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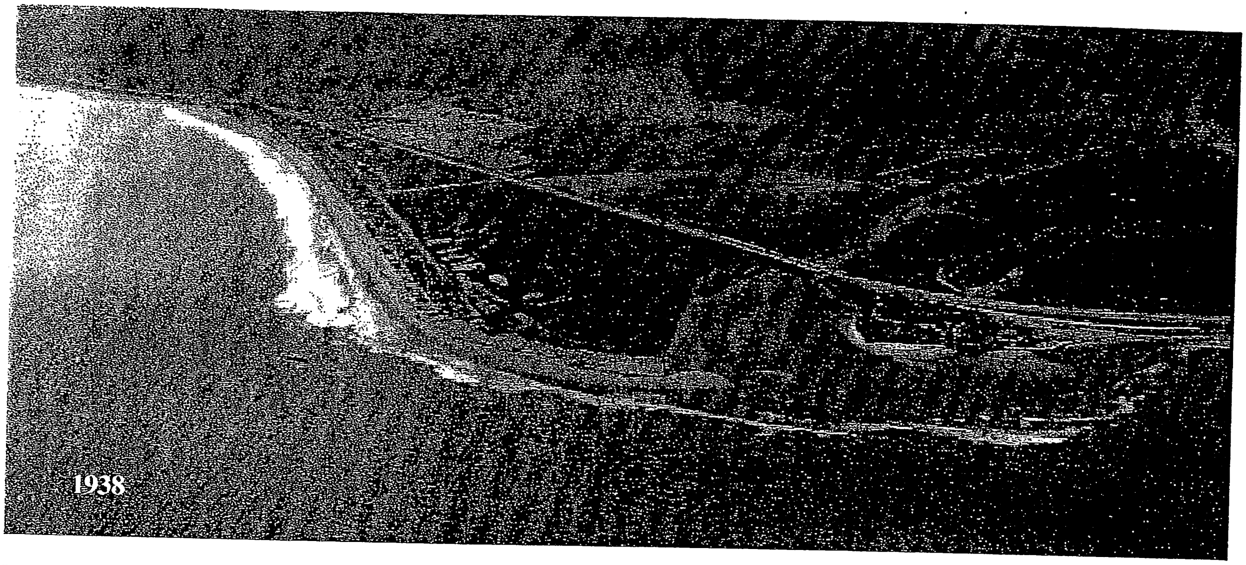
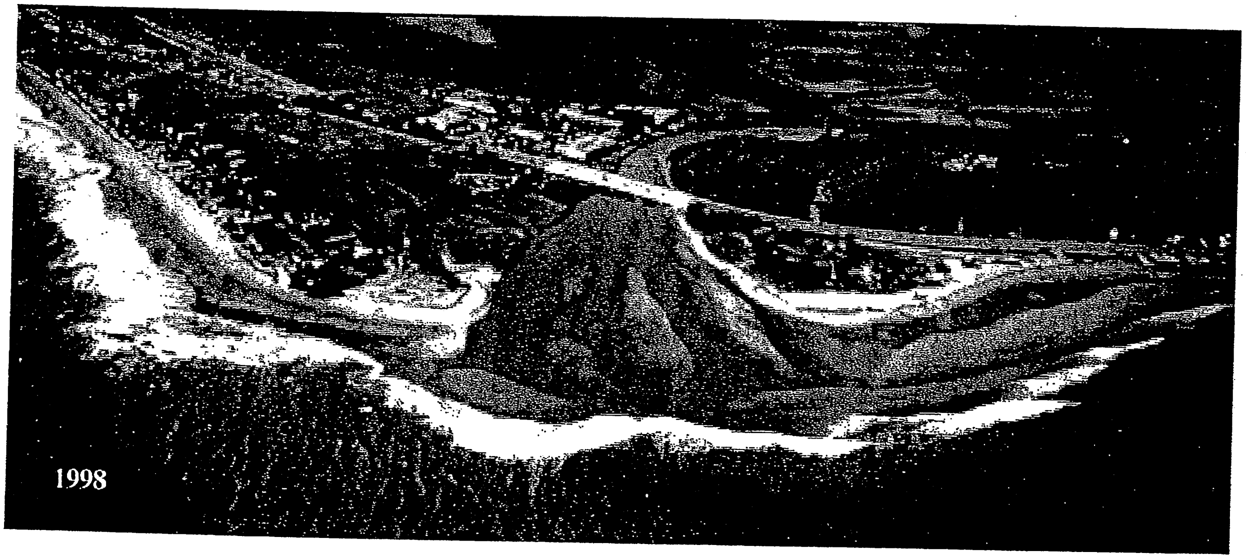
Lower Malibu Creek and Lagoon Resource Enhancement and Management





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University of California, Los Angeles

Final Report to the
California State Coastal Conservancy

May 2000

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Lower Malibu Creek and Lagoon
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Chapter 3: Biological and Water Quality Objectives and Habitat Associations

Richard F. Ambrose
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3.1. Introduction

This chapter presents the results of our literature review of biological and habitat requirements of indicator species in lower Malibu Creek and Malibu Lagoon. This work was conducted as Task 3 of the Request for Proposals (RFP), which was "to gather and analyze current information on the biological requirements of identified sensitive species inhabiting Malibu Lagoon and lower Malibu Creek," and a portion of Task 4A, specifically a habitat association analysis and a summary of threats to the habitats most suitable for various animal species in Malibu Creek and Lagoon.

Although presented in the RFP as separate tasks, the development of water quality objectives and the summary of habitat requirements both focus on indicator species of lower Malibu Creek and Malibu Lagoon and both are concerned with how species respond to their physical environment. Accordingly, we have included both tasks in this chapter. Section 3.2 considers the information that could be used to generate biological and water quality objectives. Section 3.3 considers the critical habitat characteristics for the indicator species.

3.2. Biological and Water Quality Objectives

3.2.1. Introduction

One approach to protecting the ecological health of Malibu Lagoon is to develop water quality objectives based on the requirements of the species inhabiting the lagoon. In theory, maintaining the physical conditions of the Lagoon within the preferred (or at least tolerable) ranges of its inhabitants would help ensure a healthy lagoon ecosystem.

A difficulty with this approach is that there are hundreds of different species inhabiting the Lagoon, each with its own habitat requirements. Thus, a simplified approach is to identify indicator species that could serve as "representatives" of the entire community. We selected 15 indicator species (described below) for the lower Malibu Creek watershed and Malibu Lagoon.

In the following sections, we summarize the information we found on the tolerances of these indicator species to physical characteristics or chemicals in the water that could affect their biology. We focus most on the two endangered and, arguably, most important indicator species, the tidewater goby and steelhead. Following the sections covering these two species, we summarize the information available for the remaining positive indicators, and then the information on the negative indicators. As expected, there was no information available for most of the physical parameters for most of the species.

3.2.2. Methods

Many issues need to be considered when deciding on what indicator species to use. Indicator species could be chosen to be representative of the potentially impacted community, in that they would have an "average" response to changes in environmental conditions. On the other hand, one might want indicator species to be particularly sensitive to environmental changes, so they could serve as an "early warning system." Endangered species might be included because of particular concern about the status of their populations. In addition, one might want to include species that are not currently present in the habitat, but who might occur there if conditions were appropriate. For each of these reasons to include particular species as indicators, there are also reasons not to include them. For example, if an indicator species is too sensitive, then it is only useful for distinguishing between pristine and slightly degraded conditions. Also, if an indicator species does not occur at a site, it cannot be certain that its absence is due to environmental degradation rather than other reasons (such as lack of dispersal to the site).

The indicator species we considered are presented in Table 3-1. We have used two different categories of indicators. Most of the species are "positive" indicators, species whose presence or high abundance would suggest good environmental conditions and a healthy ecosystem. There are nine fish species. Two, the tidewater goby and steelhead trout, are federally listed endangered species. The tidewater goby is presently a common member of the Lagoon ichthyofauna, though it had been extirpated from the Lagoon and the current population is the result of a reintroduction. Although the tidewater goby has particular habitat and water quality requirements, they are likely to be generally reflective of the original lagoon ecosystem at Malibu, where there was a seasonal sand bar blocking the entrance to the ocean (Swift et al. 1989). Thus, tidewater gobies may be a good indicator of lagoon conditions. Steelhead trout traditionally run in Malibu Creek, but the run is greatly diminished and steelhead are currently uncommon in the system. Steelhead trout use the lagoon as well as the creek, but they are included primarily as indicators of creek conditions; they are the only creek indicator species evaluated. The seven other fish species are all common native species occuring in Malibu Lagoon, as well as being typical species of southern California estuarine systems. These species vary in the extent of their use of estuaries, some being completely restricted to estuaries for their entire life cycle, others using estuaries as nursery habitat, and others occuring freely in estuarine and marine waters. Finally, we include two invertebrate species, the jackknife clam and mud-flat crab. Both are currently common in Malibu Lagoon.

Four "negative" indicator species were also chosen. High abundances of these species would suggest a dysfunctional ecosystem. Three of these are introduced species. The mosquitofish is currently common in Malibu Lagoon and other estuarine systems with large freshwater inputs; it is generally not common in southern California estuaries that have not experienced augmented freshwater inflows. The yellowfin goby does not currently occur in Malibu Lagoon, but it has invaded other southern California estuaries. The oriental shrimp is currently common in Malibu Lagoon. The fourth negative indicator species, a polychaete worm, is a native species most likely to be abundant in degraded environments; it is currently common in Malibu Lagoon.

3.2.3. *Species Accounts*

In this section, we first discuss tidewater gobies and steelhead in detail, followed by summaries for the other indicator species. Information about the physical tolerances of the indicator species (along with appropriate literature citations) for salinity, temperature, ammonia, pH, dissolved oxygen, nitrate, nitrite, and sulfide are presented in the text and summarized in Table 3-2.

3.2.3.1. Tidewater Goby

3.2.3.1.1. Introduction

The tidewater goby, *Eucyclogobius newberryi*, is a small (≤ 50 mm), benthic fish endemic to California's coastal estuaries from the Agua Hedionda Lagoon, San Diego County, in the south to the Smith River, Del Norte County, in the north (Moyle et al. 1989). It is the only species in the genus *Eucyclogobius* (Moyle et al. 1989), but is closely related to several eastern Pacific species (bay goby, arrow goby *Clevlandia ios*, cheekspot goby *Ilypnus gilberti*, shadow goby *Quietula y-cauda*) (Swenson 1995). Most individuals complete their life cycle within one year (Capelli 1997), although laboratory specimens have survived up to three years (Swenson 1995). Habitat loss and degradation, and predation by exotic fishes have reduced the number of tidewater goby populations to fewer than 50, leading to its designation as a federally endangered species in 1994 (USFWS 1994). The tidewater goby is known to be a weak swimmer (Swenson 1995), and is therefore easily swept into the ocean during periods of heavy flow. For example, winter storms in 1972-73 caused the elimination of a tidewater goby population from Wadell Creek (Swenson 1995). Populations are considered to be genetically isolated (Crabtree 1985), as the goby lacks a marine phase in its life history and is therefore limited in its dispersal ability. However, tidewater gobies have been recorded at sites where they were reportedly eliminated by the 1987-92 drought (Capelli 1997). This suggests that recolonization and/or genetic exchange between neighboring populations may indeed occur. A short life span, narrow habitat requirements, and isolation of populations are all factors which, combined, increase the tidewater goby's susceptibility to natural and anthropogenic environmental change.

3.2.3.1.2. Life History

Although the tidewater goby may spawn at any time of year, spawning is most prevalent from spring to mid-summer (Capelli 1997). This period coincides with the time during which most California estuaries are naturally closed to the ocean and brackish water conditions prevail. Spawning activity may continue into fall and even winter if water temperatures remain warm and the berms found at the mouths of estuaries are not breached (Capelli 1997).

Of interest to behavioral ecologists, the breeding behavior of the tidewater goby is remarkable for the dominance and aggressiveness displayed by females. Unlike other gobies, females compete for access to burrows occupied by territorial males (Swenson 1995). Furthermore, females have highly developed black breeding coloration are reported to initiate courtship more frequently than males (Swenson 1995, Swift et al. 1989)

Males excavate 10-20 cm burrows in coarse sand and protect a clutch of 300-500 eggs (Lafferty et al. 1996) until they hatch 9-11 days later (Swenson 1995). Newly hatched fry measure 4-5 mm TL (Swenson 1995), lack distinct coloration, and begin a pelagic existence. At 15-18 mm SL juveniles assume a benthic lifestyle (Moyle et al. 1989).

Tidewater gobies are known to live in a variety of habitats, although adults seem to prefer vegetated areas, which provide both cover from predators and substrate for crustacean prey (Swenson 1995). The tidewater goby feeds primarily on small crustaceans (mysid shrimp, ostracods, amphipods, etc.), aquatic insects (chironomid and diptera larvae), and molluscs (Irwin and Soltz 1984, Moyle et al. 1989), with diet depending on season and habitat (Swenson 1995).

Other gobies native to California estuaries are not thought to compete with the tidewater goby for food, as they spend portions of their lives in the ocean. However, introduced species, particularly the yellowfin goby, *Acanthogobius flavimanus*, and shimofuri goby, *Tridentiger bifasciatus*, are trophic competitors of the tidewater goby. Furthermore, these fish also prey on tidewater gobies (Wang 1984, Saiki 1993, Swenson 1995). The diet overlap between the three gobies may increase their encounter rate, and is thought to enhance the predation risk for the tidewater goby (Swenson 1995).

Resulting extinctions of tidewater goby populations could have significant impacts upon estuarine trophic dynamics. The tidewater goby is often one of the most abundant small fish population in estuaries where it is present (Lafferty et al. 1996). As secondary consumers and a prey item for larger fish and piscivorous birds, tidewater gobies are an important part of estuarine food webs (Swenson 1995).

3.2.3.1.3. Reasons For Using The Tidewater Goby as an Indicator Species

The tidewater goby *Eucyclogobius newberryi* appears to be an ideal indicator organism. A comprehensive review of the scientific literature pertaining to this species has produced a substantial amount of information regarding its habitat requirements and life history. Similar data on other Malibu Creek and Malibu Lagoon fish species, with the exception of the steelhead trout (*Oncorhynchus mykiss*), was scarce.

Eucyclogobius newberryi is also important in that it holds a unique position among California fish. The tidewater goby is one of only seven species of gobies native to California estuaries (Capelli 1997), and also belongs to a group of just three fish species living along the Pacific coast dependent upon a low salinity habitat (Swift et al. 1989).

Also of interest for using the tidewater goby as an ecological indicator is its status as a federally endangered species. Since 1900, habitat loss and degradation have resulted in its disappearance from 74% of the coastal lagoons south of Morro Bay (Moyle et al. 1989). Competition with and predation by non-native fish such as the yellowfin goby

(*Acanthogobius flavimanus*), shimofuri goby (*Tridentiger bifasciatus*), stiped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), white catfish (*Ameiurus catus*), tilapia (*Tilapia* spp.), and western mosquitofish (*Gambusia affinis*), may also be responsible for extinctions of tidewater goby populations (Saiki 1994, Lafferty and Page 1997, Wang 1984, Swenson 1995).

The native fish fauna of California is in serious decline, with 63% of its 155 taxa already extict or in danger of becoming extinct (Moyle 1995). Introduced fish species are at least partially responsible for this trend, the plight of the tidewater goby serving as a prime example. In the San Francisco Bay area, invasions by the predatory yellowfin goby *Acanthogobius flavimanus* (Brittan et al. 1970, McGinnis 1984) and the rainwater killifish *Lucania parva* (Lafferty and Page 1997) may have permanently eliminated local tidewater goby populations. In southern California, where the tidewater goby has disappeared from 74% of the coastal lagoons south of Morro Bay since 1900 (Moyle et al. 1989), over 100 non-native fish species have been reported, giving this region the distinction of exceeding all other areas of the state in numbers of successful invaders (Swift et al. 1993).

3.2.3.1.4. Habitat Requirements

Unlike virtually all other Malibu Creek and Malibu Lagoon fish, the tidewater goby has narrow habitat requirements. It is restricted to coastal brackish-water areas of coastal streams, marshes, lagoons, and estuaries in California (Swenson 1995, Swift et al. 1989, Lafferty and Page 1997).

3.2.3.1.5. Dissolved Oxygen

The EPA recommends dissolved oxygen levels ≥ 6.5 mg/L for early life stages of nonsalmonid fish. For all other life stages, the EPA recommends levels ≥ 6 mg/L (U.S. EPA 1986). The dissolved oxygen concentration range under which the tidewater goby is reported to live varies from 4-19 mg/L (Saiki 1994).

3.2.3.1.5.1. Recommendation

While early life stages of *Eucyclogobius newberryi* are present in Malibu Creek and Malibu Lagoon, dissolved oxygen levels should not fall below 6.5 mg/L. During all other times, the dissolved oxygen content should be ≥ 6 mg/L, and should never exceed 19 mg/L.

3.2.3.1.6. pH

For the maximum protection of freshwater aquatic life, the EPA recommends pH values in a range of 6.5-9.0. The recommendation for marine aquatic life is slightly narrower, at 6.5-8.5 (U.S. EPA 1986). *Eucyclogobius newberryi* is reportedly able to survive in waters with a pH range of 6.8-9.5 (Saiki 1994).

3.2.3.1.6.1. Recommendation

To best protect the tidewater goby, pH levels in Malibu Creek and Malibu Lagoon should always range from 6.8-9.0.

3.2.3.1.7. Salinity

The tidewater goby can survive in salinities from 0 to 53 ppt (Capelli 1997) and has been reported to spawn over a range of 2-27 ppt (Swenson 1995). However, most estuaries providing suitable habitat have salinities of 5-20 ppt, with the goby preferring a much narrower range of 10-15 ppt (Capelli 1997). For this reason, the tidewater goby is usually associated with estuaries that develop seasonal sand and cobble berms at their mouths, thus eliminating tidal action. Estuaries with a permanent connection to the ocean typically have higher salinities (20-33 ppt) and rarely support tidewater goby populations (Capelli 1997).

3.2.3.1.7.1. Recommendation

In areas of Malibu Creek and Malibu Lagoon where the tidewater goby is known to occur, water salinity should never fall below 2 ppt nor exceed 27 ppt, with an optimum range of 5-15 ppt.

3.2.3.1.8. Temperature

Water temperature is an important physical parameter affecting the metabolism, respiration, behavior, distribution, feeding rate, growth, and reproduction of aquatic organisms (U.S. EPA 1986).

The tidewater goby is capable of surviving in water having a temperature range of 8°C (Swift et al. 1989) to 25°C (Swenson 1995), and spawning may occur in temperatures of 9-25°C (Swenson 1995). Peak spawning reportedly occurs in 18-22°C water (Moyle et al. 1989).

3.2.3.1.8.1. Recommendation

Water temperature should be maintained between 8°C and 25°C, except during late spring through mid summer, when peak spawning occurs. During this period, temperatures should be 18-22°C, and should never fall below 9°C or exceed 25°C..

3.2.3.2. Steelhead

3.2.3.2.1. Introduction

The species *Oncorhynchus mykiss* includes both steelhead and rainbow trout native to the eastern Pacific Ocean and the coastal drainages of North America extending from the Santo Domingo River in northern Baja California (USDA 1995) to Alaska (Emmett et al. 1991). Since 1874, rainbow trout have been introduced in streams and lakes worldwide, and are currently found on every continent with the exception of

Antarctica (MacCrimmon 1971). Steelhead have a much narrower distribution, currently ranging from southern California to the Gulf of Alaska and interior British Columbia, from the coast to as far inland as Idaho (Di Silvestro 1997). Steelhead are also reportedly found in Kamchatka and Okhotsk Sea drainages in Siberia (McPhail and Lindsey 1970). Presently, Malibu Creek is the southern-most stream known to contain steelhead, with a population of up to 60 spawners (USDA 1995) and 145 juveniles (Keegan 1990). This population historically had about 1,000 adults (Nehlsen et al 1991).

Although this species was formerly known as *Salmo gairdneri*; the name was recently changed to *Oncorhynchus mykiss* due to its closer phylogenetic relationship to Pacific salmon (*Oncorhynchus*) than to Atlantic salmon (*Salmo*) (Thomas et al. 1986). *Salmo gairdneri* is the name typically encountered in the scientific literature.

Steelhead and rainbow trout frequently coexist and are distinguished not by their genetic composition, but by their life histories and behaviors. Steelhead are anadromous, meaning that they spend portions of their lives in both sea and freshwater. In contrast, rainbow trout spend their entire lives in freshwater. Interestingly, rainbow trout can give birth to anadromous fish and vice versa (Di Silvestro 1997). Why some fish go to sea and others do not is still unknown (Douglas 1995).

3.2.3.2.2. Life history

Steelhead begin life as eggs laid in the gravel of streams, where they incubate up to four months before hatching (Di Silvestro 1997). After hatching, juveniles spend one to three years in fresh water before migrating downstream, undergoing dramatic physiological changes, and entering the ocean (Carpanzano 1996). Steelhead from Oregon and Washington appear to head north to the Gulf of Alaska,while steelhead from southern Oregon and California tend to remain in offshore waters. Commercial fishing vessels have caught these steelhead as far as 3,000 miles out to sea (Di Silvestro 1997).

After spending one to five years in the ocean (Emmett et al. 1991), adult steelhead return to their natal streams to spawn. Unlike other Pacific salmonids which die immediately after spawning, approximately 20% of breeding steelhead return to the ocean and later spawn again, up to six times per individual (Carpanzano 1996). These repeat spawners are mostly female (Di Silvestro 1997).

Steelhead are known for their excellent homing abilities, a trait that has led to the development of unique stocks or races of steelhead in specific streams (Moyle 1976). At least two races are known to exist and are distinguished by when adult fish enter fresh water to spawn (Smith 1960). The summer run migrates during spring, summer, and early fall, while the winter run migrates during fall, winter, and early spring. In some large rivers with many tributaries, steelhead are presumed to migrate year-round. In California, some river mouths are closed during spring and summer, and steelhead may return only in fall after heavy rains (Fry 1973).

In freshwater and estuarine habitats, steelhead feed primarily on gammarid amphipods, small crustaceans, insects, and small fishes (Moyle 1976, Wydoski and

Whitney 1979). In the ocean, juveniles and adults feed on crustaceans, insects, squid, and fishes (LeBrasseur 1966, Wydoski and Whitney 1979).

In freshwater, steelhead are fed upon by coho salmon, char, mergansers, gulls, belted kingfisher, bears, marten, otter, and other steelhead. Its main predators in the ocean are the Pacific lamprey, seals, sea lions, and killer whales (Scott and Crossman 1973).

Mature steelhead are typically 45-70 cm in length and weigh 2-5 kg, but can reach up to 122 cm and 19.5 kg. Fish in the southern part of the range are typically smaller and spend less time in the ocean than those in the north. In a recent study, adult steelhead averaged 58.1 cm in length in California, 66.7 cm in Oregon, and 71.0 cm in British Columbia (Withler 1966).

Virtually all natural mortality (97%) occurs in the egg and larval stages, which are strongly affected by dissolved oxygen, water temperature, velocity, turbidity, depth, competition with other fishes, and pollution (Emmett et al. 1991, Shapovalov and Taft 1954).

The adult winter run of steelhead in Malibu Creek is from December to March, with the peak run in February and March (Fukushina and Lesh 1998).

3.2.3.2.3. Reasons For Using Steelhead Trout as an Indicator Species

An important reason for using the steelhead trout as an indicator species is the vast amount of information available in the scientific literature regarding its environmental requirements, a sharp contrast to virtually all other species inhabiting Lower Malibu Creek and Malibu Lagoon. For example, relevant information pertaining to both the mosquitofish, *Gambusia affinis*, and topsmelt *Atherinops affinis*, was limited to only salinity and temperature requirements. A review of the literature concerning the killifish, *Fundulus parvipinnis*, only yielded information on salinity, temperature, pH, and sulfide requirements. In comparison, relevant information concerning *Oncorhynchus mykiss* included over 100 references and information on the following water quality parameters: temperature, dissolved oxygen, ammonia, pH, salinity, nitrate, nitrite, and hydrogen sulfide. For each of these parameters, numerous studies exist.

Its narrow habitat requirements are yet another reason for choosing the steelhead trout. In Malibu Creek and Malibu Lagoon, almost all fish taxa are highly tolerant to environmental variability. For example, the killifish, *Fundulus parvipinnis*, can live in water ranging from completely fresh to that having salinities as high as 128 ppt (Moyle 1976), while the topsmelt, *Atherinops affinis*, tolerates water temperatures up to 33°C (91.4°F) (Carpelan 1955). Thus, it is difficult, if not impossible, to use these and other species as indicators of water quality in Malibu Creek and Malibu Lagoon.

Another reason for using the steelhead as an indicator species is the important role it presumably plays in southern California estuarine food chains. Research has demonstrated that salmon significantly enrich carbon and nutrient cycles near their spawning sites (Kline et al. 1990, Bilby et al. 1996). In fact, salmonids are regarded as keystone species in maintaining biodiversity, especially in areas where they are abundant (Allendorf et al. 1997).

The tremendous decline of natural populations of steelhead trout, particularly in southern California, is another important reason for choosing it as an indicator species. Despite lacking a predictable water supply, southern California's streams once sustained large runs of steelhead and resident rainbow trout. Recent estimates suggest that annual runs of 30-35,000 steelhead were found in the Santa Inez, Ventura, and Santa Clara rivers during the late 19th century (Douglas 1995). The combined effects of dam construction, stream chanelization, urbanization, and water development reduced these numbers to as few as 500 individuals by 1995 (Douglas 1995). Today, steelhead are rarely found south of the Ventura River (Emmett et al. 1991), with Malibu Creek representing the southern-most stream known to contain steelhead USDA 1995).

Since 1900, more than 23 endemic steelhead stocks have disappeared, and 43 other stocks face a moderate to high risk of extinction (Di Silvestro 1997). The Endangered Species Committee of the American Fisheries Society recently listed 214 native stocks of Pacific salmon (*Oncorhynchus* spp.), steelhead (*O. mykiss*), and coastal cutthroat trout (*O. clarki clarki*) as being at risk of extinction in California, Oregon, Idaho, and Washington (Nehlsen et al. 1991).

Due to declining natural populations, stocks have been augmented by hatchery production. In 1987, up to 17 million steelhead smolts were planted in the Columbia River Basin (Emmett et al 1991). However, the mass release of hatchery fish may have negative effects on wild populations. Studies have shown that hatchery fish have lower survival and reproduction rates than wild fish (Chilcote et al. 1986). Interbreeding with hatchery fish has led to reduced genetic diversity among wild populations and given rise to offspring with lower disease resistance (Reisenbichler and Phelps 1989).

Furthermore, anadromous salmonid species are composed of stocks that originate from specific watersheds and usually return to their natal streams to spawn, resulting in a large degree of reproductive isolation between populations. Because anadromous salmonid stocks are adapted to local environmental conditions, the loss of individual populations is likely to cause changes in genetic composition and loss of genetic diversity (Nehlsen et al. 1991).

Southern California steelhead populations frequently experience environmental conditions not encountered by northern populations. Rainfall and streamflow in southern California are highly variable and unpredictable, and long drought periods are not uncommon. Many streams dry up completely each year, and water temperatures periodically reach or exceed the upper lethal limit. These factors may in part explain recent data demonstrating significant genetic differences between populations of steelhead and rainbow trout in southern California and those north of San Simeon (Douglas 1995, Marx 1996).

3.2.3.2.4. Ammonia

The toxicity of ammonia to steelhead and rainbow trout has been studied extensively, as it is one of the two most significant water quality parameters limiting the production this species in aquaculture (Colt et al. 1980). The effects of ammonia on *Oncorhynchus mykiss* include decreased growth (Burkhalter and Kaya 1977, Rice and Stokes 1975), reduced nitrogen excretion (Fromm and Gillette 1968, Olson and Fromm 1971), increased incidence of disease (Burkhalter and Kaya 1977, Larmoyeux and Piper 1973), gill damage (Rice and Stokes 1974), and other sublethal physiological effects (Larmoyeax and Piper 1973, Mayer and Kramer 1973).

Ammonia is a naturally occurring product of biological metabolism, but high concentrations are often associated with human sources such as sewage treatment plants, agricultural and feedlot runoff, coal coking and gasification plants, and fertilizer manufacturing plants (Burkhalter and Kaya 1977).

Ammonia exists in both ionized (NH_4^+) and unionized (NH_3) forms, with its toxicity dependent on the concentration of the unionized ammonia (UIA) fraction (U.S. EPA 1986, Hofer et al. 1995). The proportion of ammonia present in the unionized form is largely determined by two other water quality parameters, pH and temperature (Alabaster and Lloyd 1982a, Trussel 1972).

Results indicate that the toxicity of ammonia, in terms of NH_3, increases at lower pH values (U.S. EPA 1984). Similarly, it has been shown that elevated water temperature increase the proportion of UIA present in an ammonia solution (Alabaster and Lloyd 1982a).

Other water quality parameters also affecting the lethal toxicity of ammonia to aquatic life include dissolved oxygen (Downing and Merkens 1955, Merkens and Downing 1957), salinity (Herbert and Shurben 1965), and carbon dioxide (Lloyd and Herbert 1960).

The toxicity of ammonia to rainbow trout has been widely studied, with 96-hr LC50 values ranging from 0.16 to 1.1 mg/L NH_3 (U.S. EPA 1984). Among numerous salmonid species tested by the EPA for ammonia toxicity, rainbow trout were the most sensitive, with lethal concentrations of ammonia as low as 0.32 mg/L (U.S. EPA 1984). The tolerance of rainbow trout to ammonia appears to increase as the fish develop through the larval stages, is greatest at the juvenile and yearling stages, and decreases thereafter (Thurston and Russo 1983).

Ammonia seems to have especially significant effects on developmental stages of *Oncorhynchus mykiss*. Growth and development of rainbow trout fry have been shown to be inhibited by long-term exposures to concentrations of ammonia as low as 0.05 mg/L (Burkhalter and Kaya 1977).

3.2.3.2.4.1. Recommendation

Following a comprehensive review of studies on *Oncorhynchus mykiss* and other salmonids, the EPA issued detailed guidelines in 1984 for ammonia in surface waters containing salmonids (U.S. EPA 1984). These criteria are based on both water temperature and pH, the two water quality parameters most strongly influencing ammonia concentration. Guidelines are listed for both 1-hour and 4-day exposure to ammonia. Criteria include both total ammonia concentration and the concentration of unionized ammonia, the portion responsible for adverse effects on aquatic life. Based upon our thorough literature review, we believe that adherence to these guidelines will be protective of steelhead trout in Malibu Creek and Malibu Lagoon.

3.2.3.2.5. Dissolved Oxygen

Dissolved oxygen (DO) is often a limiting factor in maintaining freshwater aquatic life. Low oxygen levels have a significant effect on many physiological, biochemical, and behavioral processes in fish. Depletion of oxygen levels is a common result of many forms of water pollution, and the effects on *Oncorhynchus mykiss* have been extensively studied (Alabaster and Lloyd 1982b, Barton and Taylor 1966, Davis 1975, Downing and Merkens 1955, Garside 1966, Jones 1971, Lloyd 1961, Matthews and Berg 1997, Nebeker and Brett 1976, Rombough 1988, Silver et al. 1963, Thurston et al. 1981).

Reduced dissolved oxygen concentrations are known to increase the toxicity of various poisons (e.g., ammonia, hydrogen sulfide, cadmium, cyanide, zinc, lead, copper, phenols) to freshwater aquatic life (Thurston et al 1981, Davis 1975). Studies have demonstrated low dissolved oxygen levels to increase the toxicity of ammonia (Downing and Merkens 1955, Merkens and Downing 1957), cyanide (Downing 1954), and zinc, lead, copper, and phenols (Lloyd 1961) to rainbow trout. Sublethal effects of low DO levels in steelhead trout include retarded development, reduced growth, and premature hatching and emergence of embryos (Rombough 1988).

Rainbow trout and steelhead reportedly require well-oxygenated (5-11 ppm) water (Douglas 1995). Another recent study found the optimal DO levels for rainbow trout to be ≥ 7 mg/L at temperatures $\leq 15°C$, and ≥ 9 mg/L at temperatures $>15°C$ (Barton and Taylor 1996). Spawning steelhead require at least 80% saturation, with temporary levels not lower than 5.0 mg/L (Moyle et al. 1989). The incipient lethal level for adult and juvenile rainbow trout is approximately 3 mg/L, depending on environmental conditions, especially temperature (Matthews and Berg 1997).

The extreme sensitivity of salmonids to low dissolved oxygen levels during early life is well-documented (Davis 1975, Alabaster and Lloyd 1982b, Rombough 1988). The lower threshold for the incubation of salmonid embryos is reported to be 5.0 mg/L (Reiser & Bjornn 1979), with 100% mortality of embryos occurring at 1.6 mg/L (Garside 1966, MacCrimmon 1971, Shumway et al. 1964).

A comprehensive review of the minimum oxygen requirements of Canadian aquatic life (Davis 1975) recommends DO levels ≥ 9.74 mg/L to provide the maximum level of protection for salmonid larvae and mature eggs. Symptoms of oxygen distress in larvae and eggs were reportedly noticeable at levels below 8.09 mg/L (Davis 1975). In a more recent review, the EPA recommends DO levels ≥ 11 mg/L to protect salmonid embryo and larval stages (U.S. EPA 1986).

With regards to juvenile and adult life stages, the EPA has designated levels ≥ 8 mg/L as sufficiently protective (U.S. EPA 1986), while Davis proposes DO levels ≥ 7.84 mg/L (Davis 1975).

Streams with oxygen-supersaturated water may also adversely affect steelhead trout, but such conditions are rarely encountered in nature. Elevated oxygen levels can lead to gas-bubble disease in fish, especially when accompanied by high pH values (Alabaster and Lloyd 1982b). One study found the 96-hr LC50 value for steelhead to be 116% saturation, while the 30-day LC50 was 114% (Nebeker and Brett 1976).

3.2.3.2.5.1. Recommendation

Dissolved oxygen criteria in Malibu Creek and Malibu Lagoon for *Oncorhynchus mykiss* should depend upon the life stages present, since young fish are especially sensitive to low oxygen levels. Therefore, we recommend DO concentrations ≥ 9 mg/L while embryo and larval stages are present, with levels never lower than 7 mg/L. For all other life stages, we recommend DO levels ≥ 6 mg/L, with temporary levels never to fall below 4 mg/L.

3.2.3.2.6. Hydrogen Sulfide

Hydrogen sulfide is an anaerobic degradation product of both organic sulfur compounds and inorganic sulfates, including those in sewage, algae, and other naturally deposited organic material (U.S. EPA 1986). It is a soluble, highly poisonous gas having a characteristic rotten egg odor, and can be detected in the air by humans at a concentration as low as 0.002 ppm (U.S. EPA 1986).

Data concerning the effects of hydrogen sulfide on *Oncorhynchus mykiss* was scarce. One study reported the 96-hr LC50 for rainbow trout to be 0.4μM (Bagarinao 1991). Another researcher reports rainbow trout survival in hydrogen sulfide concentrations as high as 0.45 mg/L (Ortiz et al. 1993), but this study was based on short-term (8-hour) exposure. Recent long-term field and laboratory studies demonstrate hydrogen sulfide toxicity at much lower concentrations (U.S. EPA 1986). Accordingly, the EPA recommends levels no higher than 2 μg/L of hydrogen sulfide for the protection of fish and other aquatic life (U.S. EPA 1986).

3.2.3.2.6.1. Recommendation

The scarcity of data concerning the toxicity of hydrogen sulfide to *Oncorhynchus mykiss* precludes us from drawing any definite conclusions. We recommend following the EPA criteria (≤ 2 µg/L) as long as no contradictory data causes a revision of this limit.

3.2.3.2.7. Nitrate

Nitrate is formed by the complete oxidation of ammonium ions by water microorganisms (U.S. EPA 1986). It is reportedly of little concern to aquatic life (Colt et al. 1980). There was a scarcity of data regarding the effects of nitrate on steelhead and rainbow trout. The only reference found reported the upper lethal tolerance of rainbow trout to be 1300 mg/L NO_3-N (Westin 1974). In its only recommendation regarding water nitrate levels, the EPA concluded that levels at or below 90 mg/L would have no adverse effects on warmwater fish (U.S. EPA 1986). No mention is made of any criteria for coldwater fish or salmonids.

3.2.3.2.7.1. Recommendation

At a minimum, 1300 mg/L should be set as the upper limit of nitrate in Malibu Creek and Malibu Lagoon. However, this limit should flexible and subject to change, as conclusive data concerning this water quality variable is lacking. Low nitrate levels are not a concern, as only elevated levels are potentially harmful to aquatic life.

3.2.3.2.8. Nitrite

Nitrite is a naturally occurring anion, and is produced by the bacterial oxidation of ammonia (Colt et al. 1980). Its concentration is typically less than 0.005 mg/L (Lewis and Morris 1986). Nitrite is toxic to aquatic organisms in that it alters hemoglobin, thereby reducing the total oxygen-carrying capacity of the blood (Colt et al. 1980). The toxicity of nitrite can therefore be increased by a reduction in the dissolved oxygen concentration. Temperature, which has a direct relationship with dissolved oxygen availability, could also be expected to increase nitrite toxicity (Lewis and Morris 1986). The lethal toxicity of nitrite is also dependent upon the pH (Wedemeyer and Yasutake 1978, Lewis and Morris 1986), calcium concentration (Russo et al. 1974, Wedemeyer and Yasutake 1978), and the chloride level (Eddy et al. 1983, Perrone and Meade 1977, Wedemeyer and Yasutake 1978).

Salmonids are among the most sensitive taxa studied, with little difference in tolerance among species (Lewis and Morris 1986). In a study on rainbow trout, the 96-hr LC50 of nitrite ranged from 0.19 to 0.39 mg/L NO_2-N for 2-235g fish. The incipient lethal level was reported to be 0.14-0.15 mg/L NO_2-N (Russo et al. 1974).

In another study, young steelhead were tested for 6 months and it was found that 0.015-0.060 mg/L of nitrite had no significant effect on growth (Hermanutz et al. 1987).

3.2.3.2.8.1. Recommendation

After reviewing various studies, the EPA concluded that nitrite nitrogen levels at or below 0.06 mg/L should be protective of salmonid fishes (U.S. EPA 1986). Nothing we have found in our literature review would contradict this criterion, so we propose setting this limit in Malibu Creek and Malibu Lagoon.

3.2.3.2.9. pH

Water pH levels have long been known to significantly affect freshwater communities. Most research examining the effects of pH on fish and other aquatic life has focused on low pH levels, since acidic streams and lakes are a greater problem than alkaline waters. These studies have demonstrated that salmonids, and in particular *Oncorhynchus mykiss*, are extremely sensitive to water pH values. Of four salmonid species tested in a Norwegian study (Grande et al. 1978), rainbow trout were found to be the least resistant to low pH levels. Although a laboratory study placed the lower limit of rainbow trout at pH 4.0 (Audet and Wood 1988), the lower tolerance may be as high as pH 5.5-6.0 in some natural waters (Grande et al. 1978).

Steelhead appear to grow best in slightly alkaline (pH = 7.0-8.0) water, but can survive in water ranging in pH from 5.8 to 9.6 (Moyle 1976).

Hatching and developmental stages of *Oncorhynchus mykiss* are especially sensitive to acidity (Marcus et al. 1990). Below pH 4.5, complete mortality of rainbow trout embryos has been reported (Kwain 1975), regardless of test temperatures. Other data suggests that the reproductive capacity of rainbow trout will be significantly reduced in waters of pH 5.5 or lower (Weiner et al. 1986).

Water temperature is known to play a role in determining the sensitivity of *Oncorhynchus mykiss* to acid solution. For example, the median lethal pH was 4.75 for 50% hatching success of newly fertilized rainbow trout eggs at 10°C. However, at 5°C, the median lethal pH value for 50% hatching success rose to 5.52 (Kwain 1975.

Research concerning the response of *Oncorhynchus mykiss* to alkaline water is limited, but appears to provide accurate information. Despite reports of salmonid mortality at pH 9.0 or greater (Jordan and Lloyd 1964, Yesaki and Iwama 1992), a recent study demonstrated that free-swimming rainbow trout were capable of long-term survival (28 days) at pH 9.5 (Wilkie et al. 1996). It is unknown what effects, if any, this pH level would have on developmental stages of *Oncorhynchus mykiss.*

3.2.3.2.9.1. Recommendation

The EPA recommends a pH range of 6.5-9.0 as providing the maximum level of protection for freshwater fish (U.S. EPA 1986). A thorough literature search has provided no information pertaining to *Oncorhynchus mykiss* contradictory to this recommendation. Therefore, this range appears to be reliable and is expected to protect steelhead trout in Malibu Creek and Malibu Lagoon.

3.2.3.2.10. Salinity

This section refers to the salinity found in the freshwater habitats which steelhead use for development and reproduction. Obviously, the salinity range encountered by the marine phase is small (roughly 30-36 ppt).

In a study conducted on rainbow trout, growth rates were highest in freshwater, and declined with increasing salinity (Morgan and Iwama 1991). This study also reports that metabolic rates increased with salinity and were inversely correlated with growth rates. Research conducted on other salmonid species also demonstrate that growth rates are highest in freshwater (Clarke et al. 1981, McKay and Gjerde 1985, and McCormick et al. 1989).

Several studies report 20 ppt salinity to be the upper limit for survival of juvenile (10-30 g) rainbow trout (Landless 1976, Eddy and Bath 1979, Johnsson and Clarke 1988).

3.2.3.2.10.1. Recommendation

Because steelhead smolts and adults reportedly spend little time in estuaries (Emmett et al. 1991), this recommendation will apply primarily to Malibu Creek and not Malibu Lagoon. The maximum salinity shall not exceed 20 ppt at any time, and levels should almost always approximate 0 ppt.

3.2.3.2.11. Temperature

Water temperature is a significant factor restricting the distribution of *Oncorhychus mykiss*. Consequently, numerous studies have examined the effects of temperature on steelhead and rainbow trout (Adams et al. 1973, Baltz et al. 1987, Cherry et al. 1975, Cherry et al. 1977, Coutant 1977, Garside and Tait 1958, Garside 1966, Hokanson et al. 1977, Javaid and Anderson 1967, Jobling 1981, Kwain 1975, Lee and Rinne 1980, Matthews and Berg 1997, McCauley and Pond 1971, McCauley et al. 1977, Nielsen and Lisle 1994, Peterson et al. 1979, Wichert and Lin 1996, Zaugg et al. 1972). Considerably more data exists for upper than for lower temperature limits.

Studies on northern populations report 26-27°C as the upper lethal limit for *Oncorhynchus mykiss* (Jobling 1981). Steelhead in southern California are known to inhabit streams with water temperatures as high as 28°C (Carpanzano 1996), but only when the water is saturated with dissolved oxygen (Emmett et al. 1991).

The optimum temperature for the growth of juvenile and adult rainbow trout reportedly lies between 15.7 and 17.2°C (Hokanson et al. 1977), although another researcher extends this range to 13-21°C (Moyle 1976).

This species is known to tolerate 0°C seawater (Colt et al. 1980, Saunders et al 1975), with the lower lethal limit reported to be approximately -0.7°C (Saunders et al. 1975).

During spawning, steelhead appear to be especially sensitive to water temperature. One study recommends a temperature range of 3.9-9.4°C while spawning is taking place (Reiser and Bjornn 1979), while the EPA lists 9°C as the maximum average weekly temperature for spawning in rainbow trout (U.S. EPA 1986). However, a more recent publication reports that spawning in steelhead may occur in temperatures ranging from 8-15.5°C (Emmett et al. 1991).

Steelhead embryos are also sensitive to elevated temperatures. The EPA lists 13°C as the short-term maxima for embryo survival of rainbow trout (U.S. EPA 1986), while another study recommends temperatures of 3.9-9.4°C during the incubation of embryos (Reiser and Bjornn 1979).

Another developmental stage affected by water temperatures is the parr-smolt transformation, in which freshwater-dwelling juvenile steelhead undergo dramatic physiological changes in preparation for an ocean existence. These changes are reportedly inhibited by temperatures above 15°C (Adams et al. 1973).

Research suggests that shading from streamside vegetation may play an important role in controlling stream temperatures and providing suitable habitat for *Oncorhynchus mykiss* populations . A recent study concluded that decreases in canopy cover along the banks of a desert stream resulted in significant declines in densities of trout and increases in densities of warm water cyprinids (Tait et al. 1994). Densities of northern rainbow trout populations have been shown to be correlated with stream temperature (Hawkins et al. 1983, Murphy et al. 1981). Vegetation cover may play an even more important role in southern California, where higher stream temperatures are common (Carpanzano 1996). Therefore, removal of streamside vegetation along Malibu Creek and Malibu Lagoon may negatively affect steelhead trout, and should be avoided.

3.2.3.2.11.1. Recommendation

Low water temperatures are not a concern, as this species is known to tolerate 0°C seawater (Colt et al. 1980, Saunders et al 1975), and temperatures in Malibu Lagoon reportedly do not fall below 10.5°C (Dillingham and Manion 1989). Therefore, it is probably of no practical value to set a lower temperature limit in Malibu Creek and Malibu Lagoon with regards to this species.

The upper temperature limit for steelhead trout should depend upon time of year and developmental stages present. When spawning activity and incubation of embryos is taking place, we recommend that temperatures not exceed 15°C. During the rest of the year, the upper limit in both Malibu Creek and Malibu Lagoon should be set at 28°C, as long as dissolved oxygen levels remain high. However, when the lagoon mouth is closed from tidal flushing, dissolved oxygen levels may fall and a slightly more conservative limit of 26°C in Malibu Lagoon would be appropriate. In addition, removal of streamside vegetation along Malibu Creek and Malibu Lagoon should be banned, or at least severely restricted.

3.2.3.3. Other indicators of good ecosystem health

The species in this section are native southern California estuarine species (although some of them only occur in estuaries during a limited part of their life cycle). All of these have been found in Malibu Lagoon and are characteristic of southern California estuaries. The presence of these species can be viewed as an indication of good ecosystem condition.

In this section, we first present information about fish species, followed by information about two invertebrate species.

3.2.3.3.1. Fundulus parvipinnis (California killifish)

California killifish are very abundant in Malibu Lagoon. During the Baseline Ecological Study (Manion and Dillingham 1989), this species was found in the lagoon in all samples except February's. Similarly, Ambrose et al. (1995) found killifish throughout the year. California killifish are year-round residents of the Lagoon, and during the winter and early spring the population consists of mainly adults.

California killifish are found in shallow coastal waters, occasionally found in freshwater streams or brackish lagoons of southern California (Moyle 1976). They are probably omnivorous, taking advantage of the most abundant invertebrates and algae in their environment. Allen (1982, p. 784) considers them a low-level carnivore, feeding on small crustaceans and insects. Fritz (1975, p. 101) reports that their food consists mainly of arthropods with annelids, gastropods, fish ova and algae making up a minor part of the diet. Amphipods, copepods, ostracods, and dipteran insects appear to be the most abundant food items. Breeding takes place mostly from May-June but continuing through July and into August if water temperatures are low early in the year, according to Moyle (1976) or April through September (Fritz 1975). Much suitable freshwater habitat has been eliminated, but they are still abundant in salt water.

California killifish are most abundant in saltwater lagoons and estuaries but can tolerate a wide range of salinities so populations have become established in a number of freshwater streams (Moyle 1976). According to Moyle, they can live in water ranging from completely fresh to that having salinities up to 128 ppt. Carpelan (1961, p. 36) reported that killifish can survive in salinities at least as high as 55 ppt, but the maximum tolerance was not observed. Small fish are more resistant to sudden changes in salinity than are larger fish but the larger fish can withstand lower oxygen levels.

Cairns (1982, p. 273) reports that the family Cyprinodontidae has an overall temperature range of 21-40°C, the general mean is 28-36°C. Hubbs (1965, p. 113) reported that larvae of *Fundulus* hatched at temperatures between 16.6 and 28.5°C.

Gonzales et al. (1989) studied the effects of pH on the east-coast congener, *Fundulus heteroclitus*. With an incipient lethal pH between 3.75 and 4.0, it appears that *F.heteroclitus* is much more tolerant of low pH than many freshwater species in similarly hard water (p 171).

Bagarinao and Vetter (1993) have noted that sulfide can affect fish performance. They report (p 730) that mass fish kills are often attributed to hypoxia/anoxia, salinity and temperature fluctuations, or low pH, but it is quite likely that sulfide is responsible for some fish kills. They also note that earlier studies have shown that the killifish is more tolerant to sulfide than several other species of shallow water marine fish. For example, Bagarinao (1991) reported the 96-hr 50% lethal concentration of sulfide to *Fundulus* is 700 μM, and the 8-hr tolerance limit is 5mM of sulfide, the 20-hr tolerance limit is 1.5 mM sulfide (p 61), and the acute tolerance limit is about 300 μM H_2S in seawater pH 8.3 at 16-20°C, higher than has been observed for any animal (p 138).

3.2.3.3.2. Antherinops affinis (topsmelt)

Topsmelt are one of the most common fish in Malibu Lagoon. They are opportunistic feeders, characterized as both a herbivore/detritivore and a low-level carnivore (Allen 1982, p. 784). Emmett et al. (1991, p. 188) report they are omnivorous, feeding primarily during the day. They are important prey for many piscivorous birds and fishes, including yellowtail and other large fishes. Five subspecies are currently recognized, with *A. affinis littoralis* ranging from Monterey down to San Diego (Emmett et al. 1991, p.186). Juveniles and adults are pelagic, but are found over a wide range of habitats depending on the time of year.

Topsmelt can spend their entire life cycle in marine waters. They are tolerant of higher salinities. Somewhere in the range between 80 and 90 ppt, conditions become intolerable for *Antherinops* (Carpelan 1955, p. 281). Carpelan (1955) also noted that topsmelt live throughout the year in ponds with salinity 150% that of sea water (51 ppt) (p 284). Gravid females were observed to spawn in water which had a salinity of 72 ppt (p281). Carpelan (1961, p. 39) report that as salinity increased during summer and early fall in the Los Peñasquitos Lagoon (in San Diego County), *Antherinops* thrived at the maximum salinity of 63 ppt. Middaugh and Shenker (date?, p. 235) report a tolerance to lower salinity, also, at least in juvenile *Antherinops* from Estero Americano (near Bodega Bay), who can tolerate salinities ranging from 2 ppt to approximately 80 ppt. In addition, Anderson et al. (1990, p. 11-12) report that recent laboratory studies of salinity tolerance in young *A.affinis* demonstrated that they are able to tolerate low salinities as well. Young fish, 24-days-old were acclimated from 10 ppt to 2 ppt in 2 ppt/day increments. All fish survived the period of acclimation to 2 ppt and for 29 days at the low salinity. In a second experiment, 24-day-old *A.affinis*, initially held at 30 ppt, were subjected to a 2 ppt/day increase salinity. No mortalities occurred until 60 ppt salinity. Incremental mortality occurred as salinity increased to 80 ppt where the cumulative mortality was 48%. An increase to 82 ppt salinity caused cumulative mortality to rise to 80%. Anderson et al. (1990) further note that adult A.affinis are reproductively active during May-August. This period generally coincides with low coastal rainfall and high salinities in California estuaries and coastal lagoons. While they observed optimal larval growth at 20 and 30 ppt and collected reproductively adults from Estero Americano at 34 ppt salinity, other field observations indicate that *A.affinis* adults may spawn at salinities up to 72 ppt in the Alviso Salt Ponds of San Francisco Bay (Carpelan 1957). Moreover, Carpelan (1955) reported that waters of the Alviso Salt Ponds only became intolerable for young *A.affinis* between 80 and 90 ppt.

Carpelan (1955, p. 283) reports a remarkable tolerance to temperature changes. For example, the extreme diurnal range observed in the ponds was 12°C, from a morning low of 21°C (69.8F) to an afternoon high of 33°C (91.4°F). *Antherinops* must also withstand an annual range of 25°C, from a low of 8°C (46.4°F) to as high as 33°C (91.4°F). Coutant (1977, p. 740) report an *Atherinops* sp. upper avoidance temperature of 28°C, a final preferendum of 25.2°C, and a lower avoidanceof 22°C, according to Doudoroff (1938). Cairns (1982) reports that *Atherinops* sp. preferred 25.2°C water, and the family Atherinidae has an overall temperature range of 25.2-32°C. Hubbs (1965) report that larvae of *Atherinops* hatched at temperatures between 12.8 and 26.8°C (p. 113), with the maximum developmental temperature tolerance is probably between 27 and 28.5°C. Hubbs also noted that the lower developmental temperature tolerance has not been ascertained; however, it must be not far below 12.8°C because death closely follows hatching at that temperature (p 119). Emmett et al. (1991, p. 187) found the upper and lower lethal temps for juvenile fish to be 31.7°C and 10.4°C, respectively.

3.2.3.3.3. *Clevlandia ios (arrow goby)*

Arrow gobies are small, benthic fish. The benthic life stages are strictly estuarine, but the larvae are found in nearshore coastal waters. It can reach extremely high abundances. One factor that may allow *Clevlandia ios* to dominate disturbed areas is its life history strategy (Nordy and Zedler 1991, p. 91). It matures within one year and spawns from September through June. The arrow goby is a low-level carnivore, feeding mainly on insects, benthic microinvertebrates, and zooplankton (Allen 1982, p. 784). Macdonald (1975, p. 119) report that harpacticoids, ostracods, nematodes, oligochaetes, and cyclopoids are most important food items, with amphipods, caprellids, and larger oligochaetes important only to larger fish. It is preyed upon by *Paralichtys californicus*, *Hysopsetta guttulata*, *Leptocottus armatus*, and *Fundulus parvipinnis* (Nordby and Zedler 1991, p. 91). California halibut is also probably a major predator of arrow gobies (Macdonald 1975).

3.2.3.3.4. *Leptocottus armatus (staghorn sculpin)*

Staghorn sculpin feed heavily on decapod crustaceans, such as *Hemigrapsus oregonensis* (Armstrong et al. 1995, p. 456). Haaker (1975, p. 130) reports a wide variety of food items eaten with a concentration on decapod crustaceans (*Hemigrapsus oregonensis*, ghost shrimp *Callianassa* sp., and pea crabs *Pinnixia* sp.; it also feeds on fish, mainly *Clevlandia ios* and the shadow goby, and occasionally the killifish *Fundulus parvipinnis*. Jones (1962, p. 359) reports that the diet of adults and the diet of juveniles differ most markedly in the smaller number of fish present in the juvenile diet. Where stomachs of adults contained 13.5% fish, those of juveniles contained only 0.3% fish. Juvenile staghorn sculpins undoubtedly are restricted to an invertebrate diet largely because of their small size. Few fishes in the estuary are smaller than the young staghorn sculpins to serve as prey, and intraspecific predation of juvenile staghorn sculpins, which has been observed in aquaria, is probably infrequent in nature.

Young sculpin inhabit brackish water streams and channels and move down into the estuary as they grow larger during their first year (Armstrong et al. 1995, p. 456).

Moyle (1976, p. 366) reports that staghorn sculpin are truly euryhaline, not only are they found in water that ranges in salinity from fresh to salt (34 ppt and probablyhigher), but they often move freely between waters of varying salinities. Carpelan (1961, p. 38) reports an upper limit of salt tolerance of *Leptocottus* in the vicinity of 51-53 ppt. Adults are limited to marine waters during the breeding season and are less tolerant of low salinity than are younger age groups (Jones 1962, p. 361). It spawns in winter, the young are present in the estuary only in summer when salinities are high and, therefore, require no adaptation to low salinity.

Jones (1962, p. 334) reports the eggs of the staghorn sculpin did not hatch at salinities of less than 10.2 ppt. Eggs of the staghorn hatched successfully in the salinity range from 10.2 to 34.3 ppt. In each experiment, the percentage of eggs which hatched was highest in salinities of 10.2 ppt, lowest in salinities of 34.3 ppt, and intermediate in salinities of 17.6 and 26.4 ppt. Some of the larvae of the staghorn sculpin hatched successfully at salinities from 10.2 to 34.3 ppt (p 336), appeared normal, and swam actively about the container; but others either could not swim off the bottom of the container or, because their tails were curved to one side, could swim only in circles. The hatch of normal larvae was lower in salinities of 10.2 and 34.3 ppt and higher in the intermediate salinities of 17.6 and 26.4. Two of the experiments indicated that 26.4 is closer to the optimum salinity than is 17.6. The hatch of abnormal larvae was highest in 10.2 ppt and decreased with increasing salinity (p. 337). Newly hatched staghorn sculpin larvae are more tolerant of low salinity than are embryonic stages. The maximum hatch of normal larvae occurred in water at a salinity of 26.4 ppt. However, normal larvae survived longest in the lower salinities of 10.2 and 17.6 ppt. All larvae hatched at high salinities and then transferred to 10.2 ppt survived longer than larvae retained in high salinities. At salinities of 5.1 ppt and less, the survival time of larvae was quite short, and environments with such low salinities obviously are unsuitable for newly hatched larvae (p 339). Juvenile staghorn sculpins can withstand a wide range of salinity and are more tolerant of low salinity than are either the eggs or the larvae. Survival time was shortest in stream water or tap water, both of 0.1 ppt salinity. At higher salinities, specimens survived longer, and the survival indices indicate that the optimum salinity for survival is 10.2 ppt (p 339). Small juveniles, which are present only during the spring months, are more tolerant of low salinity than are the larger juveniles present in summer and autumn.

3.2.3.3.5. Hypsopsetta guttulata (diamond turbot)

Diamond turbot, a flatfish, feed on mollusca, polychaetes, and crustaceans (Haaker 1975, p. 167).

No information on the physical tolerances of diamond turbots was found.

3.2.3.3.6. Gillichthys mirabilis (longjaw mudsucker)

Longjaw mudsuckers are strictly estuarine species.

Cairns (1982, p. 277) reports that longjaw mudsuckers prefer 22°C.

3.2.3.3.7. *Girella nigricans (opaleye)*

Opaleye are primarily marine, but juveniles use estuaries as a nursery.

Cairns (1982, p. 279) reports that 55-60mm fish preferred 26-28.2°C water. Jobline (1981, p. 447) reports the optimum growth temperature from several studies as 24, 23 °C, the final preference from several studies) as 23.5, 26°C, and the lethal temperature as 31.4°C. The family Kyphosidae has a temperature range of 26-31.2°C (Cairns 1982, p. 273).

3.2.3.3.8. *Tagelus californicus (jacknife clam)*

The jacknife clam is a suspension feeder although it belongs to the primarily deposit-feeding Superfamily Tellinacea (Page et al. 1992, p. 259). It is the only common clam species in Malibu Lagoon.

Jacknife clams are judged by laboratory tests to be intolerant of low salinities (Peterson 1975, p. 962). Nordby and Zedler (1991, p. 90) report that *Tagelus* was intolerant of the lowest salinities, 3-10% seawater, and that this species was strongly affected by lowered salinity; it was least abundant at the site nearest the source of wastewater flow. Manion and Dillingham (1989, p. 91) report that die-offs of jacknife clams in Malibu Lagoon seem directly related to continued exposure to fresh water and possibly also to pollution (August 1987 Pepperdine spill)

3.2.3.3.9. *Hemigrapsus oregonensis (yellow shore crab or mud-flat crab)*

The mud-flat crab can survive in salinities as high as 175% seawater (~62 ppt) (Gross 1961). No living *Hemigrapsus* were found in the lagoon studied by Gross (1961) when the salinities had exceeded 180% seawater (p. 300). Williason (1980) reports that *H. oregonensis* of size 9-12 mm survived up to 80 hours in water of salinity 2ppt, and that ~55% of *H. oregonensis* of size 14-24.1 mm survived 100+ hours in 2 ppt salinity. Manion and Dillingham (1989, p. 102) report that bottom salinities, where crabs are active, ranged from 2ppt to 37 ppt, which is within the range tolerated by his species. The mud crab is a species that endures moderately polluted conditions in Los Angeles Harbor, and has the ability to tolerate wide ranges of salinities, including prolonged periods of both freshwater and hypersaline conditions (Garth and Abbott 1980, cited in Manion and Dillingham 1989).

Although we found no studies specifically focusing on temperature tolerances of mud-flat crabs, in Malibu Lagoon bottom temperatures when crabs are active ranged from 10-27.5°C. Highest numbers were recorded when water temperatures were warmest (Manion and Dillingham 1989, .p 102).

Manion and Dillingham (1989, p. 108) concluded that mud crabs at Malibu Lagoon show the resiliency needed of a species which can survive there under constantly fluctuating physical conditions. In particular, these crabs seem to be able to adapt to very wide ranges of salinities where other species cannot (Zedler and Nordby 1986), and to survive during extended periods where salinity levels remain low. Since mud crabs are highly tolerant of polluted conditions, present water quality in the lagoon probably is not limiting.

3.2.3.4. Indicators of poor ecosystem health

In this section, we present information about species that do not represent desirable conditions in Malibu Lagoon. Three of these indicators are introduced species. Their presence does not necessarily indicate poor water quality, since there are a wide variety of conditions that could allow them to invade a particular habitat. We also include one native species, a polychaete, because it is common in degraded habitats, and it is often common where there is poor water quality.

3.2.3.4.1. Gambusia affinis (western mosquitofish)

The mosquitofish is a very tolerant species introduced to streams throughout southern California (and elsewhere) to control mosquito populations. The mosquitofish is a low-level carnivore, feeding mainly on insects, benthic microinvertebrates, and zooplankton (Allen 1982, p. 784). Haynes and Cashner (1995, p.1039) note that the ability of *G. affinis* to adapt to different, often harsh habitats by modifying its life history has allowed it to become one of the most successful vertebrate species on Earth. Although the species is generally tolerant of a wide range of conditions, males succumb more quickly than females to environmental stressors, suffering higher mortality when exposed to temperature extremes, overcrowding, starvation, and hypoxia (Haynes and Cashner 1995, p.1036). Leidy (1984) noted that it preferred warm, turbid, heavily silted pools, often containing rubble with moderate amounts of floating and rooted aquatic vegetation. These highly disturbed intermittent stream habitats usually contained few additional species (Leidy 1984, p. 19).

Although *G. affinis* is a freshwater species, it is tolerant of a wide range of salinities. Al-Daham and Bhatti (1977) noted that *G. affinis* was resistant to salinities of 50% seawater (20-50 ppt). Nonetheless, in southern California estuaries with a distinct salinity gradient, its highest densities are often found at the stations with the lowest salinities or greatest freshwater influence (Nordby and Zedler 1991, Ambrose et al. 1995).

Mosquitofish prefer relatively warm temperatures. Cairns (1982, p. 281) reports that adults preferred 27°C water, and 25-35mm fish preferred 34.7-35.3°C water. Winkler (1979, p. 62-63) reports field populations chose the 31°C chamber of the temperature gradient within the first 10-15 min and remained there for several days (p 62); Arkansas populations of *G.affinis* also chose preferred temperatures of 28-31°C. Coutant (1977, p 741), summarizing the results from several studies, reports a adult final preferendum of 31°C (Winkler 1973), an adult upper avoidance of 29.5°C and a final preferendum of 27°C (Bacon et al. 1967), an adult (15-19mm) upper avoidance of 32°C (Bacon et al. 1967), and an adult (<15mm) upper avoidance of 35°C (Bacon et al. 1967). Jobling (1981, p. 445) reports the optimum growth temperature from several studies (°C): 28.6, 30.9, the final preference from several studies (°C): 28, 31, and the lethal temperature as 37.3°C. The incipient lethal temperature to *Gambusia* is 37-38C°

(Wurtsbaugh and Cech 1983). The family Poeciliidae has an overall temperature range of 27-35.3°C; the general mean is 29-34°C (Cairns 1982, p. 273).

3.2.3.4.2. Acanthogobius flavimanus (yellowfin goby)

The yellowfin goby is an introduced species in California, where they are found in shallow, muddy littoral areas in fresh, brackish, and salt water. They are naturally common in shallow coastal waters of Japan, Korea, and China. Yellowfin gobies were first collected in Sacramento-San Joaquin Delta in 1963, and are now common in the Delta and are spreading rapidly (Moyle 1976, p. 348). They are well adapted for estuarine living because they are capable of withstanding abrupt changes between fresh and salt water, and can survive water temperatures greater than 28°C. They feed on a wide variety of crustaceans and small fishes associated with the bottom, as well as algae. Yellowfin gobies are strong predators and competitors and have the potential to seriously alter the communities they invade. For example, populations of the tidewater goby may be in some danger of being eliminated through competition, and in at least one area, they have partially displaced staghorn sculpins (Moyle 1976). Leidy (1984, p. 26) reported that native species of fish were extremely uncommon where *A. flavimanus* was abundant.

As noted above, yellowfin gobies have a wide salinity tolerance. They can probably complete their entire life cycle in fresh water (Moyle 1976).

3.2.3.4.3. Palaemon macrodactylus (oriental shrimp)

Oriental shrimp are an introduced species that is relatively common in Malibu Lagoon.

According to Newman (1963, p. 127), it is adapted to wide variations in salinity and temperature, adults can be maintained in normal or dilute sea water at temperatures ranging from 14-26°Celsius for indefinite periods of time.

In the laboratory, these shrimp survive well at temperatures between 14-26°C, and tolerate wide ranges of salinities (Chance and Abbott 1980, in Manion and Dillingham 1989, p. 109). At Malibu Lagoon, there appears to be no correlation between water temperature and the presence of shrimp. Shrimp appeared on surveys where temperatures extended well beyond this range, with temperatures varying from 10.5-27.5°C (p 109)

3.2.3.4.4. Polydora nuchalis (polychaete worm)

Polydora nuchalis is an appropriate indicator of negative conditions because it is an opportunistic polychaete. Opportunistic polychaetes including *Polydora ligni*, *Capitella* spp., and *Streblospio benedicti* are known to rapidly colonize and dominate benthic communities during or following disturbances such as discharge of sewage or industrial waters, nutrient additions and subsequent eutrophication, oil spills, and even severe storms and hurricanes. This response has been documented in shallow bays, estuaries, mudflats, and salt marshes throughout the world, including the Wadden Sea (Beukema 1991, Beukema and Cadée 1997) and the Venice Lagoon (Sordino et al. 1989), the coast of Japan (Tsutsumi et al. 1987), Scotland (Bagheri and McLusky 1982), Norway (Holte and Oug 1996), Portugal (Pardal et al. 1993), Holland (Reish1979), the Netherlands (Lambeck and Valentijn 1987), Massachusetts (Grassle and Grassle 1974), Connecticut (Zajac and Whitlatch 1982), Mission Bay in San Diego (Levin 1986), and the Los Angeles Harbor (Nordby and Zedler 1991). These population explosions are often are followed by equally dramatic population declines (Levin et al. 1996).

Estuarine polychaetes have a profound influence on the properties of sediments such as grain size distribution, interstitial water, and dissolved gases (Heip 1995). According to the U.S. EPA (1980), polychaetes play an important role in the movement of sediments in much the same manner as earthworms do on land. When polychaetes disappear, as during anoxic events, the physical and chemical characteristics of the top sediment layers are greatly affected (Heip 1995). Polychaetes also play an important role in providing food for birds and fish (U.S. EPA 1980).

Reish and Fauchald's (1977) review of studies of benthic soft-bottom communities in terms of density (no./m^2) showed polychaete densities to be high, averaging 44.3%, and exceeding 50% in over half of the studies reviewed. As a percentage of the total number of species in a community, polychaetes ranked high, averaging over 40% in all studies considered. Since they are such a large component of benthic communities, this group should be included in assessments of benthic communities, as many researchers including Pearson and Rosenberg (1978), Reish (1979), and Levin et al. (1996), have concurred. *Capitella capitata* is probably the most commonly used marine organism as an indicator of marine pollution (Reish 1979), while *Polydora ligni* and *Streblospio benedicti* have also been used as indicators of organically polluted sediments (Pearson and Rosenberg 1978, Levin 1984, Sordino et al. 1989). Nordby and Zedler (1991, p. 91) suggest that high densities of capitellids and *Polydora* spp. may have been encouraged by sewage spills, since both taxa are associated with pollution. In LA Harbor, *Capitella* sp. and *Polydora cornuta* were most abundant in polluted to very polluted areas (Nordby and Zedler 1991). Furthermore, the structure of benthic communities reflects the environmental conditions of the water prior to the time of sampling, whereas water samples only reflect the conditions at the time of sampling (Reish 1979, Metcalfe 1989).

Polydora nuchalis is the only species of polychaete consistently identified in the sediments of Malibu Lagoon (Manion and Dillingham 1989, Ambrose et al. 1995). It is usually found in mudflats of estuaries and bays (Woodwick 1953; *see* Manion and Dillingham 1989 p. 77 for ref). An extensive survey at Malibu Lagoon revealed that *P. nuchalis* represented 72% of all infauna collected (Ambrose et al. 1995) and was also the most frequently collected infaunal organism at every sampling location. Ambrose et al. (1995) conclude that the invertebrate fauna at Malibu Lagoon exhibits very low species richness, especially when compared to other southern California

According to Pearson and Rosenberg (1978), stable communities are characterized by high species numbers and biomass but only moderate abundances. Furthermore, high densities of polychaetes are typical of organically enriched estuaries (Bagheri and McLusky 1982). For example, polychaetes represented 63% of the individuals sampled a highly enriched estuary in Portugal (Pardal et al. 1993). It is not difficult to conclude, therefore, that Malibu Lagoon is a highly unstable environment and is probably affected by relatively high organic enrichment

Little information exists on the life history characteristics and response to organic enrichment of *Polydora nuchalis*. However, a significant amount of information exists for *P. ligni* (also referred to as *P. ciliata* in the literature). Therefore, this summary focuses mainly on *P. ligni*. Relevant data on *Capitella capitata* and *Streblospio benedicti* is also presented. This is done because they share similar characteristics, abundant information is available for them, and because both *C. capitata* and *S. benedicti* frequently co-occur with *Polydora* (Levin et al. 1987). All 3 species are of similar size (10-20 mm) and rapidly colonize disturbed areas (Levin et al. 1987). From a range of studies, Reish and Fauchald (1977) ranked the most opportunistic polychaetes as *C. capitata*, first, followed by *P. ligni* or *Streblospio benedicti* in North America and *Scolelepis fuliginosa* in Europe. According to Reish and Fauchald (1977), opportunistic species are found in greater numbers among polychaetes than in any other taxonomic group.

Polydora is one of the largest polychaete genera, with species common in coastal waters worldwide and known for their ecological plasticity (Manchenko and Radashevsky 1993). *P. ligni* is a common estuarine and near shore species (Zajac 1986) and is found in all oceans and at all latitudes (Grassle and Grassle 1974, U. S. EPA 1980). According to Dauer et al. (1981), *P. ligni* prefers sediment composed of at least 90% silt-clay and is generally found in mud or sand tubes in the upper few cm of sediment. *P. ligni* exhibits wide salinity tolerance, so may be found anywhere from the open coast to estuaries (U.S. EPA 1980). In southern California, *P. ligni* is a commonly encountered species under marine or estuarine conditions, both as a bottom-dwelling adult and as a planktonic larva (Rice 1975, U.S. EPA 1980). Sexes are separate, although some hermaphroditism has been noted (Rice 1975). Females have the potential to produce up to 8 broods, and life span in the field is estimated to be 6-8 months by Zajac (1986) and 1-2 years by Anger et al. (1986). The average life span of laboratory specimens was 13 months (Zajac 1991).

The population dynamics of *P. ligni* exhibit distinct seasonal phases in response to disturbance (Zajac 1991). The spring and early summer growth period is followed by a late summer and early fall transition period and, finally, a late fall and winter maintenance period. While the mid-summer population increase of *P. ligni* appears to be predictable, the magnitude of density changes can vary. Zajac (1991) reports that peak abundance in 1982 was almost 3 times higher than in 1983.

When high rates of organic enrichment are maintained over time, polychaetes tend to persist, and are often dominant both with respect to biomass and numbers of individuals (Grassle and Grassle 1974, Reish and Fauchald 1977, Reish 1979). A preference for high concentrations of organic matter, rather than tolerance to hypoxia/anoxia and hydrogen sulfide is thought to explain this. Tsutsumi (1990) suggests that the association of *Capitella* spp. with organically enriched areas in Japan indicates a 'physiological requirement' for highly organic food. He reached this conclusion by demonstrating that a very high sedimentary protein content was required for the presence of reproductively functional females.

Studies by Levin (1986), Grémare et al. (1988) and Sardá et al. (1996) indicate that food quality, particularly the elevated nitrogen content found in areas undergoing eutrophication, may regulate polychaete growth and reproduction. Food nitrogen content was highly correlated with both fecundities and reproductive output in *Capitella* (Grémare et al. 1988). *Polydora ligni* and *Streblospio benedicti* populations responded to nutrient and sewage enrichment by increasing dramatically (Levin 1986). Finally, experimental nitrogen fertilization stimulated high densities of *C. capitata*, *P. ligni*, and *S. benedicti* in a New England salt marsh (Sardá et al. 1996).

Numerous studies report a correlation between opportunistic polychaete abundance and mass blooms of macroalgae of the genera *Ulva*, *Enteromorpha*, *Chaetomorpha*, *Cladophora*, and *Gracilaria* (Nicholls et al. 1981, Soulsby et al. 1982, Reise 1983, Thrush 1986, Reise et al. 1989, Tsutsumi 1990, Raffaelli et al. 1991, Desprez et al. 1992, Pardal et al. 1993, Bridges et al. 1994, Everett 1994, Ahern et al. 1995, Flindt et al. 1997). Algal decomposition frequently leads to anoxia and high levels of hydrogen sulfide in the sediments below, and these polychaetes are among the few invertebrates that thrive under such harsh conditions. They are also able to take advantage of the increased food available in and under macroalgal mats (Hull 1987). *Capitella capitata* reportedly feeds on *Ulva* detritus and is capable of deriving a major portion of its nitrogen intake directly from the macroalgae (Everett 1994).

Previous researchers commonly assumed tolerance to be the most widely adopted strategy to pollution stress by macrobenthic communities (*see* Grassle and Grassle 1974 for refs). However, recent work indicates that mere tolerance to severe environmental conditions is a relatively uncommon adaptive strategy; the species that respond rapidly to organic enrichment are not unusually tolerant of hypoxia/anoxia or hydrogen sulfide (Gray 1979, Forbes et al. 1994). Rather, life history characteristics of these opportunists are probably more important than the range of tolerance of the average individual.

Reduced oxygen supply is perhaps the most serious consequence of organic pollution on aquatic life (Pearson and Rosenberg 1978). Most species of the marine macrobenthic infauna belong to the taxonomic groups polychaetes, molluscs, echinoderms, and crustaceans. Studies show that these groups exhibit different levels of tolerance to hypoxia. According to Diaz and Rosenberg (1995), polychaetes are the most tolerant taxa, followed by bivalves and crustaceans. However, Hagerman et al. (1996) report that bivalves generally have the highest tolerances to low dissolved oxygen levels, followed by polychaetes and crustaceans.

Whatever the case, polychaetes are certainly affected by low oxygen levels. Despite being tolerant of hypoxia for 14 days under experimental laboratory conditions, short periods of anoxia are known to eliminate entire populations of *Streblospio benedicti* (Llansó 1991). Additionally, no species of polychaetes were found in water having levels less than 0.3 mg/L by Crippen and Reish (1969), and a suppression of the number of polychaete species was noted when the dissolved oxygen content fell below 1.0 mg/L

Adaptations used by opportunistic polychaetes to survive under hypoxia/anoxia include a reduction in activity to decrease oxygen consumption (Llansó 1991), and switching from aerobic to anaerobic metabolism (Warren 1984, Diaz and Rosenberg 1995).

In organically enriched communities, relatively high levels of toxic hydrogen sulfide (H_2S) accumulate in the sediment as a result of the activities of certain anaerobic bacteria (Tsutsumi 1990). Hydrogen sulfide is lethal to most invertebrates and fish when present at levels of the order of parts per million (U.S. EPA 1980). However, Cuomo (1985) showed that sulfides promote the larval settlement of *Capitella*, and that settlement is enhanced both in organically enriched sediment containing sulfides and sediment-free habitats containing sulfides. These results suggest that this species may prefer the environment that sulfides provide rather than simply favoring organically enriched sediment. Cuomo (1985) also demonstrated that *Capitella* are able to successfully reproduce in the presence of H_2S. This is advantageous because H_2S is usually indicative of anaerobic organic matter decomposition, reflecting the presence of available detritus for polychaetes. According to Jørgensen (1980), polychaetes living in H_2S-rich areas resist sulfide poisoning by pumping oxic respiratory water into their tubes. When the oxygen becomes depleted, they usually creep out of their tubes and are found lying on the mud surface, limp and motionless but often still alive. High resistance to H_2S often parallels that to hypoxia/anoxia (Shumway and Scott 1983). This is not surprising as the two conditions frequently occur simultaneously (Hagerman et al. 1996).

Low salinities appear to limit the distribution of opportunistic polychaetes in coastal estuaries. In San Diego, polychaetes of the genera *Polydora* and *Capitella* in Los Penasquitos Lagoon reportedly disappeared when salinities were under 10 ppt (Greenwald and Hurlbert 1993). In a Dutch estuary, heavy rainfall over a long period of time completely eliminated *C. capitata*, *Streblospio benedicti*, and *P. muchalis* populations (Reish 1979).

Studies also show opportunistic polychaetes to be sensitive of elevated salinities. In Los Penasquitos Lagoon, *Polydora* and *Capitella* disappeared when salinities were over 40 ppt (Greenwald and Hurlbert 1993), while Pearson and Rosenberg (1978) showed *P. ciliata* was only dominant in salinities ≤ 33 ppt.

P. nuchalis is apparently able to tolerate a wide range of salinity (Woodwick 1953; *see* Manion and Dillingham 1989 for ref), while the preferred range for *P. ciliata* is reported to be 13-24 ppt (Pearson and Rosenberg 1978).

Wible (1984) found that *P. nuchalis*, which has lecithotrophic development, produced larger eggs at colder temperatures. He also found that increasing temperature (from 15°C to 25°C) significantly increased survivorship, growth rates and percentage reproduction of *P. nuchalis*.

Effects of temperature can by confounded in field studies by simultaneous changes in several parameters. For example, Greenwald and Hurlbert (1993, p. 307) report that temperature increased with increasing salinity, pH and dissoved oxygen decreased with increasing salinity.

3.2.4. *Biological Water Quality Objectives*

The principal goal behind the summary of physical tolerances of the target species is to establish biological water quality objectives that are protective of the Malibu Lagoon community. The physical tolerances are summarized in Table 3-2, and potential water quality objectives can be derived by scanning the values in this table. This task is complicated by the fact that different species, even desirable species, have quite different tolerances. More importantly, there is little information about the tolerances of most of the target species to the physical conditions of concern. Nonetheless, we have made some initial suggestions, organized by the major physical categories.

3.2.4.1. Salinity

Virtually all of the estuarine species tolerate very low salinities, since the normal seasonal cycle of souther California estuaries includes periods of very low salinity during periods of high rainfall runoff.

Where upper limits to salinity have been determined, they are typically higher than usually occur in Malibu Lagoon, greater than 40 or 50 ppt. However, a number of the species, such as tidewater gobies, prefer much lower salinities, 10-15 ppt. To protect these species, at least some low-salinity habitats must be available. With the tidewater goby, this typically occurs at the upper end of the lagoon, where freshwater enters the estuary.

3.2.4.2. Temperature

Malibu Lagoon's temperature does not differ from normal ambient temperatures, and so is within the tolerable range of most of the target species.

Temperature is a particular concern for steelhead trout. During spawning and incubation, temperatures should not exceed 15°C. At other times, temperatures should not exceed 26-28°C.

3.2.4.3. Ammonia

There is little information about the tolerated limits to ammonia in the target species. The recommended upper limit for steelhead is 0.45 mg/L of unionized ammonia.

3.2.4.4. pH

There is little information about the tolerated limits to pH in the target species. The best range for steelhead in 7-8, although they can tolerate pH as low as 4 and as high as 9.5. The range for tidewater gobies is 6.8-9.5.

3.2.4.5. Dissolved Oxygen

The minimal value of dissolved oxygen for most target species is 4 mg/L. Steelhead require a higher level, >7 mg/L.

3.2.4.6. Nitrate

There is little information about the tolerance of the target species to nitrate. Steelhead are reported to tolerate up to 1300 mg/L.

A recent report by Marco et al. (1999) indicates that amphibians can be susceptible to quite low levels of nitrate and nitrite (see below).

3.2.4.7. Nitrite

There is little information about the tolerance of the target species to nitrite. Steelhead can tolerate up to 0.39 mg/L, although <0.15 mg/L is best.

A recent report by Marco et al. (1999) indicates that amphibians are susceptible to quite low levels of nitrate and nitrite. Levels of nitrite below the drinking water standard killed over half of the Oregon spotted frog tadpoles after 15 days of exposure. Four other species tolerated higher levels, but still experienced 50% mortality at nitrite levels well below those that the US EPA considers safe for warmwater fishes.

The Marco et al. (1999) study was conducted with amphibians, which are not indicators we chose for Malibu Creek. However, the fact that very little information was available for nitrate and nitrite tolerances suggests that nitrates and nitrites might be more critical water quality factors than previously appreciated.

3.2.4.8. Sulfide

There is little information about the tolerance of the target species to sulfide. Steelhead may be able to tolerate up to 0.4 µg/L, although the EPA recommended limit of ≤ 2 µg/L would be more protective.

3.3. Habitat Association Analysis

3.3.1. Introduction

This analysis was conducted to identify the habitat associations of critical or "indicator species" in the lower Malibu Creek watershed (Table 3-4). Critical habitat characteristics, such as influences of season, diel and tidal cycles, and substrate type, are summarized for each indicator species in Table 3-5. Finally, associated threats to these species and their habitats are outlined in Table 3-6.

Although the summary of habitat associations for indicator species provided in this chapter could be useful for assessing the appropriateness of existing habitat or for planning habitat restoration projects, it is important to recognize the limited focus of this approach. Although some species can be considered "umbrella" species because their habitat needs coincide with the needs of many other species, this is often not the case, and none of the indicator species included here should be viewed as umbrella species. Information on the habitat associations of these indicator species should be considered in planning assessment or restoration activities, but they should not be given undue weight. In particular, habitat restoration should focus on overall system function rather than the presence of a particular species.

3.3.2. Methods

The issues surrounding the choice of indicator species have been discussed in Section 3.2.2. For this analysis, we included the two invertebrate species and nine fish species selected as "positive indicators" in that Section. However, for this analysis we expanded the list of indicator species beyond the aquatic species discussed in Section 3.2 to include non-aquatic species, specifically sensitive reptiles (2 species), birds (5 species) and plants (2 species). Not all of these species currently occur in the Malibu Creek watershed or Malibu Lagoon (and we did not attempt to survey the habitat for them). If species are not known to currently occur in this system, they were included because they were thought to have occurred there historically, or could potentially occur there. Categories of protected species included: Federally endangered and threatened species; Federally proposed critical habitat; Federal candidates for listing by the U.S. Fish and Wildlife Service; State endangered and threatened species; and State species of special concern (Table 3-4). In addition to the nine fish species discussed previously, the Santa Ana sucker (*Catostomus santaanae*) and the unarmed threespine stickleback (*Gasterosteus aculeatus williamsoni*) were included in this inventory because they may have once been found in Malibu Creek. In 1975, an unsuccessful attempt was made to transplant the threespine stickleback to Malibu Creek (Swift et al. 1993).

Habitats in which indicator species are found included lagoon/subtidal, intertidal mudflat, salt marsh, stream, riparian, and sandy beach and islands. Many of the indicator species inhabit several of these habitat types.

3.3.3. Results

Besides the general information provided in Tables 3-4, 3-5 and 3-6, relevant habitat association information was found only for the following species:

3.3.3.1. Eucyclogobius newberryi

Compared to the invertebrates, relatively abundant data on habitat association is available for the tidewater goby *Eucyclogobius newberryi*. According to Swenson (1995), tidewater gobies are found in a variety of habitats, including sandy lagoons, mud or gravel sections of streams, and muddy marsh pools and channels. Adults seem to prefer vegetated areas, which provide both cover from predators and habitat for crustacean prey. During the time gobies are reproductively active, they may require the presence of coarse sand, in which males excavate burrows (Lafferty et al. 1996).

Tidewater goby populations may be negatively affected by the artificial breaching of the sand and cobble berms found at the mouths of California lagoons (Capelli 1997). Artificial breaching can carry gobies into the ocean or strand them in shallow pools, increasing their vulnerability to predation. Stranding of tidewater gobies has been observed at Malibu Lagoon after an artificial breach (Manion and Ambrose, unpublished data). Artificial breaching may also adversely affect reproduction and rearing, reduce dissolved oxygen concentrations to lethal levels, and decrease the abundance of non-marine invertebrates which provide the primary food source for tidewater gobies.

3.3.3.2. Oncorhynchus mykiss

With regard to the steelhead trout *Oncorhynchus mykiss*, research suggests that plant canopy cover may play an important role in maintaining stream temperatures favorable to this species. A recent study concluded that decreases in canopy cover along the banks of a desert stream resulted in significant declines in densities of native trout (Tait et al. 1994). Densities of northern rainbow trout populations have been positively correlated with stream temperature (Hawkins et al. 1983, Murphy et al. 1981). Vegetation cover may play an even more important role in streams at the southern end of the species range, where higher streams temperatures are common (Carpanzano 1996). Removal of streamside vegetation may negatively affect steelhead trout populations in Malibu Creek and Malibu Lagoon, and should therefore be avoided.

Other steam characteristics also favor steelhead. Instream cover such as logs, rocks, and aquatic vegetation provides protection from predators and areas of decreased flow where steelhead can rest (Carpanzano 1996). Moyle and Baltz (1985) report that juveniles and adults favored deeper parts of streams, while shallower parts were favored by young-of-year rainbow trout. They also found that preferences for higher mean water column velocities increased with size of rainbow trout. In areas where stream temperatures reach lethal levels (> 28°C), thermally stratified pools provide refuge habitat for many young-of year, yearling, and adult steelhead in Northern California (Nielsen et al. 1994). Finally, juvenile steelhead are usually found in microhabitats such as pools, gravel riffles and runs, rocky turbulent stretches and plunge pools in white water torrent areas (Hartman and Gill 1968).

3.3.3.3. Palaemon macrodactylus

The oriental shrimp *Palaemon macrodactylus* is commonly found in Malibu Lagoon. In this literature search, no references were found regarding the habitat preferences of this species. However, two studies provide data for *P. adspersus*, a European species (Isaksson and Pihl 1992, Pihl et al. 1995). They show that this species is favored by a moderate increase in opportunistic filamentous macroalgae, but negatively affected by a further cover of algae. *Palaemon adspersus* probably favors this habitat because food items eaten by this species, including amphipods and copepods, live there.

3.3.3.4. Polydora nuchalis

No habitat association information is available for the polychaete worm *Polydora nuchalis* either. Again, data on a related species, *P. ligni*, will have to suffice. According to Dauer et al. (1981), *P. ligni* prefers sediment composed of at least 90% silt-clay and is generally found in mud or sand tubes in the upper few cm of sediment.

3.4. Discussion

The most common threats to indicator species in the lower Malibu Creek watershed are loss and degradation of habitat, hydrological alterations, invasion by competitors and predators, eutrophication, and erosion. Losses of habitat due to development cause species abundance to decline, leading to an associated decrease in reproductive success for many species. Hydrologic alterations, such as lagoon breaching and artificial bank stabilization, may affect critical habitat characteristics of tidal cycle and breeding habitat availability for selected species (discussed in Chapter 7). In addition, timing of lagoon breaching may be crucial to reproduction or survival of many juvenile fish. Invasion of critical habitat by humans and animal predators threatens survival and reproduction of many animal indicator species (Table 3-6). Erosion in the watershed impacts critical spawning ground habitat for several of the fish species. Causes of erosion in the lower Malibu watershed include development, loss of native, stabilizing riparian vegetation, large animal use of riparian zone, and road construction/improvements.

An initial goal of this task was to try to develop water quality objectives that would support indicator species in Malibu Creek and Malibu Lagoon. If such water quality objectives could be developed, the objectives could be compared to local enviromental conditions to determine whether the local conditions are suitable or need to be improved to support viable populations of indicator species. The development of comprehensive water quality objectives is not possible at this time, however, because the physical tolerances of the indicator species have not been evaluated for most parameters of interest. For example, except for steelhead, no information could be found on tolerances of the indicator species to ammonia, nitrate or nitrite, so it is not possible to establish a limit for these substances to protect living resources in the Lagoon or Creek.

Some general observations can be made, however. Because estuaries naturally experience extreme variations in salinity as salt water mixes with fresh water, the estuarine species generally tolerate a wide range of salinities. However, the tidewater goby prefers lower salinity, 10-15 ppt, and so provision of at least some areas of lower salinity (such as the upper end of the estuary, where the Creek empties into the Lagoon) is important for managing this species. Because Malibu Lagoon currently has a higher freshwater inflow than occurred in the pristine system, salinity conditions are very suitable for the tidewater goby. On the other hand, some estuarine invertebrates (exemplified by the jackknife clam) cannot tolerate extended periods of low salinity. The lowered salinity (or, more likely, the alterred temporal pattern of low salinity) may limit jackknife clam and other invertebrate species in Malibu Lagoon. Low salinity also favors mosquitofish, a negative indicator that is very abundant at Malibu Lagoon.

Probably the most important water quality limitation in Malibu Lagoon is the dissolved oxygen (DO) concentration. Species such as topsmelt have been shown to be intolerant of low DO, but a DO level of >4 mg/L is generally recognized as necessary for most species. Some species, such as the negative indicator *Polydora nuchalis*, tolerate low DO, but the positive indicator species apparently cannot. There is no extensive monitoring record of DO in Malibu Lagoon. However, Ambrose et al. (1995) report periods of low DO in association with algal mats in the Lagoon. Heavy algal cover and the consequent low DO have been associated with fish kills in some systems. However, we have no well-documented records of extensive fish kills in Malibu Lagoon. During the Ambrose et al. (1995) study, fish in traps on the bottom of the Lagoon were killed during low-DO episodes, but widespread fish kills were not observed.

As noted above, there is no information about the tolerances of the Lagoon indicator species to ammonia, nitrate or nitrite, so no water quality objectives can be determined on the basis of direct impacts to the indicator species. However, the recent study by Marco et al. (1999) suggests that nitrate and nitrite may have direct effects on aquatic organisms at fairly low levels. Furthermore, these nitrogenous compounds may have an important indirect effect through their enhancement of algal growth. Excessive algal growth indicative of eutrophication can result in low DO conditions that are known to impact the indicator species. The conditions leading to eutrophication are complex, however (see Chapter 5).

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Table 3-1. Indicator species for Malibu Creek watershed and Malibu Lagoon.

Common name	Scientific name	Comments
Positive indicators		
Tidewater goby	*Eucyclogobius newberryi*	Federally listed endangered species Common native estuarine species
Steelhead	*Oncorhynchus mykiss*	Federally listed endangered species
California killifish	*Fundulus parvipinnis*	Very common, native estuarine species
Topsmelt	*Antherinops affinis*	Common estuarine and marine species
Arrow goby	*Clevlandia ios*	Benthic estuarine species with marine larvae
Staghorn sculpin	*Leptocottus armatus*	Benthic estuarine/marine species
Diamond turbot	*Hypsopsetta guttulata*	Benthic species using estuaries as a nursery
Longjaw mudsucker	*Gillichthys mirabilis*	Benthic estuarine species
Opaleye	*Girella nigricans*	Marine species using estuaries as a nursery
Jacknife clam	*Tagelus californicus*	Only common clam in Malibu Lagoon
Mud-flat crab	*Hemigrapsus oregonensis*	Native estuarine species
Negative indicators		
Western Mosquitofish	*Gambusia affinis*	Very common; introduced for mosquito control
Yellowfin goby	*Acanthogobius flavimanus*	Introduced species with potentially serious impact on native species; not currently found in Malibu Lagoon
Oriental shrimp	*Palaemon macrodactylus*	Introduced species
Polycheate worm	*Polydora nuchalis*	Native opportunistic species

Table 3-2. Physical tolerances of indicator species.

Species	Salinity	Temperature	Ammonia	pH	Dissolved Oxygen	Nitrate	Nitrite	Sulfide	# References
Positive indicators									
Eucyclogobius newberryi (tidewater goby)	0-53 ppt prefers 10-15 ppt	8-25°C prefers 18-22°C		6.8-9.5	4-19 mg/L				**13**
Oncorhynchus mykiss (steelhead trout)	0-20 ppt in streams	0-28°C prefers 13-21°C	upper limit is UIA concentration of 0.45 mg/L	4-9.5 best is 7-8	>7mg/L at temps ≤ 15°C >9mg/L at temps >15°C as low as 3.75	up to 1300mg/L	up to 0.39mg/L <0.15mg/L is best	up to 0.4 microM at 20°C	**71**
Fundulus parvipinnis (killifish)	0-128ppt	16.6-40°C prefers 16.6-28.5°C						up to 300 microM	**10**
Antherinops affinis (topsmelt)	2-82 ppt	8-33°C prefers 25°C			intolerant of low DO				**9**
Clevlandia ios (arrow goby)									**3**
Leptocottus armatus (staghorn sculpin)	0-53 ppt								**7**
Girella nigricans (opaleye)		up to 31.4°C prefers 26-28.2°C							**2**

Table 3-2. Physical tolerances of indicator species (cont.)

Species	Salinity	Temperature	Ammonia	pH	Dissolved Oxygen	Nitrate	Nitrite	Sulfide	# References
Gillichthys mirabilis (longjaw mudsucker)		prefers 22°C							**2**
Tagelus californicus (jacknife clam)	lower limit is 3-10% seawater								**4**
Hemigrapsus oregonensis (yellow shore crab)	2-62 ppt	10-27.5°C prefers warm water							**3**
Negative indicators									
Gambusia affinis (mosquitofish)	0-50 ppt	38°C is upper limit prefers 28-31°C							**10**
Acanthogobius flavimanus (yellowfin goby)	0 ppt to >35 ppt	upper limit ~28°C							**2**
Palaemon macrodactylus (oriental shrimp)	normal to dilute seawater	10.5-27.5°C							**2**
Polydora nuchalis (polychaete)	10-40 ppt	wide range tolerated			needs > 0.3 mg/L				**3**

Table 3-3. Tolerance of key invertebrate species.

Species	**Tolerant**	**Intolerant**	**Salinity**	**Temperature**	**pH**	**Dissolved Oxygen**	**Feeding Ecology**
Tagelus californianus (jacknife clam)		X	intolerant of low salinities (3-10% seawater)				
Palaemon macrodactylus (oriental shrimp)	X		can tolerate normal or dilute seawater	14-26 C			
Hemigrapsus oregonensis (yellow shore crab)	X		up to 175% seawater (60-62 ppt)				
Polydora nuchalis	X		10-40 ppt				

Table 3-4. Presence of indicator species and their status in habitat types of the lower Malibu Creek watershed.

Indicator Species	Status	Lagoon/ Subtidal	Intertidal Mudflat	Salt Marsh	Stream	Riparian	Sandy Beach & Islands
Invertebrates							
California jacknife clam (*Tagelus californicus*)			X				
yellow shore or mud-flat crab (*Hemigrapsus oregonensis*)			X	X			
Fish							
arrow goby (*Clevlandia ios*)		X	X				
California killifish (*Fundulus parvipinnis*)		X	X	X			
diamond turbot (*Hypsopsetta guttulata*)		X	X				
longjaw mudsucker (*Gillichthys mirabilis*)		X	X				
opaleye (*Girella nigricans*)		X	X				
Santa Ana sucker (*Catostomus santaanae*)	C2, CSC				X		

Table 3-4. Presence of indicator species and their status in habitat types of the lower Malibu Creek watershed.

Indicator Species	Status	Lagoon/ Subtidal	Intertidal Mudflat	Salt Marsh	Stream	Riparian	Sandy Beach & Islands
staghorn sculpin (*Leptocottus armatus*)		X	X				
southern steelhead (*Oncorhynchus mykiss*)	FT	X			X		
tidewater goby (*Eucyclogobius newberryis*)	FE	X	X		X		
topsmelt (*Antherinops affinis*)		X	X				
unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*)	FE, PCH, SE				X		
<u>Reptiles</u>							
San Diego mount. king snake (*Lampropeltis zonata pulchra*)	C2, CSC					X	
Southwestern pond turtle (*Clemmys marmorata pallida*)	C1, CSC				X	X	X

Table 3-4. Presence of indicator species and their status in habitat types of the lower Malibu Creek watershed.

Indicator Species	Status	Lagoon/ Subtidal	Intertidal Mudflat	Salt Marsh	Stream	Riparian	Sandy Beach & Islands
Birds							
Brown pelican (*Pelecanus occidentalis*)	FE	X					X
California least tern (*Sterna antillarum browni*)	FE	X	X				X
Least Bell's vireo (*Vireo bellii pusillus*)	FE				X	X	
Light-footed clapper rail (*Rallus longirostris levipes*)	FE		X	X			
Western snowy plover (*Charadrius alexandrinus nivosus*)	FT, PCH			X (occasional nesting on salt flats)			X
Plants							
Gambel's water cress (*Rorippa gambelii*)	FE, ST			freshwater and brackish marshes		X	
Salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *maritimus*)	FE, SE			X			

Table 3-4. Presence of indicator species and their status in habitat types of the lower Malibu Creek watershed (continued).

Legend:

FE = Federally endangered
FT = Federally threatened
PCH = Federally proposed critical habitat
C1 = Category 1 candidate for listing by the U.S. Fish and Wildlife Service
C2 = Category 2 candidate for listing by the U.S. Fish and Wildlife Service
CSC = California Department of Fish and Game "species of special concern"
SE = State Endangered
ST = State Threatened

Table 3-5. Critical habitat characteristics for indicator species.

Indicator Species	Seasonal	Diel Cycle	Tidal Cycle	Substrate Type
<u>Invertebrates</u>				
California jacknife clam (*Tagelus californicus*)	- recruitment			- sandy
yellow shore or mud-flat crab (*Hemigrapsus oregonensis*)	- recruitment (May through August)	- feeds mainly at night	X	
<u>Fish</u>				
arrow goby (*Clevlandia ios*)	- annual species		- forage at high tide	- muddy and disturbance
California killifish (*Fundulus parvipinnis*)	- habitat/area shifts		- forage at high tide	
diamond turbot (*Hypsopsetta guttulata*)	- recruitment/ emigration (use lagoon as nursery)			
longjaw mudsucker (*Gillichthys mirabilis*)	- habitat/area shifts		- forage at high tide	- muddy
opaleye (*Girella nigricans*)	- recruitment/ emigration (used only as a nursery)			
Santa Ana sucker (*Catostomus santaanae*)				

Table 3-5. Critical habitat characteristics for indicator species (continued).

Indicator Species	Seasonal	Diel Cycle	Tidal Cycle	Substrate Type
Fish continued				
staghorn sculpin (*Leptocottus armatus*)	- recruit./ontogenetic habitat shift			
southern steelhead (*Oncorhynchus mykiss*)	- immigration/ development			
tidewater goby (*Eucyclogobius newberryis*)	- annual species - reproduction/ recruitment - seasonal breeding peaks			- gravel - sand or mud
topsmelt (*Antherinops affinis*)	- recruitment/ emigration (nursery and residents) - spawn in lower salinties in spring			
unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*)	- annual species			
Reptiles				
San Diego mount. king snake (*Lampropeltis zonata pulchra*)				
Southwestern pond turtle (*Clemmys marmorata pallida*)				- sandy shore required for laying eggs

Table 3-5. Critical habitat characteristics for indicator species (continued).

Indicator Species	Seasonal	Diel Cycle	Tidal Cycle	Substrate Type
<u>Birds</u>				
Brown pelican (*Pelecanus occidentalis*)	- lay eggs between December and July	- return to nesting colonies at night	- roosting	
California least tern (*Sterna antillarum browni*)	- only present during breeding season (April – September)		- foraging area	- light-colored sand or shells/small gravel for nesting
Least Bell's vireo (*Vireo bellii pusillus*)	- only present between mid-March and August			
Light-footed clapper rail (*Rallus longirostris levipes*)	- reproduction (mid-March to mid-August)		- influences habitat availability	
Western snowy plover (*Charadrius alexandrinus nivosus*)	- breeding from mi-March to September		- influences habitat availability	- sand for nesting
<u>Plants</u>				
Gambel's water cress (*Rorippa gambelii*)	- perennial species			
Salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *maritimus*)	- annual species		- inundation only at high tides	

Table 3-6. Threats to habitats of indicator species. X = known and potential threats to indicator species

Indicator Species	Eutrophication	Invasion	Hydrological Alterations	Other
<u>Invertebrates</u>				
California jacknife clam (*Tagelus californicus*)	**- low oxygen**		**- low salinity**	
yellow shore or mud-flat crab (*Hemigrapsus oregonensis*)		**- Green crab**		**- juveniles used for fishing bait**
<u>Fish</u>				
arrow goby (*Clevlandia ios*)	**- low oxygen**			
California killifish (*Fundulus parvipinnis*)				**- previously sold for bait**
diamond turbot (*Hypsopsetta guttulata*)	**- low oxygen**			
longjaw mudsucker (*Gillichthys mirabilis*)	**- low oxygen**			
opaleye (*Girella nigricans*)				**- used as bait in fresh and salt water**

Table 3-6. Threats to habitats of indicator species (continued).

Indicator Species	Eutrophication	Invasion	Hydrological Alterations	Other
Fish continued				
Santa Ana sucker (*Catostomus santaanae*)				- drought
staghorn sculpin (*Leptocottus armatus*)	- low oxygen			
southern steelhead (*Oncorhynchus mykiss*)	- low oxygen		X	- Siltation of streambed spawning grounds - coastal development (i.e., dams and water diversion)
tidewater goby (*Eucyclogobius newberryis*)	- low oxygen	yellowfin goby African clawed frog	X	- Siltation of spawning grounds - Barrier breaching
topsmelt (*Antherinops affinis*)				
unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*)				- reengineering of urban creeks for flood control - increased stream velocity - reduc. in streambed vegetation - occurrence of large oil seeps - interbreeding

Table 3-6. Threats to habitats of indicator species (continued).

Indicator Species	Eutrophication	Invasion	Hydrological Alterations	Other
Reptiles				
San Diego mountain king snake (*Lampropeltis zonata pulchra*)				
Southwestern pond turtle (*Clemmys marmorata pallida*)				- loss of habitat (especially sandy shore for reproduction)
Birds				
Brown pelican (*Pelecanus occidentalis*)				- high DDT and pesticide concentrations (resulting in eggshell thinning) - human and predatory animal disturbance of breeding colonies - decline in northern anchovy populations for chicks
California least tern (*Sterna antillarum browni*)		- vulnerable to predation	- fluctuating water levels flood the nesting sites	- development of beach nesting areas (expansive stretches of shoreline needed) - declines in food supply (i.e., during El Nino)

Table 3-6. Threats to habitats of indicator species (continued).

Indicator Species	Eutrophication	Invasion	Hydrological Alterations	Other
Birds continued				
Least Bell's vireo (*Vireo bellii pusillus*)		- *Arundo donax*		- parasitism by brown-headed cowbird - loss of riparian habitat (especially vegetation removal and flood control levee construction)
Light-footed clapper rail (*Rallus longirostris levipes*)		- non-native red fox predation	- *Spartina* needs tidal flushing	- loss and degradation of salt marsh habitat (especially *Spartina foliosa* used for nesting)
Western snowy plover (*Charadrius alexandrinus nivosus*)				- development and human disturbance of beach nesting sites
Plants				
Gambel's water cress (*Rorippa gambelii*)		- *Arrundo donax*	- requires a permanent water source (fluctuating water levels from adjacent agricultural activities)	- loss of suitable wetland habitat - encroachement of unsecure sand (caused by off-road vehicle use)

Table 3-6. Threats to habitats of indicator species (continued).

Indicator Species	Eutrophication	Invasion	Hydrological Alterations	Other
Plants continued				
Salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *maritimus*)			X	**- development and alteration of salt marsh habitat**