	●	●	●	●
Wave Action	◐	●	●	●	●
Optimal Currents	◐	●	○	●	●
Optimal Pressure	●	●	●	●	●
Sharp Edges	○	◐	●	●	●
Restraint	●	○	●	●	◐
	4 1/2	4 1/2	5 1/2	6	6
	11 1/2	9 1/2	7 1/2	10 1/2	8

Evaluation of Present Artificial Reefs



Chapter IX - Evaluation of Present Artificial Reefs

Definition -

In 1974, Richard B. Stone, a leading authority in artificial reefs, defined artificial reefs. He stated that "...Artificial reefs (are) man-made or natural objects intentionally placed in selected areas of the marine environment to duplicate those conditions that cause concentrations of fish and invertebrates on natural reefs and rough bottom areas. By increasing the amount of reef habitat, artificial reefs provide the potential for increasing stock sizes of fishes. We believe artificial reefs can be an effective tool that states or other management agencies can use to develop fisheries which benefit both anglers and the economy of coastal communities (Buchanan 1974) and conserve the resource by increasing the habitat."[9-1] This definition acknowledges the need to attract both fish and invertebrates. Unfortunately, many definitions simply cite the need to attract fish which is the major need of the fisherman. According to South Carolina Wildlife and Marine Resources, "an artificial reef is one deliberately placed on the sea floor by man to attract fish."[9-2] Most definitions of artificial reefs (including both of the above) indicate that anglers are the major population for which artificial reefs are established. By definition, these reefs are not designed for the diver. Therefore, not surprisingly, they do not satisfy many diver needs.

Previous Research -

Research concerning artificial reefs has been done on an international scale for many decades. A wide range of structures have been tested. Even so, the criteria for these tests is often limited to the variety of and amount within each species of biota, and to the expense and longevity of the reef. Obviously, divers have more needs than those usually cited.

"At present, research is directed toward the preparation of species lists and the determination of the rates of colonization of the different reef materials. It would be more appropriate to assess a reef's success in terms of its enhancement of the area. ..For sport diving, an assessment of the increase in the number and variety of fish species seen and the improvement in the aesthetic quality of the aquatic environment is the typical research required."[9-3] Unfortunately, even this directive for different criteria to be used to determine the success of artificial reefs does not address all diver needs. Physiological and psychological needs are not identified. In addition, "aesthetic" remains undefined.

Typical Artificial Reefs

Concrete Boxes -

In 1957, shelters designed as artificial reefs were submerged. These shelters "were made of reinforced concrete two and one-half inches thick, shaped like a box, four feet square by 17 inches deep. On all four sides, openings were arranged that could be closed to suit the requirements of the experiments."[9-4] Since the criteria for design of these boxes was solely to provide protective areas for marine life, it was concluded that "old car bodies and less expensive discarded material (should) be used instead of concrete boxes."[9-5] Later experiments followed this suggestion. Researchers ceased the use of designed artificial reefs altogether and instead utilized discarded materials such as car bodies, tires, and rubble.

Car bodies -

Car bodies have been a popular material for artificial reefs. The have "little or no economic value" while providing substrata and protection for aquatic life.[9-6]

Unfortunately, car bodies are inappropriate in other aspects. Safety for the diver is minimal. Old vehicles weather poorly underwater as they were not made to withstand aquatic conditions. Therefore, failures take place rapidly within the structure. In a period of 3 to 4 years, a car body will completely break down to small bits of rubble lying on the underwater floor.[9-7] Jagged edges and increased turbidity also produce hazards for the diver.

While referring to the positive aspects of car bodies as reefs, Iris Unger writes: "The beauty of our countryside is marred by piles of useless cars."[9-8] What Unger does not point out is that car bodies are no less "marring" in the aquatic environment. In fact, car bodies have a higher negative visual impact underwater since they are completely extraneous to that environment.

Car bodies also provide little frame-of-reference or sense of enclosure. Thus, a major motivation for diving is neglected.

Tires -

Submerged tires as artificial reefs have desirable and undesirable attributes. Positively, tires are inexpensive. They also provide substrate for sessile organisms and protective areas for smaller organisms. In addition, tires take a relatively long period to weather, lasting "more than 20 years in salt water."[9-9]

Unfortunately, tires have many negative attributes as artificial reefs. Environmental Protection Publication (SW-119) states: "Scrap tires pose a menace to public health and add to the degredation of our landscape... The majority (of tires) create unsightly waste-disposal problems for many communities."[9-10] Again, if scrap tires add to the degradation of the terrestrial landscape and are unsightly, they affect the aquatic landscape in the same manner.

To create an artificial reef from tires, tires are simply weighted and dropped to the underwater floor. This method produces a low relief. Even though the structural stability of this method poses no threat to diver safety, little frame-of-reference or sense of enclosure is afforded for the diver.

Another method of producing tires into artificial reefs is often utilized. Tires are lashed together and held upright. This does produce a frame-of-reference and sense of enclosure. Unfortunately, weathering of the structural supports takes place and poses a threat to diver safety. In addition, the tires are still scrap and are perceived as having a negative visual character.

Rubble -

Rubble which forms artificial reefs includes quarry rock, bridge rubble and tile. These materials last longer than bodies and tires. Accordingly, stone rubble is considered the best material for contructing artificial reefs.[9-12] Stone rubble also provides substrate for sessile organisms and affords smaller organisms protection from predators and excessive currents.

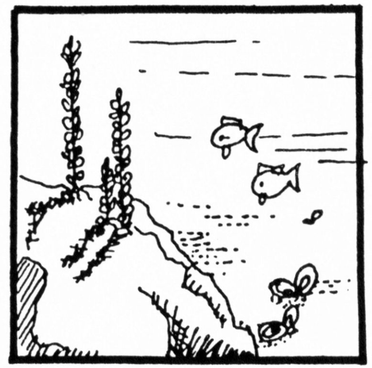
The major short-coming of rubble is that it provides little frame-of-reference or sense of enclosure for the diver. In addition, the sizes of rubble commonly used do not provide protection for larger organisms.

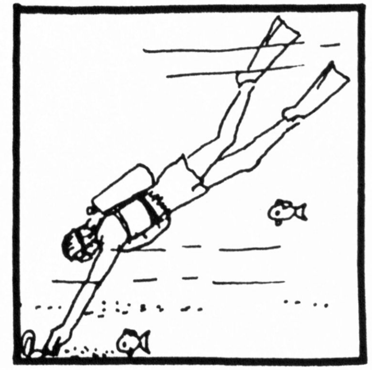
Oil Rigs -

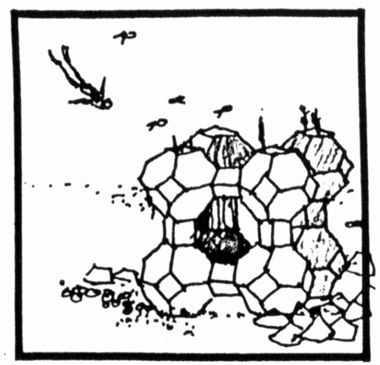
Although oil rigs are not designed to be artificial reefs, they are successful at that function. Rigs provide substrate for sessile organisms. They also afford protection to very small as well as large organisms.

Even with their gigantic size, rigs do not excessively obstruct currents. These currents flow unhindered between the structural supports. Diver safety is not threatened since rigs are designed to be free from structural failure and excessive turbidity is not created. The structural supports form a frame-of-reference and sense of enclosure for divers. In addition, rigs extend from the underwater floor to the water surface. Thus, divers may explore at any depth desired.

Design Criteria and Management Considerations







Chapter X - Management Considerations and Design Criteria

As stated in Chapter III, there are management considerations which are developed from environmental needs. Some of these considerations can be managed internally, but others must be addressed externally. Considerations that must be managed externally are done so through legislation, social consciousness, or other means beyond the control of the designer, owner, or client. Site selection for the location of artificial reefs should begin with the effective external management of these considerations. Only sites being effectively managed externally should be considered as possible locations for designed diving reefs. Site location criteria should give priority to those sites where effective internal management can greatly augment the health of the ecosystem and enjoyment and well-being of the diver. Internal management considerations should then be utilized to maximize the response to ecosystem needs (Chapter III) as well as diver needs (Chapter VI).

External Management -

External management considerations are developed from the need to minimize certain types of pollutants. An increase in suspended particles, nutrients, disease-causing bacteria, toxic chemicals, and salinity in the aquatic environment must be minimized.

In areas where dredging and/or dumping inert materials has occurred, suspended matter has increased. This increase has decreased illumination and caused precipitates to cover sessile organisms. These dumping and dredging activities must be strictly controlled. In addition, erosion near aquatic environments has increased due to the removal of vegetation. Vegetation removal must also be controlled. In the past, inadequate management of these two factors have combined to destroy much benthic life in oceans, bays, and lakes.[10-1] An example of this is Kaneohe Bay in Maui, Hawaii, where a coral reef was destroyed.

Excessive nutrients have stimulated growth of certain species to the detriment of others.[10-2] Fertilizers which wash into water bodies have stimulated phytoplankton growth which in turn has drastically reduced illumination. Light-requiring benthic life has suffered because of these blooms. Dumping raw and treated sewage has also added to the death of many organisms. Stimulated growth of phytoplankton and disease-causing bacteria contributes to this death.[10-3]

Toxic chemicals from industrial waste have damaged many aquatic communities. Through legislation, the frequency and extend of "chemical kills" has been decreased. Enforcement of this legislation is critical to the health of all communities; aquatic and terrestrial.

Healthful salinity balances are necessary. The introduction of artificially large quantities of fresh water into limited marine environments, such as bays and channels, must be limited. Increased runoff (generated by replacing permeable surfaces with impervious building surfaces) has lowered salinity somewhat in these environments. In these areas, aquifer recharge zones should be intelligently managed to reduce runoff to natural rates. This would normalize salinity in bays and channels (as well as storing fresh water in the aquifer for future terrestrial use).

Site Selection -

Site location does a great deal to maximize opportunities for satisfying the needs of the ecosystem and the needs of divers. Site selection can be dealt with in two modes. One mode is to utilize the creation of a designed reef to respond to the ecological needs of a previously disturbed site. By so diving, the site ecology can be greatly improved. The other is to chose the site which best satisfies ecosystem needs and the needs of the diver.

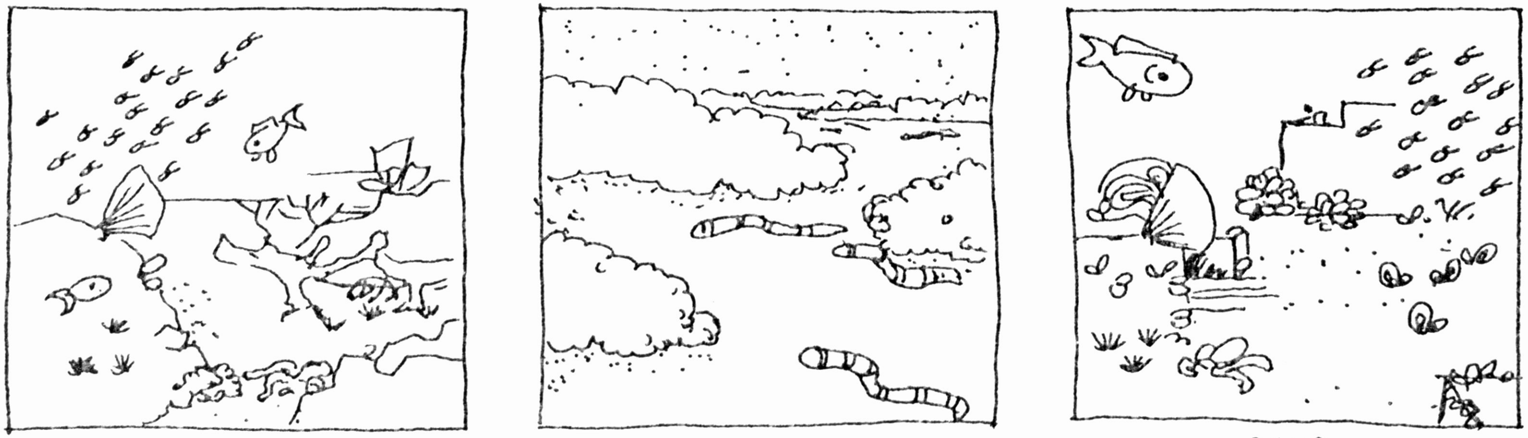
The predetermined site may be one that was destroyed by external mismanagement. For example, Kaneohe Bay in Maui, Hawaii was once a tourist attraction due to its abundant and diverse coral communities. Then, mismanagement occurred through dredging, erosion and dumping of treated sewage into the bay. The increased sediment covered coral and other benthic life while bacteria produced disease and phytoplankton grew in the nutrient solution. Now, bubble algae and sea cucumbers (worm-like decomposers) are the only prevalent megaflora and megafauna.

Once external management became effective, coral could still not re-establish themselves because of the particulate bottom. In this

	Ecosystem Needs	Diver Needs
External Management	Minimize Suspended Particles Optimize Nutrients Minimize Toxic Chemicles	
Site Selection	Maximize Illumination Maximize Water Clarity Minimize Turbidity Maximize Circulation Minimize Wave Action Optimize Temperature Maximize Substrate Diversity	Maximize Illumination Maximize Water Clarity Minimize Turbidity Minimize Wave Action Optimize Temperature Minimize Pressure Minimize Current Velocity

	Ecosystem Needs	Diver Needs
Internal Management	Minimize Turbidity Minimize Currents Maximize Circulation Maximize Substrate Diversity	Minimize Turbidity Minimize Currents Maximize Substrate Diversity Maximize Diverse & Abundant Aquatic Life Provide Frame-of-Reference Provide Elements of Design (Color, Form, Texture & Movement) Minimize Sharp Edges

Figure 10-1
Criteria for External Management Site Selection and Internal Management



1960
Coral Reefs

1980
Death of Coral & Emergence of Decomposers

2000
Reestablishment of Coral

Figure 10-2

Aquatic Environmental Mismanagement and Correction

case, the introduction of a solid designed reef can benefit the re-establishment of many species. In fact, more solid surface area can be provided than before mismanagement took place. Areas with different types of particulate matter can be supplied to support a greater diversity of species. In theory, a designed artificial reef in a predetermined site can produce a more diverse and stable aquatic community than before mismanagement, and its resultant enviornmental degradation, took place.

When a site is not predetermined, many considerations should be utilized when selecting the site. By doing so, amenities of the designed reef are drastically increased by a site which helps satisfy many diver and ecosystem needs. Considerations that should affect site location include illumination, water clarity, turbidity, wave action, current velocity, circulation, temperature, pressure (depth), and abundance and diversity of aquatic life.

Illumination and water clarity is maximized by selecting a site that has the least amount of suspended solids. Observation of the amount of erosion occurring on adjacent land and the suspended solids in adjacent tributaries is beneficial. This data should be collected at times when sediment load is likely to be at its highest. For example, cropland that is plowed for the winter and spring floods combine to create periods of high sediment load. In addition, illumination is maximized with decrease in depth.

Areas of natural turbidity should be avoided. Large boulders, drastic changes in bathymetry, and other expanses of unflexible surfaces which cut into currents produce turbidity.

Strong currents and wave action can also be detrimental to aquatic organisms and divers and therefore, they should be avoided. Strong currents are those greater than one knot. Although many organisms are able to deal with high water velocity, divers cannot without exhaustion and stress. In addition to damaging organisms and stressing divers, "strong currents and wave action can undermine (structures or cover them) with shifting sediment or softer materials. Thus, building reefs in areas of strong currents and very shallow water (less than 15 feet) should be avoided."10-4

Ample circulation is necessary to maximize sessile aquatic life. Once a structure is submerged and flora establishes, circulation is likely to be decreased. Thus, care should be taken to choose a site that has higher than minimal circulation for native organisms.

Temperature is optimal at above 70°F. Since water temperature decreases with depth (in spring, summer and fall), the site should be located at shallower depths. Thus, the site should be located within the higher thermoclines to maximize warmth.

Pressure is optimal at less than one additional atmosphere (or 33 feet of depth) for divers. Potential physiological problems are drastically reduced above this depth.

Diversity of substrate promotes diversity of organisms. Thus, the inclusion of many types of bottom material is advisable. Boulders, pebbles, gravel and sand promote much less suspended solids than do silt and clay in the presence of turbidity. Turbidity includes that produced by the fins of a diver. In addition, "soft bottoms of shifting sand, silt, or mud

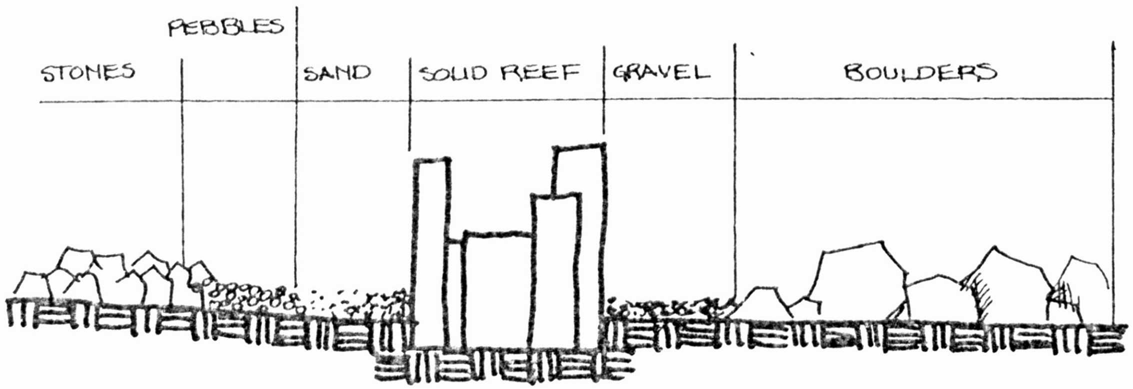


Figure 10-3

Diversity of Substrate

... serve as poor foundations and usually result in some or all of the reef materials being covered."10-5 Thus, the best foundation is "bedrock with little sediment dover" or "firm bottoms of gravel and compacted sand."10-6 Therefore, the ideal diving reef would be a solid structure with a foundation of bedrock or compact sand and gravel with different sized substrate in proximity.

To be assured of an abundant and diverse biotic community, tests for optimum innate nutrient levels must be made. If nutrient levels are not sufficient or are in excess, a stable biotic community cannot exist. Thus, all of the optimum levels for native aquatic life must be taken into account in site selection.

Although the above factors should be considered, chances are that no site optimizes them all. The site location should be selected according to the number of considerations the possible site satisfies. In addition, the designer should select the considerations that are the most vital and determine the level to which the site satisfies each consideration. The appropriate tool to achieve this analysis is a matrix (see Figure 10-1).

Internal Management -

Internal management of the underwater site should be influenced by the difference between the existing and the desired quality of environmental considerations. These considerations include turbidity, currents, circulation, substrate diversity, diver safety, frame-of-reference, and elements of design. The quality of these considerations are in some cases affected by the site location. However, once the site is selected, these considerations can be managed internally.

Increased turbidity should be avoided by allowing the currents to flow freely through the structure. To minimize turbidity, current direction of the site must first be identified. Then, non-obstructive spaces should be lined-up with the currents to minimize turbidity. For example, a tube that is oriented with the flow of water does not disturb the flow of the water as much as one that is perpendicular to the flow.

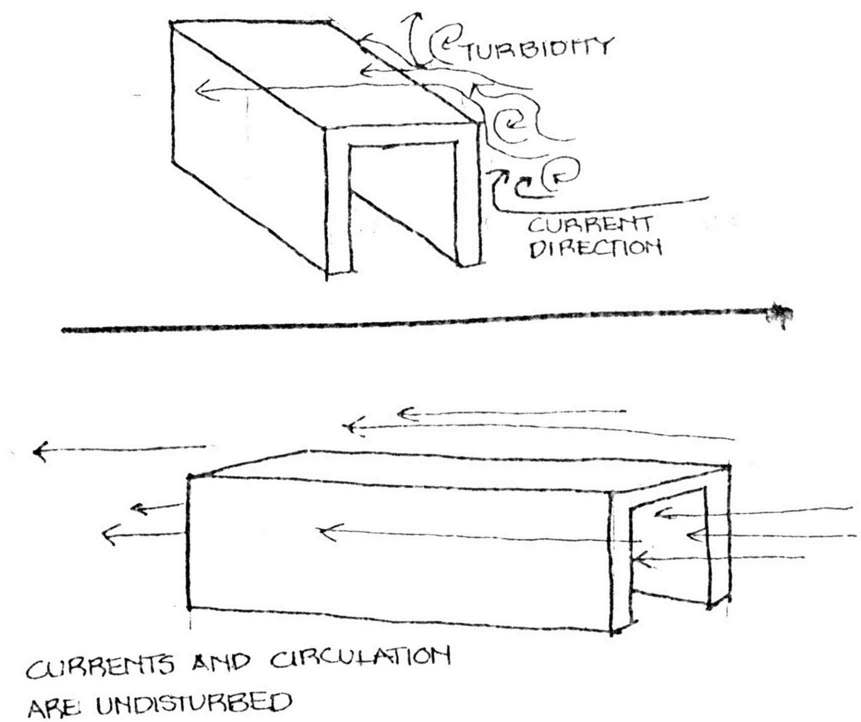


Figure 10-4
Structure Orientation

Protection from currents greater than one knot must be provided. The orientation of the structure should be such that swift currents do not penetrate an established area. If this is done, circulation must still be present to maximize the amount of sessile life in the protected area. Care must also be taken to minimize turbidity when establishing a protective area from swift currents. Turbidity is increased when currents are stopped abruptly instead of gradually. Thus, this type of structure should include a slanted or curved form rather than vertical.

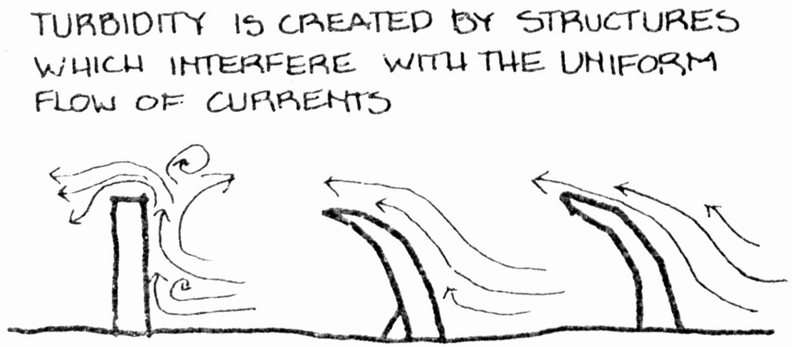


Figure 10-5
Form and Turbidity

In addition, hand holds should be placed in areas where current velocity is high to reduce diver exhaustion.

Solid substrate is provided by the structure, but the type of material may vary. "An artificial reef should be constructed of firm, inert, long-lasting material. In selecting suitable material, it must be remembered that the function of an artificial reef is to provide shelter for fish and to allow marine organisms such as algae, barnacles, mussels, coral, and hydroids to attach themselves. (Thus, it provides) food for larger fish and establishes a food chain."[10-7] Both surface area and crevices or hiding places are necessary to satisfy the need of many marine organisms which will inhabit the reef and surrounding areas.

It has been established that reinforced concrete and quarry rock satisfy many requirements. Certain metal alloys may be utilized as well as polymers, polymer-coated metals and certain fabrics. Polymer is an unusual material since it bends under force. In addition, defoulant may be added at the time of polymer production. Thus, areas were divers have an increased chance of cutting skin on sharp sessile organisms, defoulant-treated polymer may be utilized to reduce this type of growth and thereby reduce cases of cut skin (lacerations). Even so, "a quarter century's experience in artificial reef building has demonstrated that a combination of materials provides a better reef site than utilizing one material because it (diversity) provides a variety of habitat."[10-8]

Diversity and abundance of underwater life is necessary for the stability of the ecosystem as well as the psychological satisfaction of the diver. Again, providing a variety of habitats is suggested, but other techniques may be applied.

"Theoretically, fishing success (or fish and invertebrate-viewing success) increases in proportion to the horizontal and vertical dimensions of a reef. Generally this is true, but several piles of material in an irregular configuration are thought to be better than one pile of the same material."[10-9] Functionally, clumped material with broad spaces support more life than material spread evenly over the same amount of area.

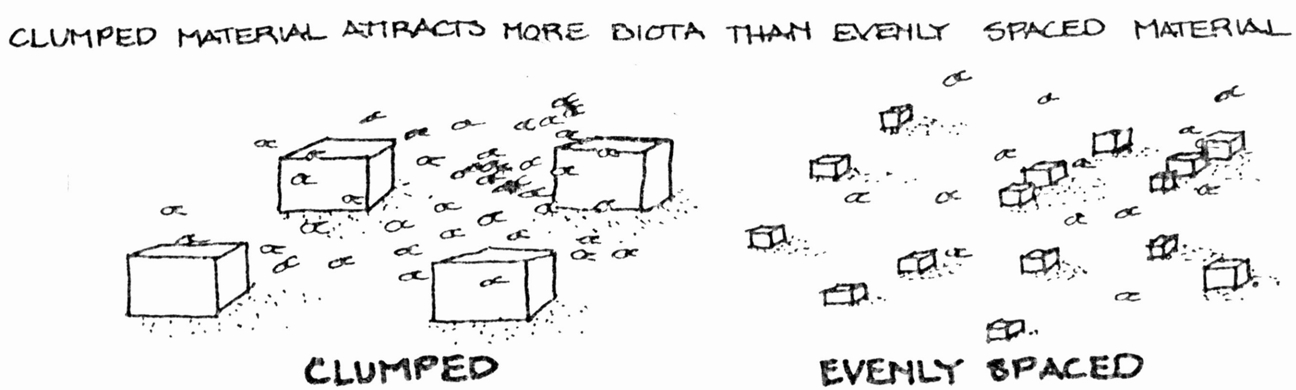


Figure 10-6
Organization of Material

It is "recommended that reefs should be constructed in a circle or square with a central opening less than 60 feet across."[10-10] Fortunately, this configuration is more likely to produce a successful frame-of-reference for the diver.

Diversity of sea life may also be expanded by transplanting desirable species to a newly submerged reef.[10-11] A marine biologist needs to be consulted for such an undertaking. The biologist would determine if the physical factors are favorable to the newly transplanted species and the best transporting method for these organisms.

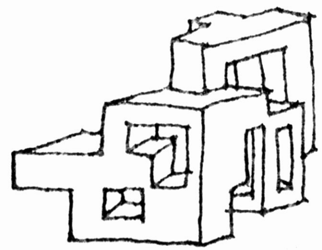
Another technique for increasing diversity of sea life is providing a variety of spacial sizes. "Japanese researchers have found that small, low objects are best for promoting growth of shellfish and seaweed. Structures with many small holes and crevices are best for attracting invertebrates (e.g., shrimp, crab, and lobster) and juvenile fishes, and higher, larger structures with numerous crevices are best for larger fishes."[10-12] All three spacial sizes should be incorporated in reef design.

Diver safety is a necessary component in designing a diving reef. No jagged edges should exist. The reef should be extremely sturdy and have a low rate of structural failure.

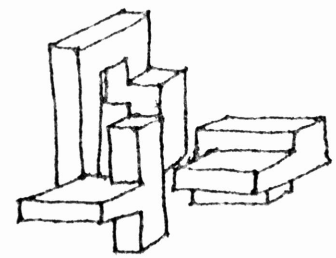
The diving reef should provide a frame-of-reference for the diver. This includes spaces into which two divers can swim and which surrounds them. This can be accomplished by either caves formed within a structure or spaces formed between structures.

As part of this study, divers were surveyed as to which type of reef they preferred. Fifty-eight percent chose a structure with caves and tunnels while 17% preferred to dive in spaces created between structures. The remaining 25% were undecided. Thus, a designer should incorporate both types of form since the survey indicated both are desired.

Caves and tunnels that are incorporated into the design should be considered carefully. Diver safety includes minimizing the possibility for disorientation. When panic occurs, disorientation is intensified so the tunnels should not be maze-like. The exit should always be accessible. Even so, 59% of the divers surveyed stated that they would enjoy the illusion of being lost with full knowledge of the location



Structure with Tunnels and Caves



Series of Structures

Figure 10-7

Spacial Organization

of exit. To gain both aspects, a curved tunnel may be utilized. The diver understands where the exits are but cannot visually see them once he/she enters the tunnel. Textures may be utilized to code diver location. Smooth textures can denote the center of the tunnel while rough signifies the end. Light holes large enough for a diver to swim through may be utilized.

Elements of design such as color, form, texture, and movement should be considered. Color perception is increased with light. Thus, water clarity and shallow depths are desirable. To enhance color, colorful species should be transplanted. Color spectrums may be incorporated into the design of the structure at various set depths. The scientific interest of the diver may be aroused with the perception of how colors change with depth. Photographers benefit also by having a scale to judge how colors are going to change with the use of a strobe.

Form is an important functional element as well as design element. As discussed, form directly affects currents, turbidity, abundance of marine life, and the frame-of-reference. However, it is also an important component of design. Unity/contrast, focal point, balance, scale/proportion, and rhythm are other recognizable principles of design.

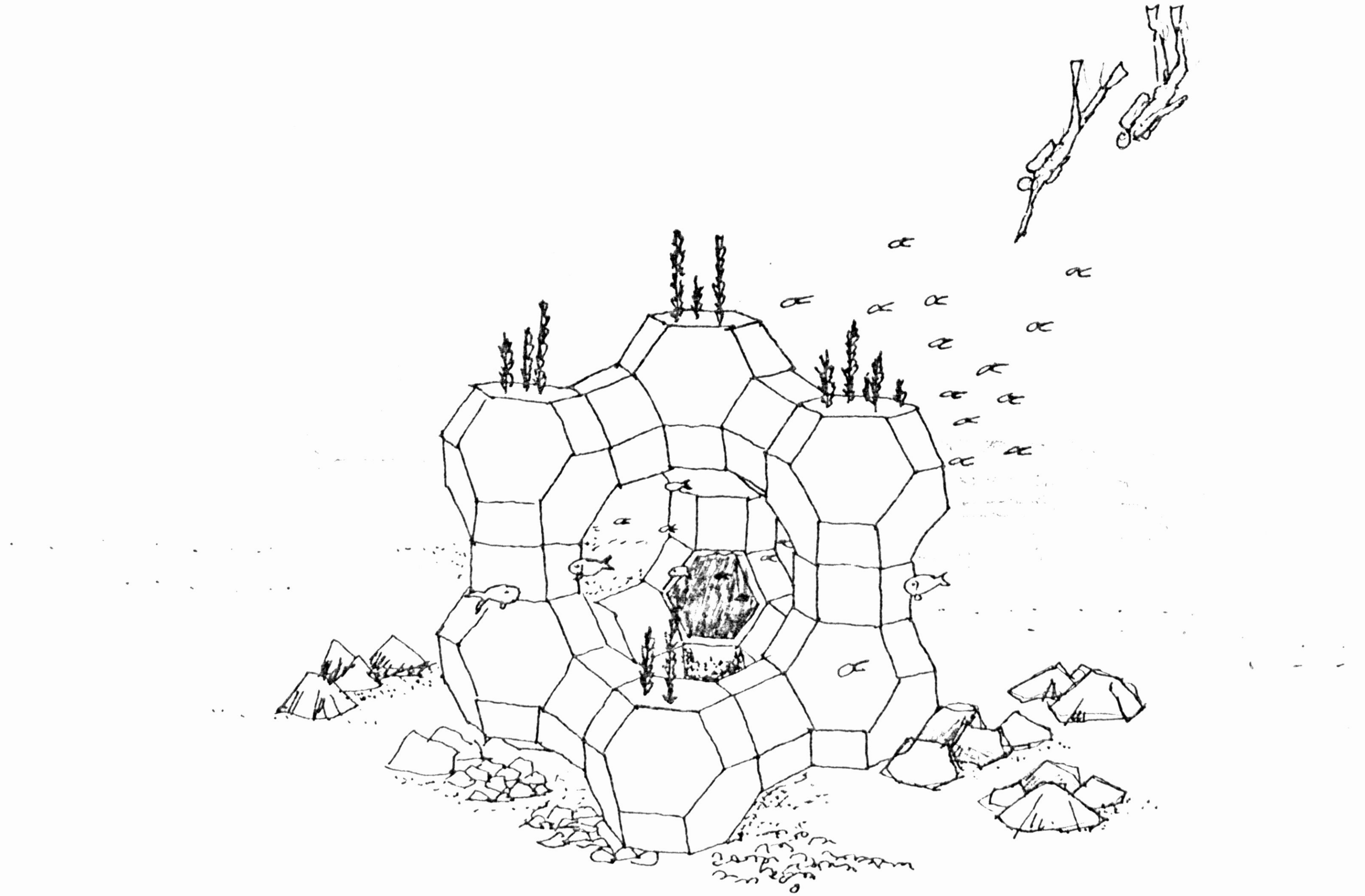


Figure 10-8

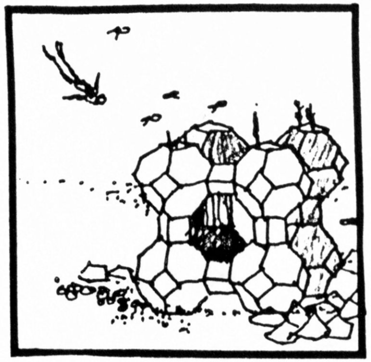
Alternative Design

The form should have a sense of unity. Repetition of pattern promotes this. Yet, contrast or variety must be present for visual interest. This may be done with an emphasis or focal point. Perhaps an entry to a large space is "played-up" as a focal point.

Visual (and physical) balance must be utilized. Psychological stress will occur if the structure appears to be unbalanced and ready to fall over. Again, different sized spaces should be incorporated to give the diver different sensations with the exploration of the third dimension. Thus, scale and proportion are varied.

The principle of rhythm should be incorporated. To achieve rhythm, patterns must reoccur repetitiously. For example, oil rigs have a truss pattern that reoccurs. This enables the eye to flow freely across the structure. This reoccurring pattern produces visual movement.

Economic and Legal Feasibility



Chapter XI - Economic and Legal Feasibility of Designed Diving Reefs

The greatest problem with designed diving reefs appears to be their financial[11-1] and legal[11-2] concerns. Economically, several sources exist for financing a diving reef. These sources may include resorts, larger dive shops, material manufacturers and the government.

Resorts that are already financially supported by divers may invest in a designed diving reef to attract more clientel. Diving reefs may then become a main point in the advertising strategy. This is true especially if the resort invests in several types of diving reefs to satisfy the needs of many different types of divers.

Larger dive shops may find the designed diving reef an invaluable tool in diver training. The diving reef represents a controlled environment. Thus, the diver trainee could learn in a reef which would approximate situations he/she might experience elsewhere with less chance of injury or death. For example, intricate cave diving experiences could be fabricated for the purpose of training cave divers.

Material manufacturers may produce a diving reef out of the materials they wish to advertise. Thus, they can prove how well their product weathers as well as providing a service to the diver.

In the past, organizations most involved in providing artificial reefs have been state governments. The California Department of Fish and Game has been installing artificial reefs since the late 1950's.[11-3] The Texas Parks and Wildlife, and others, have been active as well. Many reefs have been produced by local fishing or diving clubs with the help of state agencies.

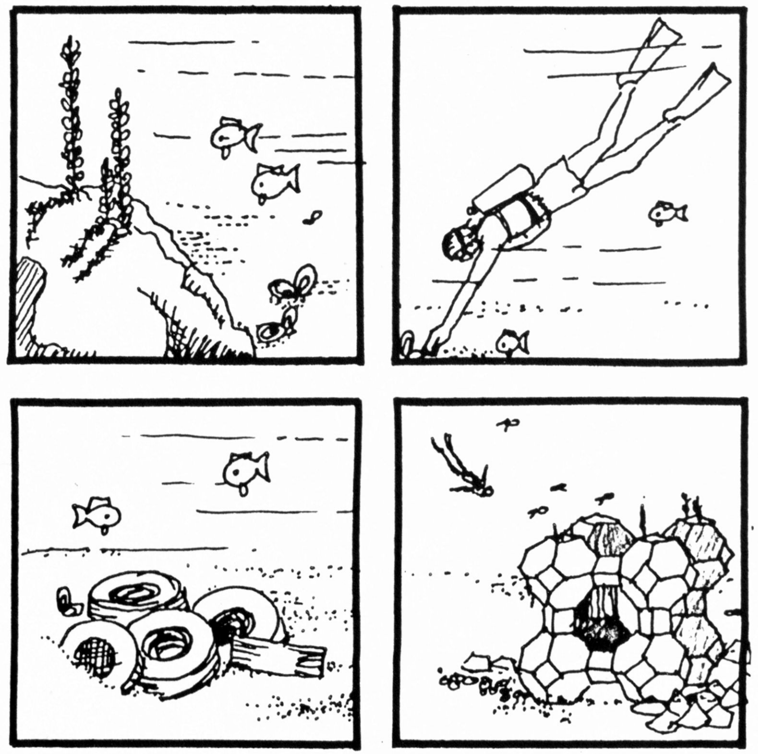
Legally, requirements for a designed reef would probably be similar to that of present artificial reefs. "All reefs must be installed under permit from the U.S. Army Corps of Engineers and States Land Commission or a city having title to submerged lands. Clearance (must also be) obtained from the U.S. Navy. Marker buoy permits (must be) obtained from the U.S. Coast Guard, (while) fishing interests (must be) consulted and kept informed of all reef placement".[11-4] Certain areas of the country have made fishing over specified artificial reefs illegal. Thus, divers have been acknowledged to have legal rights for the sole use of specified reefs.

A comprehensive survey of the legal requirements for establishment of designed diving reefs is beyond the scope of this research. However, the following articles are suggested to begin this effort:

Industrial Economics Division at Texas A&M University and the Texas Coastal and Marine Council, "Artificial Reefs for Texas." Sea Grant Report TAMU-SG-73-214, Texas A&M University, College Station, Texas, March 1974, pp. 23-32.

Parker, R. O., Jr.; Stone, R. B.; Buchanan, C. C.; and Steimle, F. W., Jr., "How to Build Marine Artificial Reefs," pp. 6-7.

Conclusion



Chapter XII - Conclusion

Through the research process, a set of considerations has been developed for the satisfaction of diver and ecosystem needs. The comparison between the evaluation of naturally occurring diving environments and popularity of these environments by the surveyed divers indicates the set of considerations is valid.

However, the purpose of this research has been to prove that structures designed specifically for divers and management of the ecosystem are more responsive to diver and ecosystem needs than present artificial reefs. By comparing the various artificial reefs and designed diving reefs against the set of considerations, an evaluation can be made.

The evaluation can be viewed as having four major aspects. They include considerations that are affected by site selection, considerations that are satisfied by all reefs, considerations that are satisfied by some of the reefs, and considerations that are satisfied by the designed diving reef alone.

Considerations that are affected predominately by the site selection include illumination, water clarity, temperature and pressure. Thus, the degree to which these considerations are satisfied by the different reefs is variable and dependent upon the site location. However, these factors affect the diver to a greater extent than the angler. Thus, these considerations will gain greater importance in the site selection for a diving reef than present artificial reefs.

Present artificial reefs and designed diving reefs generally satisfy the needs for abundant and diverse biotic community, turbidity and minimized wave action. However, the designed diving reef fulfills more of the ecosystem needs than do other artificial reefs. Therefore, a more abundant and diverse biotic community will form around designed diving reefs. Designed diving reefs also are designed to protect organisms from strong currents without increasing turbidity. The reason concrete boxes, tires, and rubble do not produce excess turbidity is the low relief which provides no frame-of-reference. Increased wave action generally does not occur with any artificial reef since ample space near the water surface is provided for boats.

Minimal sharp edges and ample circulation

Figure 12-1 Evaluation of Artificial Reefs and Designed Diving Reefs

	Concrete Boxes	Car Bodies	Tires	Rubble	Designed Reef
Illumination	◐	◐	◐	◐	◐
Water Clarity	◐	◐	◐	◐	◐
Optimal Temperature	◐	◐	◐	◐	◐
Optimal Pressure	◐	◐	◐	◐	◐
Abundant & Diverse Aquatic Life	●	●	●	●	●
Turbidity	●	○	●	●	●
Wave Action	●	◐	●	●	●
Sharp Edges	○	○	●	○	●
Circulation	◐	○	●	●	●
Optimal Currents	○	○	○	○	●
Substrate Diversity	○	○	○	○	●
Frame-of-Reference	○	○	○	○	●
Elements like Color, Form, Texture, & Movement	○	○	○	○	●
TOTAL	5 1/2	3 1/2	7	6 1/2	11
PERCENTAGE	42	27	53	50	85%

● positive
○ negative
◐ varies

are provided by some of the reefs. In both cases the designed diving reef satisfies the need. The low relief of concrete boxes, tires and rubble allow circulation, while areas within car bodies receive little or no circulation. In addition, sharp edges exist on car bodies, rubble and concrete boxes. Tires and designed reefs do not have sharp edges beyond the sessile growth. However, divers may cut themselves if they have to brush against the structure. In this instance, designed reefs may provide areas of no sessile growth with the use of defoulants where divers typically touch.

Because of their consideration for divers, designed diving reefs could fulfill many needs that are not presently satisfied artificial reefs. These include optimal currents, substrate diversity, frame-of-reference and elements like color, form, texture, and movement.

The low-relief artificial reefs do not hinder strong currents while car bodies increase current velocity (in the same manner as jetties produce rip tides). However, designed diving reefs are able to provide protection from currents, yet not increase current velocity.

Substrate diversity is not obtained by any type of artificial reef alone. At the reef site, metal, concrete, or rubber is typically the only type of substrate. However, these reefs are combined to form reefs with substrate diversity.

Frame-of-reference is provided by designed diving reefs unlike low-relief reefs and car bodies. None of the present artificial reefs define edges of spaces that are necessary for frame-of-reference.

Since materials such as car bodies, tires and rubble are dumped as refuse, no consideration to color, form, texture, and movement exists. Concrete boxes have been designed for experimental purposes associated with inhabitation of fish. Thus, no concern for elements such as color, form, texture, and movement is taken.

The designed diving reef satisfies approximately 85% of the considerations. Concrete boxes, car bodies, tires and rubble only satisfy 42%, 27%, 53%, and 50% respectively. This indicates that a designed diving reef is indeed more responsive to diver and ecosystem needs than present artificial reefs.

Diver opinion also reinforces the idea of a designed diving reef. Ninety-eight percent of the respondents stated that they would dive to a structure that is designed specifically for the diver and ecosystem.

Although this research proves that a designed diving reef is an appropriate advancement in the development of artificial reefs, case studies need to be conducted. These studies should include a variety of diving environments. Lake Tahoe (California), Lake Travis (Texas), Kaneohe Bay (Hawaii), and Destin (Florida) would provide a wide variety of environmental and cultural aspects. Lake Tahoe is a spring-fed lake, while Lake Travis is runoff-fed. Destin has clear water and a particulate-based saltwater to establish new communities. In Kaneohe Bay, the re-establishment of a community may be investigated.

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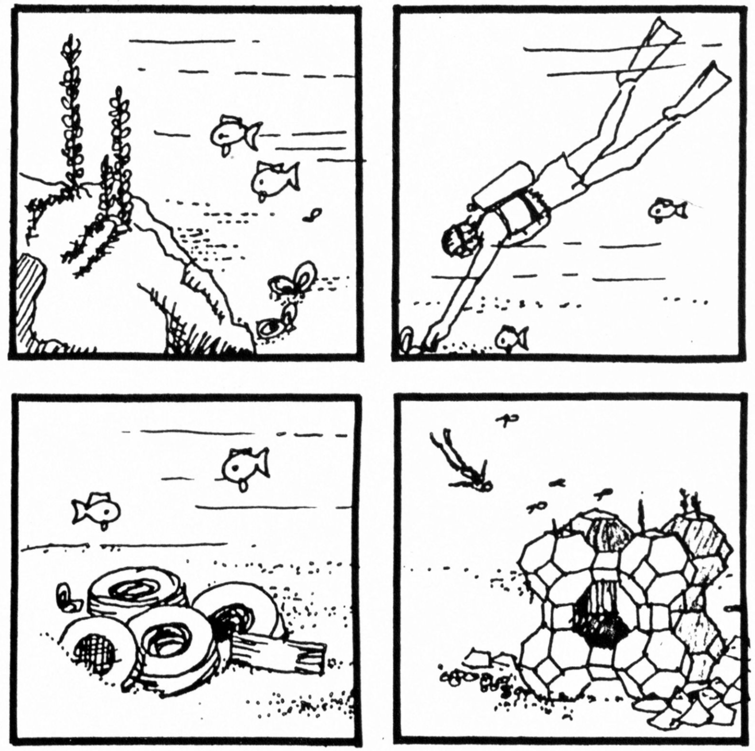

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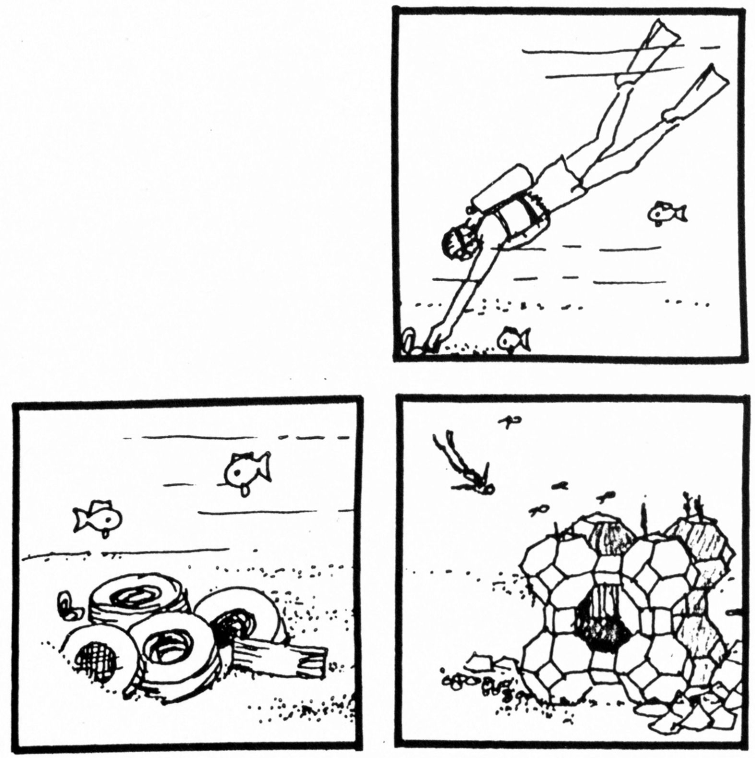
Appendix



UNDERWATER RECREATIONAL STRUCTURE RESEARCH QUESTIONNAIRE

Age ________

Resident of what City/State/Country __________

Number of Years Certified ___________

What Certification (Basic NAUI, Advanced SSI, etc.) ________________________________

Approximate Number of Dives ___________________

Have you ever panicked--Yes or No

How long ago ____________

What were the circumstances __________________

Number of dives on a manmade reef (Oil Rig, Sunken Car or Ship, Jetty, etc). __________

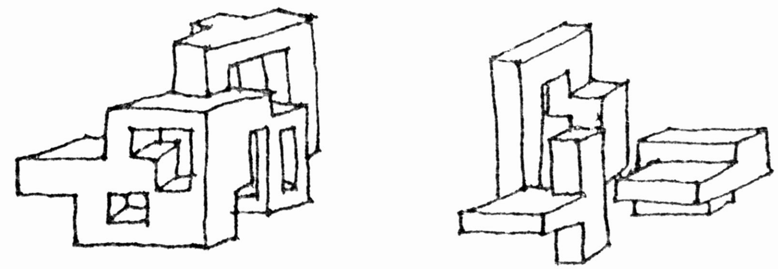
What were they (and circle your favorite) _____
____

Where do you prefer to dive __________________

Would you dive to a structure that attracted local flora and fauna and built specifically for scuba divers--Yes or No

Would you like it accessable to skin divers--Yes or No

Which would you rather dive -



*an abstraction

in a Structure with Tunnels and Caves or Around a Series of Structures

Would you like the structure big enough to create the illusion of being lost with full knowledge of how to make a quick exit--Yes or No

Why do you dive______________________________
____
____

Other ideas and comments _____________________
____
____

Appendix I