THE TIDEWATER GOBY
(*Eucyclogobius newberryi*)

Reintroduction of a geographically isolated fish species into Malibu Lagoon: A watershed perspective

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Sean Manion, Conservation Research Consultant

for

Topanga-Las Virgenes Resource Conservation District
122 N. Topanga Canyon Bl.
Topanga, CA 90290

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ABSTRACT

THE TIDEWATER GOBY (*Eucyclogobius newberryi*) REINTRODUCTION OF A GEOGRAPHICALLY ISOLATED FISH SPECIES INTO MALIBU LAGOON: A WATERSHED PERSPECTIVE

The main purpose this project was to test the efficacy of reintroducing an estuarine fish species into its former habitat. A habitat evaluation prior to reintroduction was performed to determine habitat viability for the target species, the tidewater goby (*Eucyclogobius newberryi*). The habitat evaluation was based on measurement of physical parameters selected as significant indicators of habitat requirements for tidewater gobies. The habitat parameters measured were within the tolerance limits of tidewater gobies, and 52 individuals were reintroduced in Malibu Lagoon. The third phase of this project consisted of monitoring the reintroduced fishes to determine survivability and reproductive success under wild conditions. This was done in four quarterly seines encompassing one full seasonal cycle plus one additional pre-spawning period. Results demonstrated successful breeding post-reintroduction, with a total of 468 individuals representing different age classes ranging from young-of-the-year to adults in the 40-49 mm (SL) size range. Results also confirmed the importance of the spatial and temporal juxtaposition of salinity, sediment type, and water temperature as keystone indicators of habitat quality for the tidewater goby.

The secondary focus of this paper is a description of the human-induced threats to biological diversity within the watershed that affects Malibu Lagoon. Primary threats include altered hydrologic (streamflow) regime resulting from artificially augmented streamflow input, altered non-natural breaching of the sandbar at the lagoon and sea interface, and excessive non-natural volumes of silts entering the lagoon. Finally, recommendations to ameliorate some of the human-induced stressors are suggested as part of an ecological management strategy.

Chapter I

INTRODUCTION

The biological diversity contained within the world's habitats is increasingly recognized as a critical component linking all life within the network of global ecosystems. Simultaneously, researchers are also recognizing a new, contemporary, ecological paradigm that focuses on the dynamic nature of physical and ecological processes rather than the classical static "balance of nature" paradigm (Pickett, et al. 1992). Maintaining global native biodiversity is directly dependent upon the function, structure, and composition of natural processes.

Mediterranean climate regions, such as southern California, harbor a biological diversity that rivals tropical regions (Mooney, 1985). Southern California is experiencing rapid urban settlement which is spurring the necessity for intensive ecological research and management efforts in order to stem the decline and lead the effort of preserving native biodiversity. Biological diversity is most effectively preserved by the implementation of landscape-level management strategies that focus on the maintenance of natural dynamic processes (Pickett, et al., 1992; Moyle and Leidy, 1992) and concomitant understanding of species and their life cycle requirements (Botkin, 1987).

Inside the framework of ecological management of the world's ecosystems is the science and art of restoring damaged ecosystems. Restoration ecology is increasingly viewed as a comprehensive form of ecology combining both the applied techniques for restoring systems and simultaneously performing ecological research to further develop techniques and theory regarding ecosystem function (Jordan, Gilpin, and Aber, 1987).

Ecological restoration can be defined as: "the process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal of this process is to emulate the structure, function, diversity, and dynamics of the specified ecosystem" (Jackson, 1992).

A landscape-level management approach is comprehensive in that it focuses upon physical processes and their spatial and temporal context within whole landscape systems (Pickett, et al. 1992). For example, Malibu Lagoon is viewed as a spatio-temporal component of the whole local regional landscape which is comprised of the land-water interface of both terrestrial and aquatic systems. A "local" regional landscape might include the Santa Monica Mountains, all watersheds linked to these mountains, and the Santa Monica Bay, which is the oceanic terminus of this landscape. At a larger landscape level the Simi Hills, Santa Susana Mountains, San Gabriel Mountains, and Los Padres National Forest would be included as continuous habitat with habitat linkages. The landscape-level approach is interdisciplinary by nature, requiring the cooperation of a multiplicity of experts in a variety of fields (Carr, 1987; PERL, 1990). The late pioneering marine biologist Archie Carr (1987) believed that an interdisciplinary team approach is a method of increasing value in defining and solving conservation problems. Resolving disputes among participants and building consensus is likely to be a primary conservation strategy as we approach the twenty-first century.

In order to realize a coherent, flexible, and ecologically sound management strategy within a landscape-level management approach to restoring damaged ecosystems, it is essential to understand the physical evolutionary processes or conditions that allowed for the development, both physical and ecological, of the ecosystem.

The reintroduction of species into their former habitats is an integral part of a comprehensive global conservation strategy in an effort to assist in the survival of wild plants and animals (Botkin, 1987). Reintroductions need not be measured by the sole criterion of success or failure of the target species or group to survive and reproduce in the wild. Successful reproduction in the wild is clearly significant, however, documentation of introduced individuals' decline and inability to persist may reveal valuable life history requirements to researchers and enhance the probabilities of future success (Morton, 1987). An extremely valuable method of studying and understanding something is to attempt to reassemble, repair, and to adjust it so that it functions properly (Jordan, Gilpin, and Aber, 1987). This leads to the understanding of the subtle interrelationship between the parts of a system and how they cooperatively affect one another. Primary consideration must be given to the analysis of the interaction between species and site (Aber, 1987), and interactions between species.

The reintroduction of vertebrate species into their former ranges is a relatively new and somewhat uncharted realm of restoration ecology.

Wildlife species reintroductions need to be documented in order to serve as rudimentary templates for further research. Species reintroductions can assist in restoring the known and obvious as well as subtle and little understood ecological interactions within damaged ecosystems.

The purpose of this study is to elucidate the reintroduction process and accomplish the task of restoring a previously extirpated element of biological diversity into its former habitat.

The focus of this restoration project is the reintroduction of the tidewater goby (*Eucyclogobius newberryi*) into Malibu Lagoon. This brackish water ecosystem is a habitat component within the goby's former historical geographic range. According to Swift (1982), *Eucyclogobius* occurred in Malibu Lagoon in the early 1960s but has been absent since at least 1970 and perhaps even before. Other researchers, notably Soltz (1979), failed to find any of this easily captured species at Malibu Lagoon during the 1970s, thus further substantiating research findings which indicate that *Eucyclogobius* was indeed extirpated from Malibu Lagoon by 1970. *Eucyclogobius* is found only in coastal wetlands of California. Its current geographic distribution is disjunct, from the Tillas Slough (entrance of the Smith River), Del Norte County, south to Agua Hedionda Lagoon in San Diego County (Swift et al., 1989). Localities where tidewater gobies occur correspond to those coastal areas that have littoral cells of sediment movement that allow for lagoon formation (Swift et al., 1989).

The current tidewater goby distribution pattern is a reflection of an earlier time when California's estuaries were more numerous and sometimes connected or possibly continuous (Swift et al., 1989). Geologic uplift of California's coastal ranges disrupted the widespread or continuous distribution of estuaries (Cole and Armentrout, 1979). The present configuration and insularization of California estuaries is the additive result of geologic uplift and sea level rise owing to the melting of glacier ice from 18,000 years B.P. to 5,000 years B.P. Geologically, they are young features, generally having been formed approximately 5,000 years ago when the seas reached their present level (Thurman, 1975).

A number of tidewater goby populations have been extirpated from portions of their range as a consequence of anthropogenic (human-induced) habitat modification. Historically, the tidewater goby occurred in approximately 87 locations within California (Swift et al., 1989). Since the early 1900s this species has disappeared from approximately 50 percent of the lagoon systems previously occupied. Within California south of Morro Bay, the tidewater goby has been eliminated from approximately 74 percent of its former range (USFW, 1992). As of mid-1984, there were an estimated 63 localities, statewide, where tidewater gobies persist (Swift, et al. 1989). Statewide, there are now an estimated 43 localities where tidewater gobies continue to persist (Swift, 1992). Currently there are only 16 extant populations south of Point Conception, of which one population is the recent inclusion of Malibu Lagoon in Los Angeles County. Three populations are on Camp Pendleton in San Diego County, one each is located in the Santa Clara and Ventura Rivers, and there are 10 populations between Santa Barbara and Point Conception (Swift et al., 1989).

The tidewater goby does not have a marine phase, thus indicating that recolonization between lagoons, in their present coastal configuration, seldom if ever occurs (Swift et al., 1989). Formerly widespread, this fish species has become a locally restricted, insular species. Relictual distribution with a lack of recolonizing potential renders endemic species, such as the tidewater goby, prone to extinction. In addition, when geographic isolation, low vagility, and restricted habitat in time and space are coupled with a short life span, populations of this fish species become particularly vulnerable to regional extirpation owing to environmental stochastic (chance) events, especially those that are human-generated.

Species composition in estuaries and lagoons varies according to the physical conditions and processes within a particular region. Ichthyofaunas have developed various strategies for survival in the dynamic lagoon environments of southern California. Seasonally dynamic, often intense fluctuations of streamflow discharge and sediment loading is common for Malibu Lagoon and other estuary-lagoon environments in this arid region. Tidewater gobies have evolved physiological and behavioral strategies for coping with frequent salinity changes, temperature differences, changing substrate patterns and water levels, the forcing influences of tides, sandbar breaching, and flood (storm) events that are part of the natural disturbance phenomena in Malibu Lagoon (Allen, 1985).

The California Department of Fish and Game lists this species as a "species of special concern" owing to its declining populations. In addition, *Eucyclogobius newberryi* is currently being recommended by the U.S. Fish and Wildlife Service for inclusion on the federal endangered list. The U.S. Fish and Wildlife Service (1992) states that "the tidewater goby is in imminent danger of extinction throughout its range and requires the full protection of listing as endangered under the Act [Endangered Species Act of 1973] in order to survive."

Given the current declining status of tidewater goby populations, a reintroduction effort into the Malibu Lagoon ecosystem would incrementally increase the protection and viability of this species as a whole. Individual populations are discrete units of their species' total aggregate. Thus, each population is inherently significant from the standpoint of the genetic variability it exhibits. Genetic variability maintains population vigor and species within the natural evolutionary process (Soulé, 1987). Numerous populations of a species help protect that species from being decimated by catastrophic events, either natural or anthropogenic in nature. A region-wide system of aquatic biodiversity preserves would help protect multiple populations of species from the risk of extinction.

The primary goal of this project is to successfully re-establish this fish species as a functioning member of the Malibu Lagoon ecosystem. Individual persistence, reproductive success, minimum viable population (MVP), and typical seasonal behavior patterns are indicators of attaining the primary goal. Reintroduction projects can assist the restoration process by re-establishing historical levels of native biodiversity in habitats that have previously been damaged and consequently have become depauperate of native flora and fauna.

Short-term re-establishment success is defined in this paper as breeding success under natural conditions with continued population persistence over the time span of this project. Long-term success can be characterized by the maintenance of population persistence and genetic variability under natural conditions with the capability of adaptive mutation at a rate in accordance with natural evolutionary time scale processes.

There are numerous factors that must be analyzed to determine the relative probability of a successful reintroduction. Some factors are measurable while others are grounded in the overall experience and training of the researcher. The following factors were adapted from Botkin (1977), Morton (1987), Shaffer (1987), and Swift et al. (1989), and applied to this reintroduction project. They are believed to be significant in the determination of successful reintroduction probability. These factors include, but are not limited to:

1. Innate species characteristics: these include demographic, genetic, and physiological factors.
    a. maximum longevity
    b. maximum reproductive rate
    c. post-spawning mortality
    d. egg hatch time in number of days
    e. sex ratios and seasonal ratio change
    f. how the above a. - e. change as resources change
    g. minimum viable population (MVP) - what population size is needed to avoid perceived serious consequences of inbreeding; how does this relate to the fact that tidewater goby populations have been geographically isolated by "natural" occurrence for thousands of years; data on genetic variability.

2. Biological interactions.
    a. competitor species for resources such as food or burrows, (e.g. non-native introduced fishes)

    b. predators of tidewater gobies, (e.g. non-native and native species)
    c. *Eucyclogobius* prey species - relative abundance (e.g. ostracods, etc.)

3. Habitat characteristics and physical processes
    a. natural disturbance regime
    b. hydrologic regime of the watershed, (e.g. seasonal streamflow pattern)
    c. anthropogenic disturbance to the streamflow regime
    d. micro-habitat availability
        i. sand substrate for breeding; total sand substrate area, particle size, and depth
        ii. heterogeneous mix of micro-habitats for prey availability and foraging sites for tidewater gobies
    e. salinity gradients within lagoon
    f. structure (e.g. vegetation for cover, water temperature control, and foraging habitat)
    g. water temperature
    h. dissolved oxygen
    i. pH
    j. pollution levels - toxics, fecal coliforms, pesticides, fertilizers, etc.
    k. spatial aspect - is the overall available habitat large enough for a viable population to maintain itself given the realities of natural disturbance dynamics and anthropogenic stressors; is the mix of elements a.-j. spatially supportive of a viable population
    l. temporal aspect - temporal mix of elements a.-j. For example, is more time necessary for the habitat to recover to the extent that it will be more suitable for the target species

Important factors not assessed were data on genetic variability and a complete quantitative assessment of upper watershed hydrology (some data was available but limited in scope).

Long-term success and viability of this species and all other species within this ecosystem are contingent upon the restoration and maintenance of natural ecological processes (e.g. hydrologic regime). Managing ecosystems for functional processes will be the key to maintaining native regional biodiversity (Pickett et al., 1992).

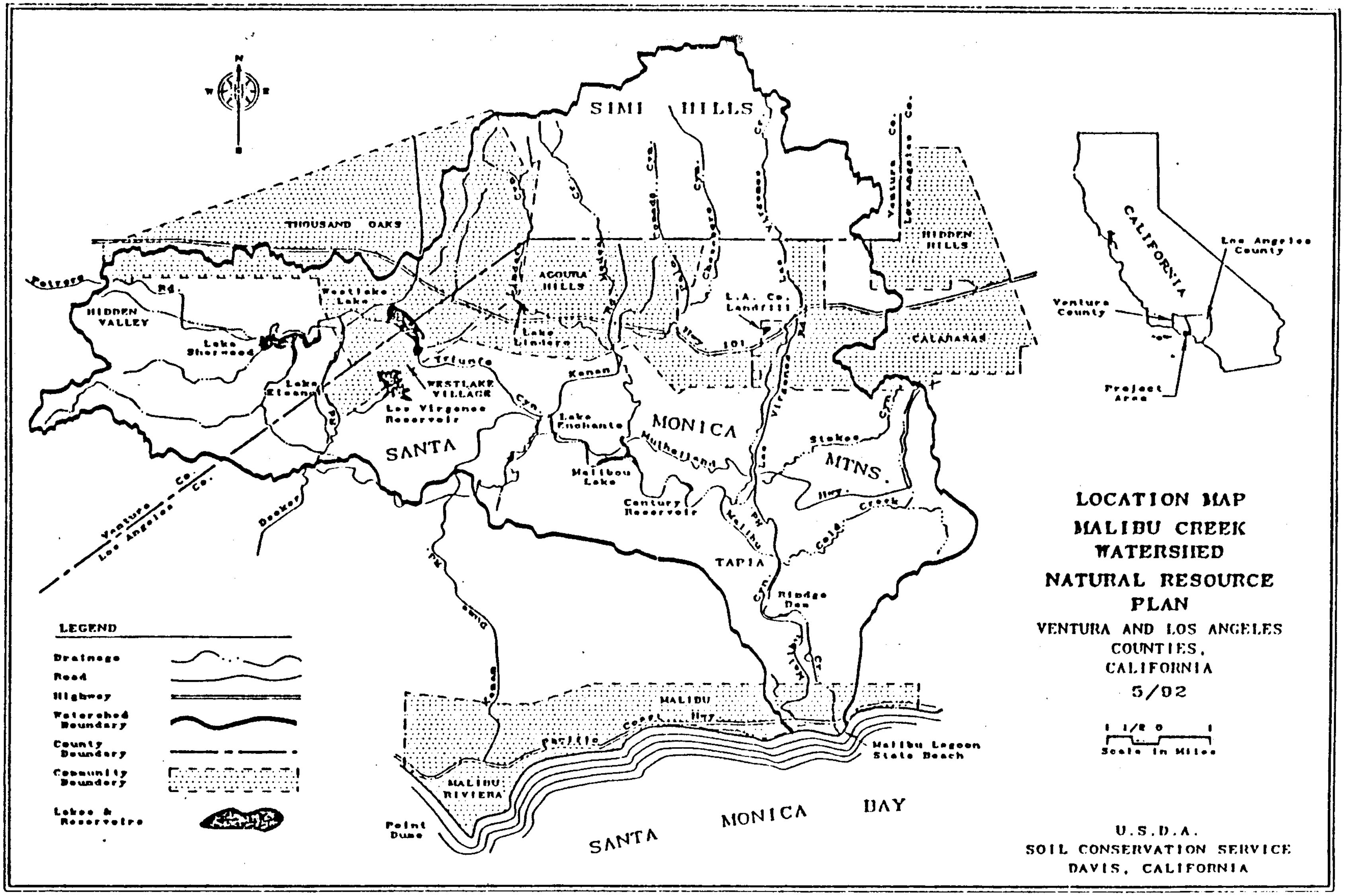
REGIONAL SETTING

Malibu Lagoon is within the physiographic region called the Southern California Bight. This oceanic region is a 100,000-square mile (259,000 km^2) submerged continental borderland extending from Point Conception in Santa Barbara County southeast to Cabo Colnett, Baja California in Mexico (NOAA, 1991; and National Research Council, 1990). The Bight system also includes a coastal mainland drainage basin of approximately 8,700 square miles (22,533 km^2) (National Research Council, 1990). Santa Monica Bay is an indentation of the Bight, bounded by Point Dume on the north and Point Fermin to the south (the exact definition of Santa Monica Bay may differ slightly, depending on the source) (NOAA, 1991). Malibu Lagoon lies towards the western extremity of Santa Monica Bay, which is partially ringed by a rising mountainous shoreline characterized by steep vertical scarps (National Research Council, 1990).

Freshwater enters the Santa Monica Bay from two principle sources: runoff from the greater Los Angeles urban area and streamflow from the watersheds in the Santa Monica Mountains. A significant component of the total water mass entering the watersheds of Santa Monica Bay is water imported from Northern California, the Sierra Mountains, and the Colorado River (National Research Council, 1990). The streamflow into Malibu Lagoon from Malibu Creek is a combination of urban runoff, discharges from the Tapia Water Reclamation Facility, and naturally occurring water sources within the watershed. Typically, under natural conditions in this semi-arid Mediterranean-type climate, freshwater flow occurs primarily during and shortly after seasonal winter storms. Currently however, due to imported freshwater, there is a year-long continuous freshwater flow into the Southern California Bight including Santa Monica Bay (National Research Council, 1990). For instance, between 1967 and 1982 the average wastewater flow into Santa Monica Bay was 346 MGD (million gallons per day), and over the same period, the stormwater flow averaged 143 MGD. Most of this stormwater flow occurred during a few winter storms, but was averaged for the year.

The Malibu Lagoon and Malibu Creek complex is a hydrologic microcosm of this larger picture. The natural streamflow regime within this watershed has been altered by the addition of imported water for domestic use. Alteration of this specific natural process produces profound changes in species diversity, density, and composition (Minckley and Douglas, 1991; Zedler, 1984).

Malibu Lagoon is located in Los Angles County, California, latitude 34°1'58" North and longitude 118°40'50" West. Malibu Creek is the largest of several streams dissecting the Santa Monica Mountains. Malibu Creek, its tributary streams, and the approximately 105 square mile area they drain constitute the largest watershed unit within the Santa Monica Mountains (Map 1). Malibu Lagoon forms at the terminus of the north-south trending Malibu Creek gorge. Watershed contributions to the Malibu Lagoon



Map 1. Malibu Creek Watershed

ecosystem include freshwater, sediments, nutrients, detritus, and urban runoff.

Malibu Lagoon is one of the last remaining estuaries in Los Angeles County. It is a small shallow water embayment covering 5.2 hectares (13 acres). The aquatic areal component (5.2 ha) plus the terrestrial areal component of Malibu Lagoon State Beach comprise a total of 14.7 hectares (35.1 acres). Malibu Lagoon is a remnant of a once more extensive group of estuaries within the Southern California region from Point Conception to the international border with Mexico.

Urban development in parts of the historic lagoon and surrounding lowland environment has reduced the size of this lagoon to its present 14.7 hectares. Prior to 1983 much of the present lagoon site was comprised of a landfill, two baseball diamonds, and was partially covered with a mixture of weedy non-native plant species along with a few native species. In 1983, after the planning phase, the California Department of Parks and Recreation began the restoration process by re-contouring and excavating three channels approximately 30 feet in width. Mudflats sloped up from the channels, rising to a proposed pickleweed (*Salicornia virginica*) marsh and upland habitat. Areas that had been graded were re-vegetated with native vegetation (Manion and Dillingham, 1989).

Salinity, water temperature, lagoon water depth levels, and substratum type are among those parameters that are quite variable due, apart from natural dynamic processes, to the human-altered hydrologic flow regime and other anthropogenic stressors on the lagoon. Stressors of concern associated with urban runoff include the following: oil and grease (hydrocarbons), biological pathogens, heavy metals, excess nutrients, pesticides, fungicides, rodenticides, excessive silty sediment deposition, trash and debris.

Chapter II

THREATS TO BIODIVERSITY IN THE MALIBU CREEK WATERSHED AND MALIBU LAGOON

THREATS TO BIODIVERSITY

Conservation strategies can only be effective if the dynamics of species decline and/or extinction and the causes (i.e. alteration of ecological processes) responsible for them are clearly understood (Falk, 1992). Assessing the threats to biodiversity in the Malibu Creek Watershed must begin with documenting and understanding the baseline dynamic conditions that allowed for development of the watershed, including the lagoon. The baseline physical conditions and processes can be compared with current conditions to determine the changes that have occurred in the physical processes and how those changes (i.e. land-use changes) have affected ecological processes, habitat area, habitat productivity, hydrologic regime, and overall habitat quality and biodiversity at all scales. This chapter will begin an assessment of the complexity of threats to biodiversity in the Malibu Creek Watershed, with emphasis upon Malibu Lagoon.

In the marine environment, the species experiencing the most serious decline in diversity are estuarine fishes, and especially those that are endemic (degree of endemism in California fishes is 60 percent) with limited and patchy geographic distribution patterns (Moyle and Leidy, 1992; Moyle and Williams, 1989). Declines in native California fish faunas are principally the result of multiple human-induced chronic and catastrophic stressors (Jensen et al., 1990; Moyle and Leidy, 1992). Multiple threats and the associated environmental stressors can impact a population in a cumulative or additive fashion, or multiple stressors can function synergistically. Multiple causes of native fish decline have been noted by many researchers but have rarely been extensively quantified (Moyle and Williams, 1990). The primary categories of multiple stressors of estuarine organisms include 1) changes in the hydrologic streamflow regimes entering the estuary/lagoon ecosystem, 2) habitat alterations, such as local native vegetation removal from upper Malibu Creek Watershed, increased silt load in the stream, dams, stream channelization and increased impermeable surfaces, owing to expanded urbanization within the watershed, 3) pollution, both lethal and sub-lethal effects of point and non-point source pollution, and 4) introduction of non-native species (e.g. green sunfish) (Moyle and Leidy, 1992; Moyle and Williams, 1990).

These categories all involve the concept of environmental change within an ecosystem and how change effects the ecosystem processes and thus the persistence (life or death) of organisms. Natural systems are contingent (Gould, 1989; Pickett, 1992); they are reflections of earlier conditions, current prevailing conditions, changing boundary or background conditions, the order and rates of events within them, and finally, other adjacent or distant ecosystems (Pickett, 1992).

Anthropogenic disturbance stressors (e.g. increased urban-induced streamflow velocities) combine with natural disturbance cycles (e.g. winter storms), and generate physical change in the environment at accelerated and frequently chronic rates. When human-generated disturbance stressors cumulatively or synergistically interact with natural environmental disturbance, rapid rate habitat changes frequently occur and species and populations can be reduced or eliminated within a brief time span. Chronic or continual rates of human-generated disturbance (e.g. pollution) are often sub-lethal in their effects upon organisms, but are insidious and difficult to detect, and over time are a major stressor component (Moyle and Leidy, 1992) associated with shifts in species composition from one dominated by native species to one of decreasing native species diversity and increasingly dominated by non-native species. Accelerated rates of environmental change in the Malibu Creek Watershed began in earnest in the 1950s and 1960s as anthropogenic stressors began to exert an influence upon the creek and lagoon ecosystem.

SYNERGISTIC AND CUMULATIVE EFFECTS OF HUMAN-GENERATED STRESSORS (THREATS)

Most apparent in ecosystems is the interrelated nature of stressors. Stressors can act both cumulatively and synergistically on a given environment.

> "Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (NEPA, 1969).

Cumulative impacts are generally perceived as additive. In contrast, a synergistic response is the cooperative or coordinated effect of discrete agencies (i.e. anthropogenic stressors such as excess sediments and habitat

normally encounter under natural wild conditions become more susceptible to many pollution stressors. Responses to multiple environmental stressors can create "a process of gradual but punctuated attrition of species diversity, marked by the passage...of sets of ecologically linked species." (Frankel and Soulé, 1981).

Synergistic effects are difficult to determine and frequently are not given extensive treatment, or are not pursued at all. This is an area greatly in need of further research, since ecological synergisms are key components of ecosystem workings (Myers, 1987; Jensen et al., 1990; Frankel and Soulé, 1981). Exploring the dimensions of synergistic relationships and biotic responses will assist in understanding and predicting extinction probabilities, thereby elucidating the requirements for the persistence of biodiversity (Shaffer, 1990).

The precise interrelated set of stressors that the tidewater goby may be able to survive may not be survivable for other members within the aquatic community, and vice versa. The complexity of response tolerance to stressors is often species specific. The survivability of the greatest variety of native organisms (biodiversity) is clearly linked to the maintenance of natural ecological processes. Natural ecological processes in Malibu Creek Watershed have been disrupted by changes in context of the landscape (i.e. land-use changes such as deforestation, habitat fragmentation, imported freshwater, impermeable surfaces, excessive fine sediments). As the contextual content of a landscape is altered, the natural ecological processes inherent in that system begin to change. Restoring and maintaining the

(1990) and Karr (1990) suggest that maintaining the ecological integrity of ecosystems can be accomplished by conserving native biodiversity.

CHANGES IN THE HYDROLOGIC STREAMFLOW WITHIN MALIBU CREEK WATERSHED

Four primary environmental stressor problems associated with hydrologic functions have led to locally impoverished native biodiversity. These stressors are connected with a myriad of other deleterious environmental impacts upon the region's biota. The four primary environmental problems include the following groups as previously stated: changes within the hydrologic streamflow regime, habitat alterations, pollution, and non-native species.

IMPORTED WATER VOLUMES

The anthropogenic increase in the volume of water entering Malibu Creek and Malibu Lagoon has greatly altered the natural historic streamflow (hydrologic) regime. As used herein, the term, historic, shall be defined as the time continuum before the importation of freshwater into the Malibu Creek Watershed as part of the urbanization process. The term, natural, is defined as a dynamic physical system, dominated by native plants and animals, which has developed through natural processes (without human-intervention) in which those physical processes continue to occur. Native biota is maintained in a dynamic evolutionary context. This definition is somewhat similar to that described by Erwin (1990).

The principle sources of imported water entering this watershed include the cities of Malibu, Calabasas, Agoura Hills, Westlake Village,

flushing of organisms from the lagoon to the sea, to osmotic shock in many organisms, and to altered species composition. For example, Nordby and Zedler (1991) found that freshwater inflows into a southern California coastal lagoon resulted in reduced populations of jackknife clams (*Tagelus californianus*), and Dagit (1989) suggests that the sudden significant population reductions of *Tagelus californianus* in parts of Malibu Lagoon may be related to extreme reduction in salinities in those areas. Some plant species, such as pickleweed (*Salicornia virginica*), require brief seasonal (winter storm season) freshwater inundation in order to germinate. However, if this period of freshwater augmentation is prolonged, the germination rate decreases (Zedler, Koenigs, and Magdych, 1984).

Artificially augmented streamflow volume can cause plant species composition changes owing to the changing soil salinities that are associated with human-induced hydrologic disturbance (Zedler, 1984). An anthropogenic increase in streamflow volumes can change ecosystem structure and function and result in species composition changes because the survival tolerance threshold for some species is exceeded. For example, Zedler, Koenigs, and Magdych (1984) state that "...summertime releases of freshwater from Rodriguez Dam no doubt played a role in eliminating benthic invertebrates from Tijuana Estuary." This has profound ecological implications for Malibu Lagoon owing to the artificially augmented streamflows of recent years coupled with the distinct potential for further increased flows due to urban expansion in the watershed.

HABITAT ALTERATION

LAND-USE IN UPPER MALIBU CREEK WATERSHED

Extensive vegetation clearance, principally in the upper watershed, has replaced thousands of acres of native vegetation with urban development. The relative ratio of impermeable land surface to permeable land surface has been radically altered by land-use changes, so that a significantly higher proportion of impermeable surfaces now exists. Data from 1990 show that in the Malibu Creek Watershed, 8,421 acres (3,408 hectares) are in urban land use, and 61,871 acres (25,039 hectares) are "open space" (Santa Monica Bay Restoration Project, 1991). In addition, approximately seven percent of the total land area within the watershed is considered as impervious surface. This reduces infiltration rates and increases overland flow from the urban environment. Ultimately, the potential for unprecedented flood volumes and streamflow velocities increases as a direct function of increased impermeable surfaces (Strahler and Strahler, 1983). This has significant implications for the ecological communities within Malibu Creek, Malibu Lagoon, and Santa Monica Bay. An increase in the impermeable surface also reduces natural groundwater recharge. Thus, the base-flow to creek channels will also be reduced (Strahler and Strahler, 1983). Much of the upper watershed north of the Ventura Freeway was once populated by oak woodland and native grassland community (Goode, pers. comm. 1993). Overgrazing, wood harvesting, and now urbanization have reduced this natural community to a remnant of its former areal extent. How much water did this historic landscape absorb,

increases or decreases. In addition, by changing the nature of the landscape surface (e.g. from native vegetation to exposed soil during development), the potential for increased sedimentation rates rises. The greater the amount of impermeable surfaces within the Malibu Creek Watershed, the larger the volume and swifter the velocity of runoff water; and thus, the greater the potential sediment loads. Highly permeable land-use types, such as areas of native vegetation, have low runoff volumes and velocities while water infiltration rates and groundwater recharge rates are high.

Most sedimentation occurs during periodic storm events as part of the natural physical processes within a given ecosystem (Childers and Day, 1990). Sediment dynamics are coupled with regional climate and storm/flood regime, and in southern California, storms occur as episodic events, usually of high magnitude and low frequency typical of arid climates (Howard, 1982). When the natural sedimentation dynamics become coupled with the additional forcing regime of imported water and the exposed pulverized soils from urban development, the alteration and consequent degradation of ecosystem function and structure is often severe. Sediment loads become ecologically excessive if they disrupt any portion of the natural life cycle of biotic elements (i.e., tidewater goby, steelhead, macroinvertebrates).

Once the earth at a development site is graded, the soil structure is broken apart and unconsolidated materials become exposed to wind and water. The soil particles most easily detached by raindrop splash include fine sands and silts (Donahue et al., 1977). During heavy rainfall and

- * This factor has been placed in the equation by the author in replacement of C = crop management factor.

Because estuaries and lagoons constitute the terminal portion of watersheds, they are natural physical sinks for sediment deposition. Fine sediments deposited at an excessive non-natural and/or non-seasonal rate and volume have the potential to seriously degrade and possibly destroy habitats within Malibu Lagoon, including the spawning areas of the tidewater goby. High levels of silty sediments could interfere with tidewater goby breeding success (Swift, pers. comm. 1993). High rates of sediment deposition have been recorded within Malibu Lagoon, and have at times resulted in a thick veneer of silty sediment on top of and within the interstitial spaces of the coarse clean sand required by the tidewater goby as breeding substrate habitat. This could potentially limit oxygen within and around the burrow and damage or destroy the burrow structure itself.

Sedimentation is filling coastal estuaries in southern and central California at an ever-increasing rate and is directly correlated with the urbanization process (Mudie and Byrne, 1980). Mudie and Byrne (1980) found that sedimentation rates in some coastal estuaries in San Diego County increased from 10 centimeters (cm) per 100 years prior to European settlement to 50 cm per 100 years during the present century. In addition, pollen markers indicated that the deposition rate at Los Penasquitas Lagoon has risen to an average of 10 cm per decade since 1950, the equivalent of 100 cm per 100 years. They add that "the post-1950 rise in sedimentation rate is consistent with the local history of large-scale urban development..."

erosion potential (USDA-SCS, 1967). The major soil types in Malibu Creek Watershed include:

1) Calleguas and Arnold Soil (CAF2) is a major soil type in the upper Malibu Creek Watershed, especially north of Mulholland Highway. It consists primarily of fine to moderate sands and shaley clay on 30-50% slopes. This soil type is classified as a severe erosion hazard (USDA-SCS 1967).
2) Castaic silty clay loam (CtF2) is found on 30-50% slopes and the erosion hazard is moderate to high (USDA-SCS, 1967). This soil class is common north of the Ventura Freeway (101) and east of Gates Canyon. Both the Calleguas-Arnold series and the Castaic series are classified by the USDA and Soil Conservation Service in Group C of the hydrologic soil groups (USDA-SCS, 1967). Hydrologic soil classification is based upon the runoff potential of soils on watersheds. Group C soils are characterized by slow infiltration rates with either a layer that impedes the downward movement of water or they have a fine texture resulting in a slow infiltration rate (USDA-SCS, 1967). Fine textured silt, for example, ranges in size from 0.05 mm to 0.002 mm.

The above two soil types are by no means the only soil types in the Malibu Creek Watershed. However, they are the dominant soil class in terms of total areal extent. They also occur within a geographic area that is under extreme pressure from urban development projects with proposed grading in some projects in excess of 35 million cubic yards of earth graded.

The timing of the seasonal sandbar formation and breaching is critical to the biological integrity of the water within the lagoon and thus is a primary factor in determining the habitat quality for native biota. Seasonal freshwater inflow after sandbar formations allows for the natural seasonal conversion of Malibu Lagoon to brackish conditions. Non-seasonal artificial breaching, such as during the summer, can result in severely altered habitat quality (Smith, 1990). Human intervention in the natural seasonal sandbar breaching pattern at the Malibu Lagoon-to-sea entrance causes significant erratic salinity changes, sudden erosion, and flushing of organisms from the lagoon to the sea, as water levels precipitously decrease. The artificial managed breaching of the sandbar at Malibu Lagoon occurs during all seasons. Historically, Malibu Lagoon had lagoon-to-sea entrance dynamics similar to other small lagoons in southern California. Typically, during summer and fall when precipitation is scarce, the influx of freshwater into the lagoons is rare or absent (Nordby and Zedler, 1991; Soltz, 1979; Swift, 1982). The lack of rainfall in concert with the local longshore current and wave conditions allow a sandbar to build up at the lagoon-to-sea entrance, thus closing the lagoon off to the sea. This creates brackish conditions that persist until winter storms exert such force as to cut through the sandbar and re-establish surface water connectivity between the lagoon and sea.

RINDGE DAM

Dams are a major environmental stressor component of native fish fauna in all watersheds in which they have been constructed (Moyle and Leidy, 1992). Dams are significant barriers to native anadromous fish

and decreased or simplified habitat diversity and complexity (Karr and Schlosser, 1978). These lead to reduction in fish and invertebrate populations, shifts in fish and invertebrate species composition, and extirpation of vulnerable species (Karr and Schlosser, 1978). Endemic species, such as the tidewater goby which is adapted to a narrow ecological niche (i.e. brackish ecosystem), are particularly vulnerable.

In general, channelization reduces the hydrologic and physical variability (i.e. less diverse sediment patterns) of the stream and estuary/lagoon system into which it flows. The result is the reduction of the diversity of native biological communities (Faber et al., 1989).

Upper Malibu Lagoon and lower Malibu Creek from Pacific Coast Highway to approximately 200 meters upstream from Cross Creek Road was bulldozed as late as the 1960s (Swift, pers. comm. 1992; Brown pers. comm. 1992; Soltz, 1979). This channelization was done under the auspices of flood prevention and was of dubious merit then, and has since been proven to be of no merit. Much of the channel bulldozing occurred in the primary spawning habitat of the tidewater goby in Malibu Lagoon. This may have been the most significant factor within the full spectrum of human-induced stressors that resulted in the late 1960s to 1970 extirpation of the goby. Channelization is usually performed to create a more linear channel to move water quickly from point to point. Faster water velocities result and this exerts a greater forcing action that can wash fishes and other species from the lagoon to the sea. Channel bulldozing and its associated destruction and degradation of tidewater goby spawning habitat has not

California, 2) restricted to a small geographic area, 3) occupants of just one watershed, 4) part of a fish assemblage of less than five species, and 5) found in isolated springs, warm water streams, or big rivers. Moyle and Williams (1990) also determined that multiple causes and the cumulative and likely synergistic effects of streamflow regime changes, introduced non-native species, and habitat degradation are the principle causes for native fish decline in temperate regions. The tidewater goby fits into the first four of Moyle and Williams' categories: 1) endemic to California, 2 and 3) restricted to a small area — tidewater gobies are restricted to a series of small isolated lagoon habitats within California, and 4) part of an assemblage of less than five species — the tidewater goby is primarily associated with upper lagoon reaches and bays with low salinity environments. Tidewater gobies are year-round residents in these brackish waters, and according to Swift (1989) they are "almost unique among fishes in their restriction to brackish-low salinity habitat." Brackish habitats typically have water salinities between 0.5 and 30 ppt (Zedler, 1986). A few native species also seasonally utilize this brackish habitat niche. Examples in Malibu Creek and Malibu Lagoon are the anadromous steelhead (*Onchorhyncus mykiss*), the Pacific lamprey (*Lampetra tridentata*), and possibly in earlier times, the silver salmon (*Oncorhyncus kistuch*) (Swift, 1982; Walker, 1992).

The native fish faunas in California are not adequately protected (Moyle and Leidy, 1992). According to Moyle and Williams (1988), seventy percent of the native fish fauna have less than ten percent of their habitat

prey upon native arroyo chub (*Gila orcutta*), possibly small steelhead, and tidewater gobies.

The black bullhead (*Ictalurus melas*) is a small member of the catfish group and occurs regularly above and below the Rindge Dam. These are restricted to freshwater and have only occasionally been found in Malibu Lagoon in winter (Swift, 1982), presumably when the lagoon was briefly freshwater during a storm event.

The golden shiner (*Notemigonus crysoleucas*) is a small minnow introduced in June, 1978, by accident when a live cage containing 12 fish was vandalized. This introduced fish species did not survive the winter (Soltz, 1979; Swift, 1982).

These non-native introduced fish are all freshwater species that, with the exception of the mosquito fish, are believed to only occasionally occur in Malibu Lagoon. The potential threat of non-native invasive fishes to the tidewater goby population in Malibu Lagoon is that they may become established or even semi-established if the salinity in the lagoon chronically declines with the additions of imported freshwater into the creek. The normally intermittent creek has and may continue to become increasingly continuous and voluminous in its flow and may create a prolonged and continuous freshwater influence in the upper lagoon. The seasonal balance of brackish water in the upper lagoon may be disrupted, thus altering the species composition of the upper lagoon and perhaps compromising the future of the tidewater goby. Soltz (1979) states that increased streamflow may lead to increased populations of green sunfish in Malibu Creek. In

Chapter III

TIDEWATER GOBY BIOLOGY

BODY FORM

The wide global diversity of fish species is reflected in the extensive array of differing body shapes they possess. Worldwide there are approximately 22,000 fish species inhabiting a variety of habitats. The plethora of habitat types means that body form design constraints are also extensive, resulting in many different body morphologies (Moyle and Cech, 1988; Moyle and Leidy, 1992).

Moyle and Cech (1988) grouped fishes into six general categories (guilds): rover-predator, lie-in-wait predator, surface-oriented fish, bottom fish, deep-bodied fish, and eel-like fish. The family Gobiidae are categorized as bottom fishes and, within this group, are further narrowed into the bottom clinger group (Moyle and Cech, 1988).

Bottom clingers are principally small fishes with blunt flattened heads, enlarged pectoral fins, eyes close to the top of the head, terminal mouths, a slender, ventrally flattened body shape, and the most distinctive characteristic — modified pelvic fins that allow them to cling to the bottom. Tidewater gobies possess a cone-shaped suction cup formed by the ventral union of the pelvic fins (Moyle and Cech, 1988). This suction cup fin enables the tidewater goby to cling to substratum.

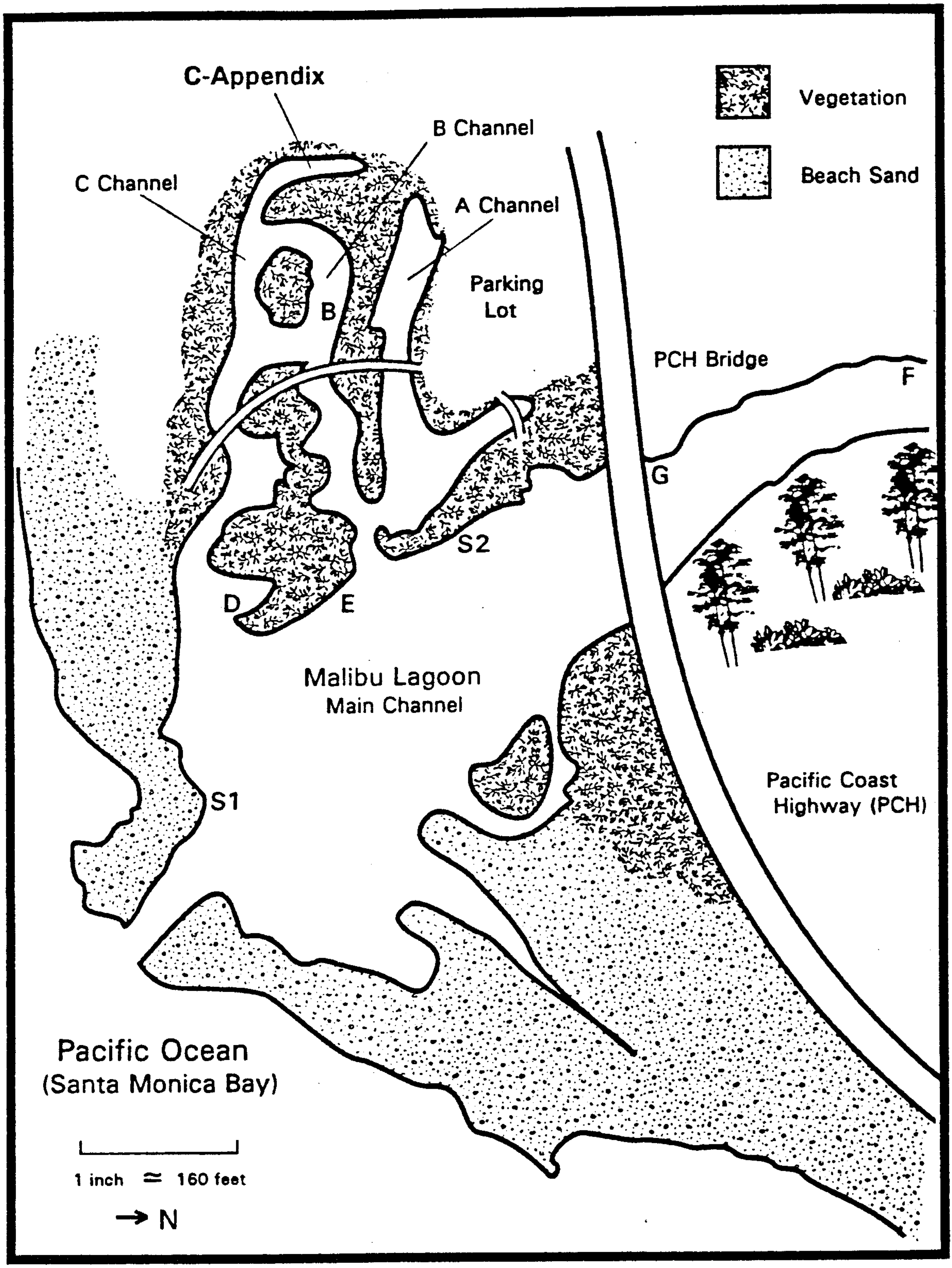
Enlarged pectoral fins and the modified pelvic fin-suction cup of the tidewater goby are crucial morphological adaptations enabling it to cling to

environments. Brackish water species typically are capable of tolerating salinities from 3 ppt to 30 ppt. Fishes inhabiting estuary/lagoon environments, such as the tidewater goby, experience continual shifts in external salinity that are dictated by stream-flow regime, tidal rhythms, wind, precipitation cycles, evaporation, and estuary/lagoon-to-sea entrance condition (Moyle, 1988; Ferren, 1985; Manion and Dillingham, 1989; Zedler, 1982). Euryhaline traits, enabling species to persist in dynamic estuarine ecosystems, are generally believed to be a function of physiological specialization over evolutionary time, fluctuating environmental conditions (especially salinity), and niche diversity over time (Nybakken, 1982). Tidewater gobies frequent the upper end of lagoon systems where salinities are often less than 15 ppt.

REPRODUCTIVE BIOLOGY

The following reproductive biology and breeding behavior are summarized from Swift et al. (1989) except where noted. Tidewater gobies seem to have an annual life cycle entirely within the estuary or lagoon environment. They typically breed in late April to early May when water temperatures average approximately 18-22 degrees Celsius with salinities ranging from 5-10 ppt. Recent captive breeding experiments indicate a wider range of salinity tolerances during breeding (Lea, pers. comm. 1991). Captive breeding behavior, however, may not be directly applicable to wild conditions. Tidewater gobies are known to reproduce at other times of the year in addition to the April-May period, indicating possible multiple

diamond turbot (*Hypsopsetta guttulata*), and the tidewater goby (*Eucyclogobius newberryi*) (Swift, 1982; Allen, 1985). Freshwater fishes utilizing Malibu Creek include the Pacific lamprey (*Entosphenus tridentatus*), steelhead (*Onchorhyncus mykiss*), arroyo chub (*Gila orcutti*), and silver salmon (*Onchorhyncus kistuch*) (Swift, 1982; Walker, pers. comm. 1992).



Map 2. Study station sites for sampling water quality parameters. Channel locations also indicated.

the west bank shore, whereas the adjacent central channel is significantly deeper.

STATION G

This station is just north of Pacific Coast Highway Bridge on the west bank of Malibu Creek/Lagoon. There was a continual release of "cleaned effluent" at this point which was discontinued in September, 1992. The cleaning process was a project to remove a prior benzene pollution problem from a nearby location. The substratum type at this station is comprised mainly of fine gravel, coarse to medium sands, some cobble, and some large chunks of cement. Compared to other sites, Stations G and F frequently have a somewhat swifter water current.

STATION S1

This station near the lagoon-to-sea entrance consists of coarse to fine sand substrate with a significant amount of drift materials (i.e. drift algae, flotsam, and trash) moving through depending upon tides and the seasonal creek conditions.

STATION S2

This station is located along the western bank of the lagoon. Coarse to medium sands predominate along with gravels, and some cobble. There is also some consolidated clay along the banks.

Chapter V
METHODS AND MATERIALS

TIME OF FIELD STUDY

The field study portion of this reintroduction project was conducted at Malibu Lagoon from January, 1990, to April, 1992. This project was conducted in three phases. The pre-reintroduction phase began in January, 1990, with data collection on selected physical parameters associated with tidewater goby biological requirements. Phase two, the reintroduction, consisted of the collection of tidewater goby stock from the Ventura River and release the same day into Malibu Lagoon on April 5, 1991. Post-reintroduction, or phase three, continued physical data monitoring of the habitat and survey seines to determine if tidewater gobies were still present in the lagoon system, and if so, were they breeding. Phase three continued through April, 1992.

PHYSICAL PARAMETERS

Data collection dates, stations, and physical parameters were placed into three groups or subsets based on year, location of station, and sample intervals: 1) Data for 1990 were taken from January 1, 1990, to July 24, 1990, three times per month and occasionally four times per month at weekly intervals. Stations for this data were B, C-Appendix, and E (Map 2). 2) Data for 1991 were taken at Stations S1 and S2 from January 8, 1991, to April 28, 1992. An average of 10.5 field samples per month were obtained, with an average of 18.5 samples per month recorded during the most critical reintroduction phase of April through May, 1991; 3) Data for 1991 and 1992 were also taken at Stations B, C-Appendix, D, E, F, and G. Data from these stations were recorded twice per month from January 10, 1991, to April 15, 1992 (Table I).

Table I. Data collection dates, stations, and sampling frequency

Year	Dates	Stations	Average # Samples/Month
1990	01/09/90 - 07/24/90	B, E, C-Appendix	3.5
1991	01/08/91 - 04/28/92	S1, S2	10.5
1991 & 1992	01/10/91 - 03/25/92	B, C-Appendix, E	2.0
	01/10/91 - 04/15/92	G (PCH Bridge)	
	06/13/91 - 04/15/92	D	
	09/13/91 - 04/15/92	F	

The physical parameters sampled include the following: salinity, water temperature, dissolved oxygen, water depth at sample site, lagoon water level, pH, entrance condition, and sediment distribution pattern. Surface and bottom salinities, temperatures, and dissolved oxygen were taken when the water level was greater than or equal to 50 cm. When water levels were less than 50 cm at the sampling station, salinity, temperatures, and dissolved oxygen were recorded as mid-level. Low water levels (<50 cm) are frequently well-mixed waters of relatively uniform salinity and temperature from top to bottom, thus the single mid-level measurement. Mid-level measurements are reflected on graphs as both bottom and surface temperature and salinity.

SALINITY

A calibrated Atago hand held refractometer was used to measure salinity to the nearest part per thousand (ppt). Salinity data from Stations S1 and S2 was collected with a La Motte's salinity kit.

WATER TEMPERATURE

Water temperature, both surface and bottom, was measured with a Yellow Springs Instrument (YSI) Model 057 meter.

DISSOLVED OXYGEN

Dissolved oxygen was measured with the YSI Model 057 meter. The probe was immersed in the water and moved to-and-fro at a rate of one foot per second until a steady reading occurred. Readings were in milligrams/liter (mg/L) with accuracy to the nearest 0.2 mg/L. The probe is held initially near the surface and then near the bottom, or in shallow water (< 50 cm) at mid-level.

SAMPLE SITE WATER DEPTH

Depth was measured with a meter stick to the nearest centimeter.

LAGOON WATER LEVEL

Overall lagoon water level was recorded at the bridge at Channel A, where a measuring device graduated in feet has been established by State Department of Parks and Recreation. The zero level was set at the mean low tide mark.

pH

Tri-reagent colorpHast pH strips were dipped in the sample and read. The values of these strips are accurate to the nearest whole number.

ENTRANCE CONDITION

The lagoon-to-sea entrance was observed visually for its open or closed status. This was a measure of visual surface water connectivity between lagoon waters and the sea.

SEDIMENT DISTRIBUTION SURVEY

This was a qualitative visual survey performed at low tide (Map 3, Chapter VI).

FISH COLLECTION, REINTRODUCTION, AND POST-REINTRODUCTION METHODS

PRE-REINTRODUCTION COLLECTION

Tidewater gobies were collected from the Ventura River, Ventura County, California, for reintroduction into Malibu Lagoon, Los Angeles County. Dr. Camm Swift, Associate Curator of Fishes, Los Angeles County Museum of Natural History, served as technical advisor. The Ventura River *Eucyclogobius* population was believed to be sufficiently high in number that collecting individuals for reintroduction would not adversely impact the local population in the Ventura River (Swift, pers. comm. 1991).

Tidewater gobies were collected at low tide on April 5, 1991, using a 20′ x 5′ x 1/8" seine with ace-type mesh. The fish were transferred to small plastic bags filled with approximately one-half water from the Ventura River (3 ppt) and one-half oxygen from tanks brought for this purpose. Each bag held 3 to 4 fish. The bags were then packed closely together in insulated styrofoam ice chests. Immediately after packing, the fish were transported to Malibu Lagoon (approximately one hour by vehicle) for reintroduction.

REINTRODUCTION

The fish were released at three sites in Malibu Lagoon (Map 4) with five artificial breeding substrate patches. Site #1 in Upper Channel C consisted of three breeding substrate patches; Site #2 in Lower Channel C under "C" Bridge consisted of one breeding patch; and Site #3 under the Pacific Coast Highway Bridge (PCH Bridge) consisted of one large breeding substrate patch (Table II).

Table II. Reintroduction Sites

Site #	Location	# of Breeding Patches
1	Upper "C" Channel	3
2	Lower "C" Channel under "C" bridge	1
3	PCH Bridge (under bridge)	1 (large)

At Sites #1 and #2, breeding substrate patches consisted of rigid plastic rings 6 inches deep and 12 inches diameter (actual inside diameter 11.5 inches) filled with clean coarse beach sand. At Site #3 (PCH Bridge) similar rings were stationed. The rings were 8 inches deep, with rocks for anchoring weight and 6 inches of sand substrate added on top. Each plastic ring had a surface area of 669.61 cm^2 (0.067 m^2 or 0.72 sq.ft.).

Site #1 - Upper "C" Channel

Consisted of 3 patches, each with 3 rigid plastic rings for a total of 9 rings totalling 6,026.49 cm^2 (0.603 m^2) of substrate.

Site #2 - "C" Channel bridge

Consisted of 1 patch of 4 rigid plastic rings totalling 2,678.44 cm^2 (0.268 m^2) of breeding substrate.

Site #3 - PCH Bridge

Consisted of one patch of 9 rigid plastic rings for a total surface area of 6,026.49 cm^2 (0.603 m^2) substrate.

Total area of artificial breeding substrate for all sites (1-3) equals 14,731.42 cm^2 (1.474 m^2).

The plastic bags bearing the fish were floated in the water at each release site in Malibu Lagoon in order to slowly acclimate the fish to slight temperature differences between the water in the bags and the specific release site waters of Malibu Lagoon. Salinities at the Ventura River and Malibu Lagoon were 3 ppt and 5 ppt respectively, enabling the fish to adjust without an acclimation period.

POST-REINTRODUCTION FIELD MONITORING

Field survey seines were conducted for a total of four surveys subsequent to the April 5, 1991, reintroduction. Survey seines were performed on August 8, 1991, October 29, 1991, April 15, 1992, and August 5, 1992.

A 20′ x 5′ x 1/8" seine with ace-type mesh was used to sample each original release site with additional seining throughout this small lagoon system. Seines were performed at low to mid tides. All *Eucyclogobius* captured during the seines were measured and released. The types of data gathered at each seine were as follows:

1. Continued presence of individuals (# of individuals recorded)
2. Presence of young-of-the-year (YOY)
3. Standard length (SL) to the nearest millimeter (mm)
4. Geographic area of occurrence within Malibu Lagoon

There were two primary groups of information gathered from the seines necessary to establish a baseline for short-term project success. First, the continued presence of individuals would indicate the persistence of tidewater gobies in Malibu Lagoon. Second, the size of individuals was recorded to determine if breeding had occurred in Malibu Lagoon. Presence of YOY size class would signify breeding success.

Chapter VI

RESULTS

PHYSICAL PARAMETERS

SALINITY

The major factor influencing estuarine environments is the variability in salinity pattern (Nybakken, 1982). Salinity patterns vary along a seasonal and spatial gradient, and influence the distribution of all estuarine organisms, such as *Eucyclogobius*, within Malibu Lagoon. Fluctuating salinities of estuarine environments typically restrict the number of species because it prevents, to varying degrees, strictly stenohaline marine species as well as freshwater species from continual use of estuaries (Moyle and Cech, 1988). Strictly estuarine species are typically habitat specialists. Rapid rate anthropogenic alterations, such as sudden increases in freshwater inflow, can cause mass mortalities of some organisms which are unable to avoid sudden low-salinity waters, either by physically flushing them from the estuary/lagoon or by osmotic shock (Moyle and Cech, 1988). Deleterious salinity effects in Malibu Lagoon stem from sudden pulses and continual non-seasonal freshwater inflow from domestic sources as well as non-seasonal lagoon entrance openings that suddenly increases salinity conditions and flushes organisms from the lagoon. Perhaps the most important salinity relation aspect for the tidewater goby is the salinity range during the primary breeding period from late April to early May (Table III). Tidewater gobies at this time of year must find suitable salinity ranges for courtship, burrow construction, and breeding behavior. It is important to note that "preferred" tidewater goby breeding salinity tolerances are not absolutes, but are guidelines for ecological resource managers to use. In the controlled environment of the laboratory, tidewater gobies have bred at many different salinity levels. However, in the wild *Eucyclogobius* seems to have a preferred salinity range of 5-10 ppt. In addition, salinity and water temperature preference may vary between geographic regions, depending upon the physical characteristics operating within the particular region.

Salinity is an extremely variable parameter in water quality at Malibu Lagoon. Salinity ranges at all stations in Malibu Lagoon varied from lows of 1.2, 2.0, and 3.0 parts per thousand (ppt) to highs of 35.0 to 37.2 ppt (See Appendix, Figures 1-17).

During the study period, samples from Stations B and C-Appendix (See Appendix, Figures 1, 2, 4, and 5) had salinities ranging from 4 ppt to 34 ppt, and 3 ppt to 35 ppt, respectively, with means of 14.2 ppt (surface) and 15.4 ppt (bottom = $\geq$50 cm) for Station B, and 15.5 ppt (surface) and 17.4 ppt (bottom) for Station C-Appendix. Salinity samples from Station D ranged from 2 ppt to 37 ppt (Figure 6), with a mean of 17.3 ppt (surface) and 18.4 ppt (bottom). At Station E, located in the main lagoon, salinities ranged from a low of 1 ppt to a high of 36 ppt (Figures 3 and 7) with a mean of 12.3 ppt (surface) and 18.7 ppt (bottom). The upper lagoon/creek Station F near the storm drain outlet was added as a station only after discovering that this was an area used by the newly reintroduced gobies. The salinity at this station is strongly influenced by runoff from the storm drain. Salinities at Station F ranged from 2 ppt to 23 ppt (Figure 8). The runoff, streamflow volumes and rates influenced by imported water into the watershed, and the fact that this station is at the upper limits of the lagoon are the reasons for low salinities. Station G had generally low salinities because, like Station F, it is located in the upper reaches of Malibu Lagoon and is influenced by freshwater runoff, in this case "cleaned effluent" from a previous pollution problem. Salinities at this station are slightly higher on average than Station F due to its closer proximity to tidal influences. Salinities at Station G (Figure 9) ranged from a low of 2 ppt to a high of 11 ppt. The mean salinity value was 5.5 ppt. Station S1 is near the lagoon-to-sea entrance and within the main lagoon body. This station characteristically exhibits extensive variations in salinities due to its close proximity to tidal influence, the current artificial breaching of the seasonal sandbar, the background imported water, the irregular pulses of imported freshwater, and normal precipitation caused streamflow. The salinity trends at S1 (Figures 10-13) range from lows of 2 ppt to a high of 37.2 ppt. The mean salinity value is 12.6 ppt (surface) and 16.8 ppt (bottom). Station S2 exhibits extensive salinity variation. Salinity ranged from 1.2 ppt to 36 ppt (Figures 14-17), with a mean of 9.9 ppt (surface) and 16.4 ppt (bottom).

WATER TEMPERATURE

Water temperature is quite variable in Malibu Lagoon owing principally to seasonal climate conditions, the shallow nature of this embayment, and probably water circulation patterns.

Water temperatures are typically higher in the summer and fall, and decline in winter. Stations B and C-Appendix had seasonally elevated temperatures from July through September, while Station E had higher water temperatures into early October (Figures 18-23). Station F data was too limited to assess water temperature trends. Station G water temperatures varied widely with one seemingly anomalous peak. Water temperatures of 21°C to 23°C occurred in mid-April to early May (Figure 26). Perhaps this is a reflection of the freshwater entering this station area from the "effluent cleaning" pumping station nearby. Station S1 exhibited typical seasonal patterns with minimum temperatures in December through January and maximum water temperatures during July through mid-October (Figures 27-30). Station S2 (Figures 31-34) had a pattern similar to S1. However, the maximum temperatures from July to mid-October were somewhat higher. For instance, maximum temperatures at Station S2 were 26°C on July 16, 1991, and 25°C three times during September and October. Both Station S1 and S2 showed similar brief periods of elevated temperatures during early to mid-April 1991.

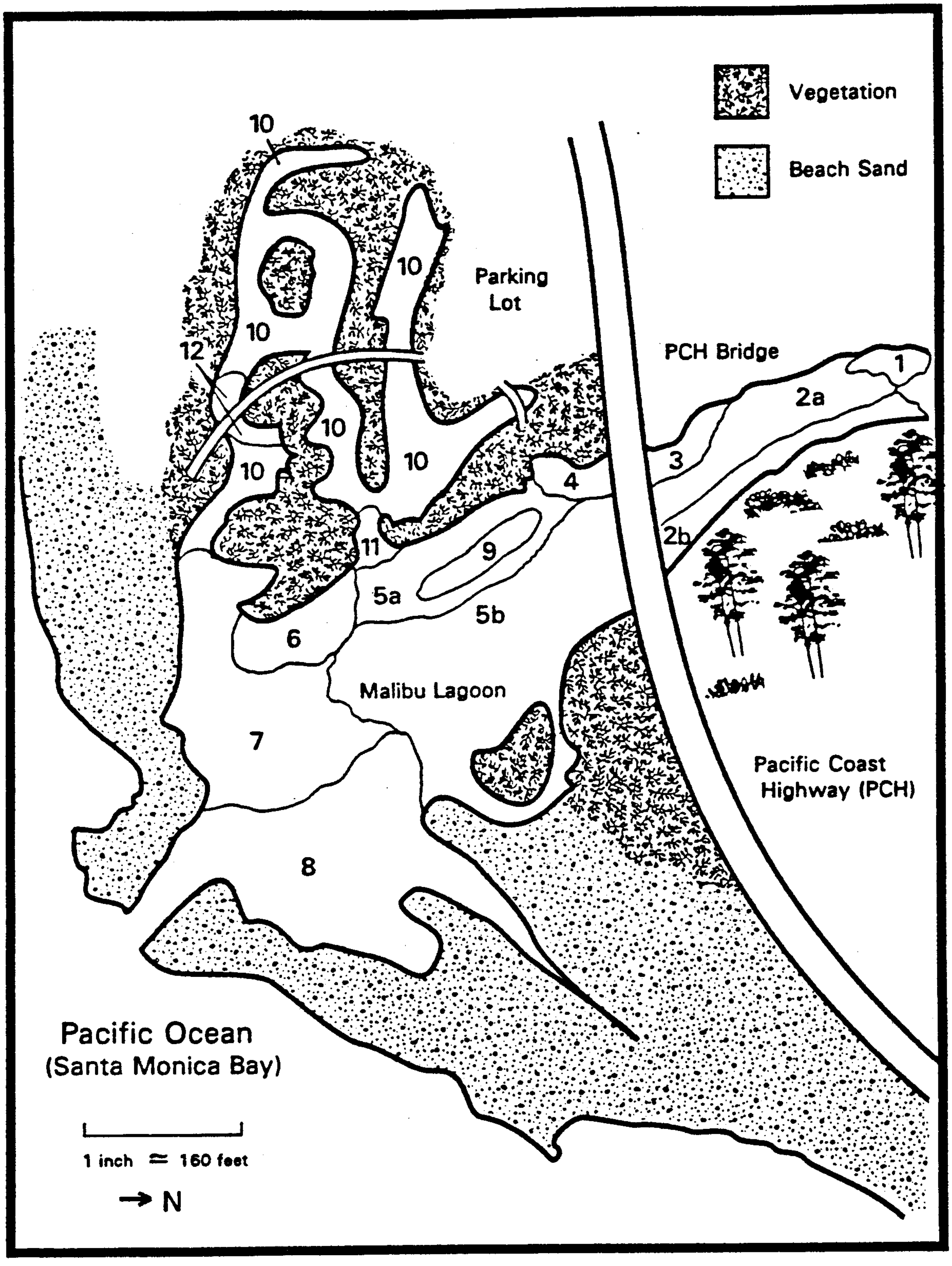
SEDIMENT DISTRIBUTION

The distribution of sediments within the lagoon influences the type, distribution, and density of organisms that inhabit estuarine environments. The main lagoon channel typically exhibits coarser sediment types than the inner channels of Malibu Lagoon. The main lagoon is composed principally of sands, gravels, and cobbles, whereas the bottom of the inner channels is comprised mainly of fine dark silts mixed with significant amounts of organic material. The ecotonal sediment regions between the main lagoon channel and the inner channels display a gradation from sands and some gravels near the main channel and inner channels interface to the fine dark silts further up each channel. This deposition pattern is due to circulation patterns and water velocities. In Channel C there are also some deep pockets of organic material near the south shore (Map 3).

The relationships between salinity, water temperature, and sediment types are among the most important variables during the primary breeding season of the tidewater goby, late April to early May. Table III depicts those relationships for each station sampled.

ENTRANCE CONDITION

Currently the hydrologic streamflow dynamics have been anthropogenically altered by the importation into the watershed of freshwater which is subsequently released into the Malibu Creek Watershed. For a description of the typical seasonal breaching pattern and the current pattern, see "Sandbar Formation and Breaching" in Chapter 2. Presently, streamflow dynamics are significantly dissimilar to the natural seasonal streamflow pre-1950s, and in particular, are dissimilar to the natural historic streamflow pattern prior to European settlement of the region. The non-seasonal input of freshwater into this stream and lagoon system influences the entrance conditions. Mechanical breaching of the sandbar entrance, owing principally to the additional freshwater inputs, also influences the current lagoon-to-sea entrance conditions.



Map 3. Spatial deposition pattern of substrate for a specific moment, April 1992, along the dynamic temporal continuum of deposition and removal. See next page for key.

Map 3. Key to Substrate Descriptions

Area 1:	Coarse to medium sand
Area 2a:	Deep channel-cobble, some boulders, cement chunks
Area 2b:	Gravels with some small to medium cobble, some coarse to medium sand
Area 3:	Fine gravel, coarse to medium sand, some cobble, some large cement chunks
Area 4:	Mostly cobble, fine gravel, and some sands, some large cement chunks
Area 5a:	Coarse to medium sand, coarse to fine gravels, cobble, some consolidated clay along bank
Area 5b:	Small to medium cobble, coarse to medium sand and gravel, pockets of silt, pockets of organics (mostly drift coastal algae)
Area 6:	Coarse sand, with an underlying clay substrate, and consolidated clay along bank with sands towards main lagoon channel
Area 7:	Mostly coarse to fine sands, some gravels, with underlying clay substrate
Area 8:	Coarse to fine sands.
Area 9:	Cobble "reef"
Area 10:	Unconsolidated fine silts and organics, overlying clay substrate, some cobble
Area 11:	Small to medium cobble and gravels
Area 12:	Unconsolidated fine sands and clay, with deep pockets of organics near south shore (coastal drift algae)

Table III. Relationships between selected parameters and tidewater goby preferred ranges during primary breeding season - April to May

Parameter	Tidewater goby preferences	Station B	Station C-App	Station E	Station F	Station G	Station S1	Station S2
Salinity	5-10 ppt is a general guide. Gobies in lab conditions have bred at higher salinities.	4-25 ppt	5-25 ppt	1-36 ppt Salinities were mostly in the higher range Apr-May.	2-4 ppt Salinity data is limited at this station. this station.	2-9 ppt	2-37 ppt	1-36 ppt
Water Temperature	18-22 deg Celsius is a general guide.	18-18.5 deg Celsius	18-20 deg Celsius	17-18.5 deg Celsius	16-20.5 deg Celsius limited data	16-23 deg Celsius	9-25 deg Celsius	12-26 deg Celsius
Substrate	Clean coarse sand	fine silts	fine silts	Coarse to fine sands	Clean coarse sand	Coarse to med sands, gravel, some cobble	Coarse to fine sands, gravels	Coarse to medium sands and gravels, cobble

Artificial or mechanical breaching is performed by California State Department of Parks and Recreation, who have a cooperative agreement with Malibu Colony residents. Artificial breaching generally occurs when lagoon water levels reach 3.5 feet (1.1 meter). Mechanical breaching is done to alleviate the perceived pollution problem of lagoon waters interacting with the septic leachfield systems of the Malibu Colony. There have been no studies to verify if this, in fact, occurs. Owing principally to funding and logistical problems, the sandbar breaching is somewhat sporadic and occurs during all seasons. Physical parameters such as salinity fluctuate widely, due in part to imported freshwater inputs and entrance management. Generally, salinities tend to decrease when the entrance is closed and freshwater input raises lagoon water levels. For example, Figure 11, from May 31 to June 12, shows a decreasing salinity trend associated with entrance closure and increasing water levels. The perceived anomaly on June 7, when the water level dropped precipitously to 2.9 feet (0.9 meter) and two days later had risen to 4.7 feet (1.4 meters) was the result of a mechanical breach that closed up within two days. Salinities remained low owing to the tidal conditions and outflow from the creek. Salinities usually fluctuate widely and trend towards increased salinities when the lagoon entrance remains open for a period of time.

pH

The total pH range at all sample stations in Malibu Lagoon was 6.5 to 9.5. Specific stations had the following pH ranges: Station B - 7.0 to 7.5; Station C-Appendix - 7.0 to 8.5 (limited data); Station D - 7.0 to 7.5 (limited data); Station E - 7.0 to 9.5; Station F - 6.5 to 7.5 (limited data); Station G - 6.5 to 7.5 (limited data); Stations S1 and S2 were considered together and had pH ranges from 6.5 to 9.5. They also had the most substantial data set of all the stations.

Values for pH generally declined when the lagoon-to-sea entrance was open, which is also associated with higher salinities. Higher pH values usually, but not always, occurred when the lagoon-to-sea entrance was closed and salinities declined. For instance, July 8, 9, and 12 in 1991 showed high pH values of 9.0, 9.5, and 9.0. The lagoon-to-sea entrance was closed during this time span and lower salinity values predominated. Surface salinities ranged from 5 ppt to 12 ppt, while bottom salinity sample values ranged from 8 ppt to 16 ppt. On July 15, 16, and 18 in 1991, the data yield for pH values was 8.2, 8.0, and 8.0, the entrance was open, and surface salinities were 25 ppt, 25.8 ppt, and 17 ppt, while bottom salinity values were 36 ppt, 36 ppt, and 25.4 ppt. pH levels in Malibu Lagoon presently do not seem to be a limiting factor in the tidewater goby life cycle.

DISSOLVED OXYGEN

Most estuaries contain ample amounts of dissolved oxygen in the water column (Nybakken, 1982). Influxes of fresh and salt water in combination with shallow embayments, turbulence, and wind mixing contribute to the availability of dissolved oxygen in Malibu Lagoon. The solubility of oxygen in water decreases as temperatures and salinity increase (Nybakken, 1982).

In Malibu Lagoon, as in most estuaries, dissolved oxygen levels tended to be somewhat higher near the surface with slightly lower levels in the middle and bottom portion of the water column. The total range of dissolved oxygen values at all stations in Malibu Lagoon was 5.0-16.0 mg/L. Specific stations had the following ranges: Station B - 7.2 to 11.0 mg/L; Station C-Appendix - 5.0 - 10.9 mg/L; Station D - 9.4 to 13.2 mg/L; Station E - 8.0 to 11.0 mg/L (limited data); Station F - 5.8 to 9.0 mg/L (limited data); Station G - 8.2 to 16.0 mg/L. Dissolved oxygen data were not available for Stations S1 and S2.

Current dissolved oxygen levels do not seem to be a limiting or problematic factor for the tidewater goby in Malibu Lagoon.

LAGOON WATER LEVEL

Water level in Malibu Lagoon is variable during all times of the year. In Malibu Lagoon, water level is primarily influenced by seasonal precipitation, imported freshwater released into the watershed system, tidal patterns, and lagoon-to-sea entrance condition (open or closed).

The total range of Malibu Lagoon water levels was from slightly less than 2 feet (0.6 meter) to a singular one day high of 7.2 feet (2.2 meters) (See Appendix, Figures 35-38).

REINTRODUCTION

PRE-REINTRODUCTION COLLECTING

Tidewater gobies were collected on April 5, 1991, from the Ventura River. A total of 103 individuals were captured. The fish were immediately transported to Malibu Lagoon for reintroduction.

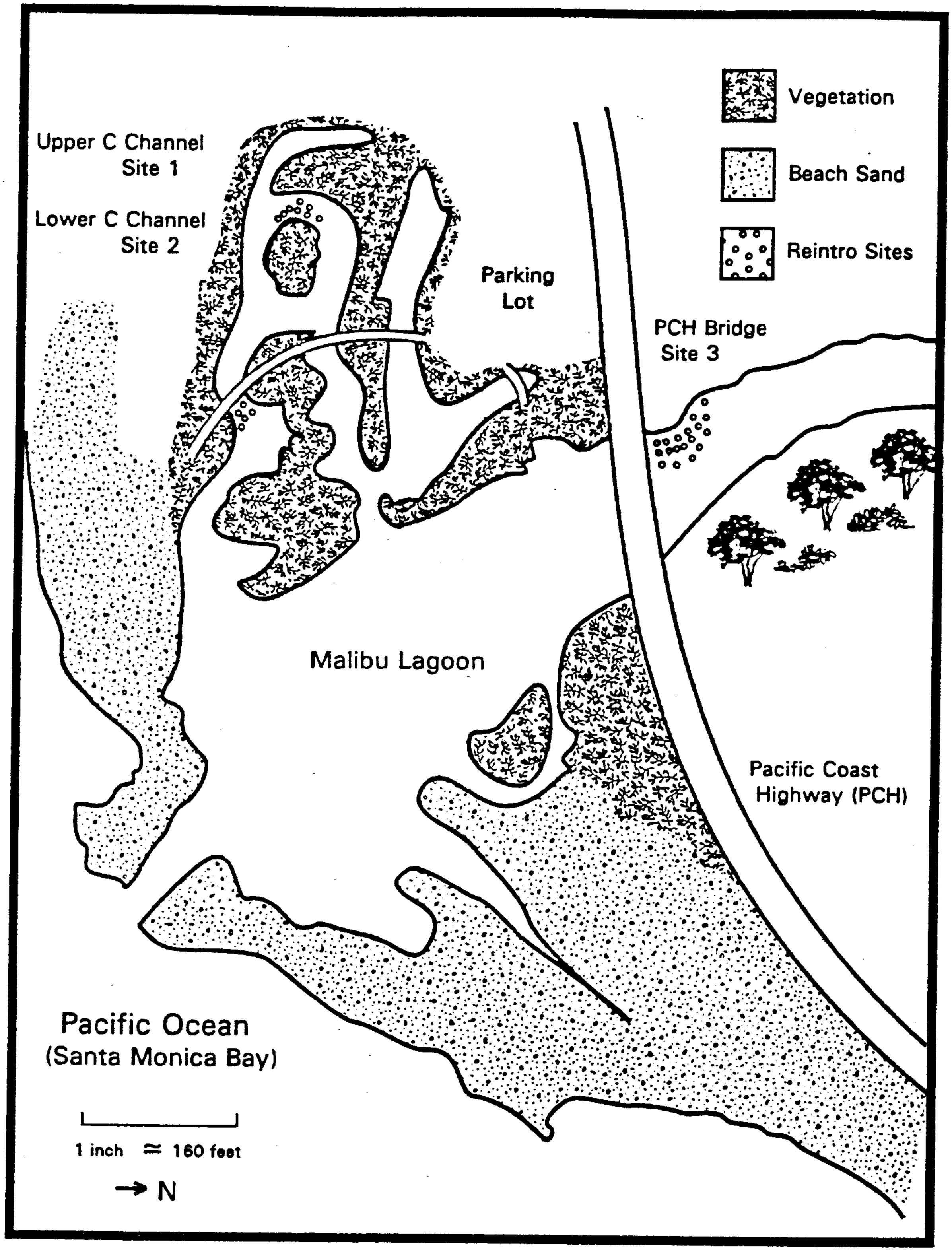
Other fishes captured and released during collecting at the Ventura River were stickleback (*Microcephalus sp.*), staghorn sculpin (*Leptocottus armatus*), carp (*Cyprinus carpio*), and topsmelt (*Atherinops affinis*).

REINTRODUCTION

The number of fish captured at the Ventura River totaled 103. During the trip from the Ventura River to Malibu Lagoon two fish died. These were most likely related to capture and/or transportation stress or injury. A total of 52 fish were released into Malibu Lagoon and 49 fish were taken by Heal the Bay to attempt to breed them in aquaria for eventual release of greater numbers into Malibu Lagoon. The tidewater goby breeding experiment by Heal the Bay was not successful, and presently no further attempt is contemplated in conjunction with introducing captive bred tidewater gobies into Malibu Lagoon.

At each release site at Malibu Lagoon the plastic bags bearing the fish were floated in the water in order to slowly acclimate the fish to slight temperature differences between the water in the bags and the specific release site waters of the Lagoon.

Fish were released at three sites within Malibu Lagoon (Map 4). Each of these three sites had artificial breeding patches of coarse sand substrate that tidewater gobies could use if suitable natural sites were lacking in spatial or temporal quality. At Site #1, the upper Channel C, twelve tidewater gobies were released directly above the breeding patches. All twelve fish immediately swam vigorously and descended through the water column and stationed themselves on the coarse sand substrate of the



Map 4. Tidewater goby reintroduction sites April 5, 1991.

artificial breeding patch. Twelve fish were also released at Site #2, the Channel C bridge. They, too, swam immediately to the breeding patch substrate. At Site #3, the Pacific Coast Highway (PCH) Bridge, the remaining 28 tidewater gobies were released. Again, these fish swam directly to the breeding patches. The majority of *Eucyclogobius* were released at this site because data indicated that this area had the most suitable overall combination of salinities, substrate, and water temperatures for reproductive success. This site had generally low salinities, a faster current, and a wider available water temperature spectrum due primarily to differing water depths and a sun/shade regime that other sites lacked. The sex of individuals was generally undetermined. However, some fish showed early signs of darkened breeding coloration typical of female tidewater gobies. Prior research indicates that most seine sampling at this point in the season yields a general 1:1 ratio of males to females (Swift, pers. comm. 1991). All fish released into Malibu Lagoon were adults.

POST-REINTRODUCTION FIELD SURVEY SEINES

Field surveys in the form of seines using the 20′ x 5′ x 1/8" net were conducted four times subsequent to the April 5, 1991, reintroduction. In addition, during the time between reintroduction and the first seine, visual qualitative field surveys were done to determine if newly reintroduced fish were utilizing the artificial breeding patches. The qualitative visual surveys showed that within two weeks, an undetermined number of tidewater gobies had constructed burrows in the artificial breeding patch substrate. However, the build-up of fine silt, especially within the lagoon channels where breeding patch Sites #1 and #2 were located, was much faster than anticipated. By early May, an excessive amount of fine silt overlaid the coarse sand breeding patches and this in combination with water turbidity made further visual surveys impossible. Because of the heavy fine silt veneer overlying the breeding patches tidewater gobies likely abandoned these sites. The source of this swift sediment build-up will be addressed in the discussion section.

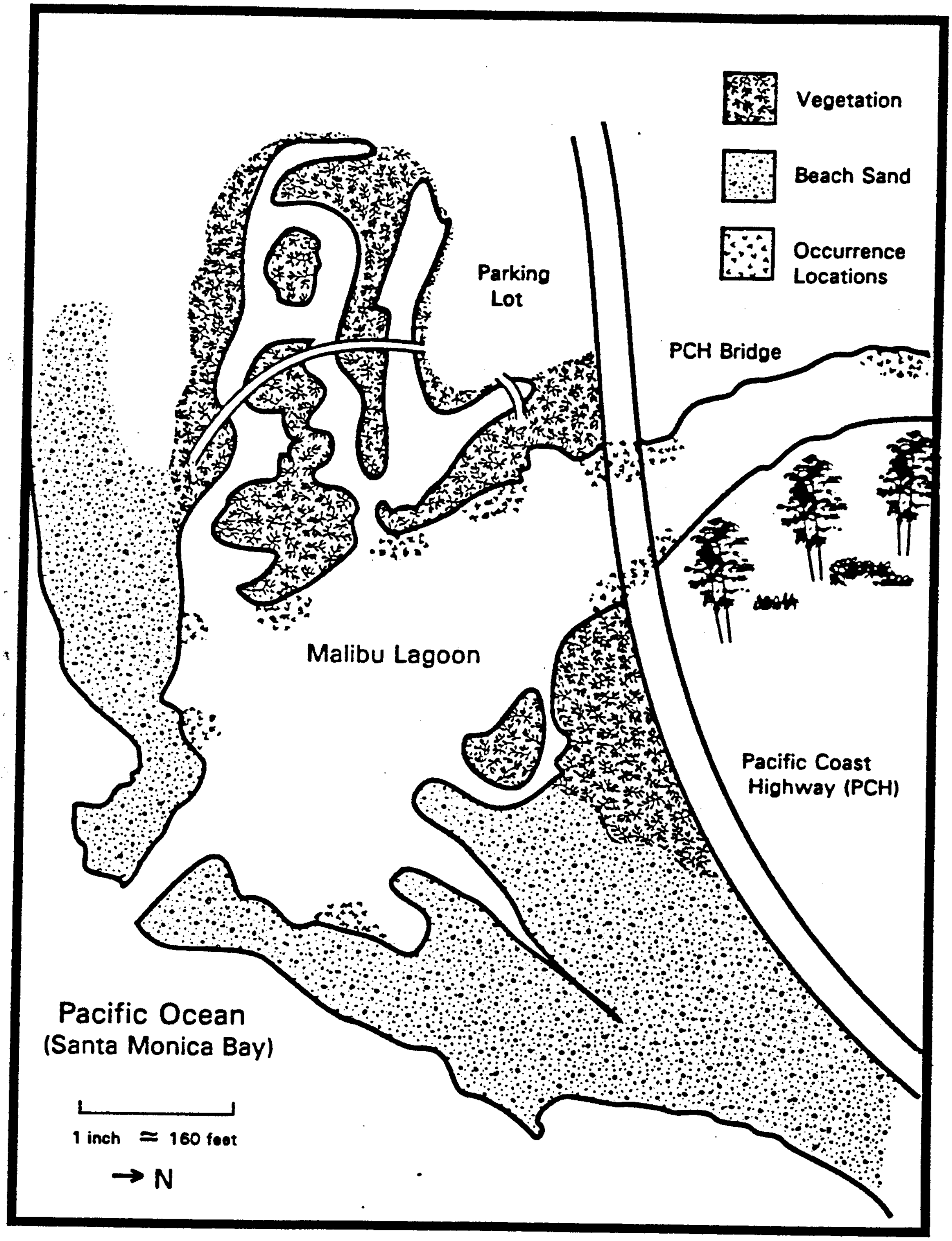
The four survey seines were conducted on August 8, 1991; October 29, 1991; April 15, 1992; and August 5, 1992, at low tides. The total number of tidewater gobies recorded for all four seines was 468 individuals, and their sizes ranged from 10 mm to 49 mm standard length (SL) over the entire survey period (Table IV). Tidewater goby occurrences were recorded at numerous locations within the lagoon over the duration of the survey seines (Map 5).

Table IV Tidewater goby survey seine results

	Seine #1 8-8-91	Seine #2 10-29-91	Seine #3 4-15-92	Seine #4 8-5-92	Total
Number of gobies captured and released	90	72	19	287	468
Length range of gobies in Standard Length (SL)	20-41mm	10-28mm	34-49mm	11-43mm	10-49mm

Survey Seine #1, August 8, 1991

The first survey seine was conducted as a lagoon-wide search with a total yield of 90 individuals. Tidewater gobies were discovered at two



Map 5. Post-reintroduction tidewater goby occurrence locations.

principle locations: the PCH bridge (near Station G), and Station F north of PCH bridge. Physical conditions at both sites were as follows: PCH bridge had a surface level salinity of 9 ppt and a bottom salinity of 29 ppt, and water depth was 50.5 cm. Nearby, Station G had a mid-level salinity of 6 ppt and water depth was less than 50 cm. At the PCH bridge water temperatures were 21.5°C at the surface and 21.0°C at the bottom. Station F had a surface level salinity of 3 ppt, a bottom sample recording of 22 ppt, and a mid-level salinity of 17 ppt. Water temperature at this site was 23°C at the surface and 22°C for the bottom sample. Adjacent to this site is a storm drain outfall where the water temperature was 18°C at the point of confluence with the creek/lagoon. The Station F area had quite a wide range of both thermal and salinity gradients, while Station G and the PCH Bridge site had a wide top-to-bottom salinity range but not a wide thermal range at this time. The lagoon-to-sea entrance condition was open and low tide that day was 1.8 ft.

The total number of tidewater gobies captured and released at Station G/PCH bridge was five. Three were approximately two-thirds grown, indicating that reproduction in Malibu Lagoon had occurred soon after the April reintroduction (Swift, pers. comm. 1991) These three fish were 29 mm and 30 mm (SL) respectively. The remaining two tidewater gobies at this station were both gravid and measured 38 mm (SL). The occurrence of gravid females in August indicates a probable second breeding period was in progress (Also see seine #2, October 29, 1991, for further evidence of a second seasonal breeding period). Tidewater gobies were also captured and released in the area of Station F. A total of 85 individuals were recorded at this station. Their sizes ranged from 20 mm to 41 mm (SL), and four appeared gravid. The size range from this station also indicates that reproduction occurred in Malibu Lagoon after the reintroduction, and the gravid females demonstrate a probable multiple seasonal reproductive cycle.

Additional fish species found during the August survey were ten gravid killifish (*Fundulus parvipinnis*), eight staghorn sculpin (*Leptocottus armatus*), numerous arrow gobies (*Clevelandia ios*), four long-jawed mudsuckers (*Gillichthys mirabilis*), and mosquito fish (*Gambusia affinis*). Twelve opaleye (*Girella nigricans*) ranging from 22 mm to 27 mm (SL) were found very near the open lagoon-to-sea entrance.

Survey Seine #2, October 29, 1991

The second tidewater goby seine survey produced a total of 72 individuals. During this seine, fish were found at five locations within the lagoon. The entrance condition on this day was closed, and the lagoon water level was 5.0 ft. during this low tide time.

The first location was the area around the PCH bridge near Station G. The salinity was 19 ppt (surface and bottom sample) and the water temperature was 19°C. A total of seven tidewater gobies were found ranging in size from 20 mm to 28 mm (SL).

The second location was approximately 80 yards south of PCH bridge in the main lagoon near Station E. The salinity was 20 ppt for both the surface water and bottom sample. The water temperature was 21°C. A total of three tidewater gobies were found, ranging in size from 22 mm to 24 mm (SL).

The third tidewater goby occurrence location during the October seine was 120 yards south of the PCH bridge also in the vicinity of Station E. The value for both surface and bottom salinities was 22 ppt and water temperature was 21°C at this location. A total of eleven tidewater gobies were captured, measured, and released. They ranged in size from 10 mm to 24 mm (SL). Nine of the eleven individuals were 10 mm to 11 mm (SL) young-of-the-year (YOY). These approximately one month old fish are definitive evidence that a second late summer spawning occurred in Malibu Lagoon. Swift et al. (1989) found in their study at Aliso Creek Lagoon that in addition to the typical April to May spawning period, late summer and fall spawning also occurred but was less successful. In addition, Swift et al. (1989) reported that in 1974-75 Goldberg (1977) found evidence of female tidewater gobies with mature eggs at all times of the year in Aliso Creek in Orange County. Swift et al. (1989) also states that "young-of-the-year were collected by us from May to December at Aliso Creek Lagoon and by Wang (1982) in Rodeo Lagoon in Marin County." YOY found in Malibu Lagoon at this time of the year also indicates the possibility of multiple reproductions per season. However, Swift et al. (1989) states that "The potential for year-round spawning exists but probably is seldom, if ever, realized because of low temperatures and disruption of lagoons by winter rains."

The fourth *Eucyclogobius* location was the lagoon-to-sea entrance vicinity. A total of 25 tidewater gobies were found and released at this location. They ranged in size from 11 mm (SL) YOY to two-thirds grown sub-adults of 27 mm (SL).

The fifth location was the storm drain area north of PCH bridge adjacent to Station F. Salinity and water temperature data were not available that day for this site. However, limited data at this site have shown salinity values usually less than 10 ppt and frequently below 6 ppt. The total number of tidewater gobies captured, measured, and released at this site was 26. They ranged in size from 14 mm to 28 mm (SL).

In addition to *Eucyclogobius*, numerous young killifish (*Fundulus parvipinnis*) and topsmelt (*Atherinops affinis*) were caught and released. A few *Gambusia* were found and one YOY diamond turbot (*Hypsopsetta guttulata*) was captured and released near the entrance at the fourth location.

Survey Seine #3, April 15, 1992

The third *Eucyclogobius* seine was performed during a low tide. This survey produced a total of 19 tidewater gobies at four locations within the lagoon. The first location was the Station F area adjacent to the Civic Center storm drain. This location had a capture and release yield of twelve tidewater gobies. These adult fish ranged in size from 34 mm to 44 mm (SL). Salinity at Station F was 4 ppt for both surface and bottom water.

The second *Eucyclogobius* occurrence location was at the PCH bridge near Station G. One tidewater goby, 41 mm (SL), was found at this site. Surface and bottom salinity was 4 ppt at this location.

The third tidewater goby location was under the PCH bridge on the east bank side of the lagoon. This location was directly across the lagoon from Station G. Four tidewater gobies were captured, measured, and released near the second pylon under the PCH bridge. These four adult fish measured 42 mm, 47 mm, 49 mm, and 49 mm (SL). Salinity for both surface and bottom water was 4 ppt.

The fourth location was in the main lagoon east of the entrance adjacent to the sandbar. The entrance condition was open that day. Two tidewater gobies were found measuring 49 mm and 47 mm (SL) respectively. The salinity values for this area were 10 ppt on the surface and 10 ppt at the bottom.

Additional fish species captured and released in Malibu Lagoon during this survey were some small staghorn sculpin (*Leptocottus armatus*), numerous large topsmelt (*Atherinops affinis*), and one adult northern anchovy (*Engraulis mordax*).

Survey Seine #4, August 5, 1992

This survey produced a total of 287 tidewater gobies at five locations, with the majority found in the vicinity of Station F, the storm drain area. In addition to enumerating the gobies captured and released in the seine, a brief visual observation was performed by Dr. Camm Swift using snorkeling gear north from the PCH bridge for approximately 50 ft. He noted "lots of tidewater gobies, both adults and YOY."

Station F yielded the majority of *Eucyclogobius* on this date. There were 219 captured and released at this station with two passes with the seine. These fish ranged in size from 22 mm to 43 mm (SL). Forty-two fish were observed to be gravid. Salinity at Station F was 3 ppt and 20 ppt for the surface and bottom, respectively. Water temperature at this station was 20°C for the surface and 22°C at the bottom, with a water depth of 45 cm.

The second occurrence location was Station G, where a total of 59 *Eucyclogobius* were captured and released. One fish was gravid, and 31 of the 59 fish were YOY. The YOY ranged in size from 11 mm to 14 mm (SL), and the adults were 21 mm to 37 mm (SL). Also, as stated above, a general snorkeling observation showed there to be hundreds of both adults and some YOY in the vicinity north of PCH bridge. These fish were observed on or near the bottom and near the streambank where there was a lower current velocity. The salinity values at this station were 5 ppt and 10 ppt for surface and bottom, respectively. Water temperature was 21°C for the surface and 22°C as a bottom value. Water depth was 23 cm. The lagoon water level was 5.0 feet and the sandbar entrance was open.

The third location was 26 yards south of PCH bridge. Three tidewater gobies were found: 35 mm, 40 mm, and 42 mm, respectively. In addition, two California halibut (*Paralichthys californicus*) were captured and released. These were 45 mm and 35 mm in length. Four *Gambusia affinis* were found, and one 25 mm opaleye (*Girella nigricans*) was also captured and released. One tidewater goby was found at a fourth location 35 yards south of PCH bridge. Twenty-two *Gambusia* were also found at this location.

A total of five tidewater gobies were found at a fifth location that was 15 yards north of the lagoon entrance. In addition to *Eucyclogobius* there

Table V. List of fish species observed at Malibu Lagoon during project.

Tidewater goby	*Eucyclogobius newberryi*
Killifish	*Fundulus parvipinnis*
Arrow goby	*Clevelandia ios*
Staghorn sculpin	*Leptocottus armatus*
Long-jawed mudsucker	*Gillichthys mirabilis*
Mosquito fish	*Gambusia affinis*
Opaleye	*Girella nigricans*
Topsmelt	*Atherinops affinis*
Diamond turbot	*Hypsopsetta guttulata*
Northern anchovy	*Engraulis mordax*
California halibut	*Paralichthys californicus*

were 29 killifish (*Fundulus parvipinnis*) ranging in size from 32 mm to 70 mm (SL), and numerous topsmelt (*Atherinops affinis*), with most of them in the size range of 38 mm to 60 mm (SL).

Note:

An additional survey seine was conducted on March 30, 1993, subsequent to the preparation of this paper. It yielded the following:

Largemouth bass	*Micropterus salmoides*
Black bullhead	*Ictalurus melas*
Green sunfish	*Lepomis cyanellus*
Pacific lamprey	*Lampetra tridentata*
Tidewater goby	*Eucyclogobius newberryi*

Thirty-nine tidewater gobies were surveyed. Their sizes ranged from 30-49 mm (SL), and nine individuals were gravid. Ten Pacific lamprey ammocoetes (larval form) were observed. They ranged in size from 79-98 mm.

Chapter VII
DISCUSSION

INSULARITY

Estuarine fish faunas usually are mixtures of species from both the freshwater and saltwater environment with some species migrating from one environment to the other while a small number are resident species (Moyle and Cech, 1988). The tidewater goby (*Eucyclogobius newberryi*) is one of the few species to have acquired the physiological and morphological adaptations necessary to become year-round residents, limited solely to the estuary/lagoon environment. The tidewater goby is restricted to brackish lagoon systems, and it is almost unique in this aspect on the Pacific coast (Swift et al., 1989).

Populations of *Eucyclogobius* are geographically isolated from one another owing to past geologic and climatic events. This fish lacks the physiological adaptations necessary for survival in the marine environment. When the lack of a marine phase in its life history is coupled with lagoon ecosystems that are separated by significant distances, it is then extremely unlikely that recolonization between habitats ever occurs (Swift et al., 1989). Crabtree (1985) found genetic differences between populations that strongly suggest that recolonization rarely if ever occurs. Swift et al. (1989) supports this finding, adding that their data at Aliso Creek Lagoon "...also indicate that the complete life cycle is spent in lagoons or upper bays." Many tidewater goby populations have been extirpated since the 1950s, which has resulted in an ever increasing physical separation between extant populations. Currently, no known cases of recolonization have occurred (Swift et al., 1989).

SPAWNING

A typical seasonal reproductive period, seasonal size class pattern, and relative seasonal population size was described for Aliso Creek Lagoon by Swift et al. (1989). The study showed that spawning begins in April or May with only large adult fish present in the lagoon at that time. The overall population size of *Eucyclogobius* at this time of year was much reduced in numbers. Spawning also occurred at Aliso Creek Lagoon during late summer and into the fall, but was much less successful than the April to May spawning season. The tidewater goby population size was generally highest in summer through fall and was represented by a wide spectrum of size classes.

Initial surveys at Malibu Lagoon indicate a close association with data obtained at Aliso Creek Lagoon by Swift et al. (1989). For instance, the April, 1992, survey seine at Malibu Lagoon revealed few individuals present and all were in the adult size class range. The seine conducted in August, 1991, indicated a typical seasonal summer increase in the population size after a successful post-reintroduction spawn in April and May. The two size classes represented in the August seine were fish about two-thirds grown (25 mm to 30 mm SL) and adult fish above 30 mm SL. The October, 1991, survey indicated a possible slight decrease in population size, but most importantly, it revealed the presence of young-of-the-year (YOY) size class. These YOY were approximately one month in age (Swift, pers. comm. 1991) and clearly demonstrated that a late summer or early fall spawning had occurred in Malibu Lagoon. The August 5, 1992, seine revealed quite high numbers of individuals compared with the seine of August, 1991. In addition, the size classes represented a wider spectrum, with tidewater gobies ranging in size in August, 1992, from 11 mm to 43 mm (SL). YOY in August seems to indicate another spawning period. This coincides with other researchers' findings who have observed spawning at various seasons. However, Swift (1989) noted that tidewater gobies rarely, if ever, reproduce when the cold temperatures of winter accompanied by seasonal storms probably inhibit spawning activity and almost surely inhibit egg, larvae, and juvenile development and survival.

Although field studies of *Eucyclogobius* in Malibu Lagoon are in the early stages, the data obtained in the first season indicates a similar life history cycle with the study done at Aliso Creek Lagoon in Orange County. Early data indicates that the tidewater goby in Malibu Lagoon follows a "typical seasonal" life cycle pattern.

TIDEWATER GOBY SALINITY RELATIONS IN MALIBU LAGOON

The results of the monitoring of physical parameters demonstrated wide salinity fluctuations for lower lagoon Stations B, C-Appendix, D, E, S1, and S2, and generally less fluctuating salinities, but lower salinity values for Stations F and G in the upper, more northern, portion of Malibu Lagoon.

Salinities in the lower lagoon stations were frequently higher than the general preferred salinity range for spawning, while Stations F and G exhibited salinities within the assumed preferred range for spawning. From this data and other data on wild tidewater goby populations, it is probable that tidewater gobies in Malibu Lagoon probably accomplished their spawning in the general vicinities of Stations F and G where suitable substrate and water temperatures were also present. This mixture, in both time and space, of habitat areas or patches with suitable salinities, substrate, and water temperatures is a measure of overall environmental heterogeneity and is an essential component for tidewater goby persistence in Malibu Lagoon.

Historically, in Malibu Lagoon under typical seasonal conditions, the sandbar entrance would usually form and remain closed from approximately April until the first major storms of winter, and the lagoon would experience a conversion to principally brackish conditions throughout most if not all of this seasonal period. The magnitude of salinity conditions dynamically changes, on a macro-scale, principally as a result of yearly climate conditions that influence storm intensity and frequency (Howard, 1982). However, seasonal brackish conditions change radically when the sandbar is artificially cut, especially to an extreme depth, and the saline tidal influence (salt wedge) penetrates further up the lagoon towards the creek. Understanding the seasonal salt wedge influence upon the upper lagoon in context with augmented freshwater inflow is an essential component to lagoon management. The artificial breaching of the sandbar seems to contribute to higher "non-seasonal" salinities within the lagoon. These non-seasonal fluctuating salinities may have the potential to interfere and negatively impact the tidewater goby spawning periods.

It is presently unclear what impact, if any, a sudden rise in salinity may have, especially if the radical salinity rise coincides with a spawning period. For instance, the physical shock of coping with a sudden change in the external hydromineral balance may potentially change some variable in the hatching or larval success rate. Swift et al. (1989) demonstrated in controlled laboratory studies that tidewater gobies lived longer when exposed to gradually increasing salinities as opposed to sudden changes from fresh water to saline and hypersaline conditions. For example, all fish held at 45.5 ppt died within six days, and fish held at 35 ppt survived 22 days (Swift et al., 1989). However, in an experiment with a gradual rise in salinity over 53 days owing to evaporation, over half the fish survived even hypersaline (i.e. 50-61.8 ppt) experimental conditions. In general, Swift et al. (1989) found that "experimental groups of fish in salinities above 41 ppt experienced high mortality." While this does not give direct evidence regarding the impact of sudden salinity rises during spawning times, it does, however, connote that physiologically, these fish seem to cope better under conditions of gradual salinity rise rather than the stress of sudden rises at "non-natural" or "non-seasonal" times of the year. The seasonal periodicity of the salinity balance in Malibu Lagoon is a critical ecological process within this ecosystem.

Laboratory experiments on tidewater goby populations in the central coast area have demonstrated that tidewater gobies will breed at zero ppt, 15 ppt, and 33 ppt (Lea, pers. comm. 1991). However, under wild conditions, Swift et al. (1989) found that at Aliso Creek Lagoon the salinity range for spawning was 5 ppt to 10 ppt. Different variables are likely to be operating under laboratory experiments versus observations taken with wild free-ranging populations.

In general, the population at Malibu Lagoon, like that of Aliso Creek Lagoon, seems to be found principally in areas of lower salinities. This conforms with Swift et al. (1989) statement that "Of 60 collections, 39 were at 0-10 ppt, 12 at 10-20 ppt, 10 at 20-30 ppt, and one at 42 ppt..."

The majority of the tidewater goby population in Malibu Lagoon frequents the areas of low salinity that also have coarse sand substrate. Areas of fairly consistent low salinities with suitable substrate are generally the upper lagoon near Station G and the storm drain near Station F.

ENVIRONMENTAL HETEROGENEITY

Spatial and temporal environmental heterogeneity is an essential, but as yet, not well understood habitat component of the Malibu Lagoon ecosystem. Environmental heterogeneity in Malibu Lagoon can be characterized as the diversity of suitable habitat patches (micro and macro scale) occupying areas of space at differing lengths of time. The natural disturbance regime is the dominant agent of change that initiates and accounts for spatial and temporal environmental heterogeneity at all scales, and affects both plants and animals at all levels of ecological organization (Pickett and White, 1985; Karr and Freemark, 1985). The natural disturbance regime in the Santa Monica Mountains includes events such as periodic winter storms, fires, landslides, as well as finer scale events or processes such as sediment deposition in Malibu Creek and Lagoon, and salinity changes in the lagoon. Virtually all naturally occurring ecosystems are dynamic mosaics or patches of environmental conditions (Karr and Freemark, 1985). Environmental heterogeneity in all ecosystems is dynamic, and especially so in southern California estuary/lagoon systems where natural disturbance is infrequent but intense. For instance, over the long-term in the semi-arid environment of southern California, seasonal storm events are biased towards higher magnitude but lower frequency (Howard, 1982). This is seen primarily as a function of precipitation where, as the total annual rainfall on a regional scale decreases, its variability and its magnitude increases (Howard, 1982).

Organisms select specific habitat patches to forage, breed, and seek shelter based upon their genetics, physiology, and behavior (Orians, 1991). In Malibu Lagoon, tidewater gobies choose to occupy patches or areas based in part upon the salinity, water temperatures, and substrate characteristics of the habitat patch. The spatial and temporal mixture of habitat patches exhibiting the above three characteristics is essential in order for the tidewater goby population at Malibu Lagoon to persist. When human-induced stressors (i.e. excess silty sediments, stream channelization, and/or sudden salinity change) disrupt essential habitat patches in time and space, extinction probabilities for tidewater gobies and other biota rise dramatically. This is undoubtedly the pattern that initiated the extirpation of the tidewater goby in Malibu Lagoon in the late 1960s or early 1970s. It is presently unclear whether Malibu Lagoon has a sufficient total areal extent and heterogeneous mixture of habitat patches to withstand and benefit from natural disturbance processes, and concomitantly to withstand current intense anthropogenic environmental stressors, and yet continue to provide adequate habitat for a viable population of tidewater gobies. Since Malibu Lagoon has been much reduced in size from its original area, the diversity and area of habitat patches and their mix, in time and space, of physical characteristics (e.g. salinity), has concomitantly been changed. Therefore, the impact of environmental stressors, especially anthropogenic ones, are likely to be severe and raise the extinction probability to an unacceptably high level.

STORM EVENTS OF 1992

The recent (February-March 1992) storms and consequent flooding deposited a large amount of sand substrate into Malibu Lagoon. The peak flow in Malibu Creek during this period was 23,300 cubic feet per second (CFS) on February 10, 1992 (Los Angeles County Department of Public Works, 1993). The areal extent of potentially viable clean coarse sand substrate ideal for tidewater goby breeding success increased dramatically. The lagoon inner channels as of May 1992 showed a buildup of fine silty sediments overlaying the recently deposited coarse sand. This is due to slower water movement in the channels and a general seasonal slow-up of water flowing in the creek. The main lagoon channel, as of May 8, 1992, had relatively little fine silt build-up on top of the coarse sands, however as seasonal flow slows additional silts will likely be deposited. The sources for the fine sediments in the lagoon are two-fold. The first source is the "normal background" erosion of material during natural seasonal erosion cycles often referred to as geologic erosion (Donahue et al., 1977). The second erosional source is anthropogenic in nature. Grading (bulldozing) of earth for urban development projects creates a significant increase in soil erosion rates and total volume of fine sediments entering the streams within the watershed and ultimately Malibu Lagoon. Erosion and sedimentation rates and volumes are also effected by the increase in water velocities and flood potential from land-use change in the upper watershed, such as the increased development of impermeable surfaces (e.g. roads, parking lots, roofs, etc.).

Stream channelization and urban development can significantly increase the level of risk of extirpation from storm-flood events (Swift, pers. comm. 1992). The late winter-early spring floods of 1992 were termed a 10-year flood event. Tidewater gobies at Malibu Lagoon survived this storm event and consequent intense flooding. However, owing to the semi-channelized nature of the upper lagoon, tidewater gobies are likely at imminent risk of being washed out to sea by a severe storm event. Prior to partial filling in of the original floodplain and Malibu Lagoon with urban development fill material, there was likely sufficient areas of protective habitat that afforded some shelter during severe storm-flood events. In moderately channelized areas, such as Malibu Lagoon, the species may be scoured out during extremely high flows. In Malibu Lagoon, the restored side channels, slight channel indentation at Station F, and PCH Bridge abutments may perhaps provide shelter for tidewater gobies during peak flood events. Urban development and the extra flow it generates in this watershed, along with the increase in impervious surfaces associated with development can act cumulatively and/or synergistically with natural storm and flood events to expose creek and lagoon biota to excessive streamflow velocities and volumes. This can "wash out" native biota and/or damage habitat occasionally or chronically and can increase the probability of population decline and possible extirpation.

TIDEWATER GOBIES AND FINE SILTS

The influx of imported freshwater inflow brings the chronic or continual transportation of fine silty sediments. Fine silty sediments deposited and overlaying the essential coarse clean spawning sands very likely damage and reduce the potential viable spawning habitat within the present configuration of Malibu Lagoon. The continual non-seasonal imported water flow, from all sources, and the occasional pulses of released freshwater from upstream are the principle anthropogenic influences driving the fine silts along the watercourses of this watershed into Malibu Lagoon and Santa Monica Bay. The major source of the fine silts is the upper watershed which, due to extensive native vegetation removal, exposes vast amounts of bare soil to erosion as a consequence of the urban development process. During the tidewater goby reintroduction project, observation of tidewater goby spawning habitat indicated that portions of available clean coarse sand spawning habitat have become overlaid by a veneer of fine silts. This can potentially impact tidewater goby reproduction success depending upon the deposition rate, volume (thickness of overlay), and seasonality (especially during spawning periods). In a ten year study on fishes, Toth et al. (1981) detail a dynamic interplay of natural and anthropogenic factors leading to the local extinction of a small cyprinid fish species. In their Black Creek Watershed study area they found that drought combined with human-induced habitat alterations (increased sediment loads due to vegetation removal) resulted in excessive siltation and thus reduced reproductive success. The synergistic effects between natural and human-induced disturbances resulted in the reduction of native biodiversity within the Black Creek Watershed. Many fishes depend upon good visibility to secure prey species (National Research Council, 1992). Fine sediments in prolonged suspension in the water column could create a visibility problem in Malibu Lagoon. A reduction in visibility could possibly hinder visual cues and negatively impact predation and reproductive success of tidewater gobies and other fish species.

In addition to the extensive upper watershed sources of fine silts is the existence of approximately 400 yards of "fill material" legally dumped into the upper Malibu Lagoon by Caltrans in 1970. Depth of this material ranges from four to seven feet. The fill material consists primarily of fine silty soil particles, blocks of cement and asphalt, and some gravels. It is located directly north of the Pacific Coast Highway bridge on the west bank of the upper reach of Malibu Lagoon. This area, prior to urban development, was very likely a primary spawning habitat for tidewater gobies due to its upper lagoon location and associated lower salinities and sand substrate. Currently, the salinities at this area of the lagoon are lower and well within the perceived tidewater goby breeding tolerance. The sparsely vegetated bank continually releases fine silts into this portion of the upper lagoon. The bank of "fill material" is also quite steep along this area and is not structurally conducive to the spreading of coarse clean sands from storm driven events. The three principle anthropogenic stressors operating at this specific site within Malibu Lagoon are loss of habitat when fill material was dumped, alteration of habitat with the current steep banks, and additional habitat alteration and degradation with the continual release and deposition of fine silts at this location. Silts released from this "fill site" are also presumably distributed within the lagoon and likely are transported into Santa Monica Bay.

NON-NATIVE FISHES

As discussed in Chapter II, non-native fishes are known to displace native fishes in many of the world's ecosystems. This study corroborates Stoltz' (1979) findings of mosquitofish, green sunfish, and largemouth bass in Malibu Lagoon. Both the green sunfish and largemouth bass were found in a spring survey (March, 1993) after substantial winter floods. The previously stated potential threat is that these predatory species may become established or may be able to semi-permanently inhabitat the upper lagoon environment if human-influenced streamflow continues or is increased and the lagoon experiences a prolonged or continuous conversion to freshwater. This study has demonstrated that the upper lagoon area (approximately Stations G to F) is the primary habitat for tidewater gobies in Malibu Lagoon, and it is also where non-native predatory fish have been recorded.

MINIMUM VIABLE POPULATIONS (MVP)

Extinction of a population is often the result of chance events, and the likelihood of extinction owing to either human-induced or environmental chance events, or a combination of both will dramatically increase as the population size diminishes (Shaffer, 1988).

The tidewater goby was extirpated from Malibu Lagoon in the late 1960s or early 1970s, most likely by multiple human-generated environmental stressors such as channel dredging (channelization) and the dumping of fill debris into Malibu Lagoon. The focus of this project was the April, 1991, reintroduction of 52 *Eucyclogobius.* Is this a viable population? A viable population is one that is able to maintain its genetic vigor and also its potential for evolutionary adaptation over time (Soulé, 1988).

The two primary elements in life and death (persistence and extinction) of a population are: the smaller the population the greater the likelihood of extinction within a given time frame; and second, the longer the time frame, the more likely extinction will occur within a population of any given size (Shaffer, 1987).

A primary question facing conservation researchers and society is, given that the likelihood of survival depends on population size and time, then "what degree of persistence constitutes preservation and how much habitat is necessary to achieve such preservation" (Shaffer, 1987). The minimum viable population concept begins to address this question.

Salwasser et al. (1982) characterizes the MVP concept "as able to persist in the face of environmental changes induced by both man and nature." Shaffer's (1981) proposed definition of MVP states that "A minimum viable population for any given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes." These definitions imply the concept of consideration of genetic diversity necessary to maintain a healthy population, and both recognize the key issues of the effects of chance events on population persistence, the time frame to consider in conservation, and the degree of preservation security desired. Soulé (1987) states that one of the most difficult and challenging problems in conservation biology is the question of "what are the minimum conditions for the long-term persistence and adaptation of a species or population in a given place?" This is exactly the question to be addressed regarding the tidewater goby and other biota within Malibu Lagoon.

Chance uncertainties or stochastic events play a pivotal role in population persistence. Shaffer (1987) defines a stochastic or random process as simply an uncertain event. For example, floods, droughts, and changes in food supplies are instances of natural environmental stochastic events (environmental uncertainties). Examples of human-induced (anthropogenic) stochastic events are non-seasonal pulses of freshwater in Malibu Creek, non-seasonal freshwater volumes, and unnaturally heavy fine silty sediment loads in Malibu Creek and Malibu Lagoon. Extirpation of the tidewater goby in Malibu Lagoon could conceivably have been caused by a single stochastic event, or more likely, multiple stochastic events that result in cumulative and/or synergistic impacts. Some chance events are natural (i.e. seasonal storms), but the most problematic (i.e. excessive silty sediment loads and habitat reduction) are anthropogenic in origin. The temporal aspect of anthropogenic stressors is an important factor. Most natural disturbance regimes are periodic and seasonal in nature. However, human-generated disturbance is usually chronic (temporally continuous) with little or no available period of recovery for biota.

In order for the tidewater goby to persist in Malibu Lagoon over the long-term, the population must be sufficiently large and maintain sufficient genetic variability to withstand natural stochastic events (i.e. seasonal floods). In addition, human-induced uncertain catastrophic events such as pollution, altered streamflow patterns, and excess silty sediment must be reduced to a negligible level for local native biodiversity, including the tidewater goby, to persist and maintain its potential to adapt over an evolutionary time scale.

Current research on minimum viable populations is at present incomplete. However, research on other species indicates that the 1991 reintroduction of 52 *Eucyclogobius* should be considered a beginning. In order to ensure sufficient genetic variability an effective genetic population size of 500 individuals may possibly be an appropriate number to consider as a beginning within a flexible resource management framework (Soulé, 1987; Lande and Barrow-clough, 1987; Frankel and Soulé, 1981). It is important to note that an MVP analysis must be determined for each species that is under consideration. Effective population sizes necessary for mutation in order to maintain sufficient quantities of genetic variation has not as yet been performed for the tidewater goby and therefore any estimate of a MVP size (i.e. 500 individuals) is a rough figure based upon studies of other species and groups.

Tidewater gobies in Malibu Lagoon are associated with slower moving water habitats when the option exists, low salinities, clean coarse sand substrate, and water temperatures between 16-23°C. This combination of conditions most frequently exists, to varying degrees, in the upper portion of Malibu Lagoon, principally from just a few feet south of PCH bridge to the storm drain inlet at Station F. Conservation efforts need to focus on this more brackish area of the lagoon as well as the *main* lagoon and channel area. The upper segment of Malibu Lagoon is an integral component within Malibu Lagoon, and ecological management of this area is important to the overall habitat quality of the lagoon. In addition, maintaining the natural physical integrity (e.g. sandbar) of Malibu Lagoon is essential to the maintenance of seasonal salinities and other biological water quality parameters required by the tidewater goby and other biota.

CONCLUSION

The ecological potential for native biodiversity maintenance within Malibu Lagoon will only be realized if the natural historic physical and biological processes (ecological processes), in their dynamic context, are restored and maintained throughout the entire watershed and stringent cooperative and regulatory pollution prevention measures are implemented. Altered streamflow seasonal patterns and excessive flooding, erosion, sedimentation, and other deleterious changes to the hydrologic regime of the watershed are spurred by urban development and increase the likelihood of extinction for local native species.

Understanding the larger landscape-water linkage perspective and the energy flow within the system is the key to discovering and rationalizing the ecological intricacies that drive the Malibu Lagoon ecosystem. The interaction of the watershed and sea cooperate in the process of structural formation and ecosystem function to beget the estuary/lagoon environment. Knowledge acquisition of both the landward watershed and adjacent ocean system plus the thin lagoonal boundary layer between them opens the way for creative and flexible ecologically driven management decisions involving restoration and conservation of this region.

Restoration ecology attempts to accomplish the task of understanding how ecosystems are put together and how they function by raising important ecological questions and testing ideas that lead to improved management techniques and ultimately to ecological management decisions. Species reintroduction methods are a keystone component of restoration ecology. Restoration ecologists employing reintroduction methods face the dilemmas of deciding on priorities for goals, calculating what information is needed to be successful, and adjusting to practical constraints — challenges which are typical of many of society's endeavors (Diamond, 1987). Reintroductions of species into their former habitats is an attempt to rebuild natural ecological communities that have been damaged. It is truly an art and a science, and as Bradshaw (1987) states, it is the acid test for ecology. Perhaps it is also the acid test for a cooperative interdisciplinary team approach within scientific disciplines and between science, policy decision-makers, and the public.

Chapter VIII

RECOMMENDATIONS FOR ECOLOGICAL MANAGEMENT

The purpose of this chapter is to present suggestions for the facilitation of an ecological management strategy in the Malibu Creek Watershed and Malibu Lagoon that will be consistent with the protection, restoration, and maintenance of 1) the natural physical habitat (e.g. water quality), 2) ecological processes (e.g. ecosystem function), and 3) native biodiversity (including humans) at all levels. In recent years, these concepts have emerged at the forefront of global ecological conservation and management as we approach the twenty-first century.

BIODIVERSITY PROTECTION PLAN

Lagoon management should adopt a native biodiversity protection plan as a primary conservation strategy. This plan would focus on the protection, restoration, and maintenance of native biodiversity at all levels. The plan would focus on the implementation of a variety of strategies including policy and regulatory measures that are key elements in restoring processes such as streamflow regime. The plan would be based on a biological characterization of the habitat, water quality and processes, and the study and monitoring of species and groups of species as indicators of systemic ecological integrity. In addition, population viability analysis (PVA) should be a component of the biodiversity protection framework. An examination of the factors that place a population or species at risk (PVA) could be done for selected species such as the tidewater goby, steelhead, and other species representing a spectrum of phylogenetic groups. The protection, restoration, and maintenance of regional native biodiversity should be seen as a subset of the need to protect the biological integrity of this watershed system. A biodiversity protection program will reflect the holistic (overall) goal of regional and watershed specific protection of biological integrity. Maintaining the integrity of an ecosystem can be best accomplished through conserving biodiversity at all levels.

CHARACTERIZING THE LEVELS OF BIODIVERSITY

Biodiversity has been defined as "the variety and variability among living organisms and the ecological complexes in which they occur," diversity occurs at three basic levels: 1) ecosystem diversity, 2) species diversity, and 3) genetic diversity (OTA, 1987). Biodiversity is more than simply the number of ecosystems, species, and genes (the above OTA definition) within a defined area. It can be further characterized as having three primary component attributes at four levels of organization (Franklin, 1988; Noss, 1990). The three attributes are compositional, structural, and functional. The four levels of organization within each of these three attributes are regional landscape, community-ecosystem, population-species, and genetic. The three attributes are described as follows:

1. Composition — the identity and variety of elements that comprise ecosystems. Included are landscape, habitat types, species diversity, genetic diversity, patterns of species distribution, guild diversity, relative abundance, and density values.

2. Structure — the physical patterns or organization within an ecosystem, such as the heterogeneity of the physical habitat. For example, the structural patterns of deep pool, riffle, and shade habitat in Malibu Creek are important variables in the survival and reproduction of steelhead. In addition, the connectivity of the Malibu Lagoon-to-sea entrance (open/closed pattern) is a structural pattern which affects species survival in the lagoon.

3. Function — the ability of the ecological and evolutionary processes to function in a manner consistent with the conditions that allowed for an ecosystem's evolutionary development. For example, natural disturbance patterns, such as periodic wildfires and the hydrologic regime (flood/drought patterns) in the Santa Monica Mountains' are part of the natural ecosystem process and must be part of the management process. Other processes which affect ecosystem health include nutrient cycling, and human land-use trends. Zedler (1990) states that the following eleven wetland functions are critical for restoration success:

1. Provision of habitat for wetland-dependent species
2. Support of food chains
3. Transformation of nutrients
4. Maintenance of plant populations
5. Resilience (ability to recover from disturbances)
6. Resistance to invasive species (plant or animal)
7. Resistance to herbivore outbreaks
8. Pollination
9. Maintenance of local gene pools
10. Access to refuges during high water
11. Accommodation of rising sea level

Moreover, the above three attributes of biodiversity (composition, structure, and function) are interconnected on a regional and global scale.

The four levels of organization within the attributes are:

1. Regional Landscape — Criteria frequently used to determine a region are the complex of climatic, physiographic, biological, economic, social, and cultural characteristics (Forman and Godron, 1986). The term "landscape" is characterized by the "mosaic of heterogeneous land forms, vegetation types, and land-uses" (Urban et al., 1987). Thus, the term "regional landscape" emphasizes the spatial heterogeneity and complexity of regions.

2. Community-Ecosystem — This comprises the populations of species coexisting in the Santa Monica Mountains, or more specifically, within the Malibu Creek Watershed and Lagoon. Measurable variables include species diversity and richness, guild proportions and other measures of community composition.

3. Population-Species — Most biodiversity monitoring is focussed at the species level, such as monitoring habitat and population variables, and the use of ecologically significant species, such as keystone and indicator species.

4. Genetics — Monitoring at the genetic level has usually been restricted to a few rare species. It is beneficial and should be a component of a biodiversity conservation program.

BIOLOGICAL CHARACTERIZATION OF HABITAT AND WATER QUALITY

In addition to Zedler's (1990) eleven wetlands functions previously listed, the following biological characterization of habitat and water quality parameters for a biodiversity protection plan include:

Indicator groups and species

Fish (native and non-native), invertebrate, and plant communities can be measured and monitored on an ongoing basis as indicator groups of environmental conditions such as habitat quality. Some suggest the use of indicator species as the best method to assess environmental conditions. However, the use of indicator species has come under recent criticism (Noss, 1990), especially when used as the sole assessment method. Use of indicator species as part of a comprehensive strategy along with indicator groups (e.g. guilds) can enhance the accuracy of assessing environmental conditions. A guild can be defined as a group of species that exploit the same class of resources in a similar manner. Species can be grouped without regard to taxonomic position. Guilds are recognized on the basis of researcher-defined resources, such as food (Morrison et al., 1992). Guilds should be selected with specific regard to time (e.g. season), location, and habitat. There is controversy surrounding the use of the guild-indicator concept and any management approach using indicator species or guilds needs to carefully assess all aspects of this approach. Noss (1990) proposes five categories of species that need to be considered for special conservation efforts:

1. Ecological indicator species — Use of ecological indicator species involves selecting a species which represents a group of species. This species is then sampled to determine how it is affected by land use practices (i.e. altered flow regime, pollutants, and soil erosion within the Malibu Creek watershed). Data obtained for this species are then applied to the entire

group of species. These indicators are chosen as representatives of a particular ecosystem, and they serve as surrogates for the welfare of a group of species (Soulé, 1989; Cooperrider, 1986). Aquatic indicator species should be sensitive so as to provide an early warning of change within the stream and or lagoon ecosystem. Indicators are best used as part of a comprehensive strategy for watershed protection. Ecological indicator guilds and groups can also be used in a similar fashion. Fishes and macroinvertebrates are two examples of indicator groups that could provide substantial information on the ecological health of Malibu Creek watershed.

2. Keystone species — pivotal species which, by its disappearance from an ecosystem, results (directly or indirectly) in the virtual disappearance of several other species, thus reducing native biodiversity. Examples include top carnivores (i.e. mountain lions and bobcats) and also certain plants that provide essential resources during times of scarcity. For example, oak and sycamore trees may be considered keystone species within the Santa Monica Mountains, for they provide food resources for deer, nesting habitat for raptors, shade, water temperature control, and fallen structure for aquatic life in Malibu Creek. Their demise causes an "environmental ripple effect" that can lead to a cascade of species decline and extinction. Inquiry into identifying aquatic keystone and umbrella species is an important component in a biodiversity protection program.

3. Umbrella species — Similar to keystone, ecologically significant umbrella species typically have large area requirements (mountain lion, bobcat), and if

given sufficient habitat protection will bring many other species under protection.

4. Flagship species — These are popular, charismatic species that serve as symbols (i.e., political) and rallying points for conservation. Some local examples are steelhead trout, mountain lion, and golden eagle. Note that flagship species are also essential ecological components.

5. Vulnerable species — These are rare, frequently genetically impoverished, usually low fecundity, short-lived species, dependent on either patchy or unpredictable resources. These species have been impacted by human-generated habitat alteration and are prone to extinction, due to life history requirements. The tidewater goby and steelhead trout are examples of vulnerable fish species in Malibu Lagoon and Malibu Creek.

Organic surface microlayer

The thin organic surface water microlayer at the air-lagoon interface needs to be studied for biological quality and pollution.

Zooplankton

Measuring of zooplankton will assist in determining food chain support and the biological characterization of water quality.

Nutrient dynamics

1. Evaluate nutrient dynamics in Malibu Lagoon.
2. A thorough study of algae, seasonal abundance, distribution, density, and importance for food chain support is needed.

3. Both 1 and 2 need to be conducted in the context of the analysis of the nutrient-algae-eutrophication complex with the goal of optimum biological water quality. Water circulaton dynamics will be an important focus of inquiry.

Biotic requirements

Develop an assessment of the ecological requirements for selected groups and species in order to assist in the identification of indicator organisms and to develop biological water quality objectives.

Biotic index

Consider selecting one of a number of biotic indices to assess the effects of organic enrichment to the aquatic system. The chosen index should concentrate on invertebrates and ichthyofauna.

Rindge Dam

Dismantle the Rindge Dam, which functions as a barrier to fish migration and alters the natural pattern of sedimentation rates and types along the watershed and entering Malibu Lagoon and Santa Monica Bay.

Excess fine sediments

Explore solutions, including stringent regulatory measures, to eliminate non-natural excess fine silty sediments generated primarily by urban development in the upper watershed from entering Malibu Creek, Malibu Lagoon, and Santa Monica Bay.

Restored wetlands

Consider restoring brackish wetlands on historic wetland sites within the Civic Center area (e.g. golf course and other areas), primarily to increase available habitat and to enhance water quality (e.g. nutrient polishing). This would be a linked stepping stone system of restored wetlands physically connected to Malibu Lagoon.

Steelhead

Initiate life history and genetic studies (to determine genetic distance) as well as cooperate with any current ongoing studies of the highly threatened southernmost population of steelhead trout (*Onchorhyncus mykiss*). Recognize that the steelhead is an "indicator" and a "flagship" species of high ecological and societal value.

Tidewater goby studies

Continue monitoring existing population. Initiate a long-term monitoring program. Continue the reintroduction process in order to achieve the perceived acceptable levels of genetic variability. Initiate additional in-depth studies of tidewater goby biology at Malibu Lagoon. Conduct sediment surveys to understand the current sediment dynamics (e.g. deposition rates, patterns, and particle sizes) and their relation to tidewater goby life cycle.

Biological inventory of Malibu Lagoon and lower Malibu Creek

Develop a comprehensive inventory of plant and animal species present. Much of these data have been already gathered by the Topanga-Las Virgenes Resource Conservation District (TLVRCD) in their publication, Malibu Lagoon: A Baseline Ecological Survey. However, lower Malibu Creek needs to be added as a sampling area and some re-sampling of Malibu Lagoon should be performed to supplement existing information.

Non-native species

Introduced species such as non-native fishes may threaten the tidewater goby in Malibu Lagoon. Non-native aquatic species frequently become established in systems where the natural hydrologic streamflow pattern has been anthropogenically altered. Consequences for native species include predation - sometimes leading to extirpation, and altered species composition, often resulting in reduction and degradation of the natural complexity and function of the ecosystem.

Non-native fish species, such as largemouth bass (*Micropterus salmoides*) and green sunfish (*Lepomis cyanellus*) do occur in Malibu Lagoon. These species are known to prey on adults, larvae, and eggs of some native species. Protection from the adverse effects, both direct and indirect, of exotics is an ecologically substantive issue. This environmental problem needs to be examined in the Malibu Creek Watershed including Malibu Lagoon.

AQUATIC PRESERVE SYSTEM

Establish a comprehensive network of aquatic freshwater and estuarine preserves. These preserves would be established in each watershed (drainage basin) within the Santa Monica Mountains region, and the conservation focus would be on protecting, maintaining, and restoring natural physical and ecological processes (function and structure), and native biodiversity. The deleterious effects of certain land-use practices within the watersheds need to be addressed in a substantive and timely manner. External forces can be particularly damaging to aquatic areas because environmental impacts occurring within the drainage may make their way through the heart of the aquatic system (Sioli, 1986). The result is habitat degradation and reduction of native biodiversity (Moyle et al., 1986). External threats include habitat fragmentation, edge effects, pollutants, exotic species, dams, impoundments, excess turbidity, and sedimentation of silts. Aquatic preserves must have buffer zones (Schonewald-Cox and Bayless, 1986). Lovejoy et al. (1986) states that "Buffer zones provide a gradient from natural to altered conditions and become increasingly effective as barriers to perturbations (e.g. anthropogenic perturbations) as their size (e.g. width) is increased and their natural qualities are enhanced." Buffer zones assist in maintaining good internal quality of aquatic systems (Moyle and Sato, 1991). Buffer zones frequently must be intensely managed due to their mixture of urban, rural, and wildland land-use types. In addition, due to their linear shape, aquatic systems have a high proportion of edge and therefore are quite vulnerable to external influences. Studies on aquatic buffer zones indicate repeatedly that they reduce a substantial amount of deleterious effects on aquatic organisms including fishes (Murphy et al., 1986). The aquatic components of an ecosystem are typically the most sensitive community (Moyle and Sato, 1991). Therefore, the aquatic community of Malibu Creek and Malibu Lagoon is a powerful indicator group of the ecological integrity of this watershed. In addition, other analogous watersheds in southern California that are in as pristine condition as possible should be used as a baseline or benchmark for comparison. Candidate ecosystems may include Gaviota Creek (two anadromous fishes as in Malibu Creek) and Cañada de Santa Anita Lagoon, in Santa Barbara County; and Las Pulgas Lagoon and the Santa Margarita River, on Camp Pendleton.

Native fish faunas in western North America have declined dramatically in recent years. There is a need for a systematic approach to aquatic reserve planning, a regional approach focussing not only on species but entire aquatic biotas, aquatic habitat quantity and quality, and the surrounding terrestrial habitats.

NATURAL DISTURBANCE REGIMES

The role of natural disturbance regimes must be integrated into all resource management planning strategies. Natural disturbance plays a central role in the function, structure, and composition of ecosystems. The conditions created by disturbance — the frequency, intensity, and predictability of disturbance events and the response of biota to those events must be incorporated into management efforts. Computer-generated watershed models are a management tool that must incorporate disturbance regime data in order to reflect the true nature of this ecosystem.

PALEOECOLOGICAL ANALYSIS

A paleoecological analysis of the long-term history of vegetative cover (e.g. oak woodland and native grasses) within the upper Malibu Creek

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APPENDIX

Graphs of Salinity, Water Temperature, and Water Level Malibu Lagoon, 1990-1992

Figures	1 - 17	Salinity
Figures	18 - 34	Water Temperature
Figures	35 - 38	Lagoon Water Level

STATION B
MALIBU LAGOON

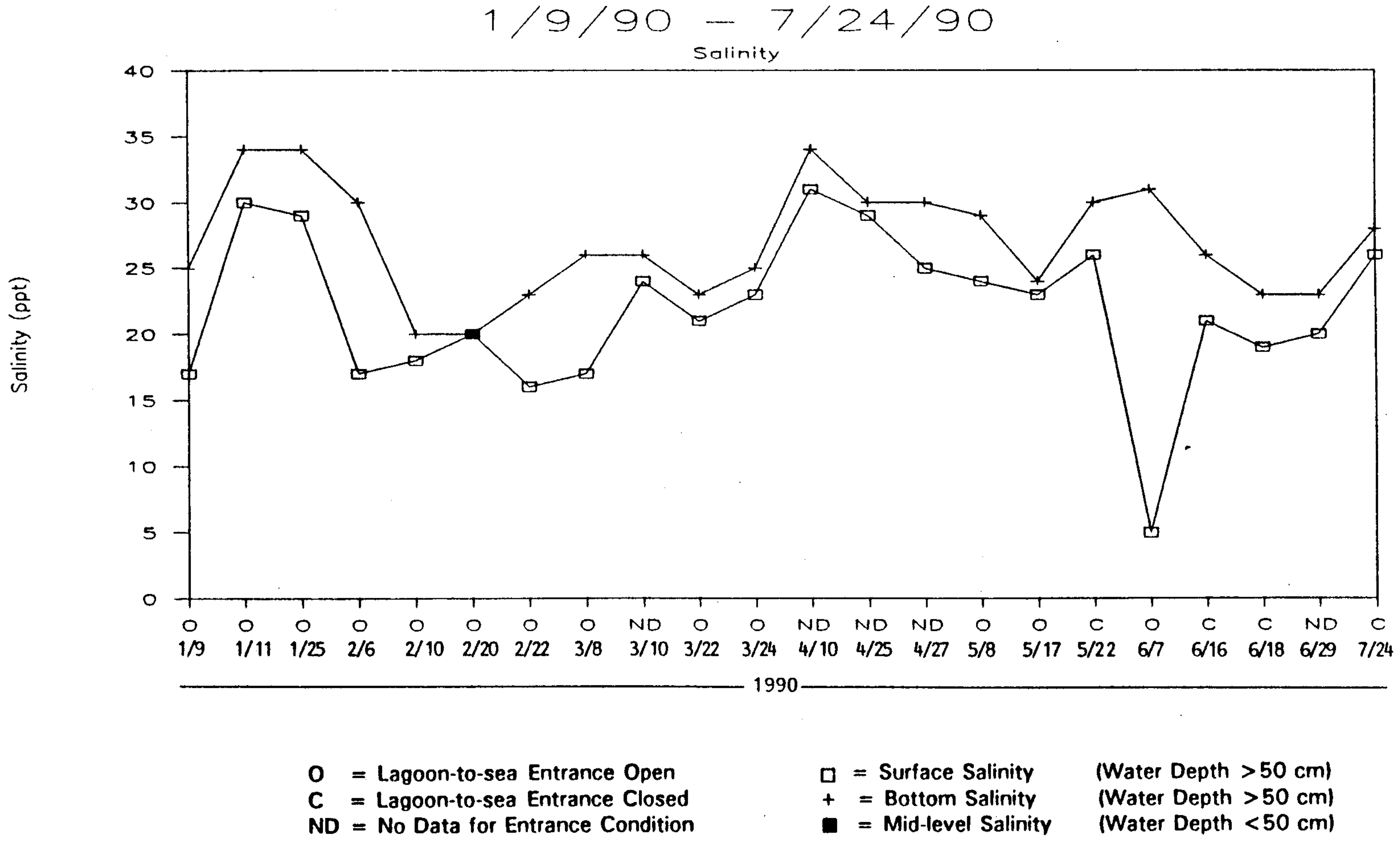


Figure 1

STATION C-APPENDIX
MALIBU LAGOON

1/9/90 – 7/24/90

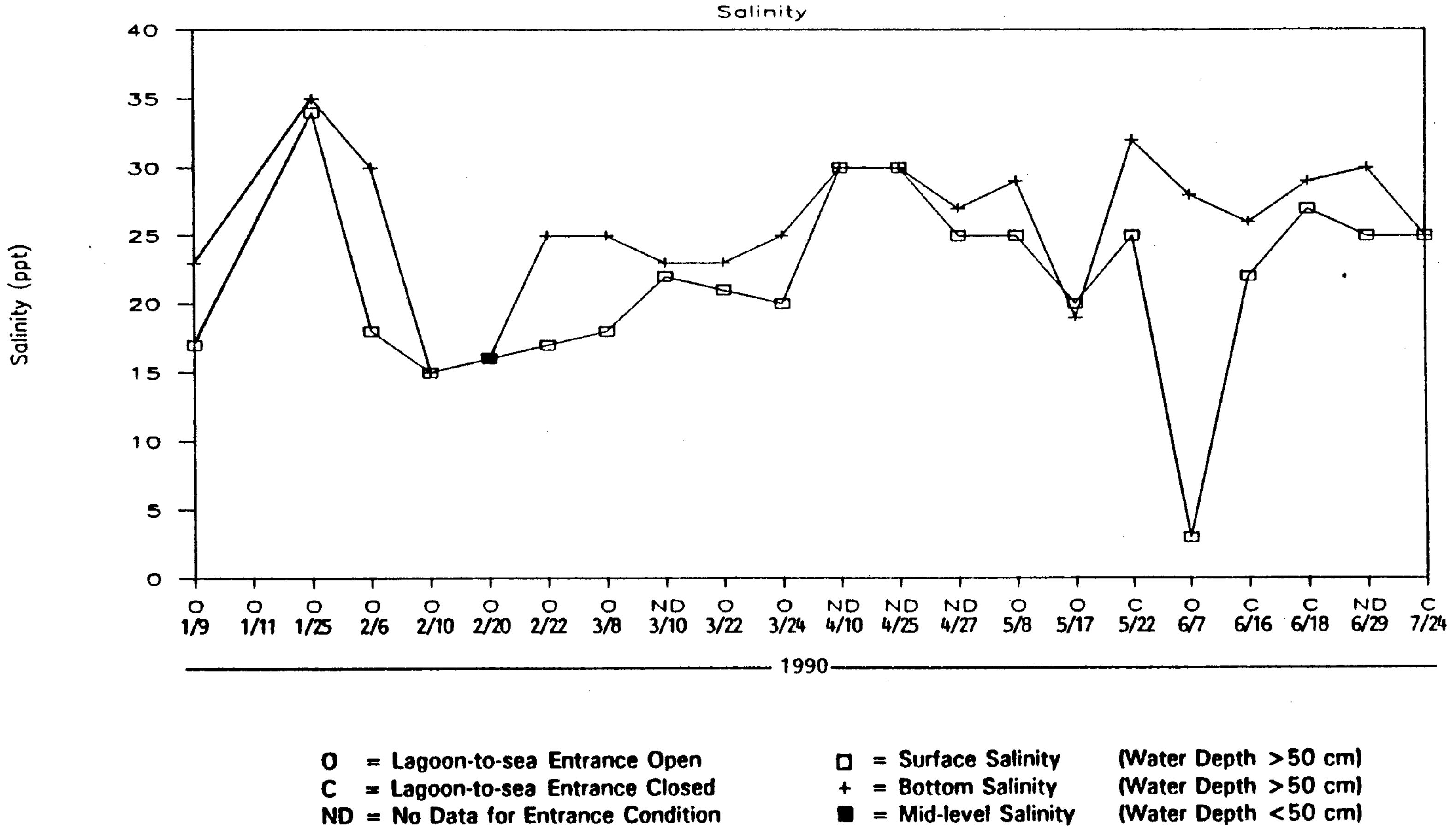


Figure 2

STATION E
MALIBU LAGOON

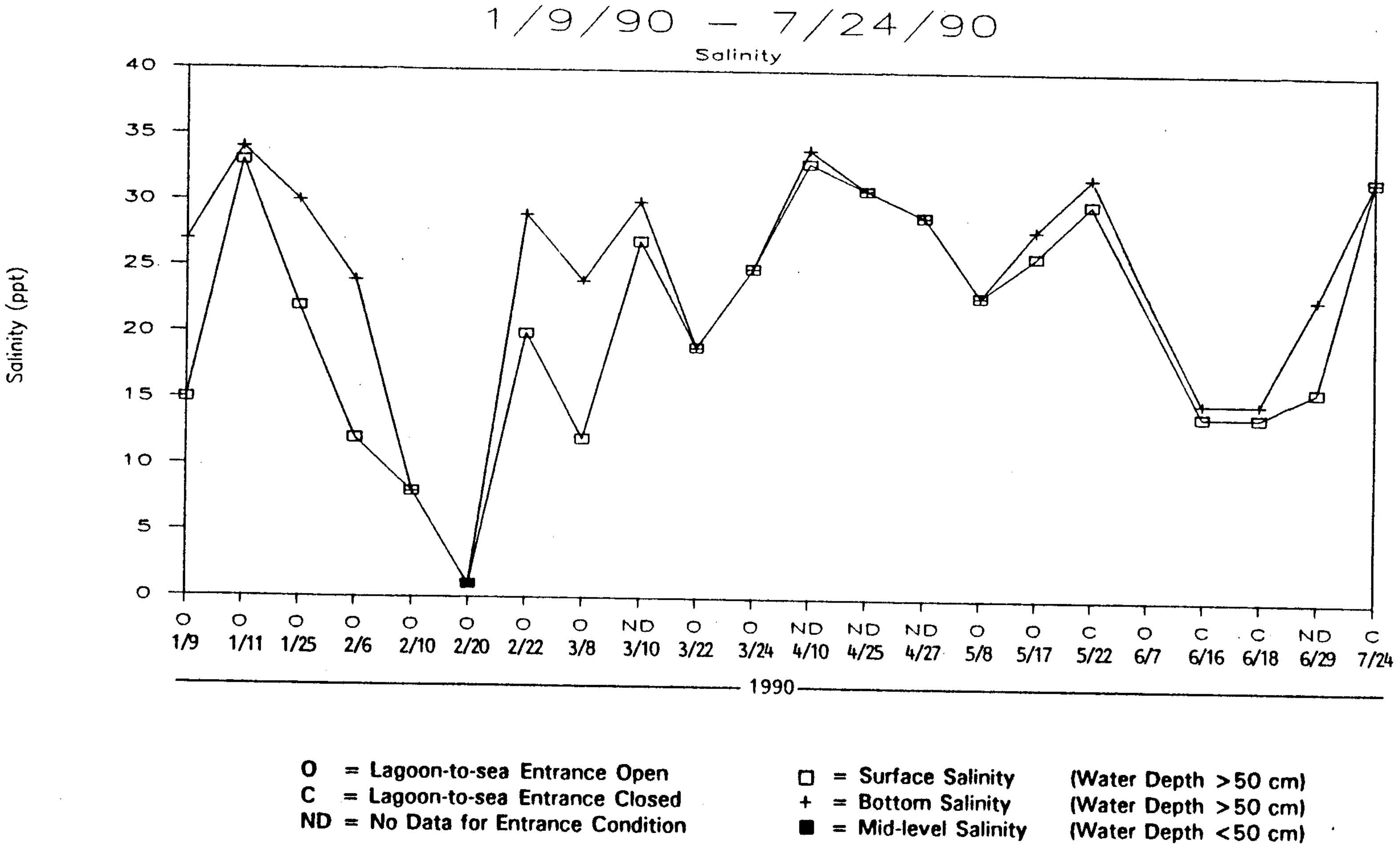


Figure 3

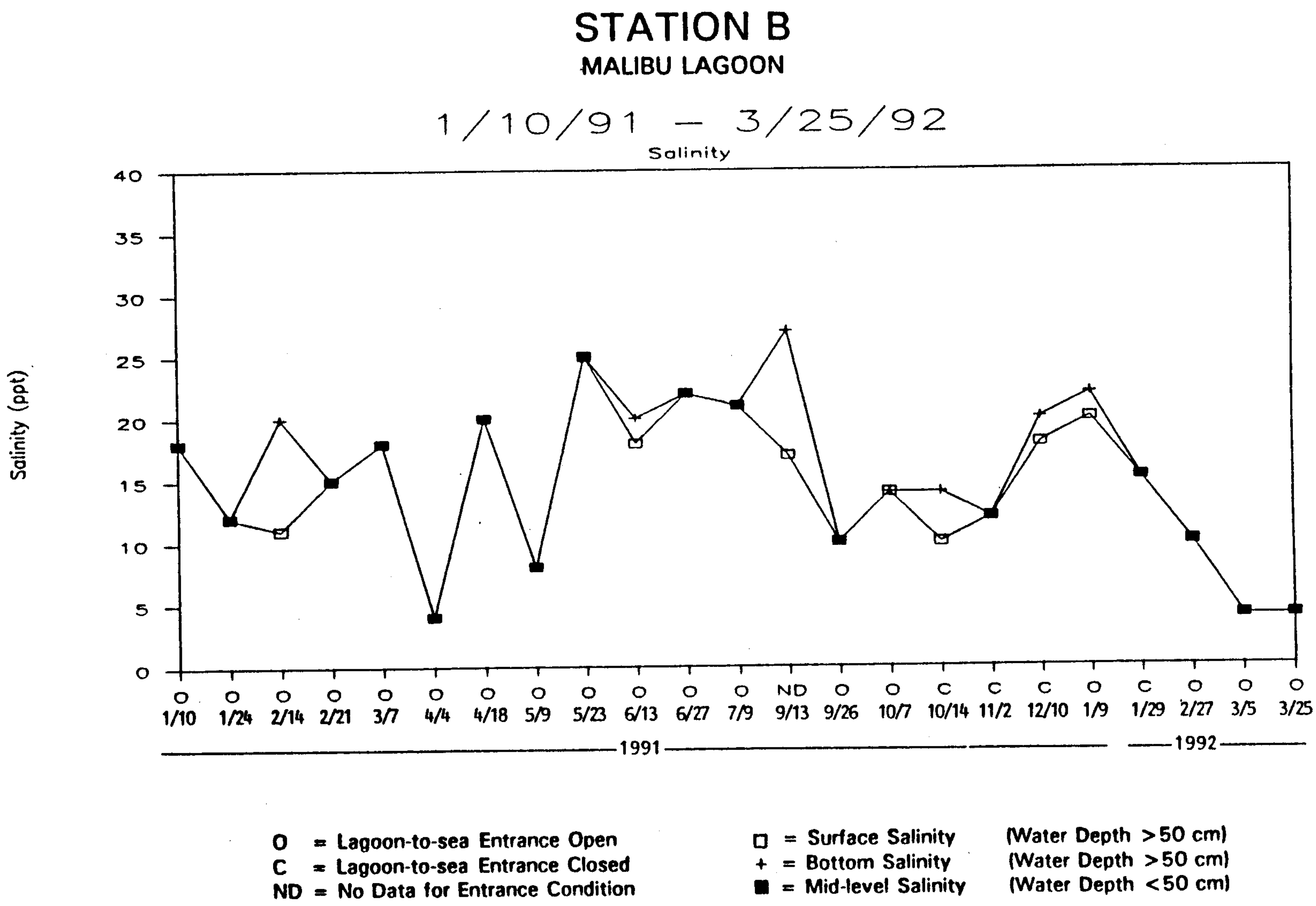

STATION B
MALIBU LAGOON
1/10/91 — 3/25/92
Salinity
Salinity (ppt)
0
5
10
15
20
25
30
35
40
O O O O O O O O O O O O ND O O C C C O C O O O
1/10 1/24 2/14 2/21 3/7 4/4 4/18 5/9 5/23 6/13 6/27 7/9 9/13 9/26 10/7 10/14 11/2 12/10 1/9 1/29 2/27 3/5 3/25
1991
1992
O = Lagoon-to-sea Entrance Open
C = Lagoon-to-sea Entrance Closed
ND = No Data for Entrance Condition
□ = Surface Salinity (Water Depth >50 cm)
+ = Bottom Salinity (Water Depth >50 cm)
■ = Mid-level Salinity (Water Depth <50 cm)

Figure 4

STATION C-APPENDIX

MALIBU LAGOON

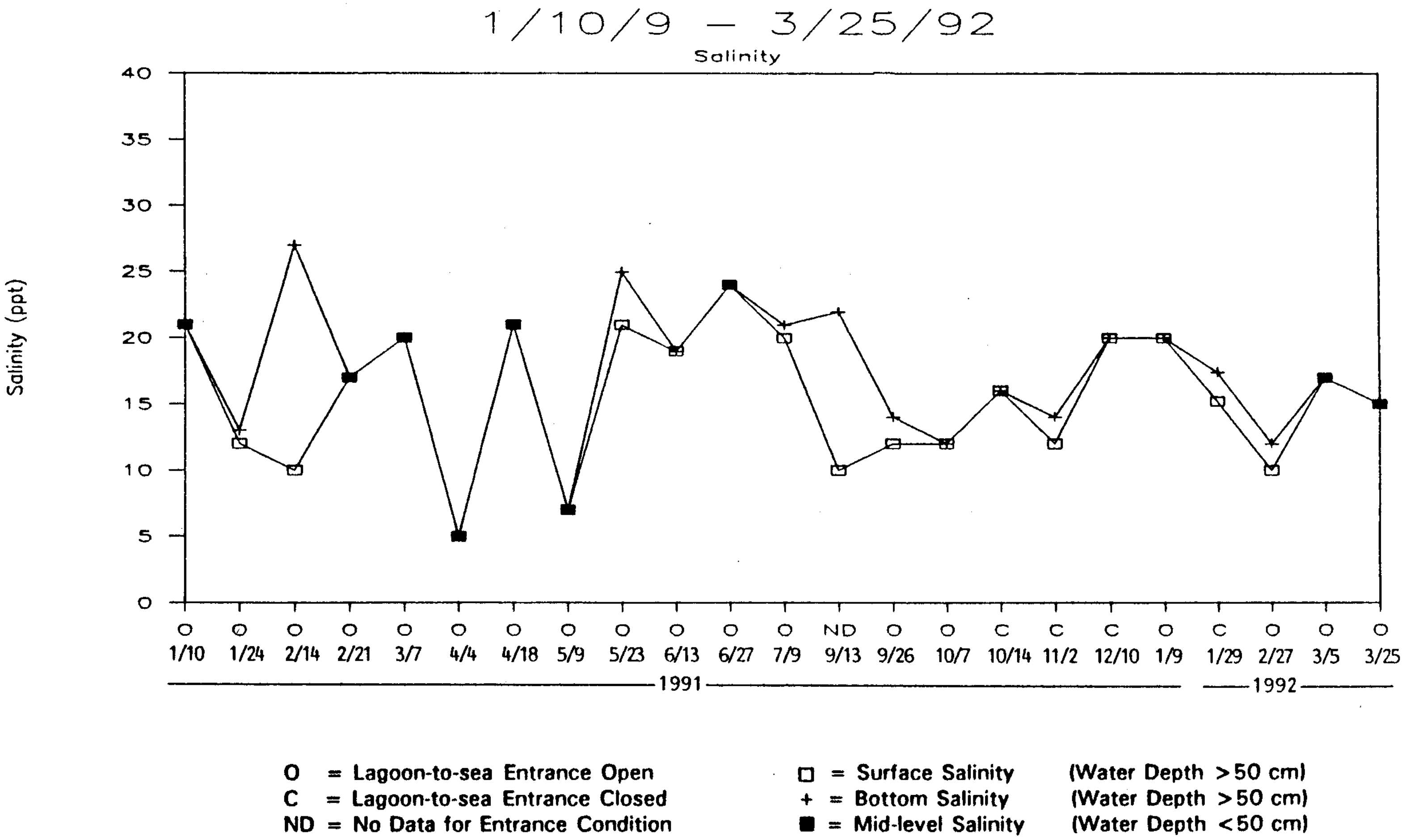


Figure 5

STATION D
MALIBU LAGOON

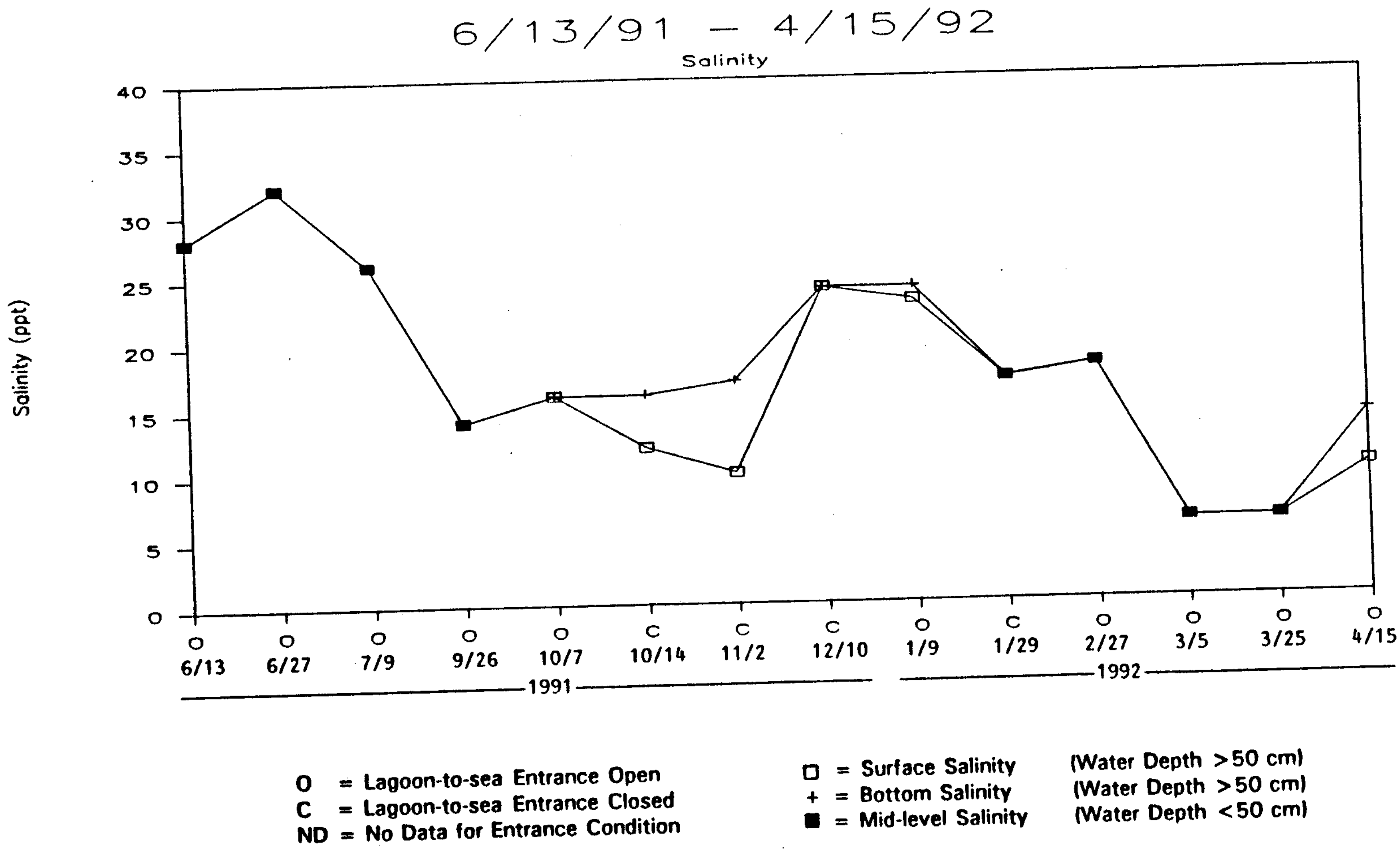


Figure 6

STATION E
MALIBU LAGOON

1/10/91 – 3/25/92

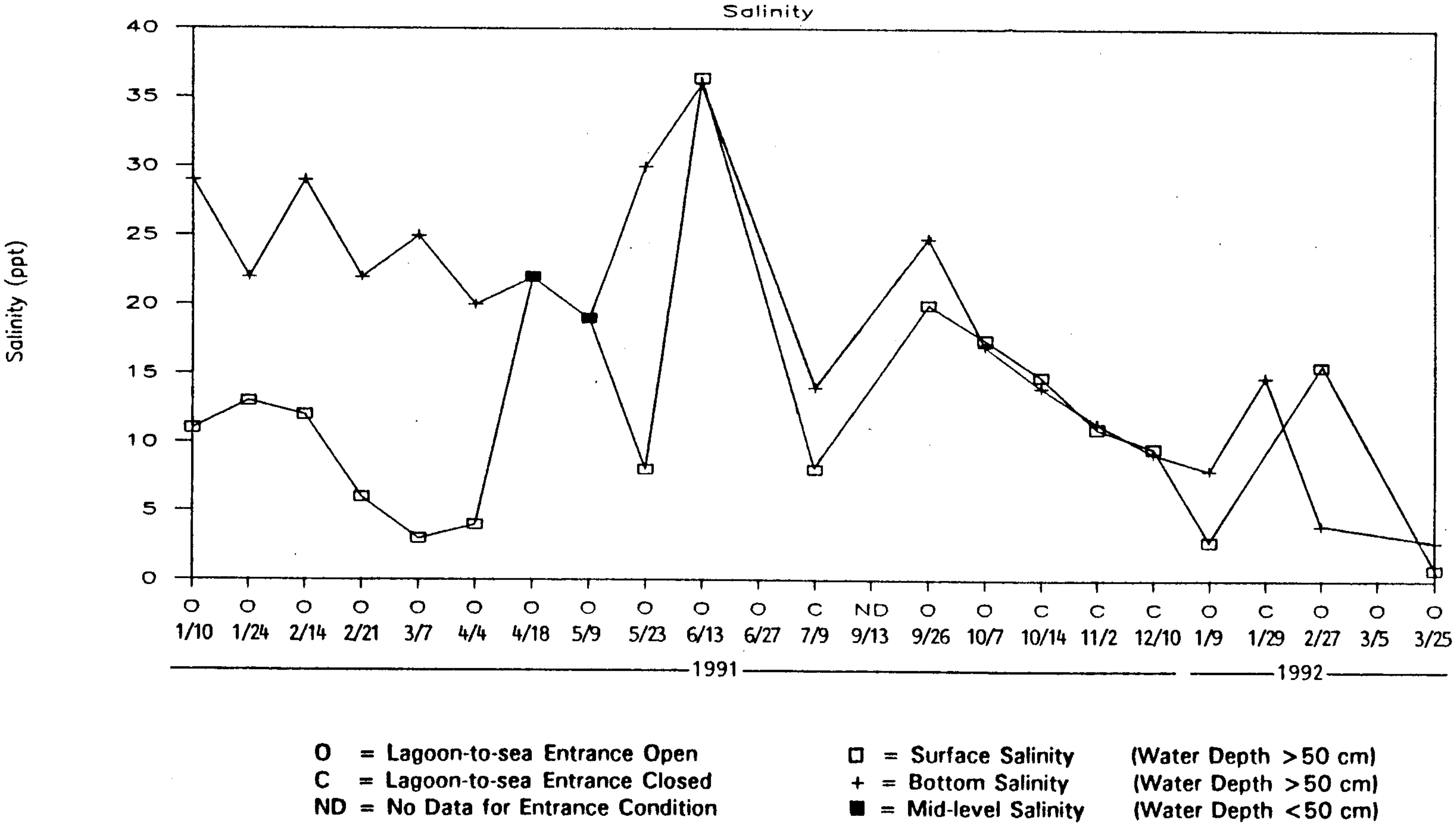


Figure 7

STATION F
MALIBU LAGOON

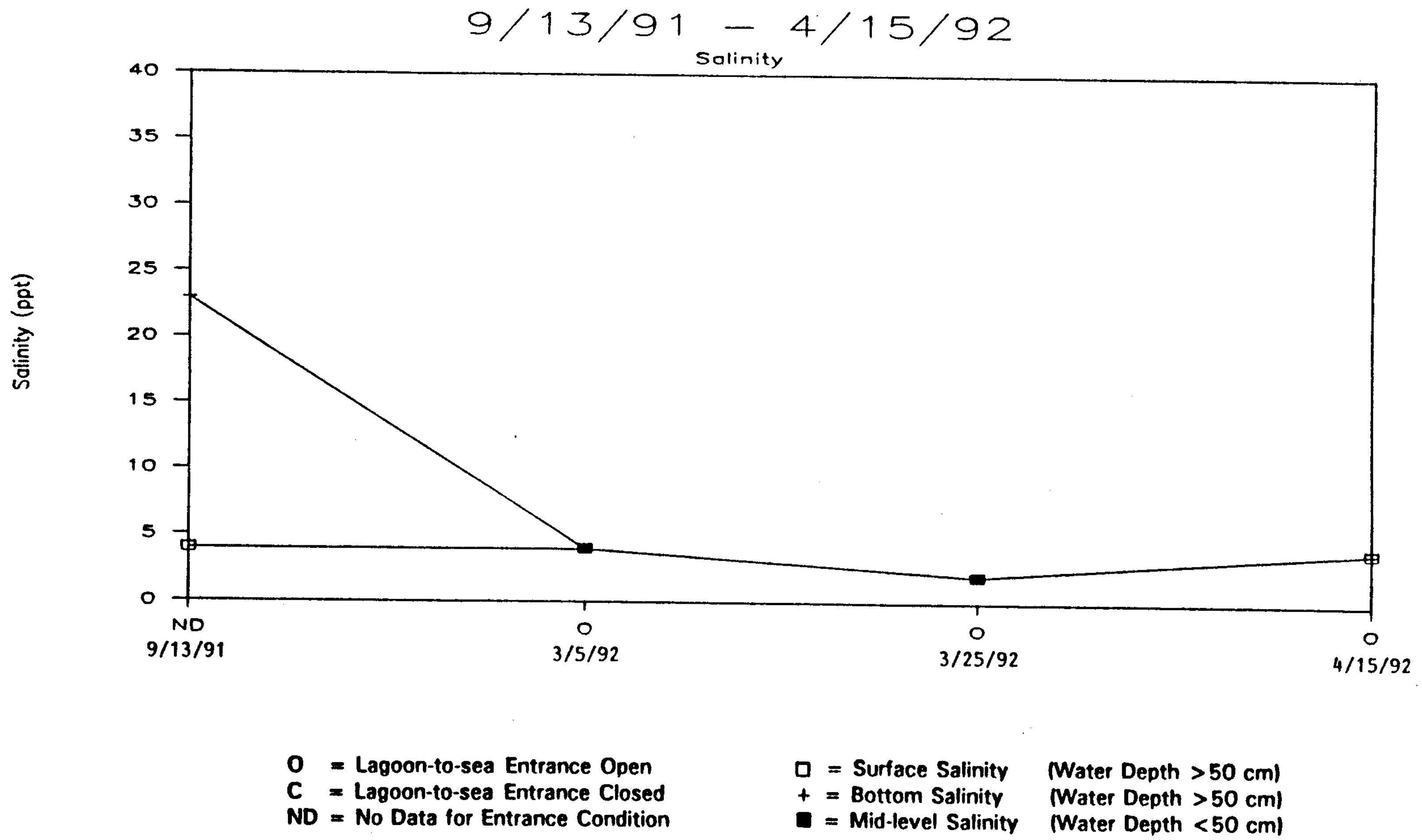


Figure 8

STATION G
MALIBU LAGOON

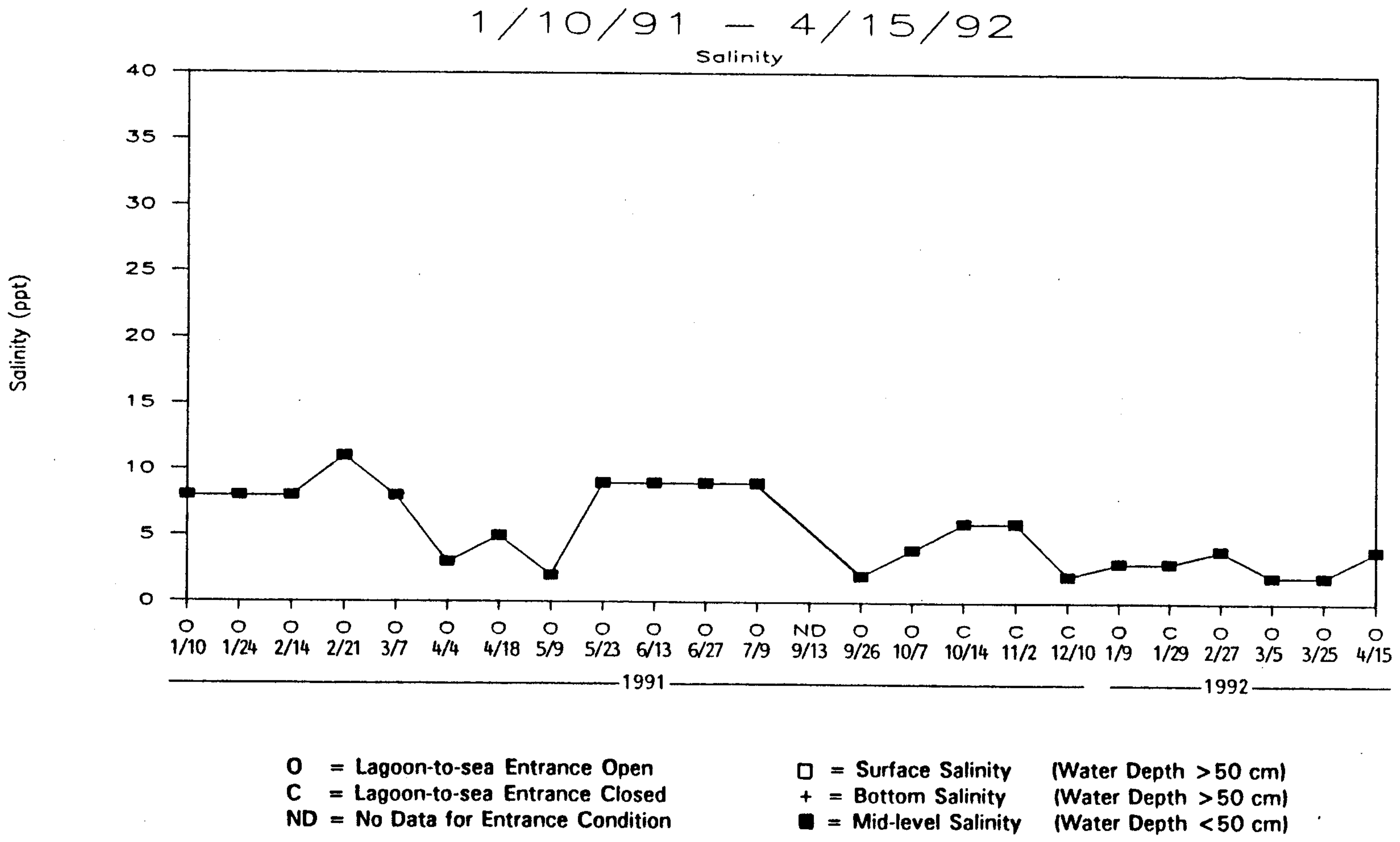
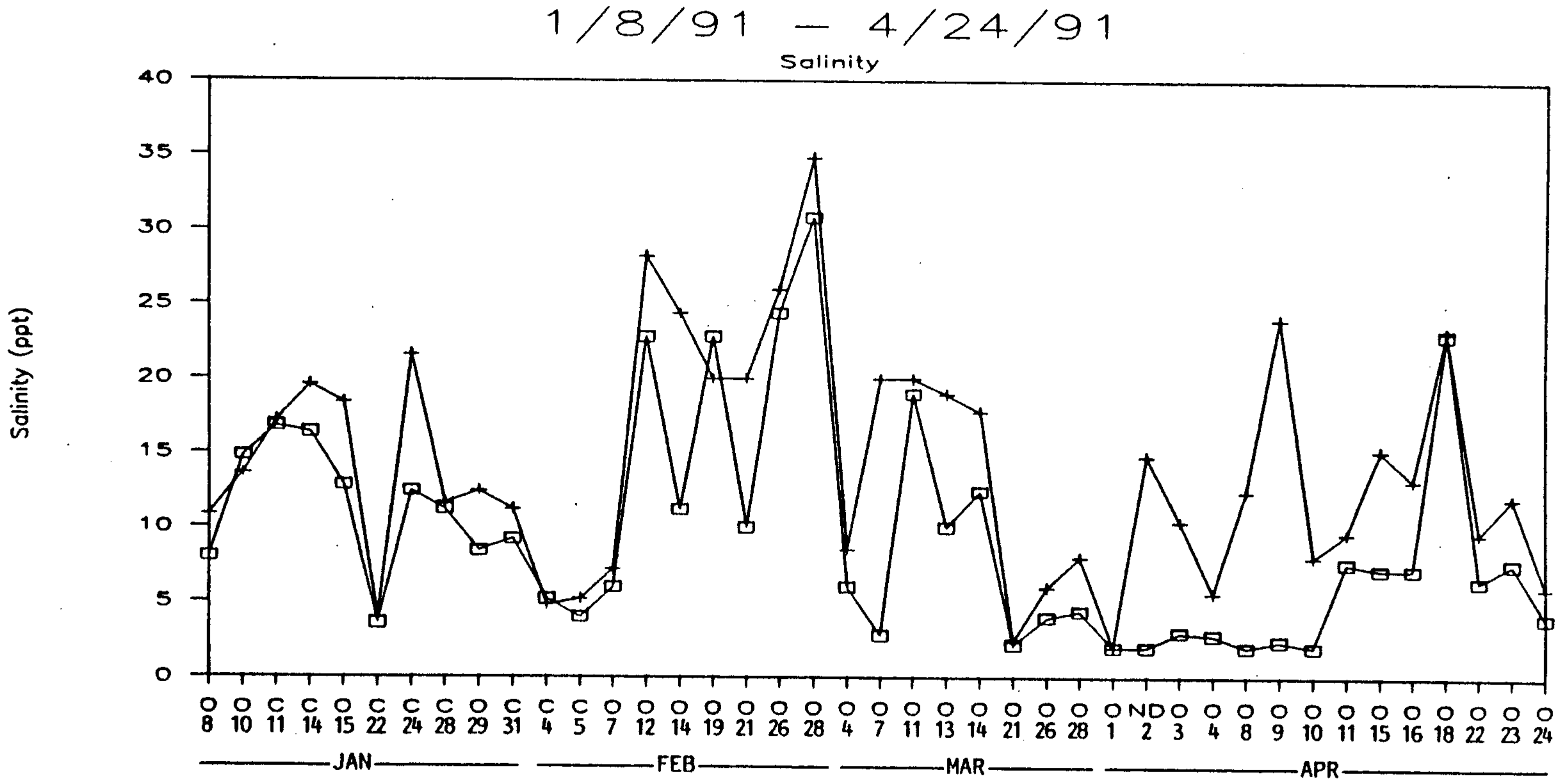


Figure 9

STATION S1

MALIBU LAGOON



O = Lagoon-to-sea Entrance Open
C = Lagoon-to-sea Entrance Closed
ND = No Data for Entrance Condition

□ = Surface Salinity
\+ = Bottom Salinity

Figure 10

STATION S1
MALIBU LAGOON

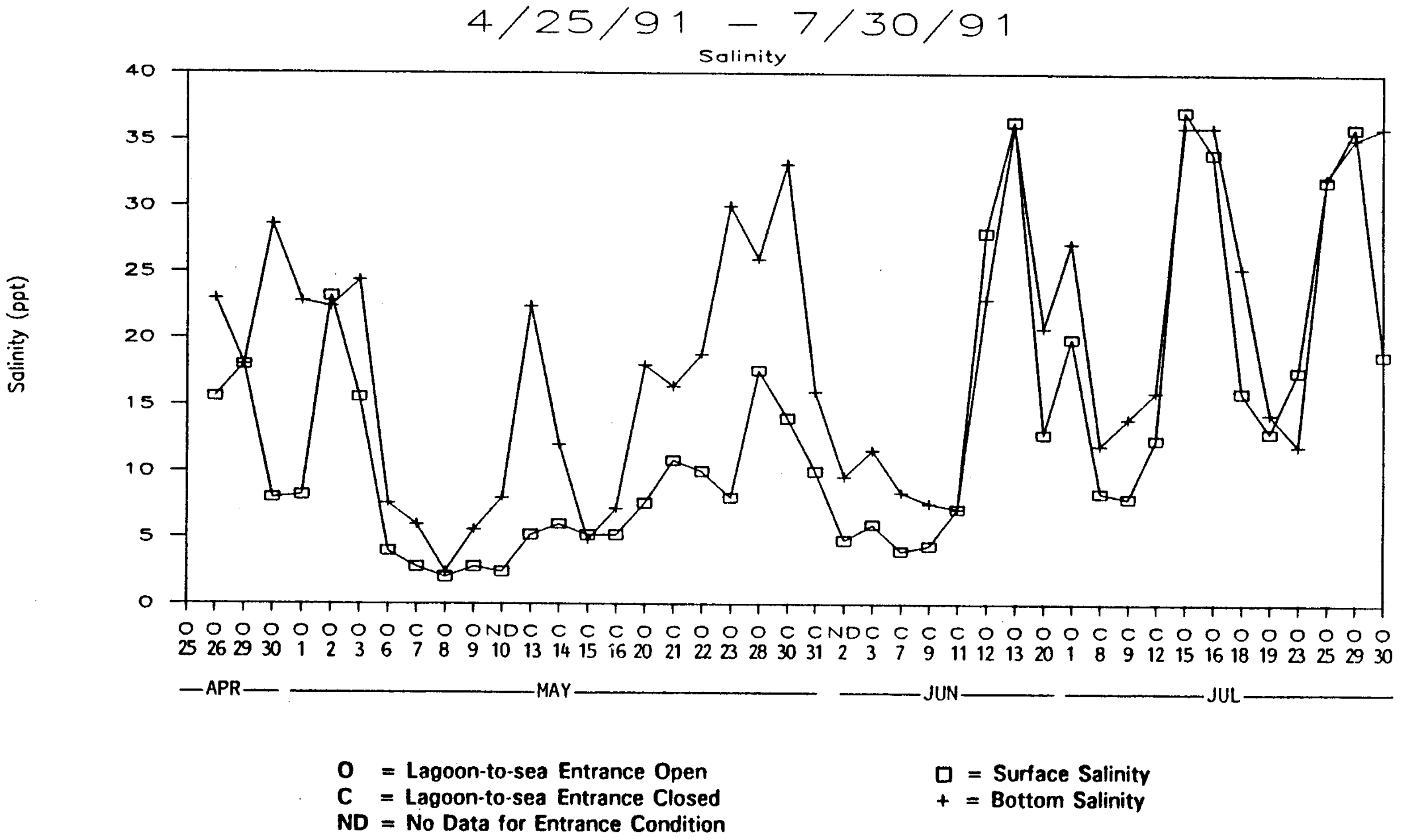


Figure 11

STATION S2

MALIBU LAGOON

1/8/91 — 4/24/91

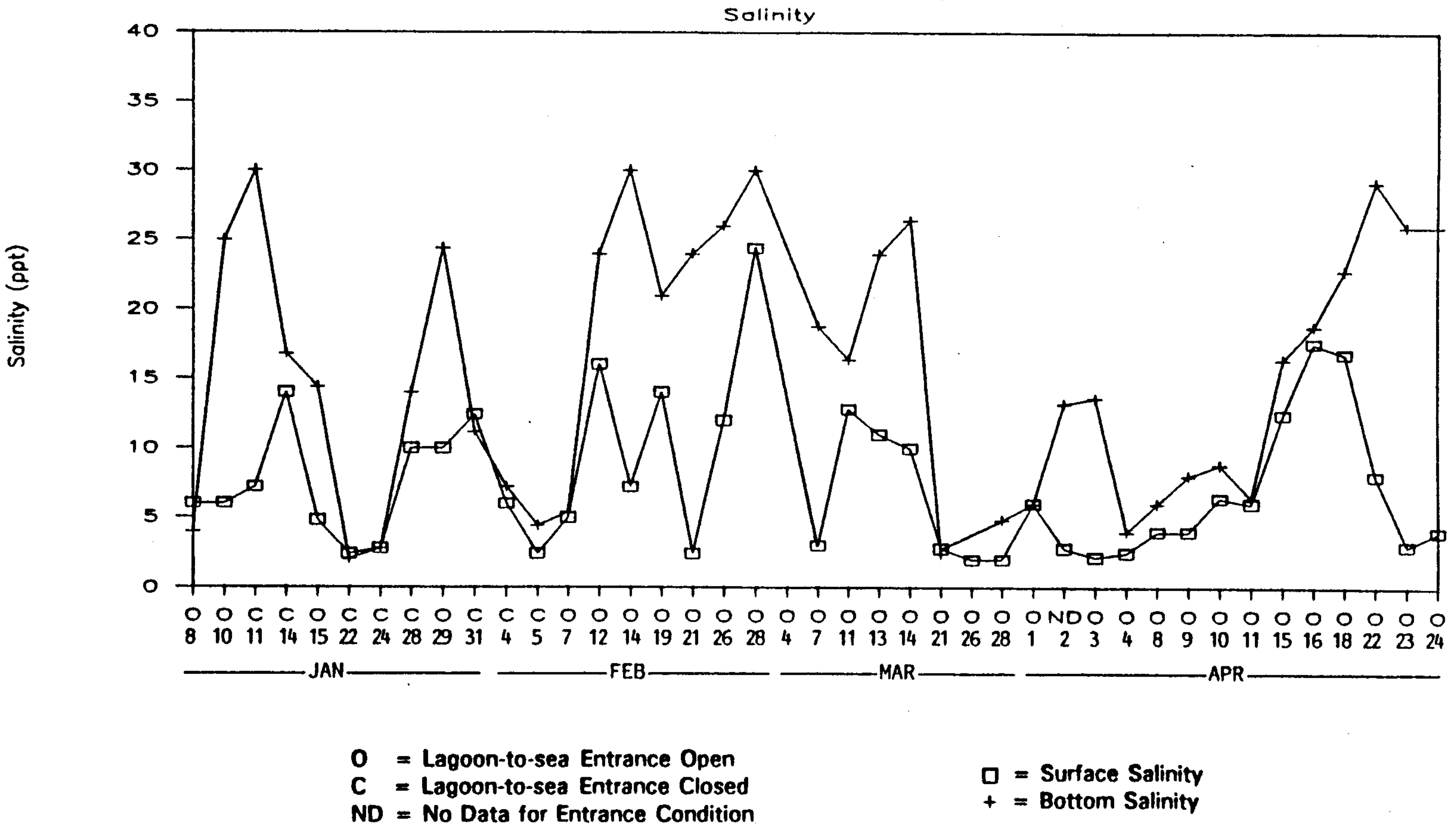


Figure 14

STATION S2

MALIBU LAGOON

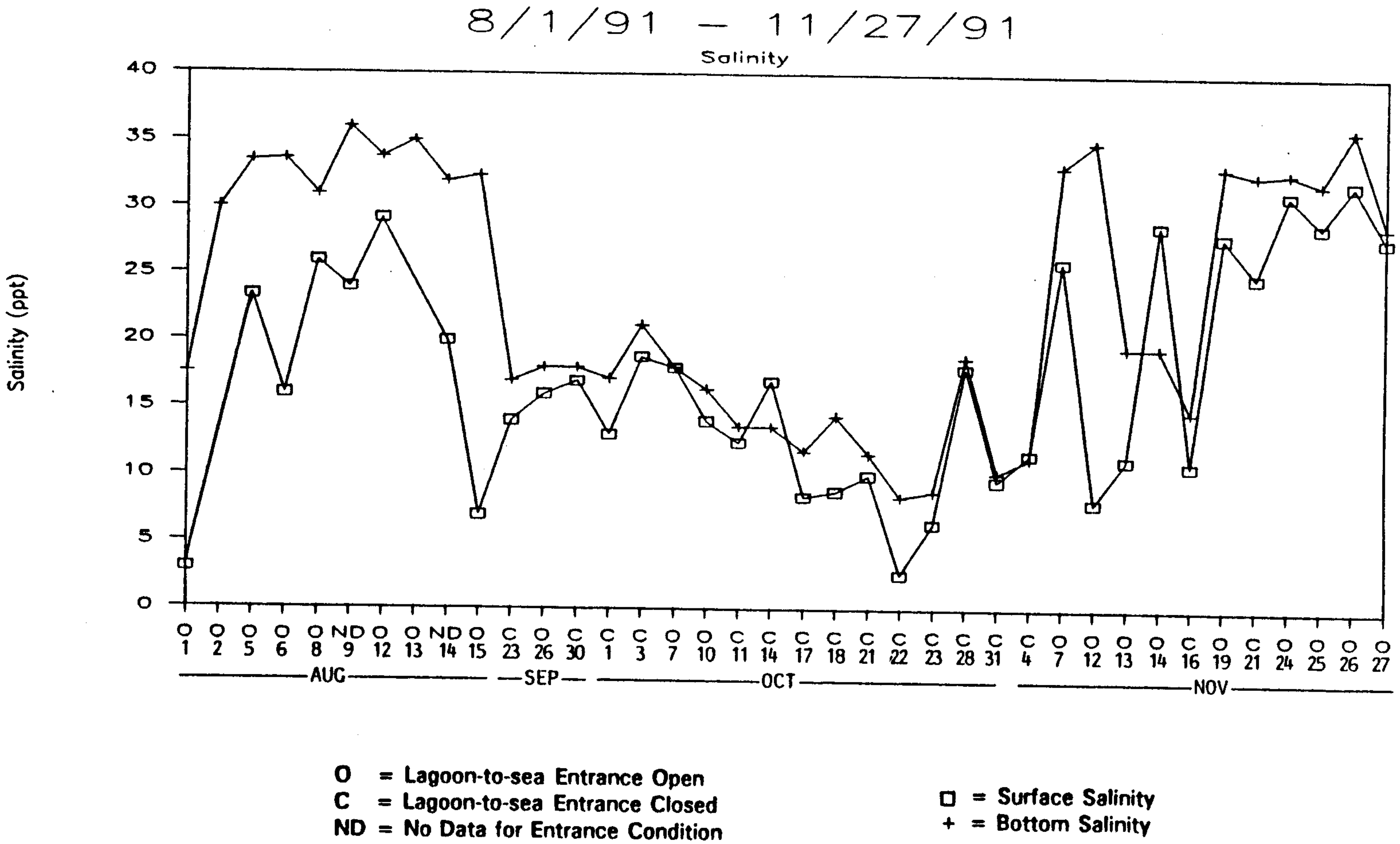


Figure 16