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BIG LAGOON WETLAND AND CREEK RESTORATION PROJECT, MUIR BEACH, CALIFORNIA PART I. SITE ANALYSIS REPORT

Prepared for

The National Park Service

Prepared by

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with

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List of Acronyms

ACOE	U.S. Army Corps of Engineers
CDFG	California Department of Fish Game
CDIP	California Data Information Program
cfs	Cubic feet per second
CNDDBB	California Natural Diversity Database
CTMP	Comprehensive Transportation Management Plan
DHS	Department of Health Services
DO	dissolved oxygen
EA	Environmental Assessment
EIR/EIS	Environmental Impact Report/Environmental Impact Statement
ESU	Evolutionary Significant Unit
GGNRA	Golden Gate National Recreation Area
JNRA	John Northmore Roberts and Associates
LWD	Large woody debris
MBCSD	Muir Beach Community Services District
MWWD	Marin Municipal Water District
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
PET	Potential Evapotranspiration
PRBO	Point Reyes Bird Observatory
PWA	Philip Williams & Associates, Ltd.
RHJV	Riparian Habitat Joint Venture
USCS	United States Coast Survey
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Services
USGS	United States Geological Survey

1. INTRODUCTION

The National Park Service (NPS) is leading the development of conceptual restoration design alternatives for the project site known as Big Lagoon. The Big Lagoon site includes the wetlands, floodplain, and lagoon at the mouth of Redwood Creek at Muir Beach, Marin County, California as shown on Figures 1 through 3. Big Lagoon and lower Redwood Creek have undergone significant physical and ecological changes over the last 150 years due to accelerated sedimentation from watershed disturbances, channelization and diking of the lower creek to create grazing pastures, and hydraulic constraints from the Muir Beach parking lot and Pacific Way. NPS has retained Philip Williams and Associates, Ltd. (PWA) to develop and evaluate restoration alternatives with the assistance of subconsultants, Stillwater Sciences (Stillwater), John Northmore Roberts and Associates (JNRA), and the Point Reyes Bird Observatory (PRBO). Funding for this restoration analysis has been provided through the NPS Fee Demonstration Program and a California Department of Fish and Game Coastal Salmon Recovery Fund grant.

NPS has identified the following goals for the Big Lagoon Wetland and Creek restoration project:

- Restore a functional, self-sustaining ecosystem, including wetland, aquatic and riparian components.
- Develop a restoration design that: (1) functions in the context of the watershed and other pertinent regional boundaries, and (2) identifies and, to the extent possible, mitigates factors that reduce the site's full restoration potential.
- Consistent with restoring a functional ecosystem, recreate habitat adequate to support sustainable populations of special status species.
- Reduce flooding on Pacific Way and in the Muir Beach community caused by human modifications to the ecosystem, and work with Marin County to ensure that vehicle access is provided to the Muir Beach community.
- Provide a visitor experience, public access, links to key locations, and resource interpretation that are compatible with the ecosystem restoration and historic preservation.
- Work with the Federated Indians of Graton Rancheria to incorporate cultural values and indigenous archeological sites resources into the restoration design, visitor experience and site stewardship.
- Provide opportunities for public education and community-based restoration, including engaging local and broader communities in restoration planning and site stewardship.
- Coordinate with the Comprehensive Transportation Management Plan (CTMP) to identify transportation alternatives that are consistent with ecosystem restoration.

The restoration conceptual design and evaluation will be presented in two report volumes. This report constitutes Part I, the Site Analysis Report, which describes historical and existing physical, ecological, visitor use, and cultural characteristics of the Big Lagoon project site. In Part II, the Feasibility Analysis Report, the conceptual restoration designs will be described and evaluated.

The site analysis report accomplishes the following tasks:

- Develops a conceptual model that describes how Big Lagoon functioned physically and ecologically before disturbance from European colonization;
- Describes watershed changes and other factors that led to the site's current condition; and
- Describes existing conditions at the site at a level appropriate for input into the Environmental Impact Report/Environmental Impact Statement (EIR/EIS) to be completed by NPS and Marin County.

This report builds on previous work completed by PWA *et al.* in 1994 on the Preliminary Environmental Assessment (EA) of restoration design alternatives for Big Lagoon. PWA, working with NPS and other agencies, studied the potential for restoring the site to mitigate for the California Department of Transportation's repair of the Lone Tree Slide on Highway One near Stinson Beach. Since the 1994 Preliminary EA, the current project boundaries have been expanded to the northwest to include NPS property between Pacific Way and Highway 1, and southwest to encompass the parking lot and beach. Since the 1994 study, additional studies have been conducted at the site and in the watershed, including assessments of biological resources, watershed sediment budget, site archaeology, and channel morphological changes. A complete list of prior studies at the site and in the watershed is provided in Appendix K. This report incorporates findings from these recent studies to update the interpretations of the historical Big Lagoon and its current condition presented in the 1994 study.

The findings of this report will guide the development of design alternatives for the project site and assessment of design feasibility. With an understanding of the historical geomorphology and ecology of Big Lagoon and how the site has changed to its present form, a series of restoration design concepts, including the no action alternative, will be developed and their feasibility evaluated given the current condition of the watershed and other opportunities and constraints.

2. HISTORICAL (PRE-EUROAMERICAN) CONDITIONS

Conceptual modeling is the process of articulating simplified mental illustrations of the most critical cause and effect pathways in a system (CALFED, 2000). A conceptual model of the Big Lagoon Wetland and Creek Restoration site describes the key physical processes that shape the site and ultimately drive ecosystem processes. By articulating conceptual models, we can provide the rationale for projecting the evolution of the project site's morphology and ecology given significant changes to geomorphic processes affecting the site.

In this section, we present a conceptual model for the geomorphic and ecological evolution of the project site since the end of the last glacial period (about 18,000 years ago) to the end of pre-Euroamerican period, designated for the purposes of this study as 1817, when significant landscape changes were initiated by grazing in the Redwood Creek watershed by European settlers. Our interpretations of pre-Euroamerican conditions are based on the only direct evidence of pre-Euroamerican times—soil cores by Wells (1994) and Meyer (2003) that capture soil stratigraphy for the past 3,500 years and a U.S. Coast Survey (USCS) map of the site from 1853. The pre-Euroamerican conceptual model is depicted schematically in Figure 4 with brief descriptions of the dominant geomorphic processes.

In Sections 4 and 5 of this report, we present conceptual models of present and future conditions of the project site.

2.1 PHYSICAL LANDSCAPE & PROCESSES

At the end of the last glacial period (about 18,000 years ago), sea level reached a minimum elevation of about 320 feet below present, and the shoreline was located along the continental shelf approximately 50 miles seaward of its current location. During this sea level low stand, the entire continental shelf was exposed and functioned as low gradient, sandy coastal plain. At this time, Redwood Creek likely flowed through an entrenched river valley that included the Big Lagoon area. With the end of the Pleistocene glaciation, sea level rose rapidly between 18,000 and 6,000 years ago, flooding the mouths of coastal streams and forming bays at the ends of the stream valleys. As rates of sea level rise stabilized around 5,000 or 6,000 years ago to rates similar to today (about 0.3 - 0.5 ft/100 yrs), wave action and littoral processes built up sand spits and beaches, blocking off the seaward end of the bays to form lagoons (Wahrhaftig, 1994).

The shoreline at the project site was approximately 1,500 feet seaward of its present position when sea level rise stabilized and has been migrating landward at a rate of 20 ft/100yrs, based on nearshore bathymetry and sea level rise (Bruun, 1988). Soil cores suggest that Big Lagoon has resembled the lagoon morphology depicted on the USCS 1853 map—a large open-water lagoon with fringing wetlands—for the past 5,000 years, although its geometry, size, and salinity have undoubtedly varied and the beach and lagoon have migrated landward over this time period (Figure 4). Thus, for the past 5,000 years, Big Lagoon's morphology and habitats have been principally controlled by the rate of sea level rise, which acted to inundate and increase lagoon area (and set the shoreline position), and the rate of sediment deposition that works to fill and decrease lagoon size. Secondary controls on the size and shape of Big Lagoon and the habitats present were (1) watershed hydrology, which determined the volume of freshwater routed to the lagoon and timing and frequency of lagoon opening and closure, and (2) coastal processes, which also dictated the timing and frequency of lagoon opening and closure, degree of tidal influence, frequency and extent of wave overwash, and lagoon salinity.

The configuration shown on the 1853 map is most likely that of a seasonally brackish lagoon (dominately freshwater in winter and spring but brackish in summer and fall) impounded behind a large dune field located near the current parking lot and picnic area. The seasonally brackish lagoon discharged through a channel that flowed through the southeast end of the dunes and into a smaller intermittently tidal lagoon. Based on the timing of the coastal surveys, the 1853 map probably depicts conditions during the rainy season between December and March (PWA *et al.*, 1994). The map (Figure 4) shows about 12 acres of open water and 13 acres of fringe wetlands in the area currently occupied by the Muir Beach parking lot, Green Gulch pasture, and riparian willows (refer to Figure 3). Redwood Creek was bordered by a meandering natural levee and entered the lagoon east of its current location, at the low point of the valley. To demonstrate the function of the lagoon, an annual hydrologic cycle is described below.

High flow events in Redwood Creek during winter storms scoured a channel through the dunes along the back beach to the ocean, flushing out saline water and creating a flooded freshwater system. These winter high flows were also responsible for transporting most of the annual sediment delivered to the lagoon. During the spring, flows in Redwood Creek would subside, and the ponded areas within the lagoon would contract. Sand transported by the prevailing winds and occasional storm surges would begin to fill the lagoon outlet channel, depositing material at the apex of frequent inundation, just above mean higher high water. This deposition would result in a hydraulic control for Big Lagoon at an elevation of about +3 feet NGVD (just above mean higher high water). Eventually, ponding would be limited to those areas below the outlet control elevation. Fringe wetlands in the lagoon would be fed by groundwater to survive the dry season. Because of the low control elevation at the seaward end of the lagoon, tidal flow would periodically enter into the lagoon, especially during storms coinciding with spring tides. By late spring and early summer, zones of brackish water would probably develop. As the high-energy wave conditions subsided over the spring, the beach berm would begin to build up, and by early to mid-summer, berm growth would close off the mouth of the tidal lagoon. The larger tidal prism of the pre-Euroamerican tidal lagoon would probably not have had a significant effect on the timing or frequency of lagoon opening and closure due to the high wave energy at the site. In the fall, lagoon water levels would have reached a minimum, and brackish conditions would remain until the return of the winter storms.

Sediment delivery to Big Lagoon during the pre-Euroamerican period was an order of magnitude lower than at present (Figure 5). Redwood Creek's watershed was undisturbed, native vegetation was intact, and surface erosion and runoff were lower than today. As sea level rose over the pre-Euroamerican period, lower Redwood Creek underwent valley alluviation, developing a mature alluvial valley through channel and floodplain deposition. The mainstem of Redwood Creek in Frank Valley therefore acted as a sediment sink. Figure 6 shows an idealized profile of Redwood Creek in the pre-Euroamerican period versus the channel profile as surveyed in 2003. In pre-Euroamerican times, the channel profile was parallel to the valley slope, decreasing abruptly where Redwood Creek entered Big Lagoon and remaining approximately flat to the ocean. Most of the bedload in transport would have been deposited at the mouth of the creek channel entering the lagoon, but the high winter flows would flush out much of the fine-grained suspended sediment to the ocean. Due to the undisturbed watershed and sediment trapping in Frank Valley, only 500 yd^3/yr of suspended sediment and 80 yd^3/yr of bedload were delivered to Big Lagoon on average annual basis (Stillwater, 2003). Assuming an area of the pre-Euroamerican lagoon as depicted in the 1853 USCS map and a trapping rate of 100% for bedload and 50% for suspended load, the rate of sediment deposition in Big Lagoon would have been approximately 0.8 ft/100yr. Depending on actual sediment trapping rates, sediment deposition in Big Lagoon would have slightly exceeded or been balanced by sea level rise (approximately 0.3 - 0.5 ft/100 yrs; Table 2-1). As a result, Big Lagoon has been a persistent geomorphic feature for at least 3,700 years, as suggested by radiocarbon dates obtained from the soil cores at the site (Meyer, 2003).

Table 2-1. Rates of Sea Level Rise in San Francisco Bay Area

Time Period	Rate (ft/100 yrs)	Rate (mm/yr)
3,500 BP to 1840 A.D.	0.3[1] – 0.5[2]	1.05[1] – 1.5[2]
1854 - 1905	0.4[3]	1.12[3]
1906 - 1999	0.7[3]	2.13[3]

[1] Meyer (2003)
[2] Atwater and Hedel (1976)
[3] Zervas (2001)

2.2 PRE-EUROAMERICAN ECOLOGY

This section describes the probable structure of the natural ecosystem in Big Lagoon in the pre-colonial period (prior to significant watershed and land use changes caused by European settlement). Records of floral and faunal occurrence and species abundances in these early years are sparse for the Big Lagoon Wetland and Creek Restoration site and Marin County in general. Most of this description is based on inferences the USCS 1853 map (Figure 4), which documents topography, water ponding patterns, and large vegetation patches, oral histories, and present-day vegetation and wildlife patterns along this and similar portions of the coast. The PWA *et al*. (1994) biological monitoring program was designed to document existing patterns, which might provide the greatest insight into historic ecology as well as realistic restoration options.

The seasonally brackish lagoon was mostly freshwater with occasional saltwater inflows from overwash events during winter storms; however, even episodic inputs of salt water can have profound impacts on wetland community structure, especially of plants (Zedler, 1984). The wetland habitats were probably surrounded by the same coastal scrub community that presently occurs along less disturbed coastal hills bordering Highway One. In addition to rich aquatic communities, the historic setting included overlapping wetland and upland assemblages of birds, mammals, reptiles, amphibians, and insects. The historic flora is described below for several major habitats within and around Big Lagoon: the riparian, seasonally brackish lagoon, tidal lagoon, and upland. Within each habitat type, plant communities follow the classification and nomenclature of CNDDB (2002), which is based on the series (= alliance) level classification described by Sawyer and Keeler-Wolf (1995) but is structured to be compatible with the earlier Holland (1986, 1990) system. All species are referred to by common and scientific names in the text, except for birds, which are referred to by common name only, using the accepted nomenclature of the American Ornithologists' Union (1983, 1985).

2.2.1 Riparian

The original riparian forest at upstream end of Big Lagoon, now referred to as the Alder Grove, was probably a Red Alder Riparian Forest (Red Alder Alliance, CNDDB 64.410.03). There were also likely patches of willow riparian scrub (CNDDB 63.100.00) in more disturbed portions of the riparian zone. On the 1853 map, riparian forest was illustrated only at the inland edge of Big Lagoon and was probably well developed along Redwood Creek from the lagoon edge to Muir Woods. The riparian forest may have been interspersed with or bordered by a coastal swale community including monkey flower (*Mimulus* spp.), sedges and related species (*Carex, Cyperus,* or *Eleocharis* spp.), rushes (*Juncus* spp.), miner's lettuce (*Claytonia perfoliata*), and lupine (*Lupinus* spp.). Heavy pulses of flooding, prolonged seasonal inundation, and occasional saltwater inflow to the freshwater lagoon favored low marshes and fringe wetlands.

2.2.2 Seasonally Brackish Lagoon

The historic habitat of Big Lagoon was dominated by a Coastal Brackish Marsh (52200) and/or the similar Coastal and Valley Freshwater Marsh (52400). Both habitats are comprised of emergent tules (*Scirpus* spp.), cattails (*Typha* spp.), and rushes (*Juncus* spp.). Vegetation in the open water lagoon was probably patchy as a result of variable water depth, river currents, and soil stability. Large, dense patches of tules, cattails, bur-reed (*Sparganium* spp.) and rushes should have been present as in many historic California wetlands. Small herbaceous pondweeds (*Potamogeton* spp.), aquatic buttercups (*Ranunculus* spp.), and smartweeds (*Polygonum* spp.) could have rooted in shallow water. Water fern (*Azolla filiculoides*) and duckweed (*Lemna* spp.) could have floated on the surface of quiet water.

At the edge of the open water, the marsh fringe probably harbored spike rushes (*Eleocharis macrostachya*), marsh pennywort (*Hydrocotyle rannunculoides*), and water parsley (*Oenanthe sarmentosa*), with water plantain (*Alisma plantago-aquatica*) in the wetter areas. Rushes, sedges (*Carex* spp.), silverweed (*Potentilla anserina*), and monkey flower probably dominated the borders of the permanent open water areas. The upper edge of the marsh was probably covered with willows (*Salix* spp.), which were transitional to the riparian forest. In similar extant habitats, strong flooding periodically scours willow thickets making canopy gaps for small stands of marsh baccharis (*Baccharis douglasii*).

2.2.3 Tidal Lagoon

The historic tidal lagoon occurred in the same general location as it does today. Most of the lagoon was covered with shallow, open water habitat, shifting seasonally from fresh water to brackish water. Northern Coastal Salt Marsh (52110) probably covered a very small area immediately north of the brackish lagoon. The physical environment was probably too dynamic for extensive salt marsh development due to storm waves, strong currents from creek flooding, and wind-blown sands. Well-developed pickleweed (*Salicornia* spp.) and cord grass (*Spartina* spp.) communities were probably not present here. Instead, the present complement of species likely dominated the historic salt marsh: silverweed, rushes, and small patches of pickleweed, salt grass, jaumea (*Jaumea* spp.), and alkali heath (*Frankenia salina*).

2.2.4 Upland: Beach Dunes and Hillsides

The sand dune plant community was probably a Coastal Foredune (CNDDB 21.020.00) or Native Dunegrass (CNDDB 41.260.00) Type, possibly grading shoreward into Central Dune Scrub (CNDDB 21.100.19) or Dune Lupine-Goldenbush Scrub (CNDDB 32.160.00). Intensive dune erosion by winter waves and floods probably kept the dune plant communities at an early successional state, much as they are today (although the lack of foot traffic would have improved conditions for plants).

The Coastal Foredune would have been vegetated by short-lived herbaceous species such as those currently present: beach-bur (*Ambrosia chamissonis*), beach sagewort (*Artemisia pycnocephala*), and beach saltbush (*Atriplex californica, A. leucophylla*). Before the dunes were grazed or trampled, they could have supported the once-widespread Native Dunegrass. This habitat, which is now rare, was dominated by dune bluegrass (*Poa confinis*) and American dune grass (*Leymus mollis*).

Historic dune and lowland communities probably graded into hillsides of Coyote Brush Scrub (CNDDB 32.060.00) and/or the intergrading California Sagebrush-Black Sage Scrub (CNDDB 32.110.00). These communities were comprised of numerous "soft chaparral species" including California sagebrush (*Artemsia californica*), black sage (*Salvia mellifera*), monkey flower (*Mimulus* spp.) and poison oak (*Toxicodendron diversilobum*). Occasional seeps or moist areas on the hillsides, could have supported low-growing perennial herbs, especially sedges and grasses.

2.2.5 Fish Communities

Historic fish species composition of Redwood Creek probably differed little from that observed today. As a coastal stream, Redwood Creek should have contained only fish species able to enter the watershed from the ocean. These species would have included steelhead (*Oncorhyncus mykiss*), coho salmon (*O. kisutch*), threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*) and coastrange sculpin (*C. aleuticus*); all of these species are still present. Riffle sculpin (*C. gulosus*) are also present in Redwood Creek, especially upstream near Muir Woods National Monument. Riffle sculpins normally are absent from small, isolated coastal streams, so they may have been introduced.

Prior to the filling and other modifications of the lagoon estuary at the mouth of Redwood Creek, the habitat conditions of Big Lagoon probably varied substantially seasonally and among years. In years when the lagoon closed late in summer or when summer streamflows were low, the summer lagoon probably remained brackish all summer. Although the system was probably shallow (< 6 feet), it may have been stratified and warm during the summer of dry years, providing marginal habitat for steelhead and coho. In years when the lagoon closed earlier or when summer streamflows were more abundant, the lagoon was probably deeper and was converted to freshwater by inflows; in those years the lagoon would have been cooler and provided good rearing conditions for juvenile steelhead, and possibly for salmon. The larger lagoon probably also provided habitat for tidewater goby (*Eucyclogobius newberryi*), which are not now present. Juvenile staghorn sculpin (*Leptocottus armatus*) and starry flounder (*Platichthys stellatus*), hatched in the ocean, may have reared in abundance in the summer lagoon. Other marine fishes, including shiner surf perch (*Cymatogaster aggregata*), topsmelt (*Atherinops affinis*), and Pacific herring (*Clupea harengus*), may have used the lagoon for feeding and spawning.

2.2.6 Other Wildlife

Most wildlife species historically present were associated with open water and emergent wetlands (i.e., freshwater lagoon) that dominated the historical Big Lagoon project area. Some riparian species were likely present, but the project site likely served as more of a corridor between the well-developed riparian areas further upstream in Redwood Creek and Green Gulch Creek. Salt marsh and dune fauna were probably present, but comprised a relatively insignificant part of the overall Big Lagoon ecosystem, reflecting the small size of these habitats.

2.2.6.1 Invertebrates

Aquatic insects, crustaceans, and other invertebrates were probably best developed in the large freshwater lagoon. Invertebrates in the historic riparian corridor were likely more diverse than the extant assemblages, primarily because the corridor was well vegetated and followed a natural path into the main lagoon, with year-round flow and much larger areas of standing water. Seasonally heavy rains and flooding would have also limited invertebrate numbers in the fast-moving sand-bedded stream more than in the expansive, quiet water marsh. The ponded areas of emergent wetlands that are present today (e.g., in Green Gulch pasture) contain more insect and crustacean individuals, taxonomic groups, and trophic levels than the channelized and dredged portions of Redwood Creek (see Existing Conditions). Stream production of aquatic invertebrates would have been greater upstream from the Big Lagoon project area in the gravel-bedded portion of Redwood Creek. The historic tidal lagoon probably harbored similar species of insects, crustaceans, and annelid worms to those present today. However, since the historic region of seasonal brackish inflow to the large freshwater lagoon was so much larger than today, the benthic and swimming fauna of the tidal lagoon was probably more widespread and abundant in the past. The elevated historical populations of insects and crustaceans likely supported many predators, particularly fish and amphibians.

2.2.6.2 Reptiles and Amphibians

Records from the Marin County museum and known habitat preferences suggest that the historic Big Lagoon harbored at least 10 species of amphibians and 12 species of reptiles (See Tables 4-5 and 4-6, respectively). Since reptiles are less dependent on wetland habitat than are amphibians, the historic Big Lagoon was probably not as important for most reptile species. Several species would likely have foraged or basked at the wetland and riparian edges, particularly near adjacent upland habitats, including the coast garter snake (*Thamnophis elegans terrestris*). The western pond turtle (*Clemys marmorata*) was probably common along the riparian corridors upstream of Big Lagoon.

Several special-status amphibian species, such as the yellow-legged frog (*Rana boyleii*), ensatina (*Ensatina escholtzi*) and California slender salamander (*Batrachoseps attenuatus*), prefer the persistent fresh water and substrates of riparian habitat, and therefore should have been most abundant further upstream in Redwood Creek. The large lagoon wetland likely served as an important migration and recruitment corridor between Green Gulch Creek and Redwood Creek. Ranid frogs (including red- and yellow-legged frogs) often occur in small groups or demes (Storm, 1960) dependent on movement between different habitat patches. The Big Lagoon corridor should have promoted interbreeding, aided restocking of naturally-disturbed habitat, and overall population resilience of riparian species.

The cattail and/or bulrush habitats within the historic Big Lagoon wetland likely provided suitable breeding sites for the California red-legged frog (*Rana aurora draytonii*), since freshwater or slightly brackish water (< 4-5 ppt) was probably present in the November–March breeding season (Hayes and Jennings, 1986; Jennings and Hayes, 1985). Pacific tree frogs (*Hyla regilla*) and California newts (*Taricha torosa*) could have also commonly bred in Big Lagoon during winter.

2.2.6.3 Birds

Bird assemblages were likely the most conspicuous fauna in the historic Big Lagoon. The large area of open water and the patch mosaic of emergent vegetation would have attracted many more breeding and wintering species and individuals than are present today. The large shallow pond likely provided foraging areas for piscivorous species such as osprey, belted kingfishers, great blue herons and pie-billed grebes. Aerial insectivores, including several swallow species and the black phoebe, should have been even more conspicuous than they are today because of the large ponded area.

Shallow water near marsh edges was likely heavily utilized by mallards, American coots, common moorhens, ruddy ducks, great and snowy egrets as well as green-backed and black-crowned night herons. Common snipes, soras, Virginia rails, American bitterns, marsh wrens, salt marsh common yellowthroats, song sparrows and flocks of tricolored and red-winged blackbirds are likely to have been common residents of the marsh edge and emergent vegetation. These species could have used the low wetlands or forested riparian areas for nesting (Shuford, 1993). Today, only red-winged blackbirds, mallards and to a lesser extent great blue herons and snowy egrets are common inhabitants of the wetland area (see Existing Conditions).

The species number and abundance of wintering and migrant waterfowl seen along coastal Marin County today (Shuford et al., 1989) probably represents a fraction of those which historically used Big Lagoon. The extensive shallow water portions of the pond and nearby edge vegetation should have supported large flocks of waterfowl such as American widgeons, buffleheads, northern pintails, northern shovelers, canvasbacks, redheads, common goldeneyes, gadwalls, green-winged, blue-winged and cinnamon teal. Of these, only American widgeons occur in significant numbers today.

Relatively few species of riparian birds likely lived in the historic Big Lagoon because most of the riparian habitat was further upstream along Redwood Creek. However, riparian habitat bordering the wetland probably provided preferred nesting habitat for some wetland-foraging species. For example, belted kingfishers could have nested in holes along stream banks, and tree swallows could have nested in riparian tree cavities adjacent to foraging areas over open water. Long-eared owls might have nested in vacant stick nests built by other species in trees offering dense cover. Transitional willow edges, stream banks, and nearby upland scrub and riparian forests could have provided nest sites for a great variety of birds foraging in the Big Lagoon region, such as yellow, orange-crowned, and Wilson's warblers.

The intermittent sand dune and beach habitat at the mouth of Big Lagoon probably provided a relatively small area for roosting and feeding by a variety of gulls, brown pelicans and shorebirds. The threatened snowy plover may have nested on the historic beach, however the relatively flat and dry areas within the dunes, the preferred nesting habitats, probably covered a very small area of the historic beach, as they do today. Muir Beach is also subjected to frequent wave disturbance washing over most of the low dunes and into the tidal lagoon. Other beaches to the north, such as Stinson Beach spit and Point Reyes Beach where snowy plover nests have been documented in recent years (Shuford, 1993), were probably always much more important breeding sites.

Known nesting and prey preferences of raptors (Shuford, 1993; Mansell, 1980) suggest they were common predators of rodent, bird and fish prey in the open lowland habitat of historic Big Lagoon. Short-eared owls and northern harriers nest on ground covered by marsh vegetation and feed on abundant small mammal populations. Black-shouldered kites, nesting in bushes and moderately-sized trees such as willows, also consume small mammals. Red-shouldered hawks could have foraged in the historic wetlands for a variety of prey, including amphibians, reptiles, small mammals and insects, returning to nest sites in adjacent mature forests. Peregrine falcons should have flourished on the abundant wetland bird prey and nested on adjacent seacliffs. Perhaps less often, Cooper's hawks, kestrels, red-tailed hawks, long-eared owls, great horned owls and turkey vultures would have foraged in the wetlands, joined occasionally by California condors (apparently last sighted at Mt. Tamalpais in the 1950's; Evans 1988).

2.2.6.4 Mammals

Two large mammals that are no longer present were likely to have historically used Big Lagoon and the immediate area. California grizzlies likely foraged on the beach, and Tule elk likely utilized the wetland habitat. Other smaller species, such as mountain beavers and otters, were likely present and used the riparian corridors. Bats relied directly on large flying insect populations from the lagoon. Numerous small mammals and their intermediate-sized predators occurred in the adjacent conifer and oak forest habitats and would have used the Big Lagoon wetlands and riparian forest to some extent. A list of likely mammal species present in the area under pristine conditions is given in Appendix H.

3. CHANGES FROM PRE-EUROAMERICAN PERIOD TO PRESENT

This section describes the various land use and physical changes that have occurred within the watershed since the pre-Euroamerican period, and their effect on site morphology and ecology.

3.1 LAND USE CHANGES

Over the past 200 years, land use in the Redwood Creek watershed has shifted from grazing and logging, to agriculture and residential development, and most recently to public park.

3.1.1 Pre-Euroamerican Period

In the pre-Euroamerican period, it is assumed that Big Lagoon and the Redwood Creek watershed were shaped primarily by natural processes with little human disturbances. However, available evidence suggests that Native Americans, the Coastal Miwok, were living on relatively stable alluvial and alluvial fan deposits adjacent to the Big Lagoon wetland, presumably to take advantage of the various resources offered at the site. A subsurface geoarchaeological investigation at the site shows that at least three separate prehistoric "shell midden" sites are located around the perimeter of Big Lagoon, but the nature and extent of these sites is not yet well understood (Meyer, 2003). The human activity with the most significant effect on the landscape during the pre-Euroamerican period was human use of fire. The Coastal Miwok practiced periodic burning to control the hillslope grasslands (Duncan, 1989), and likely also used fire to drive game, facilitate the collection of acorns and seeds, kill insects and small animals for food, promote growth of seed-bearing annuals, increase the extent of grazing areas, and to provide open areas for camping and travel (MMWD, 1995).

3.1.2 1817-1920: Resource Extraction

The pre-Euroamerican period ended with the Spanish settlement in Marin County around 1817, and initiated a new culture of resource extraction within the watershed. The Spanish began using Marin County for grazing or agriculture after the Mission San Rafael was established in 1817. The mission recorded having 8,000 cattle, horses, and other grazing animals (Munro-Fraser, 1880). In 1838, William Richardson was granted Rancho Sausalito by the Mexican governor in San Francisco. The Rancho boundaries extended from the southern tip of Marin County to Mt. Tamalpais, including the Redwood Creek watershed. Richardson was reported to graze "thousands of cattle, horses, and sheep" on his holdings (Munro-Fraser, 1880).

In the latter half of the 19th century, land uses were chiefly resource extraction and agriculture, including logging, grazing, and dairy farming. Logging was concentrated on the ridges above Muir Woods, while grazing was distributed among the grassland areas (Jebens, 2001). Early Euro-American settlers also used fire through the 1900s to increase grazing lands for livestock.

In 1856, Samuel Throckmorton took financial control of Rancho Sausalito and began running large dairy operations in the area. Throckmorton subdivided and leased the land to Portuguese dairymen, mostly from the Azores, who eventually became the primary managers of the Redwood Creek watershed until the mid-20th century (Duncan, date unknown). A small, isolated agricultural community developed in the area, centered on the beach, with farmhouses throughout the valleys and a culture that reflected the heritage of the small European farm communities from which the immigrants came.

By 1870, the County Road from Bolinas to Sausalito was completed along the current alignment of Highway 1. In 1905, William Kent purchased Sequoia Canyon, which he donated to the federal government in 1907 and was designated a national monument in 1908. This protected most of the redwood forest in the watershed from logging.

3.1.3 1920-1980: Agriculture and Residential Development

In the mid-twentieth century, residential development expanded in the watershed, and the final large-scale natural resource extraction activities occurred.

Muir Beach was a popular tourist stopover. In 1919, Antonio Bello, a Portuguese dairyman, established a hotel at Muir Beach. The hotel later burned down and was replaced by a tavern and small vacation cabins built by Jacob Weil and Louis Harris of the Muir Beach Company in 1928. During this period the improvement in roads and increase in the Bay Area population resulted in increasing recreational use of the beach and watershed. In 1925-26, the Frank Valley and Muir Woods roads were upgraded, and the Panoramic Highway was opened in 1928 (Jebens, 2001). This was also the period in which subdivision and home building began to occur within the Muir Beach community (Duncan, date unknown). The Bay Area urbanites who began to move into this formerly isolated rural area brought with them a respect for rural life, but also a new urban culture that increasingly contrasted with that of the small farm community.

During the 1930's, the family-owned dairies were still the primary land use on private land within the watershed, although the Banducci family was raising vegetable and flower crops at several locations in the lower watershed during this period. Historic photographs show that by the mid-20th century there was little or no riparian vegetation along the creek through Frank Valley, due to grazing and clearing by the dairy farmers (PWA, 2000). Gravel was extracted from the Redwood Creek bed by county road builders and local farmers (Banducci, personal communication).

In 1945, Green Gulch and the Muir Beach area were purchased by George Wheelwright. In the early 1960's, he extensively modified Redwood Creek and the adjacent pasture areas downstream of Pacific Way (described in following section). In 1967, Wheelwright donated the Muir Beach area to the State Park system and sold Green Gulch to the San Francisco Zen Center.

Kent Canyon was logged in the 1960's—over 1,300 acres of old growth redwoods were selectively removed by tractors (PWA, 2000). Many of the residents of the Muir Beach area began expressing their environmental concerns, including a desire to protect the watershed from further degradation. For a time in the 1960’s, Muir Beach became a rural center of San Francisco’s counter-cultural revolution, and events at the tavern in particular drew thousands of young people to the area. The tavern and cottages at the beach were removed in the late 1960's after the California Department of Parks and Recreation acquired the beach. After the Golden Gate National Recreation Area (GGNRA) was founded in 1972 as part of the National Park Service, the federal government purchased several properties then or formerly used as farms. From this time on, cattle grazing within the watershed was phased out, ending in 1990. The State Parks Department constructed a parking lot in the current location at the beach in the late 1960's or early 1970's. By the 1980's, a new Bed and Breakfast/alehouse, The Pelican Inn, was in operation at the intersection of Highway 1 and Pacific Way.

As more people settled in southern Marin, fire suppression became the prevalent practice. Fires were often ignited, but they were generally suppressed and confined to small areas. As a result, fire frequency in the watershed has been greatly reduced. The recorded fire history of the Redwood Creek watershed is shown in Table 3-1.

Table 3-1. Recorded Fire History of Mt. Tamalpais

Year	Location	Comment
1859	Mt. Tamalpais	Burned for three months
1881	Mill Valley through NE portion of Redwood Creek watershed	65,000-acre wildland fire. Accidentally spread from a brush pile fire in Mill Valley.
1891	From Ross over to the extreme northern portions of the watershed.	12,000 acres of Mt. Tamalpais burned. Fire started near Ross.
1913	Mt. Tamalpais Summit, Blithedale and Cascade canyons, most of Fern Canyon.	2,600 acres burned, started near West Point Inn, probably ignited by railroad sparks
1919	From Pipeline Reservoir to Muir Woods	
1929	Mill Valley to Fern and Cascade canyons	"Great Tamalpais Fire" burned 2,500 acres
1931	Muir Woods	Illegal campfire charred redwoods in Cathedral Grove
1932	Panoramic Highway to Muir Woods	60 acres burned, including 2 acres within the Muir Woods boundaries
1959	Kent Canyon	50 acres burned near logging operations on Brazil Ranch.
1965	¼-mile from Muir Woods southeast boundary	150 acres burned

Source: MMWD1995

3.1.4 1980-Present: Residential and Recreational Use

Currently, 95% of the Redwood Creek watershed is under public ownership and is generally protected from further development. Major land uses include intensive recreation at Muir Woods and Muir Beach and hiking in the backcountry. The Zen Center/Green Gulch Farm, a residential community of approximately 60 people, occupies the Green Gulch watershed and operates an organic farm on the valley floor. Green Gulch Farm also serves educational and spiritual functions, offering space for retreats and periodic events for the outside public. A horse riding stable operates in the former dairy buildings at the intersection of Pacific Way and Highway 1 and grazes horses in the lower portion and hillslopes of Green Gulch. Approximately, 150 residential homes are in the Muir Beach community, in addition to the Zen Center/Green Gulch Farm.

3.2 PHYSICAL PROCESS CHANGES

The land use changes described above, as well as physical modifications to Redwood Creek and the project site, have altered the physical processes that shape the site, most notably, sediment production, transport, and deposition.

3.2.1 1817-1900: Lagoon Filling

The extensive grazing and logging activities beginning in 1817 led to dramatic changes in vegetative cover in the watershed (PWA, 2000; Jebens, 2001). Logging of redwoods in the upper watershed tributaries and removal of riparian and valley woodlands thinned hardwood tree cover. Forest cover was also probably cleared for cattle grazing, and cattle would have contributed to erosion, gullying, and sediment loading, particularly in the upper watershed (PWA, 2000). These land cover changes led to greater runoff, generating higher peak flows on Redwood Creek and inducing channel incision along the mainstem of Redwood Creek in Frank Valley (PWA, 2000; Stillwater, 2003). At the same time, introduced European grasses replaced native grass species in the watershed. The European grasses provide less resistance to surface erosion due to shallower roots, increasing sediment yields to the mainstem and tributary channels (Stillwater, 2003). Stillwater (2003) suggests that the tributary channels began to downcut in response to the lower base level set by mainstem incision. As a result, a more hydraulically connected mainstem-tributary network evolved, further enhancing peak flows and incision in the mainstem of Redwood Creek. Disconnected from the floodplain in Frank Valley, lower Redwood Creek no longer acted as an effective sediment trap but rather a significant sediment source. The lower creek reaches were also capable of transporting coarse material due the new confined channel geometry and higher discharge (Stillwater, 2003). The landscape changes and increased surface erosion that were initiated by grazing and logging were likely exacerbated by a large fire on Mt. Tamalpais in 1859 and a large flood in 1862.

The net result of the increased watershed sediment production and channel transport capacity was an order of magnitude increase in sediment delivery to Big Lagoon (Figure 5). Stillwater (2003) estimates that average annual sediment delivery increased from 600 yd^3/yr in the pre-Euroamerican period to 5,300 yd^3/yr between 1840 and 1920. This abrupt increase in sediment delivery overwhelmed the rate of sea level rise. In this period, sedimentation rates in the lagoon increased from an estimated 0.8 ft/100 yr to 7.6 ft/100 yr (assuming a trapping efficiency of 100% bedload and 50% suspended load), while sea level continued to rise at about 0.4 ft/100 yr (Zervas, 2001). Therefore, the near balance between watershed sediment delivery and sea level rise that had maintained Big Lagoon for the last 3,700 years was broken, and Big Lagoon began to fill. In the 1892 Tamalpais Land and Water Company map, Big Lagoon is mapped as two distinct channels, suggesting that the lagoon filled in less than 50 years, since the 1853 map was prepared.

3.2.2 1900-1980: Diking and Channelization

In the early 1900's, agricultural and residential development led to direct modifications of the lower Redwood Creek channel and floodplain. Between 1900 and 1946, Redwood Creek was rerouted towards Pacific Way and confined by levees to protect structures and agricultural lands located on the adjacent floodplain. Much of the historical dune field was removed to provide sand for road and other construction activities (PWA *et al*., 1994). The Mt. Tamalpais Sportsman Club began impounding the lower reaches of Redwood Creek to enhance trout fishing.

The most dramatic physical changes to lower Redwood Creek and the project site since the influx of sediment in the late 19th century were initiated by George Wheelwright who purchased the property currently owned by Green Gulch in 1945. George Wheelwright dredged the lower portion of Redwood Creek to form a large deep channel, in which water was impounded behind a dam near the current footbridge location. A levee was constructed separating the lower Green Gulch pastures from the Redwood Creek floodplain and fill was brought down from the hillsides in Green Gulch to raise the pastures by 1 to 2 feet (Banducci, personal communication). Drainage from Green Gulch was rerouted into two artificial channels which drained through culverts under the levee and into the backwater section of the lower Redwood Creek channel. Most of these modifications remain in place today.

Constructed levees confined creek flows and increased erosion of the bed. Eroded sediment would deposit behind the dam, and the lower creek channel required periodic dredging. After the dam was destroyed in the late 1970's, sediment continued to be deposited in the artificially dredged section of Redwood Creek.

Further upstream, Redwood Creek through Muir Woods was channelized in the 1930's, and revetment was placed on the channel banks to reduce flooding and bank erosion. Until approximately 1986, Muir Woods National Monument staff removed downed trees and log jams from the channel.

3.2.3 1980-Present: Rapid Channel Aggradation and Flooding

Beginning in the early 1980's, a series of events occurred that led to rapid channel aggradation in lower Redwood Creek and increased flooding of Green Gulch pasture and Pacific Way. In 1983, NPS raised the Muir beach parking lot elevation by 2 to 3 feet with fill material from nearby landslides. Prior to this time, overbank flood flows from Redwood Creek were able to spill over the parking lot onto the beach (PWA *et al.,* 1994).

During the 1982 El Niño flood, the entire Green Gulch pasture was inundated by several feet of water, and the pasture levee failed immediately upstream of the footbridge. Riprap and other debris from the failed levee filled the channel just downstream of the footbridge, forming a barrier to channel downcutting and raising the elevation of the thalweg. Following this flood, NPS planted willows and repaired the pasture levee with gabions. The buried rubble, which limits channel scour, in conjunction with the growth of the willows, have raised thalweg elevations downstream of the footbridge. The 1992 survey in this area showed maximum thalweg elevations of +5 feet NGVD (PWA *et al.,* 1994) (Figure 7). This high elevation point has caused significant backwater effects in surface and groundwater elevations and reduced the frequency of wave overwash events into the former lagoon area.

GGNRA and NPS surveyed the channel thalweg and channel cross-sections in several locations in 2002 and 2003. These surveys indicate that maximum elevations downstream of the footbridge (now called the Willow/Alder Grove) increased by 1 to 2 feet to +6.5 feet NGVD since 1992, as vegetation growth increased sediment-trapping efficiency (Figure 7). The increase in thalweg elevations worsened drainage of Green Gulch pasture and raised groundwater elevations, killing riparian alders. As dead alders fell into the channel, the channel roughness between the footbridge and Pacific Way Bridge increased significantly, contributing to additional sediment deposition upstream. Between the parking lot and Pacific Way, the channel aggraded between 2 and 5 feet from 1992 to 2002 (Figure 7). The loss of channel capacity from sedimentation has exacerbated flooding of Pacific Way, creating access problems for Muir Beach residents and visitors. In fact, downstream of Pacific Way, the channel thalweg is actually 1 to 2 feet above Pacific Way and Green Gulch pasture, the low point of the valley (Figure 6). From comparing the 1992 and 2002 surveys, it appears that approximately 300 yd^3/yr of sediment has been trapped in the channel between Pacific Way and the Willow/Alder Grove. This is a conservative estimate of total bedload delivery to the channel, however, because a significant but unquantifiable amount of bedload deposition has also occurred outside the main channel in the riparian willow area, north of the parking lot. Nevertheless, this rate of deposition is in relative agreement with Stillwater's (2003) average annual bedload estimate of 435 yd^3/yr between 1980 and 2002. The high rates of sedimentation in lower Redwood Creek can be attributed to the following:

- Elevated average annual sediment delivery to lower channel reaches (legacy of 19th and 20th century land use changes);
- Significant flow and sediment delivery events during the 1982-83 and 1997-1998 El Niño winters;
- Decreases in flow depth upstream of Pacific Way Bridge when flows overtop channel banks;
- Backwater effects caused by Pacific Way Bridge, levee road, and Muir Beach parking lot;
- Increased channel roughness downstream of Pacific Way Bridge; and,
- Decrease in stream gradient downstream of Pacific Way due to deposition in Willow/Alder Grove.

GGNRA has assumed a more active management role in lower Redwood Creek due to the increased flooding and high groundwater table. In September 2002, the main channel was excavated by 1 to 3 feet from just upstream of Pacific Way Bridge to the former backwater channel (NPS, 2002a; Figure 8).

During high winter flows in December 2002, the dominant channel switched from the right channel to the left channel (back water channel), as the right channel became almost completely silted up and plugged with debris jams. In September 2002, a pilot channel was also excavated through the Willow/Alder Grove to the ocean, reducing thalweg elevations in the Willow/Alder zone to +4.5 feet NGVD (Figure 9). The pilot channel was excavated to improve drainage from flooded areas following storms. The channel thalweg was re-surveyed in April 2003. No significant change in bed elevation was detected at monitoring stations through the excavation zone, but immediately upstream of Pacific Way, the bed aggraded by 1 to 2 feet (Figure 9). Deposition upstream of Pacific Way Bridge between October 2002 and April 2003 surveys indicates an estimated annual bedload trapping rate of approximately 240 yd^3/yr, again comparable to Stillwater's (2003) average annual bedload estimate.

The pilot channel has reduced backwater effects and lowered groundwater elevations, improving drainage of the Green Gulch pasture. The pilot channel also appears to be downcutting in response to the lowered base level, although adjustment is occurring slowly due to the cohesive sediment along the bed (scour of approximately 0.5 feet documented between October 2002 and April 2003 surveys). In addition since the pilot channel is landward of historical channel location, wind blown sand has filled the former back beach channel, encroaching on the Willow/Alder Grove.

3.3 ECOLOGICAL CHANGES

The ecology of the Big Lagoon site has changed significantly in response to land use and physical changes that have occurred over the past 150 years.

3.3.1 Changes in Vegetation

Since the 1850's, oral history, maps, and photographs document a striking decrease in the cover of native plant communities in the upland hills, along the riparian corridor, and in Big Lagoon. Riparian and wetland habitats were replaced by crop land and grazing land for dairies. Fire suppression has altered the distribution of grasslands in the area. This heavily altered landscape remained until after 1952, and up to 1970 in some places. The combined results of land use in the watershed and at the project site, as well as structures at the project site (e.g., the levee and parking lot), have been to 1) reduce native grasslands, 2) reduce wetland and openwater habitat; 3) increase riparian vegetation; 4) decrease dune habitat area; and 5) introduce non-native plant species.

3.3.1.1 Uplands

The hillside communities surrounding Big Lagoon were chronically overgrazed and trampled since the 1850's, resulting in extensive erosion and loss of productive topsoil. While in later years grazing was phased out and finally ended in 1990, the impacts were substantial and persistent. Even relatively recent aerial photos of the hillsides (1946-1970) show little shrubby cover. The cover of native perennial grasses was surely impacted early; they are preferred food of domestic livestock. More than other native upland vegetation, the native grasses were probably continuously suppressed by chronic grazing, trampling, and competition with introduced Mediterranean annual grasses.

With suppression of fires in the area, native grasslands that once dominated the upland hillsides are slowly converting to shrublands. Two sources of information describing historic grassland vegetation and changes over time for the Mt. Tamalpais area are available: 1) Leonard Charles and Associates (MMWD, 1995), who compiled historical photographs taken in the watershed and took current photographs from those same locations; and 2) Bicknell et al. (1993), which relied on a combination of review of historical accounts, interpretation of aerial photography, dendrochronological evidence from trees in the watershed, analysis of phytolyths to document pre-historic (i.e., prior to occupation of Mt. Tamalpais State Park area by Euro-American settlers), and current vegetation conditions. The Leonard Charles and Associates photographs have not been quantitatively analyzed, but show a sharp reduction in grassland area and an increase in shrubland area on Mt. Tamalpais since the 1920's. Bicknell et al. (1993) conclude that grassland area has been reduced by approximately 64% since European settlement, due to conversion of grasslands to shrubland and shrubland/grassland mosaic.

3.3.1.2 Wetlands

The extreme human impacts on the Big Lagoon ecosystem may be best documented in a series of photographs taken from the northern hillside in the 1920's. These show the tidal lagoon in its present position, but all the wetland habitat inland of the lagoon was grossly modified. Big Lagoon was a large pasture cut by drainage ditches, Redwood Creek and Green Gulch Creek. This was also a period of regional drought, permitting even greater wetland conversion to drier land use. The photographs revealed no riparian trees or bushes in the Big Lagoon area.

The Big Lagoon freshwater pond and fringing marshes were converted to pasture by the turn of the century. This is clear in the 1920 photographs and persists in the aerial photographs from 1946 and 1952. In 1965, aerial photographs show well-organized patterns of ditches and rows indicating cultivated cropland in the pastures. Aerial photos from 1946 to the present show little change in the size of the surviving marsh area. The Green Gulch pasture and a parking lot now cover the large, flat fill which was a large part of the historic freshwater lagoon, dune, wetland, and riparian habitats along lower Green Gulch Creek.

In 1992–1993 the elevated areas of Green Gulch pasture were dominated by non-native white clover (*Trifolium repens*) and several species of non-native annual grasses, predominantly rabbit's-foot grass (*Polypogon monspeliensis*) and Italian rye (*Lolium multiflorum*). Three native perennial species were encountered relatively frequently along during 1992–1993 surveys, but rarely accounted for significant cover: meadow barley (*Hordeum brachyantherum*), aquatic knotgrass (*Paspalum distichum*) and coast clover (*Trifolium wormskioldii*). The 1992–1993 surveys showed a strong correlation between the type of vegetative cover and proximity to horse trails and grazing (PWA *et al.* 1994). Transects that were closest to the grazing area, located between Green Gulch Creek and the unnamed tributary, were dominated by weedy annual species and contained large areas of bare ground during winter months. Winter die-off of annual grasses and die-back of clovers combined with continued grazing resulted in significant reduction of plant cover (PWA et al. 1994). Over the past 10 years, as a result of increasing surface and groundwater levels (see discussion in Section 3.2.3), the Green Gulch pasture has transitioned to support more obligate and facultative wetland species.

3.3.1.3 Riparian

The riparian forest became established along the present course of lower Redwood Creek only during the last three decades. Aerial photographs from 1946 and 1952 show the diverted creek course running through close-cropped agricultural lands, a setting consistent with observations of residents at the time. By 1965, photos show the double row of Monterey pines planted along the road, adjoining riparian trees, and some riparian trees or shrubs extending upstream. By then, the dense willow forest adjacent to the present parking lot was established in the area previously occupied by roads and buildings. Changes in the last ten years are discussed in Section 4.3.1.1.

3.3.1.4 Dunes

Since the 1850's, the sand dunes along the shore of Big Lagoon were probably constantly trampled, subjecting loose sands to wind erosion and reducing dune vegetation to remnant patches. Ground photographs from the 1920's show a beach similar to today's condition: bare sand with hummocks topped with vegetation along the east end, where bare sand extended to the base of the hillside.

3.3.2 Changes in Wildlife

The dramatic reduction of wetland area caused a parallel reduction in the number of species and population sizes of most if not all of the native wetland fauna. Animals living in the adjacent, highly disturbed upland habitats probably experienced the same reduction. All of the aquatic insects and amphibians are highly dependent on either running water, ponded water, or wetland vegetation, which all became less frequent and less widespread habitat features. The conversion of wetland to dry pasture undoubtedly had the most severe impacts on aquatic animals.

Amphibians may have been the animal group hardest hit by the land-use changes. There were probably healthy populations of red-legged frog inhabiting the freshwater lagoon at the confluence of Redwood and Green Gulch Creeks. Yellow-legged frogs would have been present in the faster-moving creekbeds and upper reaches of the creeks. Additionally, healthy populations of both red-legged and yellow-legged frogs could have been maintained in the riparian areas along the creeks. California and rough-skinned newts (*Taricha torosa* and *T. granulosa*, respectively) probably would have had larger populations due to the more numerous and larger areas of standing water for breeding sites. However, populations of upland species such as ensatina (*Ensatina eschscholtzi*), California slender salamander (*Aneides lugubris*) would not have been greatly altered from present conditions. Because they do not need standing water for reproduction and lay their eggs underground, the impacts of grazing do not significantly deter their numbers.

The seasonally brackish lagoon would have been prime western pond turtle habitat (*Clemys marmorata*) so turtle numbers would probably have been much higher. The vegetation cover in the riparian corridor would have provided cover for females on their way to nesting sites, resulting in more successful breeding.

Wetland bird species, whether year-round residents or visitors, lost virtually all habitat previously available for nesting and foraging at Big Lagoon by the turn of the 19th century. In addition, several species were directly impacted by hunting. Snowy and great egrets were greatly reduced in number by hunters in the feather trade (Grinnell and Miller, 1944). White-tailed kite populations were significantly depressed through the early 1900's due to egg-collecting. Duck hunting along the coast of San Francisco Bay and Marin County in the late 1800's severely depleted populations of not only waterfowl, but shorebirds and rails (Grinnell et al., 1918). Many of the waterfowl populations were concurrently being depleted by wetland reclamation efforts which destroyed nesting habitat in the Sacramento-San Joaquin Delta (Herbold and Moyle, 1989) and the rest of the San Francisco Bay region (Skinner, 1962). Most raptors which were probably common prior to human settlement decreased significantly in number due to egg-shell thinning caused by high pesticide levels in prey, intentional poisoning by laced carcasses on ranchland, and shooting. Though these factors have been largely eliminated, many raptor species will probably not regain former abundances due to widespread and often irreversible habitat loss. Raptors significantly affected by these past human activities include peregrine falcons, turkey vultures, osprey, northern harriers and Cooper's hawks (see species accounts, Shuford, 1993).

Uncontrolled and feral pets are disturbances introduced incidental to the establishment of ranches and, more recently, residential development. Dogs and cats undoubtedly increase mortality and decrease the foraging time available to birds dependent on prey resources near or on the ground. They also decrease breeding success of ground- and near ground-nesting birds, including most wetland species. Feral cats may be particularly detrimental due to their secretive habits. However, it is unknown how the magnitude of these recently introduced disturbances are balanced by concurrent human-induced decreases in predation by bobcats, gray foxes, raptors and others.

Brewer's blackbirds and mourning doves were probably uncommon members of the historic Big Lagoon avifauna. Today Brewer's blackbirds are the most frequently observed bird species in the Big Lagoon area. Both species prefer foraging in open, sparsely vegetated ground, such as the heavily-grazed pastures and hillsides. Other new visitors include the introduced European starlings and rock doves, which are common in disturbed landscapes including the pastures, hillsides, park facilities, residential areas, and so on.

3.3.3 Changes in Fish Communities

Although the stream itself is relatively undisturbed, some stream banks have been modified, increasing channel confinement along some reaches of the creek upstream of the project area, such as the Banducci site and Muir Woods National Monument. Past management actions, such as channelization, revetment and woody debris removal, reduced pool frequency and depth. However, the stream channel of Redwood Creek, upstream of the beach area, is in generally excellent condition, with good pools, escape cover (root wads and undercut banks) and substrate free of excess sediment.

Water diversion for domestic and agricultural use may have affected conditions in Redwood Creek, most likely impacting the distribution of coho salmon (Snider 1984; Arnold 1971; Smith, 1995–2001). Additionally, based on habitat surveys during annual monitoring, the NPS has concluded that lack of pools exceeding 1.6 feet in depth is one key factor limiting coho production in the Redwood Creek watershed, particularly during low rainfall years. Habitat surveys indicated that deep pools are sparse in the creek, especially within the Muir Woods National Monument (Fong, 2002a). An additional factor that has likely affected the historical stream fish community has been the heavy harvesting of coho salmon by sport and commercial fishermen.

Although steelhead and coho spawning runs are probably significantly smaller than in the past, coho have been documented in Redwood Creek from 1956 to the present (CDFG 1956, 1976, 1977, 1984, as cited in CDFG 2002; PWA 1994; Fong 1996, 1997a, 1997c; Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001; Laidig 2003). Their continued presence in the watershed points to the regional importance of Redwood Creek spawning habitat for anadromous salmonids. At the present time, Redwood Creek is one of the few remaining free-running coastal streams in the southernmost range of coho salmon, and remains one of only a handful of Marin County creeks to support a run of coho salmon. Other coastal streams in Marin County that historically supported large coho salmon populations, such as Lagunitas Creek, have been dammed, significantly reducing the amount of available habitat for anadromous fish (CDFG, 2002).

The extensive modification of lower Redwood Creek and the tidal lagoon has had more substantial effects on the fish community. The present small estuary/lagoon lacks any calm water refuge during major storms and is inadequate to sustain tidewater goby. The small lagoon at best provides only limited summer rearing habitat for steelhead and may be too warm for coho salmon. The small lagoon also provides only limited potential habitat for juvenile marine fish, such as Pacific staghorn sculpin or starry flounder. Perhaps most importantly, the small estuary probably does not provide a good brackish water transition zone for steelhead and coho smolts as they migrate through to the ocean. A brackish water zone is important in helping migrating smolts, especially smaller ones, gradually adjust to sea water before entering the ocean.

Two fish species introduced to San Francisco Bay, striped bass (*Morone saxatilis*) and yellowfin goby (*Acanthogobius flavimanus*), now rear in the lagoon. The goby also occurs in the stream immediately upstream of the lagoon. It is uncertain whether the goby is reproducing in the system, as it requires brackish water for spawning.

A pond in Green Gulch contains Sacramento perch (*Archoplites interruptus*), Sacramento blackfish (*Orthodon microlepidotus*), and prickly sculpin. The first two species are not native to Redwood Creek, and a few specimens of each have been collected in the creek, near the beach parking lot. The Sacramento perch and Sacramento blackfish are native to California, although the Sacramento perch is now nearly extirpated within its native range. Prickly sculpin are native to the creek, but if they were introduced to the pond from the same source as the blackfish and perch, they are probably the southern/inland subspecies, rather than the northern/coastal species found in the creek.

3.4 VISUAL CHARACTER - PRE-EUROAMERICAN THROUGH PRESENT

As the physical environment has changed, so has the visual character of the Muir Beach area and its landscape. In pre-Euroamerican times, there would have been generally low growing coastal scrub and grassland vegetation on the hillsides, densely wooded stream corridors, grassy valleys, and coastal oak woodlands transitioning to the dense mixed evergreen woodlands and redwood forests in the upper reaches of the Redwood Creek and tributary valleys. At the coast, the small enclosed sandy beach would have been backed by sand dunes through which the stream meandered. Behind the beach and dunes was a seasonally variable lagoon, with open water that would vary in size depending upon the climate and season. The area of the Big Lagoon would have been generally open with low growing emergent marshy vegetation at the margins. The visual effect would probably have been that of a large open expanse of water and low marsh vegetation behind the dunes, set within a grassy plain and surrounded by steep shrub and grass covered hills. In contrast to this open landscape, willow and alder trees would have marked the edge of the upstream creek banks and the more dense upstream woodlands.

During the period of agricultural and residential developments between the mid 1800's and late 1900's, the riparian woodlands along the valley floors were gradually removed, homesteads and farmyards sprung up within the valleys, and the valley floor was transformed to agricultural uses. The images of the area were more pastoral, with cattle and horse grazing, crops in the farm fields, farm buildings, and gardens. Residential developments on the hillsides brought with them more roads, trees, and residential gardens transforming the former shrubby landscape into more of a forest with largely exotic plants. The higher density of the residential developments would have created the sense of a town center near the beach with outlying agricultural areas. The dune landforms were mined of sand, and the beach would have become more open to view. Siltation from upstream erosion, however, quickly filled the lagoon, eliminating it as the predominant landscape feature by the turn of the 19^{th} century.

Between the 1950's and the 1970's, the central lagoon area was visibly changed from wetlands to pasture lands with severe alterations to the stream and low-lying meadows. The community's image at its core changed to a far more pastoral landscape with grazing herds in place of natural wetlands. Although rural in character, visual evidence of a healthy underlying natural system with wetlands, riparian forests, and an integrated mosaic of native vegetation was diminishing and being replaced with a more obviously constructed landscape.

The change to public ownership of most of the watershed from the 1970's to the present, plus the advent of new land management techniques directed at restoration of natural landscapes, has had a dramatic effect once again on the visual character of the area. Native riparian forests are returning to the stream banks, and much of the mosaic of native vegetation is being restored throughout the watershed. With the exception of Green Gulch Farm, farming is mostly gone from the area, and with it scenes of farm activities. Many of the farm buildings remain, however, providing iconic glimpses of the earlier developments. The pastoral image at the Big Lagoon site is changing back to more of a wetland, a result not of any restoration efforts but of the inevitable impacts of preserving the stream alterations of the earlier era. The general character of the area today is more of a natural area gradually being restored, with pockets of more dense residential developments at the edges.

4. EXISTING SITE CONDITIONS

This section presents a summary of existing physical, ecological and visitor experience conditions at the Big Lagoon site. This information establishes the project setting, will inform the restoration design, and will facilitate the EIR/EIS process for the project. In an attempt to present a complete picture of project conditions, we have compiled, reviewed and analyzed numerous studies and data collection efforts performed at the site. More detailed information on specific studies and data is provided in the report appendices.

4.1 EXISTING CONDITIONS CONCEPTUAL MODEL

A schematic diagram summarizing the principal physical processes currently shaping the morphology of the project site is depicted in Figure 10. Lower Redwood Creek below the Highway One Bridge is still receiving a sediment load that is an order of magnitude above pre-Euroamerican conditions, and this elevated sediment delivery is expected to continue over the next 100 years or more (Stillwater, 2003). The sediment transport capacity of the lower creek reaches has been reduced by Pacific Way Bridge, the levee road, and the parking lot, which constrict flows, and by accumulation of woody debris in the channel, which increases channel roughness. These obstructions to flow have created a depositional zone from upstream of Pacific Way Bridge to the parking lot, which probably traps most of the bedload and some of the coarse sand in suspension. Since the channel is separated from the historical floodplain by the levee road, this deposition is concentrated in the channel and the vegetated area east of the parking lot, rapidly filling the channel. Because of the reduced channel capacity, high flows escape the channel in at least two locations between the Highway One and Pacific Way bridges, following the valley contours and forming a nascent channel along the low point of the valley. These overbank flows are responsible for flooding of Pacific Way near the Pelican Inn.

NPS is attempting to temporarily reduce flooding and prevent channel avulsion by stabilizing banks, dredging the channel up and downstream of Pacific Way Bridge, and excavating a pilot channel downstream of the footbridge. The pilot channel has reinvigorated flows in the lower project reaches, improving drainage of Green Gulch pasture. However, the modest channel incision along the pilot channel will probably not propagate upstream far enough to initiate transport of significant quantities of sediment accumulating immediately downstream of Pacific Way Bridge.

The tidal lagoon still operates in a manner similar to the pre-Euroamerican lagoon, although it is smaller in area and volume. High flows during the winter scour the back beach channel and open the lagoon mouth. As flows subside in the spring and summer, the lagoon mouth closes, as the summer berm is re-established. The pilot channel is located further landward than the pre-Euroamerican channel, allowing the beach to migrate inland and stabilize with vegetation.

4.2 PHYSICAL RESOURCES

Redwood Creek drains an approximately 8.9-square mile coastal watershed in Marin County, California. The creek originates on the southern slopes of Mt. Tamalpais (+2571 feet NGVD) and flows approximately 6 miles through a heavily forested watershed before discharging into the Pacific Ocean at Muir Beach. The watershed originates on the southern slopes of Mt. Tamalpais. Major tributaries to Redwood Creek include Fern Creek (west and east fork), Spike Buck Creek, Rattlesnake Creek, Bootjack Creek, Kent Canyon, and Green Gulch (Figure 1).

4.2.1 Geology and Soils

Bedrock in the area is comprised of the Franciscan formation, a highly sheared mixture of sedimentary, metamorphic and igneous rocks of Late Jurassic and Cretaceous age (Jennings, 1977; Martin, 2000). Redwood Creek has downcut through these rocks to form Redwood Canyon and Frank Valley. Frank Valley has been subsequently filled with unconsolidated alluvial deposits (Martin, 2000). The depth of alluvial fill is at least 37 feet (Martin, 2000) and could be as much as 90 feet (Laudon, 1988).

Elevations in the watershed range from about 2 feet at the lagoon to 2600 feet NGVD at the peak of Mt. Tamalpais. Hillslopes are steep, with slopes ranging from 15 to 75% (PWA *et al.*, 1994). Soils on the steep hillsides and ridges in the watershed are generally moderately deep loams and gravelly-loams (Kashiwagi, 1985). Permeabilities are low to moderate, and the potential for runoff and erosion is high. Alluvial and alluvial fan deposits predominate on the valley floors. These consist of very deep silt loams and clay loams with low to moderate permeabilities. Runoff and erosion potential on the alluvial soils is low, primarily because of the low slopes (2 to 5%).

4.2.2 Hydrology

4.2.2.1 Surface Water

NPS has recorded daily rainfall within the watershed at Muir Woods since 1941. Mean annual precipitation within the watershed is 37.5 inches, as measured at Muir Woods over water years 1942-1986 and 1989-2002. Average monthly rainfall values vary from 7.60 inches in January to 0.07 inches in July. On average, 94 percent of the annual rainfall occurs from October through April. The mean monthly distribution of rainfall and evaporation is shown in Table 4-1.

Table 4-1. Monthly Precipitation and Evaporation

Month	Mean Precipitation[a] (in)	Mean Evaporation[b] (in)	Mean PET[c] (in)	Available Water[d] (in)
OCT	2.08	2.39	1.67	0.41
NOV	5.42	0.98	0.69	4.73
DEC	6.75	0.53	0.37	6.38
JAN	7.69	0.39	0.27	7.42
FEB	6.15	0.84	0.59	5.56
MAR	4.99	2.68	1.88	3.11
APR	2.36	3.71	2.60	0.00
MAY	1.05	5.53	3.87	0.00
JUN	0.39	6.42	4.49	0.00
JUL	0.07	7.30	5.11	0.00
AUG	0.15	5.68	3.98	0.00
SEP	0.43	3.91	2.74	0.00
TOTAL	**37.52**	**40.36**	**28.26**	**9.26**

Notes:

a. Precipitation data from Muir Woods daily records from water years 1942-1986, 1989-2002.

b. Evaporation data from Lagunitas Reservoir Pan.

c. Potential Evapotranspiration (PET) computed from Pan Evaporation using a pan coefficient of 0.7

d. Available water is the water left after evapotranspiration losses, Mean Precipitation – Mean PET.

There are sporadic records of flow on Redwood and Green Gulch Creek dating back to 1962 (Table 4-2). Between 1962 and 1973, the USGS measured annual peak flows in Redwood Creek upstream of Frank Valley (contributing area is 6.38 sq. miles). Between 1986 and 1988, the USGS measured flows during summer and winter flow conditions at Pacific Way Bridge and Muir Woods.

Table 4-2. Historical Flow Measurements

Date	Location	Agency	Conditions	Flow (cfs)
02/13/62	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	880
10/13/62	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	800
01/20/64	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	100
01/06/65	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	410
01/04/66	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	1300
01/21/67	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	295
01/30/68	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	630
12/15/68	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	1040
01/21/70	Redwood Creek at Frank Valley Road	USGS	Annual Storm Peak	1780
08/74	Lower Redwood Creek	NPS	Dry Weather	0.56

Date	Location	Agency	Conditions	Flow (cfs)
09/74	Lower Redwood Creek	NPS	Dry Weather	0.31
01/31/86	Redwood Creek at Muir Woods	USGS	Winter	51
01/31/86	Redwood Creek at Pacific Way	USGS	Winter	86
01/30/86	Green Gulch Creek	USGS	Winter	9.9
06/26/86	Redwood Creek at Muir Woods	USGS	Summer	0.77
06/26/86	Redwood Creek at Pacific Way	USGS	Summer	0.66
06/25/86	Green Gulch Creek	USGS	Summer	0.01
02/13/87	Redwood Creek at Muir Woods	USGS	Winter	114
03/13/87	Redwood Creek at Pacific Way	USGS	Winter	30
03/13/87	Green Gulch Creek	USGS	Winter	1.2
06/10/87	Redwood Creek at Muir Woods	USGS	Summer	0.62
06/12/87	Redwood Creek at Pacific Way	USGS	Summer	0.68
06/12/87	Green Gulch Creek	USGS	Summer	0.01
01/05/88	Redwood Creek at Muir Woods	USGS	Winter	42
01/05/88	Redwood Creek at Pacific Way	USGS	Winter	73
03/23/88	Green Gulch Creek	USGS	Winter	0.04
06/07/88	Redwood Creek at Muir Woods	USGS	Summer	0.7
06/07/88	Redwood Creek at Pacific Way	USGS	Summer	0.78
06/02/88	Green Gulch Creek	USGS	Summer	0.01
09/04/88	Redwood Creek at Frank Valley Road	NPS	Dry Weather	0.06

PWA established the first continuous records of flow on Redwood Creek, monitoring daily flows from March 1992 through September 1993 at Pacific Way Bridge. Since 1998, NPS conducted continuous monitoring of flows at the Highway One Bridge, using an automatic stage level recorder. To establish the return period of peak flow events, PWA (2000) performed a log-Pearson type III analysis of the annual maximum series using the US Army Corps of Engineers statistical analysis program HEC-FFA. The annual maximum series was compiled from several sources and translated to Redwood Creek at the Highway One Bridge (PWA, 2000). Data from the neighboring Arroyo Corte Madera were used to fill missing years in the Redwood Creek record (transformed on the basis of corresponding peak flow measurements in the over-lapping records). Table 4-3 and Figure 11 summarize the results of this analysis.

Table 4-3. Flow Frequency at Highway 1 Bridge

Return Period (Years)	Peak Discharge (cfs)
2	805
5	1,600
10	2,270
50	4,140
100	5,100

The hydrologic regime of Redwood Creek is similar to that of many northern California coastal streams. Early season storm flows are comprised primarily of direct storm runoff and recede quickly after rainfall ends. By January, groundwater storage is sufficient to maintain high baseflows, and post-storm recessions can last for over 7 days. Flows in the late spring and summer dry season are derived from groundwater and springs in the upper watershed. Limited groundwater storage is available in the alluvial deposits in the lower valleys, and during the dry season the creek commonly loses water to groundwater in the lower reaches in Frank Valley (PWA, 1995). By the end of the summer dry season, the creek can have virtually no surface flow. Figure 12 shows the recorded daily average flows in lower Redwood Creek from March 1992 through February 2003. Peak recorded average daily flows have ranged from 145 to 338 cfs, while minimum flows of less than 0.01 cfs were measured from mid-August 1992 to the end of October 1992.

Previous USGS monitoring efforts have recorded storm flows as high as 10 cfs on Green Gulch Creek. The watershed has limited groundwater storage, and flows are diverted and stored in two small reservoirs for irrigation. As a result, the creek contributes no observable flow to the lagoon during the dry season (PWA, 1994). NPS has been monitoring flows on Green Gulch since November 2002. At this time, the data are still preliminary, but stage has varied from 0.09 feet in November 2002 to 0.9 feet in January 2003.

4.2.2.2 Groundwater

Groundwater at the site was monitored bi-monthly to monthly in five shallow monitoring wells located in the Green Gulch pasture from September 1992 to October 1993 and has been monitored bi-monthly in 7 wells and two staff gauges since February 2003. The locations of the 1992-1993 and 2003 wells and staff gauges are shown on Figure 13, and all monitoring data are presented in Appendix A. Based on soil corings, the stratigraphy of this area consists of artificial fill material, ranging in thickness from about 1.5 to 8 feet, underlain by lagoonal silts and sands and some buried terrestrial alluvial deposits (Wells, 1994; Meyer, 2003). The fill material is comprised of pebbly silty sands and sandy silts. Groundwater is present in both the fill material and the historic alluvial and lagoon deposits.

The annual pattern of groundwater elevation at PWA Well 4 in Green Gulch pasture (see Figure 13 for location) is shown for the 1993 water year in Figure 14. Groundwater increased from a minimum elevation at the start of the water year to within about a foot of the ground surface from January through April and then decreased at a rate of about 0.5 - 1 feet/month through the summer. In the winter, groundwater levels followed the surface topography, with the highest elevations in the upper Green Gulch pasture. In the summer, the highest water levels were adjacent to the levee, as groundwater flowed from the upper pasture areas nearest the creek towards Green Gulch and the lower pasture.

In 2003, average groundwater elevations were about 1 to 2 feet higher than in 1992-93 due to backwater effects of the Willow/Alder grove, the higher thalweg of Redwood Creek, and the poor drainage of Green Gulch pasture (Figures 15). Groundwater elevations at NPS Well 4 followed a similar pattern as at PWA Well 4 in 1994, with groundwater just below in the surface in the winter months and decreasing at a rate of about 0.5 - 1 ft/month through the summer (Figure 14). Groundwater levels are expected to decrease with the new pilot channel improving drainage.

The alluvial aquifer in Frank Valley is a heterogenous aquifer that is hydrologically interconnected with surface flow from Redwood Creek. Groundwater elevations and surface flow in Redwood Creek are impacted by groundwater pumping upstream of the project site by Muir Beach Community Services District (MBCSD). (See Section 4.2.2.3 below for further detail.) Martin (2000) concluded that pumping water at the MBCSD well induces infiltration from Redwood Creek to the alluvial aquifer, with streamflow depletion accounting for 70-80% of the pumping rate of the well. In 1995, PWA concluded from groundwater modeling that the MBCSD pumping decreased instantaneous flows in Redwood Creek by as much as 0.09 cubic feet per second (cfs). This decrease in flow is really only significant in the late dry season, when flows are naturally on the order of 0.1 to 0.2 cfs (PWA, 1995). Lower Redwood Creek completely dries up naturally approximately once every 4 years; however MBCSD pumping could increase this frequency to approximately once in 3 years (PWA, 1995). Groundwater also used to be extracted from an irrigation well on the Banducci site, but pumping was halted in 1995. The pumping at Banducci had larger impacts on flows on lower Redwood Creek than the MBCSD well, (reducing instantaneous flows by as much as 0.14 cfs), thus the well abandonment has reduced pressure on groundwater resources (PWA, 1995).

4.2.2.3 Water Rights

Water is diverted directly from Redwood Creek and its tributaries by Marin Municipal Water District (MWWD) and Green Gulch Farm. The water rights claims in the Redwood Creek watershed are listed in Table 4-4, and their locations are shown in Figure 16.

MMWD has rights to divert water from seven locations in the upper watershed on Fern, Laguna, Spike Buck, and West Fork Rattlesnake creeks. Diversions on Fern and Laguna creeks are used to supply the West Point Inn and for fire fighting. The West Fork Rattlesnake Creek diversion provides water to Mt. Tamalpais State Park and for fire fighting. The remaining diversions have not been used in recent years. MMWD also supplies water to Muir Woods National Monument from sources outside of the watershed.

Green Gulch Farm inherited from George Wheelwright an elaborate system of reservoirs to store and divert flow from Green Gulch Creek and two of its tributaries for irrigation, stock watering, fire protection, recreation, and domestic use. This system includes five small reservoirs and diversions on Green Gulch Creek and two reservoirs on tributaries to the creek. The farm also has a state water right to divert 17 acre-feet of flow from Green Gulch annually. The farm has a point of diversion on Redwood Creek in Big Lagoon that has a water right for 47 acre-feet annually to be withdrawn between April 15 and September 30 (Johns, 1993). This diversion is not currently in use. Green Gulch also relies on two developed springs for additional water supply.

MBCSD supplies water to the Muir Beach community, which includes 147 service connections serving approximately 350 people (Martin, 2000). The MBCSD operates a well in the floodplain of Redwood Creek near the Banducci property. In 2001, the MBCSD received a permit from the State Water Resources Control Board to withdraw up to 50.6 acre-feet from the well annually. The permit includes special terms and conditions aimed at avoiding impacts on the creek, particularly during periods of low streamflow. These terms and conditions include requirements to develop a water conservation plan, evaluate the feasibility of obtaining water from alternate sources, and evaluate the feasibility of increasing storage capacity in the system.

Table 4-4. Ownership of Redwood Creek Watershed Water Rights

ID No.	Current Owner	Basis of Claimed Water Right	Source	Year First Used or Application Filed
671	MMWD	Appropriation prior to 1914	Rattlesnake Creek	1908
672	MMWD	Appropriation prior to 1914	Spike Buck Creek	1908
673	MMWD	Appropriation prior to 1914	Laguna Creek	1906
674	MMWD	Appropriation prior to 1914	Fern Creek	1903
675	MMWD	Appropriation prior to 1914	Fern Creek	1894
680	MMWD	Appropriation prior to 1914	Laguna Creek	1900
681	MMWD	Appropriation prior to 1914	West Fork Rattlesnake Creek	1900
29331	MBCSD	Application for permit to appropriate	Redwood Creek	1988
9845	Zen Center	License to appropriate	Redwood Creek	06/30/1964
8691	Zen Center	License to appropriate	Green Gulch and unnamed stream	03/16/1962
03-104	NPS (Banducci Tract)	Unknown	Redwood Creek	Unknown
03-105	NPS (Allard Tract)	Unknown	Redwood Creek	Unknown
02-194	NPS (Felix Tract)	Riparian right	Redwood Creek	Not applicable
02-138	NPS (Calif. Tract)	Riparian right	Redwood Creek	Not applicable
02-103	NPS (MWRO Tract)	Riparian right	Redwood Creek	Not applicable
02-105	NPS (MWRO Tract)	Riparian right	Redwood Creek	Not applicable
02-107	NPS (MWRO Tract)	Riparian right	Redwood Creek	Not applicable
02-108	NPS (MWRO Tract)	Riparian right	Redwood Creek	Not applicable
1806	NPS (Libra Tract) State Camp Hillwood	Appropriation prior to 1914	Unnamed tributary to Redwood Crk	1900
1807	NPS (Libra Tract) State Camp Hillwood	Appropriation prior to 1914	Unnamed tributary to Redwood Crk	1900

Source: Johns, 1993

4.2.2.4 Water Quality

Water quality data from a variety of sources (USGS, MBCSD, NPS, Marin County DHS) are available for locations along Redwood Creek and Green Gulch. Studies conducted by the USGS between 1986 and 1988 provide the most comprehensive spatial and seasonal baseline data sources. More recent studies conducted since the 1990's focused on pollutants that would be anticipated from stormwater runoff (*e.g.*, stables and agricultural activities), such as bacteria and other pathogens, ammonia, nitrates, nitrites and phosphorus. Appendix B summarizes the water quality data available from the mid-1980s to the present. A thorough discussion of the major water quality parameters (temperature, salinity, dissolved oxygen, nutrients, bacteria, etc.) is provided in Appendix B.

Designated beneficial water uses of Redwood Creek depend on water quality from the surrounding watershed. Beneficial uses (abbreviations in parentheses) range from shellfish harvesting (SHELL), agricultural production (AGR), irrigation and potable water supply (MUN), recreation (REC-1, REC-2), and support of the fish (FRSH, WARM, COLD, SPWN) and wildlife (WILD) resources that inhabit the project study area (SFRWQCB 1995). The beneficial uses by ecological resources include cold and warm water aquatic habitat, spawning, shellfish and wildlife. With the possible exception of bacterial contamination of municipal and recreational uses, the aquatic resources listed above are generally considered to be the most sensitive beneficial uses. Although no shellfish harvesting is known to occur on the site, the State Mussel Watch Program established a site (M59) in 1979 off of Muir Beach (Figure 6-2, SFRWQCB 1995). There are no known water quality impairments for agricultural and municipal uses, and since these withdrawals are all taken outside of the project site, the discussion below focuses on the impacts of water quality on the remaining recreational and ecological uses described above.

4.2.2.4.1 <u>Recreational Uses (REC-1, REC-2)</u>

In general, recreational uses relate to whether receiving waters are safe for human contact, swimming and the incidental ingestion of water from these activities. At sites influenced by point sources (*e.g.,* storm drains) or non-point sources (*e.g.,* agricultural runoff, septic leachate) of pathogenic contaminants, the Marin County Environmental Health Services Department (DHS) has assumed responsibility for monitoring of whether concentrations of bacteria or pathogens exceed recommended guidelines.

Appendix B shows that bacterial concentrations have been in excess of single-sample exceedence criteria in the past. Although recent monitoring conducted since the exclusion of horses from the project area shows general decreases in bacteria concentrations, Muir Beach was posted in summer 2003 due to 20-day exceedance violations for Enterococcus in ocean water samples collected by DHS. Although the planned restoration designs will not lead to increases in bacterial loadings, unknown sources of the continuing bacterial loading to the project area may continue to limit beneficial use attainment. Since most enteric pathogens can live with or without oxygen (i.e., facultative), the restoration design(s) could incorporate larger open water areas with well-oxygenated conditions as a means to promote the growth of competing bacteria.

4.2.2.4.2 Fish and Wildlife Uses (FRSH, WARM, COLD, SPWN, WILD)

Protection of water quality for aquatic and terrestrial uses depends upon a range of narrative standards within the Basin Plan (SFRWQCB 1995). At sites influenced by point sources (*e.g.,* storm drains) or non-point sources (*e.g.,* agricultural runoff, septic leachate, etc.), the identification of locations of degraded water quality and habitat conditions relies upon numeric water quality objectives within the Basin Plan (Chapter 3, SFRWQCB 1995). In addition to specific Basin Plan water quality objectives listed in Appendix B, the discussion below centers upon a habitat suitability for identified fish and wildlife resources at the site.

Temperature Water temperatures within the project site, generally range from 11–15 ^{o}C, with occasionally higher temperatures up to 18–19^{o}C in late summer and early fall (Appendix B). Although these temperatures are not in violation of Basin Plan objectives and are within the tolerance of many aquatic organisms, lack of shading, shallow water and salt water stratification in the lower portions of the study area (e.g., backwater) may create unfavorable conditions for fish in summer and fall, since no deeper predator refuge or cool water refuge is available.

Salinity Because of the episodic nature of beach closure and salt water intrusion, salinity extremes in the lower portions of the study area represent a natural disturbance common to the ecology of all estuarine systems. Examination of the historical data record (Appendix B) shows these conditions occurring in summer months in some years. As for temperature above, salinity in the lower portions of the project site (e.g., backwater) may create unfavorable conditions for salmonids and other freshwater fish in summer and fall, since no deeper predator refuge or cool water refuge is available. Nevertheless, these conditions are not in violation of Basin Plan standards and are minor when compared to periodic salt-water inflow events that naturally occur during storm surges to the lower portions of the study area.

Dissolved Oxygen (DO) DO concentrations within the project site are generally near saturation conditions (Appendix B). However, episodic exceedances of Basin Plan objectives have occurred at various times in the data record. Although conditions appear to have improved in recent years, there is some evidence for eutrophic conditions from historical reports of diurnal fluctuations in pH and DO concentrations in the downstream areas of the site (PWA *et al.* 1994). Because sampling is generally conducted in daylight hours, low oxygen levels may still occur in the night time and early morning as the result of plant, algal and bacterial respiration. Although it is uncertain as to whether these conditions could limit fish and wildlife uses within the Big Lagoon study area under the planned restoration scenarios, oxygen impacts are likely to be limited to the downstream portions of the study area.

Biostimulatory Substances Examination of the data record for nutrients within the project site suggests continuing contributions above natural background levels (Appendix B). Algae and plant growth under eutrophic (high nutrient) conditions, along with their subsequent decomposition in the water column lead to: 1) increased oxygen consumption (discussed above), 2) reduced light penetration, and 3) reduced visibility. The reduced penetration of light in the water in turn limits plant photosynthesis in deeper waters, and in combination with increased oxygen consumption (due to decomposition), may lead to oxygen depletion in deeper pools. Ammonia levels at the site appear to have declined since the implementation of horse management practices at the Golden Gate Dairy (Appendix B). Despite reductions in ammonia levels to below Basin Plan objectives in recent years, without further changes in the management of agricultural fertilizer, animal and human wastes in the Redwood Creek watershed, elevated nitrate levels (i.e., > 1–5 mg/L) may be expected to continue into the future. Depending on the design of the planned restoration alternative, tidal mixing, sunlight and other conditions, the expected nitrate concentrations may contribute to episodic algal blooms in the downstream open water lagoon areas. This may be no more than a nuisance during the first year or two following construction, or may represent a long-term influence on DO depletion and pH fluctuation in the lower portions of the study area. Although daily fluctuations in DO and pH from excess nutrients may limit the distribution of many aquatic species, it is unclear whether the site has pH variations great enough (approx pH 9.4 for the release of free ammonia) to create chronic or acute effects.

Suspended Sediment and Turbidity Sediment loading to the project site may result in the major water quality limiting factor in the planned restoration designs. Turbidity impacts relate to temperature and DO. In addition to the potential for fish habitat impairment from DO depletion and salinity, long-term excesses in turbidity and light absorption by sediments and algae may reduce water clarity, interfering with fish foraging and lead to decreased growth rates.

Bacteria Bacterial contamination of the water supply of Muir Beach as well as the backwater and beach areas has been an ongoing water quality concern (Appendix B). While the implementation of horse management practices have led to a decrease in fecal coliform concentrations in the Golden Gate Dairy tributary and lower Redwood Creek, bacterial water quality violations have continued to occur in the ocean at Muir Beach, leading to a 30-day beach posting in June 2003. Although bacterial loadings shown in the data record to date will not likely affect beneficial uses for fish and wildlife, beach postings will have a direct effect on recreational uses of the beach area. A more thorough investigation of bacterial sources and loadings to the study area would be required before the implementation of any source control measures.

Summary

In summary, the absence of shade in the downstream portions of the study site, the low water exchange rates in summer and the influence of nutrients and salinity may potentially combine to constrain the habitat area with suitable temperature conditions for fish to upstream or shaded sites within Redwood Creek. Although riparian shade and pool depths in the restoration designs can be managed, nutrient and bacterial loadings to Redwood Creek and Big Lagoon will not be altered from present day conditions by the planned restoration activities. It is anticipated that further long-term source reduction efforts in nutrients and bacterial loadings will be required for the Big Lagoon study area to reliably attain its designated beneficial uses.

4.2.3 Channel and Floodplain Morphology

4.2.3.1 Channel Capacity and Flooding

Since dredging activities ceased more than 20 years ago, lower Redwood Creek has lost conveyance capacity as the channel has undergone significant aggradation. As described in Section 3.2.3, the channel aggraded between 2 and 5 feet (over 3,000 yd^3 of sediment) from 1992 to 2002 between the parking lot and Pacific Way Bridge (Figure 7). Additional sediment has been deposited outside the main surveyed channels in the willows north of the parking lot. Channel deposition volumes agree with average annual bedload estimates (Stillwater, 2003), suggesting that the channel in this aggradation zone has been trapping most of the bedload in transport. Additional trapping of bedload and suspended load has occurred in the densely vegetated riparian willows, southeast of the parking lot. Deposition in this zone has filled the former main channel (i.e., the right channel), and the left channel is now the main channel.

Due to sediment deposition and subsequent loss of channel conveyance, moderate flows (approximately 1- to 1.5-year events) escape the lower Redwood Creek channel below Highway One, flooding Pacific Way near the Pelican Inn. Redwood Creek has not occupied the low point of the valley since being realigned along the western edge of the valley. For example, in April 2003, the thalweg of Redwood Creek at Pacific Way Bridge was +11 feet NGVD, while Pacific Way reaches a minimum elevation of approximately +9.5 feet NGVD. As a result, two small channels have formed below Highway One from overbank flows following the valley contours across Pacific Way, ponding water on Pacific Way near The Pelican Inn 1 to 2 feet deep over the winter and spring. This flood channel continues down the middle of Green Gulch pasture and re-enters the main channel through a culvert and over the levee road into the former backwater channel (see Figure 10). During moderate to large flow events, most of Green Gulch pasture is inundated, and floodwaters reach within a 1 to 2 feet of the parking lot elevation as flows converge at the south end of the pasture towards the beach.

In fall 2002, the NPS placed willow mattresses at the entrance of these overflow channels to reduce scour in these channels and reduce the potential for capture of the main channel of the creek. The Marin County Department of Public Works also constructed a 2 to 3 feet high gravel berm on the shoulder of Pacific Way downstream of the bridge to prevent flooding of the road. Without continued dredging upstream and downstream of the Pacific Way Bridge and maintenance of the channel banks, the channel can be expected to avulse and re-occupy its historical location.

4.2.3.2 Sediment Supply, Deposition and Transport

Stillwater (2003) estimates that lower Redwood Creek received approximately 2,670 yd^3/yr of suspended sediment and 435 yd^3/yr of bedload, on average, between 1981 and 2002. Stillwater (2003) attributes the contemporary sediment sources to the following:

- Hillslope erosion (19%);
- Tributary bank erosion (29%);
- Mainstem channel erosion (28%); and,

- Road and trail erosion (23%).

In its sediment budget, Stillwater (2003) concludes that, although the watershed land cover has generally recovered from the 19th century grazing and logging, excess sediment will continue to be produced from tributary erosion. Stillwater (2003) predicts that sediment delivery (combined suspended and bedload) over the next 50 to 100 years will be about 15% less than sediment delivery between 1981 and 2002, or approximately 2,700 yd^3/yr (Figure 5).

The elevated sediment delivery in conjunction with channel and floodplain alterations have resulted in three significant depositional areas in the project site:

- Upstream of Pacific Way Bridge;
- Between Muir Beach parking lot and Pacific Way Bridge; and,
- The Willow/Alder Grove area downstream of the footbridge.

4.2.3.2.1 Upstream of Pacific Way

The deposition upstream of Pacific Way Bridge is likely related to decreases in flow depths when flows overtop the banks towards the new channel forming along the low point of the valley. Flow obstructions caused by the bridge also contribute to sediment deposition. The Marin County Department of Public Works estimates that the capacity of the bridge prior to NPS excavation in 2002 was approximately 600 cfs, insufficient to convey a 2-year flow event of 805 cfs (Klein *et al*., 2002). Klein *et al*. (2002) also suggest that the bridge is not oriented parallel to the channel flow, reducing flow velocities and contributing to aggradation. In September 2002, the NPS excavated 2 to 3 feet of sediment from the channel in two areas: one extending from 220 feet upstream to 100 feet downstream of the Pacific Way bridge, and one extending from 384 feet to 524 feet downstream of the Pacific Way bridge. By April 2003, over 200 cubic yards of sediment had been trapped in this reach, re-filling about half of the excavated area upstream of Pacific Way Bridge.

4.2.3.2.2 Pacific Way to Parking Lot

From 1992 to 2002, 2 to 5 feet of sediment accumulated in the channel between the parking lot and Pacific Way Bridge (shown in Figure 7) due to the combined effects of flow constrictions by the levee road and parking lot and high channel roughness caused by trees that fell in the channel over this period. The parking lot, picnic area, and levee road have reduced the natural floodplain corridor by 80%, constricting flows upstream, reducing flow velocities, and contributing to sediment deposition. Initial hydraulic modeling results suggest that the current parking lot configuration effects flows over 750 and 800 feet upstream during the 5-year and 50-year flow events, respectively. During the 5-year flow, for example, the parking lot raises water surface elevations in the channel by about 1 foot. High groundwater levels have killed a number of trees in the riparian zone downstream of Pacific Way Bridge. The hydraulic roughness of the channel was increased as these trees fell into the channel, slowing flow velocities and contributing to channel deposition. A major log jam was responsible for 2 feet of deposition immediately upstream of the division of the main channel into two branches. This log jam was removed during the channel excavation in September 2002 described above. Smaller log jams contributed to the filling of the left and right channels in the dense willow area north of the parking lot.

4.2.3.2.3 Willow/Alder Grove

The third area of significant channel deposition is in the Willow/Alder Grove downstream of the footbridge. Since 1992, maximum elevations in the Willow/Alder Grove have increased by 1 to 2 feet to +6.5 NGVD (Figure 7). This deposition has probably been caused by increased roughness in the channel and reduced flow velocities due to the maturing and spreading of willows and alders. The pilot channel has re-invigorated flows and has begun to slowly erode the channel bed (approximately 0.5 feet of downcutting has been documented between September 2002 and April 2003).

Initial modeling results of the shear stress distribution along the channel during a 5-year event generally support the patterns of deposition observed (Figure 17). Shear stress is the force available to entrain sediment into the water column as bedload or suspended sediment transport. A threshold shear stress that varies according to the size and density of the sediment must be reached to initiate transport. Below this critical shear stress, bed sediment will not be entrained into the water column, and sediment already in transport may settle out of the water column if flow velocities fall below the sediment settling velocity. Negative gradients in shear stress are found in each of the three major depositional areas described above. Shear stress decreases by about 85% from about 1000 feet upstream of Pacific Way Bridge to the bridge. Shear stress decreases again approximately 450 feet downstream of the bridge as the channel encounters several small debris jams upstream of the former backwater channel. Shear stress increases rapidly downstream of the parking lot but decreases almost immediately in the Willow/Alder Grove.

4.2.4 Coastal Resources

4.2.4.1 Oceanography

Waves on the California coast are comprised of both seas and swells. Seas consist of short period waves created by local winds, while swells are long period waves that originate from offshore storms, typically in the northern Pacific Ocean. Figure 15 depicts a wave rose for wave conditions measured 21 miles west of Pt. Reyes in a water depth of 1800 feet from 1997 to 2002. The dominant wave direction is from the northwest (290 to 315 degrees); however, there are periods where seas and, less frequently, swells arrive from a southwesterly direction (Figure 18; CDIP, 2003a). Wave heights are greatest during winter storms between November and March, when significant wave heights average 9-10 feet and maximum wave heights can reach over 25 feet (Figure 19; CDIP, 2003a).

Wave erosion potential is primarily controlled by wave power, which is proportional to the square of the wave height (Komar, 1998). Given the dominant north-northwesterly wave direction, Muir Beach is generally characterized by significantly lower wave heights than at the Pt. Reyes wave gage, due to wave shadow effects of Pt. Reyes, Pt. Bolinas, and the local northern headland at Muir Beach. Waves from the north-northwest direction must diffract around these headlands to reach the beach, losing considerable energy in the process. For example on June 23, 2003, the CDIP wave model for the Golden Gate region predicted wave heights of 1 to 2 feet when waves measured at Pt. Reyes were 7.4 feet from 325 degrees (CDIP, 2003b). Muir Beach is directly exposed to south-southwesterly swell and seas, but waves from this direction lose energy due to shoaling on the San Francisco Bar.

The orientation and morphology of the beach and headlands are also important for sand transport. Along northern California, the net longshore transport (sand movement parallel to the shoreline) is from north to south, due to the north-northwest dominant wave approach. Sediment transport is not well characterized along the Marin County coast, where headlands and irregular rocky nearshore bathymetry create complex sediment transport pathways. The headlands and offshore bedrock topography act as barriers to longshore transport of sand, except during high-energy conditions when sediment can be more easily entrained around these rocky obstacles. During low energy conditions, sand movement at Muir Beach is driven more by on- and off-shore transport rather than longshore transport. This also implies that Muir Beach may be more dependent on sand supplied from Redwood Creek than upcoast littoral drift.

4.2.4.2 Beach Morphology

Muir Beach is a sandy pocket beach, bounded by rocky headlands at the mouth of Redwood Creek, a very typical morphology for northern California. Muir Beach undergoes significant seasonal changes in shape as wave conditions vary over the year as shown in Figure 19. At the end of the summer or early fall when typically calm seas occur, a well developed beach berm develops, and the beach reaches its peak width. Over the winter, high-energy, steep waves tend to move sand offshore, lowering and flattening the beach profile. As the high-energy conditions subside in late spring and early summer, the beach recovers as sand is moved on-shore, rebuilding the beach berm. Typical winter and summer profiles at Muir Beach were surveyed by PWA in 1992 and 1993 (Figure 20). Muir Beach experiences most severe erosion when high-energy wave conditions coincide with elevated sea levels, allowing waves to penetrate a greater distance inshore and dissipate less energy via bottom friction. The 1982-83 and 1997-98 El Niño winter storms caused severe beach and cliff erosion along California's coast for this reason—high waves arrived at the coast during a period of super elevated sea levels due to anomalously high sea surface temperatures and often during high winter tides (Storlazzi *et al*., 2000). Erosion was especially severe because waves during these El Niño events arrived from the west to southwest direction and therefore lost minimal energy through refraction and diffraction processes. El Niño events typically occur every 3 to 7 years and will likely cause severe but temporary beach erosion at Muir Beach.

Between the 1992 and 2003 topographic surveys, the beach appears to have shifted landward by approximately 50 feet. The berm heights appear to be similar, but the 2003 berm has shifted landward, filling and narrowing the tidal lagoon. The topographic data on the beach are not as reliable due to photogrammetric limitations related to image contrast (Willis, 2002), so these data should not be treated as absolute. However, this landward shift is consistent with our conceptual model of the back beach creek channel-beach interaction. Annual high winter flows scour the back beach, inhibiting the landward migration of the beach. Since 1992, flows on the beach have been reduced due to flow constrictions and backwater effects caused by the Willow/Alder Grove. The pilot channel, excavated in 2003, has reinvigorated flows, but the channel was excavated more than 100 feet inland of its historical location. Moving the scouring action of the channel further inland has enabled wave overtopping and wind transport to maintain higher beach elevations in the back beach area.

Muir Beach's morphology also varies in a shore parallel direction, rising from a minimum elevation (approximately +1 to 2 feet NGVD) at the northern end of the beach to the maximum elevation (approximately +17 feet NGVD) at the dune crests at the southern end of the beach. Local winds typically blow from the north-northwest, building up dunes at the southern end of the beach. The low elevation at the northern end of the beach is maintained by flows from Redwood Creek. Historical maps and photos consistently show the mouth of Redwood Creek at the northern end of the beach. The creek flows to the northern end because it is the most sheltered from wave energy (due to refraction around the northern headland) with the least wave power to rebuild the beach and provide resistance to creek flows. Since the 1992 topographic survey, the beach elevations in the southern dune area have increased by about 3 feet as a result of a dune restoration program initiated in 1995.

4.2.4.3 Dunes

The only well developed dunes at Muir Beach are located at the southern end of the beach, where the dominant north-northwest winds are able to transport sufficient quantities of dry sand to form dunes. Maximum dune heights are approximately 17 feet NGVD. The small dune field has expanded to the north since NPS fenced off the field in 1995, limiting slope disturbances from foot traffic.

4.2.4.4 Lagoon

Coastal lagoons have highly dynamic features that are shaped by beach berm evolution, wave climate, tidal flows, and freshwater inflows. The vast majority of previous research has focused on lagoon opening and closure dynamics in lagoons larger than 10 acres in surface area. The 1994 PWA et al. report was one of the first attempts to characterize the dynamics of a small coastal lagoon system.

Lagoon outlets are maintained and scoured by a combination of tidal and freshwater flows. In larger systems, the tidal component (quantified by the tidal prism) tends to control lagoon opening and closure frequency. Conversely, the freshwater inflow component is dominant in small lagoon systems. Wave dynamics and sediment transport also play an important role by determining the shape and elevation of the beach berm. During the winter, high-energy waves erode the beach, and creek flows are sufficient to maintain an open lagoon inlet. In the summer, waves transport sand onto the beach and the lagoon may close depending on tidal and inflow conditions. Closed lagoons fill with freshwater inflows and lose water to evaporation and seepage through the beach berm. The lagoon will breach when the ponded elevation exceeds the beach berm height. In systems with high summer flows, this may occur several times in a season. In lagoons where losses exceed summer inflows, the lagoon remains closed until winter storms breach the outlet.

A number of studies have attempted to use empirical data to predict the frequency of lagoon opening and closure. The most widely applied of these empirical methods is the Johnson method, based on data from over 30 west coast lagoons (Johnson, 1973). Johnson (1973) relates closure frequency to deep water wave power and tidal prism. Applying these criteria to Big Lagoon shows that tidal flows in this case are not sufficient to maintain a stable opening. In fact, increasing the size (or tidal prism) of the lagoon would have little impact on closure frequency. Therefore, the existing tidal lagoon will remain open only as long as freshwater inflows are sufficiently high to scour an outlet channel through the beach berm.

The lagoon exhibits four seasonal modes of behavior, defined as follows:

1. <u>Fully Closed:</u> The lagoon outlet is entirely filled with sand, and the beach berm is at +6 feet NGVD or higher. The lagoon may fill initially with freshwater, but eventually diminishes due to evaporation and seepage. This mode occurs following closure in the mid-summer, and persists until the first major winter storms.

2. <u>Open, Nontidal:</u> Periods of strong onshore sand transport build the beach berm up to a level that prevents tidal inflow. At the same time, freshwater inflows are sufficient to maintain an open channel across the berm. During the field monitoring of 1992-1993, this occurred in March of 1993.

3. <u>Open, Tidal on Spring Tides:</u> The beach berm is built up to a level that allows tidal inflows only during spring higher high tides; neap tides do not enter the lagoon. Freshwater inflows are still sufficient to maintain an open outlet. This occurs in the spring and early summer prior to full closure.

4. <u>Open, Partially Tidal:</u> The outlet channel is scoured to as low as +1 feet NGVD, allowing tidal inflow during all tidal cycles. Low tides are still muted. This mode occurs during the winter when flood flows are very high and the beach profile is eroded by winter storm waves.

Volunteers organized by the National Oceanic and Atmospheric Administration (NOAA) have been monitoring the status of the tidal lagoon mouth since the fall of 1998 approximately every two weeks. The status of the lagoon mouth (i.e., open or closed) observed from 1998 to 2002 generally support the seasonal pattern described above. The mouth was observed to be open on 44% of fall field visits, 100% of winter and spring field visits, and 80% of summer field visits. A fully closed lagoon mouth was generally observed only in late summer and early fall.

Since 1994, the lagoon surface area has decreased as the back beach flow was initially reduced then moved landward. By moving the scouring action of the back beach channel landward, wave overtopping and wind transport have filled the tidal lagoon and reduced its area. A more complete description of this process is presented in Section 4.2.4.2.

4.3 BIOLOGICAL RESOURCES

Between 1992 and 1993, PWA *et al.* (1994) monitored existing and former wetland habitats within the historic Big Lagoon ecosystem. The biological monitoring focused on major wetland-dependent floral and faunal groups to establish a qualitative and quantitative description of species composition and relative abundances. The description was made in part to help develop potential restoration alternatives, and also to document existing biological conditions and patterns of seasonal change as a baseline from which to compare the results of future restoration efforts. Vegetation and wildlife groups that depend on existing wetland habitats and are sensitive to increases or decreases in the quality and quantity of wetland habitat were monitored, including plant assemblages, aquatic invertebrates, fishes, reptiles, amphibians, and birds. For each group, monitoring sites were selected to characterize different types of existing habitats or potential restored habitats within the larger wetland complex. This information was summarized in the 1994 Preliminary Environmental Assessment (PWA *et al.* 1994).

The biological resources information contained in the 1994 PWA *et al.* report has been updated to reflect recent knowledge and changes in existing conditions since 1993, based on existing information made available from NPS and the PRBO. This includes updated vegetation mapping completed as part of 2002 and 2003 wetland delineation, classification (following Cowardin *et al*. 1979) mapping, post-1993 survey results for wildlife and fish species, and updated information on the status and presence of special-status species at the site. No new field monitoring was conducted specifically for this report. If certain vegetation or wildlife communities have not changed significantly, or if no new information was provided, the 1994 PWA *et al.* descriptions and survey results provide the sole source of information. No additional historical information (i.e., prior to 1992) has been added.

4.3.1 Vegetation/Habitat Types

Existing vegetation at the project site is largely comprised of riparian forest and scrub, and seasonally to semi-permanently flooded emergent wetlands (Figure 21), containing both native and non-native plant species. The NPS has compiled a plant list (Appendix C) from various surveys conducted in the Big Lagoon project area, including the species reported by PWA *et al.* (1994). Of the 219 species reported, 64 percent (n = 140) were native and 36 percent (n = 79) were non-native. Predictably, most non-native vegetation grows in disturbed areas currently impacted by human activity (e.g., roadsides, trailsides, and picnic areas). In contrast, species number and cover of native species are greater in less-impacted riparian, aquatic and upland sites. In general, non-native species (e.g., annual grasses and white clover [*Trifolium repens*]) dominate the higher, drier areas of the Green Gulch pasture, and a mix of native species and non-native weeds (particularly invasive Mediterranean annual grasses) have established on habitat edges such as the levee. Riparian, aquatic, dune and marsh habitats are comprised mainly of native species. The dune area has the lowest species richness (n = 16) compared to all other habitat types (Appendix C).

Six major plant associations in the lowland were quantitatively sampled during 1992–1993 as part of the 1994 EA (PWA *et al*. 1994; see Appendix D, Figure D-1 for transect locations). They were, with approximate area, pasture (8 acres), salt marsh (1 acre), disturbed (1.25 acres), riparian (4.25 acres), aquatic (nearly 1 acre), and dune (1.5 acres). Eight transects were established for quantitative seasonal surveys along the major subhabitats within the existing and historic wetland: one in disturbed habitat dominated by Kikuyu grass (*Pennisetum clandestinum*), one in the salt marsh, one in the lower riparian (or aquatic), and five in the Green Gulch pasture. An additional transect was established in the upland hillsides. Details about qualitative and quantitative survey methods can be found in Appendix D.

Since the 1993 surveys, there have been four additional surveys that have included vegetation within the Big Lagoon project area:

- PORE survey in 2002 (cited in Appendix C);
- Rare plant surveys within the project boundary, spring 2002 and spring 2003;
- ACOE Jurisdictional Wetland Delineation, 2003 (Figure 22)**;**
- Wetland mapping using the Cowardin classification system, 2002, with additional area within the project boundary mapped in 2003 (see Figure 21 and Appendix E, which associated plant species list by polygon).

These recent surveys document an expansion of the riparian forest south and east of the parking lot, and a shift from dry upland pasture in the Green Gulch pasture to a seasonal wetland with increased inundation and saturation (see Figures 3 and 21). More specific information on changes since 1993, species composition, and location within the Big Lagoon project area by habitat type is discussed below.

4.3.1.1 Riparian Forest and Scrub

In 1993 the riparian corridor included areas of low, aquatic herbaceous vegetation grading into the tidal lagoon and in the quiet water along the levee. The main riparian forest/scrub at the site extended between the present and former creek channels, bounded by the levee road, Pacific Way, and the parking lot (Appendix D, Figure D-1). Today riparian vegetation also extends 1) in a small linear strip along the eastern side of the levee road; 2) around the eastern and southern side of the parking lot, on sediment deposited downstream of the footbridge more than a decade ago; 3) along Green Gulch Creek; and 4) in the vicinity of and continuing upstream of the Pacific Way bridge (Figures 3 and 21). Most of the riparian vegetation in these areas is no more than 40 to 50 years old and is recovering from agricultural clearing (aerial photographs taken in 1947 indicate that the riparian corridor along Redwood Creek downstream of Pacific Way was cleared for grazing [Vick, 2002]).

Riparian vegetation at the site is composed primarily of a dense canopy of red alder (*Alnus rubra*), arroyo willow (*Salix lasiolepis*) and yellow willow (*Salix lucida*), and an understory of thimbleberry (*Rubus parviflorus*), blackberry (*Rubus ursinus* and *Rubus discolor*), and red elderberry (*Sambucus racemosa*) mixed with thick stands of nettles (*Urtica dioica*), water parsely (*Oenanthe sarmentosa*), hedgenettle (*Stachys ajugoides*), native morning glories (*Calystegia* spp.), and non-native cape ivy (*Delairea odorata*) and English ivy (*Hedera helix*). Patches of cattail (*Typha latifolia*) and other emergent vegetation grow at the waters edge.

Fifteen of the 49 species (31 percent) identified in riparian areas were non-native (Appendix C). Most of the non-native species occupied the riparian edge; however, a relatively high cover of non-native English and cape ivy occurred well within the forest. Alvarez (1999) conducted a field study to determine the effects of cape ivy invasion on plant communities within the GGNRA. Within the Redwood Creek vicinity, plots where cape ivy was dominant (> 70 percent cover) had lower plant species diversity, altered species composition in favor of non-native species, and reduced abundance and diversity of seedlings (Alvarez 1999). In plots where cape ivy was removed, there was a significant increase in plant species richness, predominantly due to increases in seedling recruitment of grasses and forbs (Alvarez 1999). Cape ivy invasion has also been found to alter the riparian terrestrial invertebrate community within Redwood Creek (Fisher *et al*., 1997). Plots invaded by cape ivy had significantly lower abundance of flies (Diptera) and beetles (Coleoptera) and increased abundance of springtails (Collembola) than plots that were devoid of the ivy (Fisher *et al*., 1997). These alterations in riparian community structure and composition may affect vertebrate taxa as well. Restoration efforts should consider removal of cape ivy as a priority.

4.3.1.2 Seasonal Wetlands in the Green Gulch Pasture

The Green Gulch pasture area (Figure 3) was historically a wetland, and then was filled with as much as 6 feet of sediment (through deposition and mechanical fill), as discussed in Section 3.2.2. The Green Gulch pasture area has since transitioned from a relatively dry, elevated, flat grazing area dominated by grasses, back to a seasonal wetland as surface and groundwater levels have risen over the past 10 years (discussed in Section 3.2.3).

There are currently three distinct water regimes and corresponding vegetation communities in the pasture, moving from west to east (Figures 3 and 21), including 1) a semi-permanently flooded region that runs adjacent to the levee road and is dominated by cattails (*Typha latifolia*) transitioning into 2) a seasonally flooded emergent wetland area; and 3) the seasonally saturated rectangular field between Green Gulch Creek and an unnamed tributary (Field 7; see Figure 3). In addition to cattails, dominant native species include obligate or facultative wetland species such as spikerush (*Eleocharis macrostachya*), water plantain (*Alisma plantago-aquatica*), silverweed (*Potentilla anserine*), and water parsley (*Oenanthe sarmentosa*). Of the 56 plant species recorded, however, 30 (54%) were non-native (Appendix C). These non-native species, including annual grasses (*Polypogon monspeliensis, Lolium perenne*), penny royal (*Mentha pulegium*), creeping bent (*Agrostis stolonifera*), clustered dock (*Rumex conglomeratus*), bull thistle (*Cirsium vulgare*), poison hemlock (*Conium maculatum*), and ox-tongue (*Picris echioides*) are concentrated around disturbed areas (e.g., adjacent to the levee road, trail, or horse paddock area) and areas that are more elevated and dry (e.g., the pasture between Green Gulch Creek and the unnamed tributary, which is dominated by annual bluegrass [*Poa annua*]). A few native trees grow along the pasture side of the levee, including black cottonwood (*Populus balsamifera*) (native to coastal California but not historically locally native), California buckeye (*Aesculus californica*), shore pine (*Pinus contorta*), and an elderberry (*Sambucus* spp.).

Recent management activities by NPS conducted in late 2002 to excavate the channel (discussed in Section 3.2.3) have reduced backwater effects and lowered groundwater elevations, improving drainage of Green Gulch pasture. If these efforts continue, the vegetation within the pastures will likely shift from obligate wetland species to more facultative and upland species such as those present during 1992–1993 surveys (see Section 3.3.2).

Cattails, which can spread both vegetatively and by seed, currently dominate the semi-permanently flooded area of the Green Gulch pasture. Although cattails are native, they can clone rapidly and produce a large leaf surface area, which outcompete other emergent vegetation and produce a dense, monospecific stand. Restoration efforts will need to address continued encroachment of cattails into any perennially wet areas to ensure that a diversity of native wetland vegetation is allowed to establish at the site. It should be noted, however, that the cattails are currently providing breeding habitat and cover for California red-legged frogs in the study area (see discussion under Section 4.3.2.1), so the benefits of habitat diversity versus red-legged frog habitat will need to be considered.

4.3.1.3 Permanently Flooded and Intermittently Exposed Habitat

PWA *et al.* (1994) considered areas with standing water, such as channels or broad regions of low elevation, to be aquatic habitat. These included human-made excavations that held or conducted water most or all of the year. The channels included Redwood Creek, as well as two channels or ditches through the Green Gulch pasture (Figure 3). Currently, the only areas mapped as permanently flooded or intermittently exposed habitat (Figure 21), besides the willow/alder grove already discussed in section 4.3.1.1 (Riparian forest and scrub), are the Redwood Creek channel and the unnamed tributary through the Green Gulch pasture (see Figure 3).

Nineteen of the 52 species (37%) recorded in permanently flooded or intermittently exposed habitat within the Big Lagoon project area were non-native (Appendix C). Although the area of permanently flooded or intermittently exposed habitat has decreased, the species composition has not changed significantly since the 1992–1993 surveys (Appendix E). During 1992–1993 surveys in lower Redwood Creek, non-native species were concentrated along the lower creek edges; the dominant cover here included ox-tongue (*Picris echioides*), creeping bent grass (*Agrostis stolonifera*) and pennyroyal (*Mentha pulegium*). The non-native knotgrass (*Paspalum* spp.) covered much of the shallow water flats downstream of the footbridge. Three emergent native plants were most common: three square rush (*Scirpus americanus*), cattail (*Typha latifolia*), and species of bulrush (*Scirpus* spp.). Other native wetland species which grew along the transect area included water plantain (*Alisma plantago-aquatica),* tall cyperus (*Cyperus eragrostis*), monkey flower (*Mimulus guttatus*), and small red alders. Other species present today include water parsley (*Oenanthe sarmentosa*), dotted smartweed (*Polygonum punctatum*), floating marsh pennywort (*Hydrocotyle ranunculoides*), silverweed (*Potentilla anserina*) and Baltic rush (*Juncus balticus*).

4.3.1.4 Brackish Marsh

A brackish marsh area is present between the tidal lagoon and the parking lot, divided by a former beach access trail, and bounded by the willow/alder grove and the hillside residential area. A buried retaining wall (built in conjunction with the former tavern) appears to serve as a barrier between the brackish marsh community and the disturbed area dominated by Kikuyu grass located immediately adjacent to the parking lot (discussed in the following section). Recent wetland mapping shows the area between the tidal lagoon and the parking lot, excluding the willow/alder grove, as a mix of seasonally to semipermanently flooded emergent wetland, with a small strip of permanent tidal emergent wetland (Figure 21). The species composition is currently dominated by salt rush (*Juncus leseurii*), salt grass (*Distichlis spicata*), and silverweed (*Potentilla anserina*), similar to that described following quantitative surveys during

1992–1993 by PWA *et al.* (1994). There are not very many communities like this south of Point Reyes (NPS Technical Scoping Notes, 2002).

Two salt marsh species were observed in 1992–1993 in the marsh in very small patches (less than 1 m^2 each). A few alkali heath (*Frankenia salina*) plants grew along the sandy northwest edge of the marsh and a patch of jaumea (*Jaumea carnosa*) grew along the east side of the path. Neither species was observed during 2002 wetland mapping (Appendix E). One gum plant (*Grindelia stricta*) plant was observed in 2003.

4.3.1.5 Disturbed Habitats

The existing condition and composition of plant communities on most of the wetland habitats in the project area indicate that the area was historically and continues to be disturbed by human land use. In addition to habitat edges and high traffic areas (e.g., the levee road and trail), a disturbed association begins immediately adjacent to the parking lot (beach-side) and grades into the brackish marsh area. The name refers to the weedy and invasive nature of the plants comprising that association. Although the disturbed site does not cover a large area, it should be considered as a candidate site for restoration efforts both to restore native habitat and to reduce the risk of non-native plants spreading to other areas.

This disturbed site was noted in PWA *et al.*(1994) as a site of heavy human use throughout this century. Kikuyu grass comprised nearly 100 percent cover along the transect sampled in 1992–1993, except during the spring when non-native vetch (*Vicia sativa*) was a co-dominant. Kikuyu grass graded into the brackish marsh where rushes and silverweed became dominant; into the urbanized upland dominated by weedy and ornamental species; and into the parking lot/picnic area covered by herbaceous weeds such as annual grasses and scarlet pimpernel (*Anagallis arvensis*). The only native species observed were occasional rushes. Today, grasses, curly dock (*Rumex* spp.) and creeping bentgrass (*Agrostis stolonifera*), typical of the seasonal wetland that used to be more dominant in the Green Gulch pasture area, dominate vegetation of the area between the tidal lagoon and the parking lot (NPS Technical Scoping Notes 2002). It is interesting to note that a buried retaining wall from the old tavern appears to be a barrier between the brackish marsh and this disturbed association.

Some of the introduced species provide a major challenge to eliminate. None may be more difficult than Kikuyu grass. This species is a perennial, with leaves that brown seasonally, but build up heavy, suffocating cover that makes it difficult for other species to establish seedlings. The grass grows in a large variety of habitats, produces a deep, thick root system, is difficult to eliminate with herbicides, and is not preferred forage for grazing animals.

4.3.1.6 Dunes

The dune community at the site occupies the narrow fringe between the intertidal zone and the lower creek channel (Figure 3). This area has historically been degraded by visitor use and has been the focus of restoration efforts conducted by the NPS since 1995 (Shoulders, *pers comm*, 2003). The area continues to provide restoration opportunities to improve natural dune formation processes and the presence of a more diverse native plant community.

In 1992 and 1993, PWA *et al.* sampled three tiers of dunes: four low mounds above the high intertidal zone, two large back dunes footing the upland hillside, and two larger mounds intermediate between the first two tiers. Sixteen species of plants were observed on dune habitat. Only three true dune species occurred: beach bur (*Ambrosia chamissonis*), native dune grass (*Leymus mollis*) and sand verbena (*Abronia latifolia)*. An additional coastal native species, lizard tail (*Eriophyllum staechadifoliym*), was found in the backdune. However, it is not restricted to dunes, but is common in coastal scrub communities as well. Seven non-native species grew in the dune habitat, including the highly competitive European beach grass (*Ammophila arenaria*), ripgut brome (*Bromus diandrus*) and Hottentot fig (*Carpobrotus edulus*) (ice plant). One non-native, sea rocket (*Cakile maritima*), is actually considered a favorable early colonizer of the lowest, wave- and wind-disturbed foredunes. The other non-natives were typical of upland habitat and were not abundant.

The low count of native dune species was indicative of the degraded state of the habitat. Though the narrow area available between foredune and hillside restricted development of mid- or backdune plant communities, the most important inhibitor to the establishment of a healthy dune community was overuse by visitors. Trampling killed plants, destabilized sands, and thus precluded re-establishment of native vegetation. The foredunes were more species-poor and had lower vegetative cover than healthy dune communities in other coastal areas, such as the better developed local dunes at Stinson Beach. Species present included both natives (beach bur) and highly invasive non-native species (ripgut brome and European dune grass). Middunes were also vegetated by natives (e.g. beach bur, dune grass) and non-natives (Kikuyu grass). Back dunes graded into the hillside and supported moderate to dense cover of natives (mugwort [*Artemisia douglasiana*], sand verbena and native dune grass) mixed with a significant cover of non-natives like ripgut brome and mustard (*Brassica* spp.).

Beginning in 1995, NPS has made several efforts to protect and restore the dune community in this area, including protective fencing, re-direction of pedestrian traffic, and removal of invasive non-native plant species (Shoulders, *pers comm*, 2003). Dune restoration since 1995 has also included removal of nearly all iceplant from the dunes. With these efforts, the dune area has expanded, although the lobes that have developed continue to be disconnected by visitor paths across the beach, limiting the processes of natural dune formation (Shoulders, *pers comm*, 2003). Additionally, the dune plant community is still characterized by very low species diversity, and non-native weeds such as ripgut brome are more extensive than native species (Shoulders, *pers comm*, 2003). Dominant species include beach burr, sand verbena, and sea rocket. Dune grasses (*Leymus* spp.) also occur at the foredunes, and some riparian species such as mugwort (*Artemisia douglasiana*) and California bee plant (*Scrophularia californica*) occur where dunes intergrade with wetland areas.

Natural disturbance of the dunes by wave wash may have almost as much impact on dune vegetation as human disturbance. Winter storms commonly wash most of the central and northern section of the beach, with sea water running into the tidal lagoon. This disturbance occurred during several high tides and winter storms in 1993.

4.3.1.7 Upland Hillsides

Upland habitat of modified coastal scrub grows adjacent to the site on the surrounding hills. The upland hillsides adjacent to the project site have not been quantitatively sampled recently. One plant transect was regularly surveyed along the hillside coastal scrub community during PWA *et al*. (1994) surveys (see Appendix D, Figure D-1). The site was dominated by high cover of non-native annual species, including hair grass (*Aira caryophyllea*), soft chess (*Bromus hordeaceous*), geranium (*Geranium dissectum*), annual fescues (*Vulpia* spp.), hedgehog dogtail (*Cynosurus echinatus*), and plantain (*Plantago* spp.). These non-natives comprised 47 percent of the species recorded in upland sites (Appendix B). Needle grass (*Nassella pulchra*), blue wild rye (*Elymus glaucus*) and yarrow (*Achillea millefolium)* were the most common natives recorded.

Aside from the single upland transect station, only a broad qualitative assessment was made of the uplands near th site as part of the PWA *et al*. (1994) efforts, and no attempt was made to generate a comprehensive species list. However, 49 plant species were recorded along or near the transect, a large number considering the small area sampled. About one half of them were non-native.

A nearly 150-year history of cattle grazing is likely responsible for the high proportion of non-native plant cover observed during 1992–1993 surveys. In addition to non-natives recorded, dense thickets of Harding grass (*Phalaris aquatica),* thistles and poison hemlock grew in swales where cattle had likely congregated in the past. Many smaller, short-lived non-natives were numerous and indicative of heavy grazing disturbance.

Recent photos (1991) document some recovery from livestock disturbance. The hillside grassland of non-natives is apparently being replaced in some areas by native shrubs, probably mostly coyote brush (*Baccharis pilularis*). Native herbaceous species, including perennial grasses such as needle grass and blue wildrye, are present. However, the abundance of non-native species indicates that the uplands are still significantly damaged from past disturbances.

4.3.1.8 Discussion

The existing plant communities indicate a wetland complex that is recovering from historical disturbance, and certain areas (e.g., the dunes) that continue to be disturbed. The number of non-native and invasive species is high, covering parts of Green Gulch pasture and surrounding permanent human structures such as the parking lot, roads, and levee road. Many of these species present a major challenge to eliminate.

The plant communities with the greatest native composition and cover were usually wetter, occupying the riparian and aquatic habitats. The species present in these communities (e.g., willows) are typically first to colonize bare, wet surfaces, and have quickly established in degraded areas fenced off from visitors by the NPS in 1998 and 1999 (e.g., the small wetland area near the pedestrian bridge, and the former picnic area south of the parking lot) (Shoulders, *pers comm*, 2003).

However, the wetlands are highly susceptible to invasion by non-native plants as the landscape dries. The Green Gulch pasture community is an excellent example. These historical wetlands were elevated, ditched, and drained to create pasture for grazing, most notably during the time the property was owned by George Wheelwright (1960s). The number of non-native invasive species was likely high, especially since some of the non-native grasses were introduced or encouraged for grazing (e.g., meadow foxtail and white clover). Surface and groundwater levels in the pasture have risen over the last 10 years, and the pasture is returning to a wetter condition supporting more obligate wetland species, especially in the area immediately adjacent to the levee. Now, cattail and bulrush have established. Recent efforts to improve drainage may cause the pastures to dry again, returning the area to a condition susceptible to re-invasion by non-native grasses.

The pattern is also present in the tidal lagoon, where the dry years of the 1980s probably diminished the health of rushes and silverweed, allowing non-native weeds to become established and persist (evident during 1992–1993 surveys). Weed abundance was likely stimulated by chronic disturbance from wandering dogs and people. Many of the weeds may be inundated and die back during wetter years (e.g., growth of silverweed in the summer of 1993 appeared more robust than the previous year, perhaps a response to wetter conditions), but the large seed bank and ability to outcompete natives would likely allow quick re-establishment, in both the brackish marsh and the Green Gulch pasture, when conditions dry.

4.3.2 Fish and Wildlife

This section presents summary discussions of available data for amphibians, reptiles, birds, mammals, fish, and invertebrates in the Big Lagoon project site. In addition, more complete results of wildlife surveys (invertebrates, bird, mammals, and fish) over the past 15 years are presented in Appendices F through I.

4.3.2.1 Amphibians

Several surveys focused on two special-status species, the foothill yellow-legged frog (*Rana boyleii*) and California red-legged frog (*Rana aurora draytonii*), have recently been conducted at the project site (Fong 2000, Cook 1998, Fellers and Kleeman 2003, Fellers and Guscio 2003). Incidental observations of other amphibian species made during these surveys are presented in Table 4-5. Amphibian surveys conducted in the project area in 1992 and 1993 focused on key amphibian habitats. In addition to the creeks and riparian zones, these included locations where ponded surface water was present (e.g., in the pasture areas). Species composition and relative abundance were estimated in qualitative surveys made each month and more frequently during wet periods when wetland usage was greater (see Appendix D for survey methods). The results are summarized below, and special-status information is provided in Section 4.3.3.3.

4.3.2.1.1 Red-legged frog surveys (2002–2003)

Fellers and Guscio (2003) conducted nighttime and egg mass surveys for red-legged frogs at the site in the fall, winter, and spring of 2002–2003. The surveys found that adult red-legged frogs were present in small numbers (likely a maximum of 10 individuals) in the area, and that the frogs were reproducing on a limited basis (three egg masses were found in the vicinity of the levee road adjacent to the lower stretch of Redwood Creek, and one red-legged frog tadpole was also found). Most of the frogs were found in the dense cattails just east of the levee road (in the Green Gulch pasture), indicating that a fairly small portion of the total site area is being used. Unfortunately, successful reproduction was unlikely, as the area where egg masses were found dried before tadpoles would have had a chance to metamorphose (Fellers and Guscio, 2003). No frogs, egg masses, or tadpoles were found in the Green Gulch drainage, nor were they observed in Redwook Creek upstream of Highway 1.

Nine male red-legged frogs were fitted with radio transmitters as part of a larger telemetry study conducted at nine different sites in west Marin County (Fellers and Guscio, 2003; Fellers and Kleeman 2003). Preliminary results indicate that of the 117 frogs tracked, the frogs typically disperse approximately 600 feet to the nearest suitable non-breeding area (Fellers and Kleeman, 2003). The tagged frogs from the Big Lagoon project area typically moved only 30 to 75 feet between locations, although one frog traveled 1300 feet (Fellers and Guscio, 2003). This indicates that red-legged frogs present in the project area are limited to a small portion of the site, and may not move out of the area.

4.3.2.1.2 Winter frog breeding surveys (1998–1999)

Winter frog breeding surveys were conducted by trained volunteers during 1998–1999 (Cook, 1998, as cited in Fong, 2000) and 1999–2000 (Fong, 2000) in Lower Redwood Creek, the Big Lagoon project area, and Green Gulch Creek. Red-legged frogs were the focus of the surveys, which included weekly night calling and egg mass surveys (see Fong, 2000 for further discussion of survey methods). Red-legged frogs were heard calling in the project area on one occasion (January 27, 1999), although no egg masses were observed in the area (Fong, 2000). In addition, adult Pacific tree frogs and California newt egg masses were observed in abundance. No red-legged frogs were observed in the Green Gulch Creek area from 1998 to 2000.

4.3.2.1.3 1992–1993Amphibian Survey Results

Seven of the 10 native amphibian species historically present were found during surveys conducted from April 1992 to September 1993 (PWA *et al*. 1994, Ely 1993) (Table 4-5). No non-native species, including bullfrogs, were observed, although extensive surveys were conducted up Redwood Creek and the ponds at the Green Gulch Farm (PWA *et al*. 1994). California newts (*Taricha torosa*) were the most abundant adult individuals observed. Their numbers peaked with breeding concentrations in January, but individuals were present throughout the year (PWA *et al*. 1994). California newt spawning occurred from December to February (PWA *et al*. 1994). Other adult amphibian species occurred in low numbers year-round (PWA *et al*. 1994). Adult Pacific tree frogs were seen or heard from December through May. The ensatina (*Ensatina eschscholtzi*) and slender salamander (*Batrachoseps attenuatus*) were occasionally encountered on the margins of wetland habitat in the winter and spring months. The California red-legged frog was observed on at least two occasions during spring.

Table 4-5. Amphibian Observations in the Big Lagoon Project Area and Vicinity

Common Name	Scientific Name	Observations				
		Historic[1]	1992-93[2]	1998-99[3]	1998[4]	2003[5]
Arboreal salamander	*Aneides lugubris*	X	X			
California slender salamander	*Batrachoseps attenuatus*	X	X			
Western toad	*Bufo boreas*	X	X			
California giant salamander	*Dicamptodon ensatus*	X				
Ensatina	*Ensatina eschscholtzi*	X	X			X
Pacific tree frog	*Pseudacris regilla*	X	X	X	X	X
California red-legged frog	*Rana aurora draytonii*	X	X	X		X
Foothill yellow-legged frog	*Rana boyleii*	X				
Rough-skinned newt	*Taricha granulosa*	X	X		X	X
California newt	*Taricha torosa*	X	X	X	X	X

[1] Adapted from PWA *et al*. 1994.
[2] Source: PWAet al., 1994 and Ely, 1993.
[3] Source: Fong, 2000. Survey targeted for winter frog breeding. Other amphibians observed were incidental.
[4] Source: Cook, 1998. Survey targeted for California red-legged frog and bullfrogs. Other amphibians observed were incidental.
[5] Source: Fellers and Guscio, 2003. Survey targeted for California red-legged frogs for radiotracking. Other amphibians observed were incidental.

Larval stages of four amphibian species were also observed during the 1992–1993 surveys at the site. California newts and Pacific tree frogs were most abundant; California newt larvae were found into October as a result of prolonged rains. Pacific tree frog larvae were found April through July in suitable localized breeding areas in Green Gulch Creek near the confluence with the backwater channel, in the ditch south of the lower pasture, and in the channel near the entrance to the lower lagoon. Two other species, the western toad and rough-skin newt, were found in much lower numbers and only in larval stages in 1992–1993 (PWA *et al*. 1994).

In addition to the surveys performed at Big Lagoon, Ely (1993) conducted four afternoon surveys between April and September 1993 in reaches of Redwood Creek within Muir Woods. These surveys were specifically targeted for foothill yellow-legged frogs, however, although high quality habitat was observed, no foothill yellow-legged frogs were reported. Ely also reported that California red-legged frogs were present, but uncommon, throughout the Marin Headland drainages (including Rodeo Creek, Tennessee Creek, and Redwood Creek).

4.3.2.1.4 Discussion

Amphibians are among the most sensitive and threatened vertebrate species in California freshwater wetland systems (Moyle 1973; Jennings and Hayes 1985; Hayes and Jennings 1986; Jennings 1991). In recent years they have been indicators of global environmental conditions (Phillips 1990; Cowen 1991) and habitat destruction (Jennings and Hayes 1985, Pechmann *et al*., 1991). Most amphibians are closely tied to an aquatic environment due to their aquatic larval stage. With the exception of ensatina, slender salamander and arboreal salamander, which are upland terrestrial species without larval stages, the amphibian species observed at the site were documented primarily at ponded or channeled areas. These standing water locations are essential to the viability of the amphibian assemblage at the site. It is in these localized wet spots that wetland vegetation provides necessary cover for reproductive activities and a basis for amphibian prey species. The current complement of amphibians at the site both in terms of numbers and species no doubt reflects the marginal size and health of available wetland habitat.

Pacific tree frogs and California newts appear to be the most successful breeding species in the area. Insect surveys during 1992 and 1993 indicated appropriate prey were available to developing frog and newt larvae in the ponded sites (see Appendix F). The large Pacific tree frog larval population observed during 1993 surveys probably reflected the above-average rainfall, which provided suitable breeding habitat in drainages until at least mid-July (PWA *et al*. 1994). Pacific tree frogs are closely tied to the water throughout their life history, though they require standing water only for chorus, breeding, spawning and a short 3-month tadpole stage. This species is thus able to breed successfully in the pasture ponds.

Only two species that were historically abundant in this region according to museum records were not observed during recent surveys: the California giant salamander (*Dicamptondon ensatus*) and the yellow-legged frog (Table 4-5). These species are more likely to be found farther up in the Redwood Creek drainage. The California giant salamander occurs primarily in humid well-forested areas (Stebbins, 1954), and the yellow-legged frog lives in riffled streams with at least cobble-sized substrate (Hayes and Jennings, 1989). However, habitat conditions for yellow-legged frogs in Redwood Creek were found to be excellent during 1993 surveys by Ely, but no adult frogs or larvae were found (see Section 4.3.3.3).

Recent efforts by NPS to improve drainage in the area (i.e., dredging downstream of the footbridge) have lowered surface water in lower Redwood Creek and groundwater in the Green Gulch pasture, degrading habitat for red-legged frogs and potentially threatening their continued survival at the site (Fellers and Guscio, 2003). NPS will be conducting interim measures in fall 2003 to encourage ponding in this area until implementation of the restoration project. More extensive cattails and additional areas of ponded water that remain wet long enough for metamorphosis to occur would improve site conditions for the frogs (Fellers and Guscio, 2003).

To date, no bullfrogs have been reported within the project area, although they are common in the nearby Tennessee Valley and could conceivably enter the site. Bullfrogs indicate a modified pond habitat that is less suitable for native species. Red-legged frogs may be particularly intolerant of bullfrog invasions (Moyle, 1973; Hayes and Jennings, 1986). It is not clear if bullfrogs are the sole factor or, more likely, if habitat alteration coupled with predation and competition by bullfrogs cumulatively have caused extensive red-legged frog declines throughout California (Moyle, 1973; Hayes and Jennings, 1986). Bullfrog range has expanded since their introduction to California in 1896 (Heard, 1904 in Hayes and Jennings, 1986), while the range of the red-legged frog has diminished by at least two-thirds.

4.3.2.2 Reptiles

Historically, 12 reptile species have been observed in the project area (Table 4-6). Less than half of these species were observed in the early 1990s. Surveys specifically for reptile species have not been conducted recently, so it is unclear how current conditions compare to those from 5 to 10 years ago. Three reptile species were incidentally observed in 2002 during surveys for red-legged frogs (Fellers and Guscio 2003), including yellow-bellied racer (*Coluber constrictor*), western fence lizard (*Sceloporus occidentalis*), and western terrestrial garter snake (*Thamnophis elegans*) (Table 4-6). Five reptile species were observed during 1992 and 1993 herpetological surveys at the site (PWA *et al*. 1994, Ely 1993): the western pond turtle (*Clemys marmorata*), western fence lizard, western terrestrial garter snake, northern alligator lizard (*Elgaria coeruleus*), and the western aquatic garter snake (*Thamnophis couchi aquaticus*). No western pond turtles were observed at the site during species-specific surveys conducted in 1996 (Fong 2002b). The western fence lizard occurred as an upland resident, and the coast garter snake was observed foraging in upland as well as wetland and riparian habitats. While garter snakes were less common in the afternoon amphibian surveys (PWA *et al*. 1994), they were seen in substantial numbers during qualitative reptile surveys (survey methods described in Appendix D).

Many reptile species known to historically occur in the area were not observed during surveys conducted in the early 1990's. Several of these species are associated with drier sites or open areas at the margins of forests, such as the western skink (*Eumeces skiltonianus*), southern alligator lizard (*Elgaria multicarinata*), and the yellow-bellied racer (*Coluber constrictor*). Typically these species are more common residents of upland areas, which were not included in the 1992 and 1993 survey efforts. The upland and drier sites likely support substantial populations of lizards and snakes (Ed Ely, pers. comm., as cited in PWA *et al.* 1994). A few reptile species that were not observed, however, are known to forage in wetland areas (ring-necked and sharp-tailed snakes) or in pools and along stream banks (rubber boa). Increasing the size and quality of these habitats may improve conditions for these species at the site.

Two special status snakes, the federal and state listed endangered San Francisco garter snake (*Thamnophis sirtalis tetrataenia*, a subspecies of the common garter snake) and the state listed threatened giant garter snake (*Thamnophis couchi gigas*), a subspecies of the western aquatic garter snake, occur farther to the south and east and are not expected to occur at Redwood Creek.

Table 4-6. Reptile Observations in the Big Lagoon Project Area and Vicininity

Common Name	Scientific Name	Observations			
		Historical[1]	1992-93[2]	1996[3]	2002[4]
Rubber boa	*Charina bottae*	X		NA	
Western pond turtle	*Clemys marmorata*	X	X	none found	
Yellow-bellied racer	*Coluber constrictor*	X		NA	X
Ringneck snake	*Diadophis punctuatus*	X		NA	
Northern alligator lizard	*Elgaria coeruleus*	X	X	NA	

Common Name	Scientific Name	Observations			
		Historical[1]	1992-93[2]	1996[3]	2002[4]
Southern alligator lizard	*Elgaria multicarinata*	X		NA	
Western skink	*Eumeces skiltonianus*	X		NA	
Gopher snake	*Pituophis melanoleucus*	X		NA	
Western fence lizard	*Sceloporus occidentalis*	X	X	NA	X
Western aquatic garter snake	*Thamnophis couchi*	X	X	NA	
Western terrestrial garter snake	*Thamnophis elegans*	X	X	NA	X
Common garter snake	*Thamnophis sirtalis*	X		NA	

[1] Adapted from PWA *et al*. 1994.
[2] Source: PWAet al., 1994 and Ely, 1993. Surveyed only for western pond turtles.
[3] Source: Fong, 2000b. Survey was targeting California red-legged frogs. Reptile observations were incidental.
[4] Source: Fellers and Guscio, 2003. Survey targeted for California red-legged frogs for radiotracking. Other amphibians observed were incidental.

4.3.2.3 Birds

Four primary sources of recent information on birds exist for the Big Lagoon project area:

(1) PWA *et al*. (1994) conducted seasonal surveys for 1.25 years, 1992/1993. A total of 11 surveys at 16 stations were conducted in all seasons. Survey stations were stratified by general habitat type. The objective was to measure seasonal use of a range of habitats that would potentially be affected by restoration activities.
(2) Stallcup (1995) produced an annotated bird list for the site by surveying the entire area once per month for one year (May 1994 to April 1995) and summarizing the National Audubon Society's Christmas Bird Census from 1978 to 1992. These data represent an excellent inventory of the avifauna of the site and immediate environs.
(3) PRBO has been monitoring breeding bird populations in the project area using nationally standardized protocols from 1997 to the present. This study focuses on passerines and near passerines and is part of a much larger monitoring effort in the GGNRA and the Point Reyes National Seashore (Gardali and Geupel 1997, Gardali *et al*. 1999, Holmes *et al*. 1999, Scoggin *et al*. 2000, Gardali *et al*. 2001).
(4) Dybala (2002) conducted surveys for waterbirds at the site beginning on December 12, 2001, and continuing approximately every two weeks until February 12, 2002. In total, 5 surveys were conducted at the site in the Green Gulch pasture and horse paddock (Figure 3). Surveys were conducted at three sites: Pasture A, Pasture B, and the Riding Ring (see Appendix G for site map). Visual surveys were conducted from a fixed point at each site. The duration of each survey was at least 15 minutes per site.

The results from PWA *et al.* 1994 are summarized in Appendix G. Results of the other three studies are described in more detail below. A complete inventory of bird species documented in the site project area is also included in Appendix G (Table G-1), as are all of the tables referred to in the text below.

4.3.2.3.1 *Annotated Bird List (Stallcup, 1995)*

One hundred eighty-five species were identified; 85 more than previous work (PWA et al. 1994). Of these, three are not native to North America, 45 were documented as breeders, 6 others were noted as possible breeders, and 12 were considered accidental. Riparian habitats were identified as "the most thoroughly used" in all seasons, which is in agreement with PWA et al. (1994). Stallcup (1995) did not quantify species abundance. However, he notes that some of the most common nesting species were Swainson's thrush (*Catharus ustulatus*), Wilson's warbler (*Wilsonia pusilla*), song sparrow (*Melospiza melodia*), Brewer's blackbird (*Euphagus cyanocephalus*), and American goldfinch (*Caruelis tristis*). Stallcup (1995) noted that confirmed breeding of Towsend's warblers (*Dendroica townsendi*) reported in PWA et al. (1994) is in error.

4.3.2.3.2 *Riparian Monitoring (PRBO, 1997 to Present)*

Methods for the following results have been described in detail elsewhere (e.g., Gardali et al. 1999, Holmes et al. 1999) and use nationally recommended guidelines (Ralph et al. 1993, Martin et al. 1997). In general, four permanent point count survey stations were establish at 200 meter intervals along the riparian corridor in the Big Lagoon project area and one nest monitoring and territory mapping plot spanned the extent of the point count survey stations and was restricted to riparian habitat. Mist-netting was conducted nearby at the Banducci site in the autumns of 2001 and 2002. Point counts survey all bird species while nest monitoring focuses on those using the riparian vegetation. Autumn mist-netting provides information on habitat use of birds during migration (species abundance and composition), post breeding, and an index of reproductive productivity (number of young captured and young-to-adult ratio); it does not provide a complete inventory.

In all of the tables discussed below (located in Appendix G), we highlight (species name in **bold**) riparian focal species as designated by the Riparian Habitat Joint Venture and California Partners in Flight (RHJV 2000). Focal species were chosen so that, as a group, their breeding requirements represented the full range of critical riparian ecosystem/habitat elements. Individual species were chosen so that they also met as many as possible of the following criteria: (1) use the riparian habitat as their primary breeding habitat, (2) warrant special management status, (3) are from a variety of taxonomic groups, and (4) are useful for monitoring management actions because they have large enough populations to obtains good sample sizes. Additionally, they are thought to show quick, strong or consistent responses to habitat attributes, management, or restoration. Hence, focus should be placed on these species for monitoring post-restoration.

Point Counts.
A total of 51 species was detected by point count (not including those species flying over) from 1998 to 2002 (Table G-2). Red-winged blackbird, song sparrow, Swainson's thrush, cedar waxwing, Wilson's warbler, American robin, and black-headed grosbeak were the most commonly detected species. All of these species breed at the site with the exception of cedar waxwing (flocks often counted in early spring migration).

Territory Mapping.

PRBO mapped the territories of breeding birds from 1997 to 1999 at the site. These data provide information on breeding densities of territorial species (versus an index of abundance from point counts). Appendix G presents territory numbers for RHJV (2000) focal species (Table G-3). The song sparrow and common yellowthroat are year-round residents while the other four species are Neotropical migrants. The song sparrow held the most territories in all three years.

Nest Monitoring.

A total of 151 nests for 26 species were located and monitored at the Big Lagoon project area from 1997 to 1999 (Table G-4). Results (reproductive success) from nest monitoring are a better indicator of ecosystem health than simple presence or abundance as obtained from other methods. Note that none of the Wilson's warblers nests were successful.

Mist-netting.

Mist-netting was conducted at the nearby Banducci site during fall migration in 2001 and 2002. This site likely has similar species composition and abundance as the Big Lagoon project area. The year-round resident song sparrow was the most commonly captured species followed by hermit thrush, warbling vireo, Pacific-slope flycatcher, Swainson's thrush, and Wilson's warbler (Table G-5).

4.3.2.3.3 Waterbird Monitoring (Dybala, 2002)

Dybala (2002) observed the peak number of waterbirds at the site on December 20, 2001, with 27 individuals, a 125% increase over the peak number observed by Osbourn (unpublished data, as cited in Dybala, 2002) during the winter of 2000–2001. Surveys on December 12, 2001 and January 23, 2001 resulted in the lowest number of birds observed, which may have been correlated with excessive noise due to roadwork on the adjacent levee trail.

Species diversity during Osbourn surveys was very low, with only mallards (*Anas platyrhynchos*) observed at the site. Surveys by Dybala (2002) the following year observed three species: mallards, killdeer (*Charadrius vociferus*), and bufflehead (*Bucephala albeola*), yet mallards represented 88% of the total number of individuals observed (Table G-6).

4.3.2.3.4 Discussion

The bird surveys and incidental sightings recorded document a predictable assemblage of coastal riparian and wetland birds that varies seasonally according to the breeding and wintering habits of each species. Big Lagoon harbors bird species that are members of several wetland communities, including freshwater marsh, freshwater stream, coastal riparian forest, and more restricted brackish marsh and coastal dune communities (Shuford, 1993). As discussed in Section 2, all are remnants of what were once large expanses of coastal wetlands and watersheds. Current numbers of species and individuals are undoubtedly a fraction of what this system supported 200 years ago, prior to human-induced filling of stream corridors and wetlands, decreases in freshwater input, severe habitat fragmentation, replacement of native wetland

and upland vegetation with non-native pasture vegetation, and ongoing disturbance by human visitors and pets. Enhancing the quality and size of wetland habitat should significantly increase the diversity and abundance of native birds at the site. As a note, one of the biggest impacts on the success of the songbird breeding season at the area is trash from the site and the nearby communities, which attracts ravens, raccoons, brown-headed cowbirds and other nest predators/nest parasites (NPS Technical Scoping Notes, 2002).

4.3.2.4 Mammals

Though no mammalian surveys were conducted at the site during 1992–1993 field work by PWA *et al*. (1994), three species were incidentally noted in the project area (O. Onorato, P. Slattery pers. obs., as cited in PWA *et al*., 1994). Mule deer tracks were observed in the dense willow thicket between bird stations 5 and 10 in spring 1993, and occur here relatively commonly. Both bobcats and gray foxes were seen infrequently along the riparian corridor. Gray foxes regularly use the dense willow thicket as a denning area. Appendix H lists all the mammals that were historically found or may currently be found in the vicinity of the Big Lagoon wetlands, and that may at least periodically use a large freshwater wetland as a source of food or water.

Live trapping for small mammals was conducted at the site from 28 October to 1 November 2002 by the USGS (Takekawa *et al*., 2003). Traps were set in dune, pasture, riparian, tidal lagoon, and wetland areas. The following four species were captured, in order of abundance: western harvest mouse (*Reithrodontomys megalotis*), deer mouse (*Peromyscus maniculatus*), California vole (*Microtis californicus*), and roof rat (*Rattus rattus*). Deer mice were only captured in the dune area. No special status species (e.g., salt marsh harvest mouse, Pt. Reyes jumping mouse) were detected, despite careful examination of tail characteristics that distinguish the more common western harvest mouse from the endangered salt marsh harvest mouse.

Takekawa *et al*. (2003) characterized vegetation along each trapping grid location, including species present, litter, bare ground, and height, and percent cover was then calculated. They noted that pasture and wetland habitat had very similar plant community composition and structure, and also had the highest abundance of small mammals (primarily western harvest mice), as defined by number of captures per 100 trap nights. This is consistent with dietary requirements (seeds, grasses, leafy plants) and is where dense vegetation affords the best cover. Restoration efforts should promote dense vegetative cover in order to improve habitat conditions for small mammals in the riparian and pasture areas (Takekawa *et al*., 2003). Additionally, roof rats, a non-native species and known predator of riparian passerines, were only found in the riparian areas. Removal of this species as part of restoration efforts may be necessary in order to ensure more successful breeding of riparian bird species (Takekawa *et al*., 2003).

No small mammals were captured in the tidal lagoon area, presumably because of lack of tidal wetland vegetation (e.g., *Spartina* and *Salicornia* spp.). Improving tidal flows within the lagoon may encourage establishment of these plant species and improve conditions for their associated small mammal community.

4.3.2.5 Fish

Several investigations have been performed since 1992 to document fish distribution and abundance in Redwood Creek and its estuary. Fish surveys were conducted in 1992 and 1993 for the Preliminary EA (PWA *et al.,* 1994). Subsequent investigations have included a report on the use of lower Redwood Creek and Big Lagoon by juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) (Fong 1996), annual distribution and abundance surveys for juvenile coho salmon and steelhead (Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001), salmonid outmigrant trapping in 1996 (Fong, 1997a), an anadromous salmonid spawner and carcass survey, conducted in the winter of 1996-1997 (Fong, 1997c), and a study of the use of the Big Lagoon estuary (and other central California estuaries) by rearing coho salmon and steelhead (Laidig, 2003). Table 4-7 shows the fish species documented in the above surveys. Smith (1994a, 1994c) also analyzed the effects on coho salmon and steelhead of streamflow reductions in Redwood Creek due to drought and groundwater pumping. In addition to the species documented during the above surveys, NPS has observed Sacramento blackfish (*Orthodon microlepidotus*) and yellowfin gobies (*Acanthogobius flavimanus*) at the site.

Table 4-7. Fish Species Documented in Big Lagoon Estuary and Redwood Creek, 1992–2002

Fish Species	Native (N) or Introduced (I)	Year(s) Observed	Source	Tidal Lagoon	Redwood Creek
Sacramento blackfish (*Orthodon microlepidotus*)	I[a]	1992	PWA (1994)	X	
topsmelt (*Atherinops affinis*)	N	1995	Fong (1996)	X	
coho salmon (*Oncorhynchus kisutch*)	N	1992-1998 2000-2002	PWA (1994); Fong (1996, 1997a, 1997c); Smith (1994b, 1995, 1996, 1997, 1998, 2000, 2001); Laidig (2003)	X	X
steelhead (*Oncorhynchus mykiss*)	N	1992-1998 2000-2002	PWA (1994); Fong (1996, 1997a, 1997c); Smith (1994b, 1995, 1996, 1997, 1998, 2000, 2001); Laidig (2003)	X	X
threespine stickleback (*Gasterosteus aculeatus)*	N	1992-1996 2001-2002	PWA (1994); Smith (1994b); Fong (1996, 1997a); Laidig (2003)	X	X
prickly sculpin (*Cottus asper*)	N	1992-1996	PWA (1994); Smith (1994b); Fong (1996, 1997a)	X	X
coast range sculpin (*Cottus aleuticus*)	N	1995	Fong (1996)	X	
riffle sculpin (*Cottus gulosus*)	N	1992 1993 2001	PWA (1994); Smith (2001)		X

Fish Species	Native (N) or Introduced (I)	Year(s) Observed	Source	Tidal Lagoon	Redwood Creek
Pacific staghorn sculpin *(Leptocottus armatus)*	N	1992 1993 1995	PWA (1994); Fong (1996)	X	
striped bass (*Morone saxatilis*)	I	1992 1995 2002	PWA (1994); Fong (1996); Laidig (2003)	X	
Sacramento perch (*Archoplites interruptus*)	I[a]	1993	PWA (1994)	X	
yellowfin goby (*Acanthogobius flavimanus*)	I	1992 1993	PWA (1994)	X	
starry flounder (*Platichthys stellatus*)	N	1992 1993	PWA (1994)	X	

[a] Native to other California river systems; introduced into the Redwood Creek drainage.

In addition to the limited aquatic habitat data collected as part of several of the above fish investigations, a comprehensive stream habitat inventory was conducted in 1995 by GGNRA staff (Fong, 2002a). This inventory includes data on channel morphology, substrate, water temperature, habitat types, large woody debris (LWD), residual pool volume, streamside cover, riparian canopy density, and benthic macroinvertebrates for approximately five miles of Redwood Creek, from the project site upstream to Bridge 4 in Muir Woods National Monument. In a separate study, woody debris abundance and distribution in Redwood Creek from 1994–1996 were reported by Vore (1996) for reaches in and immediately downstream of Muir Woods. The results of the numerous fish surveys performed between 1992 and 2002 are summarized in Appendix I.

Smith (1995–2001) repeatedly noted that groundwater pumping from the wells near the community of Muir Beach can exacerbate the effects of low stream flows in lower Redwood Creek and the upper portion of the tidal lagoon. This portion of the watershed has shown to be used extensively by rearing coho salmon and steelhead when suitable conditions exist, at which time it appears to provide important rearing habitat. The effects of low stream flows in this area include reduced availability of rearing habitat and macroinvertebrates for juvenile coho and steelhead, as well as poor water quality (elevated temperature, low D.O.). This is especially important in dry years, when flows are naturally low. Smith hypothesizes that habitat availability (especially pools for rearing coho) and food production are likely the two most important factors limiting salmonid production in the system.

Although only limited data are apparently available on LWD frequency in Redwood Creek, this habitat feature is known to be of key importance for rearing salmonids. Restoration efforts with a goal of increasing coho salmon and steelhead abundance in Redwood Creek and its tributaries should focus on ways to improve LWD recruitment.

4.3.2.6 Invertebrates

An inventory of benthic macroinvertebrates was conducted in August 1995 and November 1997 (Fong, 2002a) in Redwood Creek. In April 2002, invertebrate sampling was conducted at seasonally and perennially inundated sites at Muir Beach (Fong *et al*., 2003). These two surveys are summarized briefly below, and a summary table of all invertebrates observed at Big Lagoon from 1992 – 2002 is provided in Appendix F, Table F-1. Surveys specifically for California freshwater shrimp (*Syncaris pacifica*) have also been conducted and are discussed in Section 4.3.3.2. Aquatic insects were sampled both qualitatively and quantitatively as part of the 1992–1993 survey efforts for the EA (PWA *et al*., 1994) as discussed separately in Appendix F.

In addition, the western monarch butterfly (*Danaus plexippus*) is known to occur in the Muir Beach area (Monroe 2003). GGNRA staff and volunteers have been monitoring the Muir Beach area for monarch butterflies for over 15 years, using a monitoring protocol developed by the Xerces Society, the Monarch Program, and others. Observations are made starting in early fall, and continuing until early January. Large numbers of monarchs overwintered in the Muir Beach area during the 1970's and 1980's (up to 15,000), aggregating primarily at a stand of Monterey pines (*Pinus radiate*) located above Pacific Way at the Terwilliger Grove, and occasionally roosting in the Green Gulch Farm area (Monroe, 2003). Due to site changes at the Terwilliger Grove, monarchs have not been observed overwintering in such numbers since 1997, although they are still present in the area (10–20 monarchs can be observed on sunny days in the early fall) (Monroe, 2003).

4.3.2.6.1 1995 and 1997 Benthic Macroinvertebrate Inventory

Qualitative surveys presented by Fong (2002a) were conducted in 1995 and 1997 at six sample locations to provide a taxa list of stream macroinvertebrates and some index of relative abundance and "health." Species observed at the Pacific Way Bridge station are listed in Appendix F, Table F-1. The sampled invertebrate community at the downstream-most station in the watershed, below the Pacific Way Bridge, had significantly different metric values than other stations (Fong, 2002a). This station had significantly lower Shannon diversity than two out of the other five sample locations in 1995, and also had significantly higher proportion of dominant taxa when compared to the other sites (Fong, 2002a). This dominance was associated with extremely large numbers of *Malenka* larvae, a stonefly (Fong ,2002a).

4.3.2.6.2 2002 Invertebrate Inventory

The objectives of the 2002 study were to (Fong *et al.,* 2003):

1. establish a baseline taxa list and reference collection of aquatic and semiaquatic macroinvertebrates from seasonally and permanently inundated sites within the project area; and
2. compare aquatic and semiaquatic macroinvertebrate fauna diversity and relative abundance between open water and emergent-open water interface habitats.

Samples were collected at six locations in April 2002 (Figure F-1). Freshwater wetland sites had higher invertebrate densities than other sites, which is similar to the results reported by PWA *et al.* (1994). PWA *et al.* (1994) reported higher production of zooplankton and insects in the late winter and spring for the pasture wetlands when compared to open water habitat in Redwood Creek.

At each wetland site, the sample near the vegetated edge had greater density and greater taxa richness than the open water samples, suggesting a more heterogeneous habitat and most likely greater food availability. However, samples obtained in more stream influenced sites had opposite results. Samples along Redwood Creek at the backwater and below the pedestrian footbridge had higher densities at open water rather than the vegetated margins (Fong *et al* 2003).

The majority of the taxa collected were still-water taxa; however, three typically stream taxa were collected at the Below Footbridge sample sites, including the baetid mayflies (Ephemeroptera) *Centroptilum* and *Diphetor*, and the brachycentrid caddisfly (Trichoptera) *Amiocentrus*. Appendix F, Table F-1 lists all the species that were observed during 2002 surveys. Relatively high dissolved oxygen concentration and relatively low temperatures were evident at this site indicating the influence of Redwood Creek. No sensitive invertebrate taxa were encountered in surveys (Fong *et al* 2003).

The brackish wetland sample sites (Big Lagoon Marsh and Parking Lot Wetland) had lower abundance of invertebrates than the freshwater wetland sites. The brackish wetlands likely had variable salinities throughout the prior winter and spring depending upon the frequency and amount of rain and overwash from the ocean. These sites also had water depths that were typically lower than other sample sites, which may imply a greater tendency towards fluctuating conditions (e.g., water temperature). Such dynamic conditions may be difficult for the production of invertebrates (Fong *et al* 2003).

4.3.2.6.3 *<u>Discussion</u>*

The aquatic invertebrate sampling conducted in 1995, 1997, and 2002 (Fong 2002a, Fong et al 2003) generally confirms the conclusions presented in PWA *et al.* (1994) (see Appendix F). Aquatic invertebrate abundance and species composition varies with habitat type. Within the project site, aquatic invertebrate production and diversity appear to be highest in freshwater wetlands (e.g., Pasture Wetland A and B in Fong et al 2003) and lowest in the brackish wetlands (e.g., Parking Lot Wetland and Big Lagoon Marsh in Fong et al 2003), with stream habitats supporting intermediate levels of diversity and abundance. Sampling of invertebrates and physical habitat parameters indicate that water quality appears to be generally good. The brackish water wetlands appear to have the harshest conditions for invertebrates, with fluctuations in salinity, temperature, and dissolved oxygen likely limiting invertebrate production and diversity.

Increasing the amount of perennial freshwater wetlands should substantially increase the numbers, diversity, and persistence of aquatic insects and crustaceans found in the Big Lagoon project area. However, the greatest diversity of invertebrates and general food web support for vertebrate species (fish, amphibians and birds) will be provided by maintaining a diversity of aquatic habitat types (perennial and seasonal freshwater emergent marsh with patches of open water, stream habitat with well-shaded pools, brackish tidal marsh and open water lagoon) in the project area. Maintaining or creating more topographic complexity in the wetland areas should provide more complex habitat conditions, with deeper permanently inundated areas providing a refuge for some species that require water year-round, while promoting seasonal inundation of vegetated areas where invertebrate production may be quite high and many invertebrates can find a partial refuge from predators (such as fish). In addition, promoting improved connectivity of the stream channel and the wetlands in its floodplain on the project site should help maintain general water quality, enhance invertebrate abundance and diversity, and improve food web support.

4.3.3 Special Status Species

4.3.3.1 Plants

A rare plant survey was conducted in the Big Lagoon project area during 2002 (Faden, 2002) and spring 2003 (Shoulders, pers comm). No threatened or endangered species were found. Two CNPS 4 (watch list) plant species were found in the hills near Muir Beach, California bottle-brush grass (*Elymus californicus*), and San Francisco wallflower (*Erysimum franciscanum*). California bottle-brush grass, which is well-documented in Muir Woods, was documented near the Middle Green Gulch Trail in the spring of 2003. No endangered, threatened or special status species of plants were observed on the site during surveys in 1993–1994 (PWA *et al*. 1994). Several additional CNPS-status species occur in lowland habitats in Marin County and could have occurred in Big Lagoon historically (Appendix J, Table J-1). These species may be considered for reintroduction as a conservation effort during restoration.

4.3.3.2 Invertebrates

Potential habitat exists for the federally endangered California freshwater shrimp (*Syncaris pacifica*) in the project area (B. Cox pers. comm., L. Serpa, *pers comm*, as cited in Fong 1999). However, surveys in March and August 1997 found no shrimp in lower Redwood Creek (Fong 1999), and no sensitive invertebrate taxa were encountered during surveys in April 2002 (Fong *et al.,* 2003).

Monarch butterflies were historically present in great numbers in the vicinity of the project area, but now are only present in small numbers (as discussed in Section 5.3.2.6). Other special-status invertebrate species that depend on coastal or marsh communities and may be locally present include the Myrtle's silverspot butterfly (*Speyeria zerene myrtleae*), Ricksecker's water scavenger beetle (*Hydrochara rickseckeri*), and the San Francisco fork-tailed damselfly (*Ischnura gemina*).

4.3.3.3 Amphibians and Reptiles

Herpetological surveys documented that the site currently supports at least one special status species: the California red-legged frog (*Rana aurora draytonii*) (federally listed threatened[1], state listed species of special concern). The entire site is within the Point Reyes Critical Habitat Unit (Unit 12), defined by the USFWS (66 FR 14625–14674). This unit contains one of the largest known populations of red-legged

[1] The federal listing excludes areas in Sonoma and Marin counties, west and north of San Francisco Bay drainages and Walker Creek drainage, which includes the Big Lagoon project area.

frogs (Federal Register 2001, as cited in Fellers and Guscio 2003). Western pond turtles (*Clemys marmorata*) (state listed species of special concern) were seen throughout the year during 1992–1993 surveys by PWA *et al*. (1994) in two locations along the dredged portion of Redwood Creek, but were not observed during species-specific surveys conducted in 1996 (Fong 2002b). This species has not been observed at the site for several years and is not considered to currently occur at the project site. In addition, suitable habitat for foothill yellow-legged frog (*Rana boyleii*) (state species of special concern) exists further upstream in the Redwood Creek watershed, although the species has not been recently documented. The results of these surveys are discussed further in Sections 4.3.2.1 and 4.3.2.2 above.

4.3.3.4 Birds

Fully 36 species that have been documented within the Big Lagoon project area and immediate environs have at least one special status designation (Appendix J, Table J-2). One species, the California brown pelican, is federally listed as endangered and three species, California brown pelican, American peregrine falcon, and willow flycatcher, are state listed endangered. Five of the 36 (14%) special status species breed at Big Lagoon and three of these species use riparian vegetation (Allen's hummingbird, olive-sided flycatcher, and California Swainson's thrush). The special status species mostly likely to be affected (positively or negatively) by changes to the project area are those that primarily use the riparian and freshwater marsh habitats (14 of 36; 39%). A complete list of bird species within or near the Big Lagoon project area that have special status designation(s) are presented in Appendix J.

4.3.3.5 Mammals

No special status small mammal species (e.g., federal and state listed endangered salt marsh harvest mouse) were detected during trapping surveys within the Big Lagoon project area in fall 2002, despite careful examination of tail characteristics that distinguish the more common western harvest mouse from the endangered salt marsh harvest mouse (Takekawa *et al*., 2003). Although no special-status large mammals have been observed recently at the site, Appendix H includes those that might occur (or historically did occur), including three species of bats, and four species of larger carnivores.

4.3.3.6 Fish

Fish communities currently found in the Big Lagoon site are discussed in more detail in Section 4.3.2.5. Of these, three species have special status.

Coho salmon in the Redwood Creek watershed belong to the Central California Coast Evolutionarily Significant Unit (ESU). Coho salmon belonging to the Central California Coast ESU were listed as a state endangered species by the California Department of Fish and Game (CDFG) effective December 31, 1995. The Central California Coast ESU was listed as threatened under the federal Endangered Species Act on October 31, 1996 (61 FR 56138–56149).

Steelhead in Redwood Creek belong to the Central California Coast ESU, which includes populations distributed from the Russian River south to Aptos Creek in Santa Cruz County. Steelhead belonging to the Central California Coast ESU were listed as threatened by the NMFS under the federal Endangered Species Act on August 18, 1997 (62 FR 43937–43954). This steelhead ESU is not currently listed under the California Endangered Species Act.

The tidewater goby, which is believed to have historically occurred in the Redwood Creek estuary, is a federally listed endangered species (59 FR 5494–5499). Critical habitat for the goby was designated by the USFWS in 2000 (65 FR 69693–69717). The USFWS proposed delisting the tidewater goby in 1999 (64 FR 33816–33825), but the proposal was withdrawn in 2002 (67 FR 67803–67818). This species is not currently known to occur in the Redwood Creek estuary.

4.3.4 Jurisdictional Wetlands

In 1993 Caltrans performed field surveys and mapped the wetland areas that would be under the jurisdiction of the ACOE under Section 404 of the Clean Water Act (PWA *et al*. 1994, Figure IV-40). Wetlands were mapped according to the methods described in the Corps of Engineers Wetland Delineation Manual (USACE, 1987). In 2003, NPS updated the delineation of potential ACOE jurisdictional wetlands (Figure 22), and is currently preparing the delineation report.

According to the 2003 wetland mapping, 26.6 acres are potential jurisdictional wetlands, and 3.5 acres are waters of the United States (Figure 22). The 2003 jurisdictional wetland area now includes the alder forest just upstream of Pacific Way (not included in the original 1993 area), the entire Green Gulch pasture, and additional areas south and east of the parking lot (Figure 22). See Section 4.3.1 for further discussion of wetland vegetation.

For comparison, jurisdictional wetlands identified in 1993 included brackish marsh between the tidal lagoon and the picnic areas, seasonal wetlands and drainages in the Green Gulch pastures, and riparian wetlands along Redwood Creek (PWA *et al*. 1994, Figure IV-40). Included within the 33-acre study boundary were 9.1 acres of wetland, 0.8 acres of wetland/drainage, 5.8 acres of riparian wetland, 2.2 acres of waters of the United States, and 15.1 acres of upland.

Most of the lower study area lies within jurisdictional wetlands, except the levees, parking lot, and small areas along Highway One. Note that with the exception of Redwood Creek, most of these wetlands exist in their current form because of recent site modifications, and generally do not reproduce the historic functions of the pre-1800's natural system. Efforts in late 2002 to improve drainage (discussed in Section 3.2.3) are decreasing the backwater effect and likely drying portions of the Green Gulch pasture similar to that seen under 1993 conditions, with seasonal wetlands rather than semipermanently flooded wetlands.

4.4 RESIDENT AND VISITOR USE

Muir Beach is a heavily used coastal recreational area. NPS estimates of visitor use at the site range from 225,000 to 430,000 people per year, depending on the year and the method upon which the estimate is based (NPS, unpublished data). NPS will collect additional visitor counts in 2003. The beach and trails are primary recreational resources for the local residents of the community of Muir Beach, and the beach in particular is the central defining feature of the community. Located near the center of the metropolitan San Francisco Bay Area, the beach and trails are also popular recreational destinations for Bay Area residents, responsible for over 66% of the annual visitation (Godbe, 2002). The proximity of the beach and trails to Muir Woods National Monument and Mt. Tamalpais State Park make them frequent destinations for state, national, and international visitors as well. Approximately 17% of visitors to the beach have visited or plan to visit Muir Woods on the same day (Godbe, 2002).

Most visitors to the site approach from one of two directions – either by moving down Frank Valley from Muir Woods along Muir Woods Road or the Redwood Creek Trail, or over the hill from Mill Valley along Shoreline Highway (State Highway 1) and down the Green Gulch drainage. From both approaches, the visitor is greeted with an open grassy field at the confluence of Green Gulch and Redwood Creek at the Pacific Way intersection with Highway 1. The visitor is less aware of the confluence of the two stream channels than of the seemingly natural meadow, a once large open lagoon. Although the recently rising water table is now returning the meadow to a wetland, it remains mostly an open grassy expanse with the streams pushed to the outer edges. The visitor has arrived at the center of a small rural community, nestled at the edge of high coastal hills surrounding an open pastoral landscape and fronting an enclosed ocean beach. The contrast with the dense urban scenery of the nearby metropolitan Bay Area, just minutes away, is striking.

The beach is behind willow/alder thickets, unseen from the road except from higher elevations. The narrow Pacific Way access road dips down to cross a now normally flooded section of road, then rises to cross a bridge and winds along the tree-lined toe of the hill to the parking lot. The exposed, dusty gravel parking lot turns abruptly to be parallel to the beach, with dramatic vistas of the ocean unblocked by dunes. The visitor has arrived at the beach, the principal destination, after having passed through a disturbed, but pastoral, rural setting.

As popular and interesting as this area is for residents and visitors alike, many of the recreational opportunities are limited or incomplete. For instance, regionally significant trails, including the Coastal and Redwood Creek Trails, are discontinuous without satisfactory connections through the Muir Beach area. The beach itself offers a somewhat wild, natural beachfront experience, but the public landscape upstream of the beach is very badly degraded and generally overlooked by most visitors, thereby limiting the extent of the natural coastal ecosystem experience. The parking and access system efficiently serves the beach, but the uninviting parking lot in particular bears little relationship to the natural setting other than proximity to the ocean.

As with any residential community near a popular public recreational area, the local residents use the resource regularly along with a steady stream of ever changing outside visitors. Conflicts occasionally arise between local residents and the visitors, although in general most users share similar values in relation to the resources themselves. The conflicts in this case are primarily related to traffic and parking, especially on heavy use days at the beach. The visitors and many of the local residents share the same congested access road, Pacific Way, with a single intersection off the main Highway. The parking lot is often not able to handle the number of visitors arriving on busy summer recreation days, so the overflow cars park on the road shoulders further conflicting with local traffic.

The existing use patterns for this area will be described in terms of the vehicular and trail access systems, the general visitor experience offered at the site, the other major land uses that affect the project area, and other important site features. Technical data describing the existing vehicular access systems and trails is taken from the draft Comprehensive Transportation Management Plan (CTMP) for Parklands in Southwestern Marin (Peccia, 2002). The June, 2002 draft of the CTMP Intercept Interviews by Godbe Research & Analysis is also a basic source for this section (Godbe, 2002).

4.4.1 Vehicle Access

The site is located adjacent to the approximately 150-home Muir Beach residential community on the bluffs above the beach, and shares a single access route from Shoreline Highway (State Highway 1) via Pacific Way with many Muir Beach residents. Pacific Way is a narrow county-maintained road with several sharp bends and a one-lane bridge in poor condition. Most people make their own arrangements to visit the beach, rather than visiting on tours, with over 95% arriving by private vehicles. Weekday transit service to the site is provided by the West Marin Stage, operated by Marin County on a two-year pilot basis. There is no transit service to the site on weekends when the visitation is highest. The vehicular destination is the existing 175-car gravel parking lot at the end of Pacific Way with a one-way circulation pattern and no delineated parking spaces.

4.4.1.1 Traffic Congestion and Circulation

Pacific Way, the narrow shared single access road, is very congested, particularly on peak recreational weekends, and the intersection at Highway 1 is impacted by the heavy traffic on the access road. The road is essentially a cul-de-sac terminating in the parking lot. During preparation of the CTMP, a maximum arrival rate of 122 vehicles/hour was observed, straining the capacity of both the existing parking lot and access road. Frequent flooding on Pacific Way in recent years has exacerbated the traffic congestion, as vehicles must slow down to ford the flooded section of the road. The sharp bends in the narrow road make access for over-sized vehicles particularly difficult.

When the parking lot overflows, visitors tend to park along the shoulders of Pacific Way, which adds significantly to the congestion, and seriously compromises emergency vehicle access to the beach and residential area. At these times, safety concerns for pedestrians in particular are heightened since there are no separate pedestrian paths along the road, forcing people to walk on the roadway to the beach. Overflow vehicles also park along the Muir Woods Road, Highway 1, and on the neighborhood streets of Muir Beach, thus causing congestion and safety concerns in those areas as well.

4.4.1.2 Parking

The existing 175-car parking lot was constructed in the late 1960's in the present location to serve the beach at the newly created State Park. NPS raised the parking by approximately 2 to 3 vertical feet in the

1980's. There is no overflow parking provided in the area, so the overflow vehicles tend to park on the shoulders of Pacific Way and the adjacent roads. According to recent counts, the lot overflows its capacity approximately 12 days during the peak season of June, July, and August (NPS, unpublished data).

Parking for the Green Gulch Farm is contained within the Zen Center/Green Gulch Farm compound east of the project area. Green Gulch Farm also uses a remote shuttle and carpooling for special events. Parking for the Pelican Inn and the Golden Gate Dairy horse stable is also contained within their own sites.

Input from recent workshops indicates that residents, visitors, and the NPS perceive the parking lot itself as somewhat of an eyesore. The lot is dusty and bare with no trees or other vegetation to screen the vehicles. It is configured in a manner that makes it highly visible to the surrounding areas, jutting out across the narrow neck of the valley just behind the beach. The configuration and size also conflict with the natural ecology of the creek, as discussed elsewhere.

The CTMP has been assessing the parking demands for Muir Beach. Their draft findings regarding existing uses during peak and off-peak seasons, weekends and weekdays are shown in Table 4-8 below. In summary, the *weekend peak* parking demand exceeds the present parking capacity by 20 cars (+/-114% of capacity) resulting in overflow parking on the shoulders of nearby roads. The *weekday peak* demand is less than the present parking lot capacity by 20 cars (+/- 89% of capacity). These findings do not project future demand.

Table 4-8. Summary of Existing Parking Demands at Muir Beach

	Number of Cars	
	Weekday	**Weekend**
Peak Season	160	200
Shoulder Season	115	160
Off-peak Season	30	120
Existing Parking Lot Capacity	175	175

Parking data represents average demand levels during the various seasons.
Source: draft CTMP (Peccia, 2002)

4.4.2 Trails

The recreational use of trails is the second most important reason visitors come to the Muir Beach area, after beach use. Over 25% of all respondents to the CTMP survey (Godbe, 2002) said that hiking, jogging, or biking was the primary reason for their trip to Muir Beach. Popular Marin Headlands trails including the Coastal Trail, the Redwood Creek Trail, the Green Gulch Trail, and the Dias Ridge Trail all lead to the Muir Beach area (Figure 23). Most are full multi-use trails serving hikers, mountain bikers, and equestrians. Several trails currently do not allow or have specific restrictions on bikes.

The existing parking lot at the beach serves as a trailhead for the Green Gulch and southern Coastal trails with parking and restrooms available. The other trails, however, are discontinuous in this area, with dangerous or non-existent linkages to both the parking lot/staging area and the other trails. Specifically, there is no provision for trail use between the parking lot and the locations where the Dias Ridge, Redwood Creek, and northern Coastal Trails meet Highway 1.

The existing levee road helps make a local multi-use loop for the trails within the site in conjunction with Pacific Way and the lower Green Gulch Farm access roads. It also serves as an emergency access route to the southerly end of the beach and southerly bluffs. A slightly widened area behind the dunes at the end of the levee road trail serves as an emergency staging area for rescues in the southerly portions of the site.

4.4.2.1 Trail Linkages

Linkages among the southerly trails and between those trails and the Muir Beach parking lot/staging area are well established. The Green Gulch Trail and the southern Coastal Trail merge together at the valley floor and tie directly to the beach (Figure 23). The link to the parking lot is via the footbridge across lower Redwood Creek just upstream of the beach.

The southerly Coastal Trail is currently not connected with the northerly Coastal Trail, however. The northerly segment ties into Highway 1 near the top of the coastal hills above the residential areas of Muir Beach. There is currently no provision for a trail from this location to the beach. Nor is there a provision for a separate trail through the open space to the north of Highway 1 to the other regional trails in the lower reaches and the other side of the valley, such as the Redwood Creek Trail and the Heather Cut-off Trail. Both the NPS and the general public have expressed a strong desire to create these linkages, utilizing portions of the project site where feasible. There are serious safety concerns where the discontinuous trail intersects with the Highway 1 with no obvious linkage.

Similarly, the Redwood Creek Trail ends abruptly near the intersection of Highway 1 and the Muir Woods/Frank Valley Road with no trail link to either the beach area or the other trails. The Dias Ridge Trail abruptly drops to Highway 1 well above Green Gulch Farm at a steep and windy portion of the road. There are similar safety concerns because of these conflicts. The shoulders of Highway 1 in the vicinity of the trail connections are also too narrow for safe bicycle use.

Formalized trail access to the beach is currently available only in one location, near the southerly end of the parking lot. There is direct beach access from the southerly trails without crossing Redwood Creek. Access from the existing parking lot, however, requires crossing the creek using the existing footbridge. A secondary, informal beach access route from the parking lot across the tidal lagoon was closed in summer 2003.

The current discontinuous trails create some confusion for trail users attempting to make regional linkages. The trails are not connected in obvious and safe ways, and there are few if any helpful signs directing the trail users to the next link.

4.4.2.2 Golden Gate Dairy

The Golden Gate Dairy is a horse boarding facility managed by Ocean Riders and located at the intersection of Highway One is Pacific Way (Figure 3). Under a special use permit, the barns are used for equestrian activities including stables for boarding, short-term paddock space, and as the base for trail riding. Horse manure is contained on site and supplied to Green Gulch Farm for use as a soil amendment in the farm fields and gardens. The Golden Gate Dairy is also an important community gathering space. It serves as the regular vet clinic for horses and other community pets, and has been used as the county bookmobile stop and by the Muir Beach Volunteer Fire Department.

Equestrian use of many of the trails in the Marin Headlands is an important and well-established recreational activity. The Middle Green Gulch Trail, southern Coastal Trail, and the levee road are multi-use trails which accommodate horses, as well as bikes and hikers. The Green Gulch Trail, Heather Cut-off Trail, and the Redwood Creek Trail allow for equestrian and hiking use, but not bicycles.

Ocean Riders currently use the small paddock on Green Gulch Farm property year-round for turning out their horses. They also use Field 7 and the hillsides of Green Gulch Farm (northeast portion of the project site) (Figure 3). The fenced riding ring near the paddock is also used in the summer for turning out and exercising horses. Visiting equestrians also use these facilities, particularly those passing through from other stables in the park.

4.4.3 <u>Visitor Experience</u>

At present, the primary experience that is offered to visitors of this site is the beach. The beach is the major recreational destination, although many people come to the area to engage the landscape from the trails. The roads and parking bring people directly behind the beach delivering them as close as physically possible. It is easy to bring all the accoutrements of a day on the beach – ice chests, picnic baskets, etc. – from the car direct to the sand. The beach access path and footbridge takes the visitor across the creek and through some re-emerging sand dunes, so the visitor gets a small taste of the landscape context of this coastal ecosystem before actually getting to the destination.

The beach itself is relatively small, enclosed by dramatic coastal bluffs, with a small and wind protected tidal lagoon on the backside. Although it is heavily used, it retains the sense of a somewhat wild, chilly northern California beach with steady winds and a powerful surf. There are lots of dogs, families, joggers, and strollers – people visiting for a few hours and others for shorter periods. The calmer shallow water in the tidal lagoon behind the beach is a magnet for small children. There are very few other places this close to the metropolitan center of the Bay Area that offer the same sense of accessible wildness with well protected and safe edges.

The landscape setting for the beach – the natural ecosystem of which the beach is but one part – is not so clearly evident, however. The areas behind the beach and upstream through the project area are badly degraded and generally not as available for people to use and enjoy. The space is designed for people to pass through to get to the beach, rather than to pause and engage the landscape. Seen from afar while moving along the roads, the pastoral rural landscape looks quite pleasant. Close at hand, however, the degradation is more apparent, with the extensive and rather crude manipulations to the landscape eroding unceremoniously.

The parking lot is the place where drivers become pedestrians. It is the place where one leaves the landscape of the vehicle and enters the landscape of walkers and other creatures. The present lot, however, extends the experience of the roadway rather than transforming the experience to the more richly textured landscape of the park. The lot is dusty, windy, exposed, without a clear landscape context, and with portable toilets as the main human reference. The transition from road to park occurs at some distance from the vehicles, and the experience of the roadway is carried quite a way into the park instead of the park experience extending into the parking area. The perceived zone of influence of the road and parking is greater than the actual space occupied by the parking lot because of its design.

Respondents to the CTMP Intercept Interviews indicated a range of purposes for coming to Muir Beach, which are helpful in understanding the perception of the present users about their current experience of the site (Godbe, 2002).

The list of uses in order of frequency of response include:

Visit beach/coast/ocean	56.9%	
Hiking/jogging	23.4%	
Other	22.2%	
General Rest and Relaxation	20.7%	
Picnicking		14.4%
See views from mountain		10.4%
See Redwood trees		7.5%
Seek solitude		6.1%
Go for a drive		3.1%
Biking/mountain biking		2.7%
Nature study		2.0%
Surfing		0.9%

These responses reflect the site in its current conditions, not what the respondents think it might become.

4.4.3.1 Visual/Scenic Resources

The project site and environs offer a wide range of visual delights that will be important factors in conceiving future developments. The area is rural with a history of human settlement. The supporting natural landscape is clearly evident. Although heavily manipulated and degraded in several areas, natural systems are re-establishing themselves as more visually prominent parts of the setting than they were only a few years ago. The area contains a rare blend of views of wild nature, agricultural heritage, pastoral scenery, and residential developments within the context of a clearly defined coastal watershed.

There are several important views and visual sequences that underlie the overall perceptions of the project area.

1. *Landscape Setting from the Hills*. Most of the trails, the residential areas, and the Highway 1 access road overlook the coastal valley and ocean cove, and the view is of the natural landscape setting. The view of the entire continuous landscape, from the bluff-enclosed ocean beach through the dunes and flat back-beach wetlands to the upstream riparian woodlands is rare and available from all the surrounding hills. In these views, and at the scale from which the setting is seen, the residential and agricultural developments are secondary but integrated into the natural landscape.

2. *Natural Landscape at the Center of the Community*. The open, natural landscape near the intersection of Highway 1 and Pacific Way, and at the confluence of Green Gulch and Redwood creeks, is one of the central defining features of the community of Muir Beach. It is visible from the road as approaching from each direction and provides an open-space introduction to the community. From the surrounding trails at the lower elevations, it provides the landscape transition between the beach and the upstream forests, and serves as the visual foreground to the larger landscape setting.

3. *Visual Sequence from Highway 1 to the Beach*. The route from the highway to the beach takes the visitor through a series of landscape enclosures and openings, culminating with a dramatic open vista of the ocean at the end framed by the coastal bluffs. The changing sequence of views builds to a dramatic and pleasant surprise at the beach, even though the destination is anticipated. It is not the specific existing sequence of views along the roadway that is important, since much of what is seen is a modified landscape that is not able to sustain itself. Rather, it is the nature of the sequence, the way in which the beach experience is made available after a circuitous introductory landscape experience, that is important. A similar sequential experience, though spatially different from the road, is available along the lower Green Gulch access road from Pacific Way, around to the open meadow to the south side of the site, and through the dunes to the beach. In each case, a visual context for the beach is acknowledged, making both the beach and the introductory landscape setting partners in the overall experience.

4. *Natural Woodlands along Stream Corridor*. The densely wooded Redwood Creek corridor leading through Frank Valley, across Highway 1, through the Alder Grove, and into the former lagoon site creates a natural edge to the experience of arriving at the lagoon and beach. Views of surrounding hills and valleys are alternately screened and open with glimpses through the woodlands. The woodlands themselves help to visually define the upstream limits of the open lagoon area, and the experience of being within the dense enclosed woodland offers a striking contrast to the open landscapes further downstream.

5. *Icons of Historic Rural Life*. Throughout the valley, reminders of former settlement patterns and land uses are readily found, and their presence often enriches the current experiences. The iconographic row of mailboxes at the intersection of Pacific Way and Highway 1 is one example in the vicinity of the project site. The historic dairy structures, the windrows at Green Gulch Farm, and the fields of heather on the hillside above Banducci's farm are other examples.

6. *Forests in the Hilltop Residential Areas.* The residential developments surrounding the project site are in settings that were not forested in their natural state before the houses were constructed. The scale of the houses in the style and density they have been constructed would have visually overwhelmed the hillsides if the setting were left as the native coastal scrub. The planted forest, not native to this site, however has given a scale and context to the residential area so that it doesn't overwhelm the setting. And the overall effect is to give the residential development the sense of connection with the landscape.

4.4.3.2 Interpretive Facilities

Existing signage and interpretive facilities throughout the project area are minimal. The area, however, is rich in interpretive potential. NPS staff and visitors to the area have expressed an interest in expanding the interpretive programming to reflect the diversity of the resources. Programs that encourage self-discovery as well as more facilitated interpretation are both appropriate in this area.

Existing conditions would support interpretation of a wide variety of resources. There is a history of the pattern of human settlement in this coastal enclave including important archeological findings, historic farm developments, and more recent residential and community building. Historic interventions into the natural, ecological systems and the restoration of those systems as the self-sustaining framework for the park developments are central to the current work and important for visitors to understand. Connections between this portion of the watershed landscape and the entire watershed in terms of comprehensive planning and environmental health are readily visible and transferable to other places and individual components of this landscape, such as coho salmon cycles, can be observed and tracked.

A key ingredient of a rich and diverse interpretive program is a self-sustaining framework that will evolve naturally over time while acknowledging the heritage of the site. A balance of the many forces that lie behind the present and future condition of the site would reflect the interests of the range of users of the site as well as the NPS.

4.4.4 Other Important Site Features

The development and use of the site will be influenced or partially affected by land uses of adjacent properties.

4.4.4.1 Green Gulch Farm

Green Gulch Farm is a 111-acre private property within the boundaries of GGNRA, owned and managed by San Francisco Zen Center. A residential community of approximately 60 permanent residents lives at the Farm. Zen training, meditation practice and meditation programs are the primary focus of the farm. A guest house and conference center and educational facilities accommodate the public and program participants. Between 10 and 15 acres are used for organic herb, flower, and vegetable gardens. Water supply for Green Gulch Farm relies on use of the site's water resources, including developed springs, wells, and retention ponds.

Public trails connecting to Muir Beach and the GGNRA trail system pass through or connect to Green Gulch Farm, including the Green Gulch Trail, Middle Green Gulch Trail, Coastal Trail, Redwood Creek, the levee road, and the lower Green Gulch access road.

A substantial portion of the project will be implemented on property owned by Green Gulch Farm. As a result, Green Gulch Farm is one of the partners in the project. Its residents and guests have been frequent users of the old lagoon area as well as the beach.

4.4.4.2 Muir Beach Community

The Muir Beach Community comprises approximately 150 residences located on the hillside above Muir Beach. The community also includes Green Gulch Farm, the Golden Gate Dairy horse stable, and the Banducci site. The community of Muir Beach is surrounded by GGNRA lands, which include the Banducci site and Golden Gate Dairy. The MBCSD is responsible for providing the community's water supply and fire protection, and for maintaining community roads and providing recreation. A community center is located within the residential area. The Muir Beach Community Plan supports continued horse use on GGNRA land and protection of Redwood Creek water quality from pollution. The plan acknowledges the natural values of Redwood Creek and states that the Redwood Creek floodplain, including the lower Green Gulch fields, should be protected from development and allowed to flood in winter. Muir Beach residents receive water from a well operated by the MBCSD about 1-mile upstream from Muir Beach (see Section 4.2.2.3).

4.4.4.3 Golden Gate National Recreation Area

GGNRA lands surround the community of Muir Beach, and include the hills above Green Gulch Farm (Coyote Ridge), the Golden Gate Dairy, Dias Ridge, the Banducci site, and approximately 25 acres at Muir Beach. Upstream public land-holdings within the Redwood Creek watershed include Muir Wood National Monument (NPS), Mt. Tamalpais State Park, and MMWD lands. Trails from Muir Beach connect to GGNRA and Mt. Tamalpais State Park lands, and are used by hikers, bicyclists, and equestrians (Figure 23).

The GGNRA General Management Plan (NPS, 1980) identifies its lands at Muir Beach as a Natural Landscape Management Zone, where natural resources and processes will remain as undisturbed as possible and management activities will focus on protection of wildlife and vegetation from overuse and misuse. Green Gulch Farm is within a Special Use Zone, which includes lands not expected to be acquired in the foreseeable future because of compatible land management practices. Redwood Creek and Big Lagoon have been identified as unique and threatened resources of the park in the Natural Resource Management Plan, and have been studied to identify needed management actions.

Approximately 180 acres of land upstream of the project area was purchased by the GGNRA in 1976 from the Banducci family and subsequently leased back to the family for agricultural use. The agricultural uses continued until 1995 when flow diversions from Redwood Creek were halted. NPS is currently in the process of restoring about half of the 28 acres of former flower field to functioning floodplain.

The GGNRA has initiated and chaired a comprehensive Vision Process for the Redwood Creek Watershed. The intent of the process was to create a common and widely supported vision for the future of the watershed that will guide each of the agency partners with management responsibilities for lands within the watershed. The agency partners include Marin County, California Department of Fish and Game, California Department of Parks and Recreation, MMWD, MBSCD and NPS. Wetland restoration at Muir Beach, trails, visitor access and parking are among the issues to be assessed within the context of the relationship to the overall watershed.

4.5 CULTURAL RESOURCES

NPS is currently analyzing cultural resources at the project site and will prepare a separate report that documents these cultural resource values. Soils and archaeological information obtained from the geoarchaeological investigation performed by Meyer (2003) is summarized below.

4.5.1 Subsurface Stratigraphy

In the geoarchaeological investigation conducted by Meyer (2003), 16 subsurface cores were collected at the Big Lagoon site. Most of the cores extended to a depth of 12 feet, with exception of one core that extended to a depth of 24 feet in the Muir Beach parking lot. Deposits of artificial fill were found across most of the Big Lagoon site sampled in the coring program. The depth of artificial fill varied from a minimum of about 1.5 feet in the vicinity of the old beach tavern near the southwest corner of the parking lot to a maximum of more than 8 feet in the Green Gulch pasture. The artificial fill deposits overlie lagoon silts and sands deposited in the historical marsh and lagoon environment and buried soils associated with formerly stable sand dunes in the parking area and with formerly stable alluvial fan deposits at the Pelican and Lower Fan archaeological sites.

4.5.2 Archaeological/Heritage Sites

The geoarchaeological coring indicates that at least three separate prehistoric “shell midden” sites are located around the perimeter of Big Lagoon, but additional archaeological study is need to understand the nature and extent of these sites (Meyer, 2003). Available evidence suggests that Native Americans occupied relatively stable alluvial and alluvial fan deposits adjacent to the Big Lagoon wetland, perhaps to take advantage of the various resources offered at the site. The sites are located in the vicinity of the Pelican Inn (Pelican Site), an alluvial fan east of the footbridge (Upper and Lower Fan Site), and by the historical beach tavern location near the southwestern corner of the parking lot (MRN-333). The prehistoric archaeological deposits are known to contain marine shell fragments, some flaked stone items, charcoal, and probable heat-altered rock, but likely contain many other types of artifacts and possibly human remains. Radiocarbon dating of charcoal collected from the Lower Fan site produced a date of 290 years before present (Meyer, 2003). NPS will collect additional cores for the geoarchaeological assessment in 2003.

5. CONCEPTUAL MODEL FOR FUTURE CONDITIONS

With continued active maintenance of the channel, NPS may be able to maintain the current conditions as described above, but flooding of Pacific Way will likely not improve. A schematic diagram summarizing the principal physical processes that are expected to shape the morphology of the project site is depicted in Figure 24. In the absence of channel management, the lower reaches of Redwood Creek will continue to lose capacity from deposition upstream and downstream of Pacific Way Bridge. As the channel fills, overbank flows are likely to occur more frequently during high flow events. A new channel will probably form along the low point of the valley between the Highway One and Pacific Way bridges, flowing down the center of Green Gulch pasture and reconnecting to the backwater channel at the southern end of the pasture. The new channel may be composed of several distributary branches until a dominant channel evolves. Over this evolutionary period, a main channel may not be well defined, potentially preventing upstream migration of andramodous fish species. Diffuse flow pathways may lead to higher groundwater elevations in Green Gulch pasture, an increase in wetland vegetation (e.g., cattails), and an increase in back beach elevations from the migration of wind blown sand.

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7. REFERENCES

Alvarez, M., 1999. The influence of Cape ivy (*Delairea odorata*) on three plant communities. Master's thesis, Sonoma State University.

American Ornithologists' Union, 1983. Check-list of North American Birds. Sixth Edition. A.O.U., Washington, D.C.

American Ornithologists' Union., 1985. Thirty-fifth supplement to Amer. Ornith. Union Check-list of North American Birds. Auk 102:680-686.

APHA, Ed, 1998. Standard Methods for the Examination of Water and Wastewater. 19th Edition. Washington, DC, American Public Health Association.

Arnold, J.R. 1971. A study of the silver salmon (Oncorhynchus kisutch) and steelhead rainbow trout (Salmo gairdneri gairdneri) in Redwood Creek, Marin County, California. U.S. Department of Interior, National Park Service, Contract 14-10-9-990-33.

Atwater, B. F., and C. W. Hedel, 1976. Distribution of seed plants with respect to tide levels and water salinity in the natural tidal marshes of the northern San Francisco Bay estuary: U.S. Geological Survey, Open File Report 76-389.

Banducci, A., 1993. Personal communication. Manager of flower bulb and heather farm in Frank Valley.

Bell, M. C., editor, 1991. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, U. S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Beutel, M., 1998. Golden Gate National Recreation Area Stormwater Monitoring Program 1997/1998. Final Report. Submitted to National Park Service Division of Resource Management and Planning Golden Gate National Recreation Area, San Francisco, CA. June.

Bicknell, S.H., R.P. Godar, D.J. Bigg, and A.T. Austin. June 1993. Mount Tamalpais State Park Prehistoric Vegetation Final Report. Humboldt State University for California Department of Parks and Recreation.

Bruton, M. N., 1985. The effects of suspensoids on fish. Hydrobiologia 125: 221-241.

Bruun, P., 1988. The Bruun Rule of Erosion by Sea-Level Rise: A discussion of Large Scale Two and Three-Dimensional Usages. *Journal of Coastal Research* 4: 627-648.

CALFED, 2001. Ecosystem Restoration Program Plan: Strategic Plan for Ecosystem Restoration. Final Programmatic EIS/EIR Technical Appendix. July 2000.

California Data Information Program, 2003a. Pt. Reyes Station, 1997-2002. http://cdip.ucsd.edu/tmp/stream_frame05069.html

California Data Information Program, 2003b. San Francisco Bay Area Wave Model. http://cdip.ucsd.edu/models/sf.gif

CDFG (California Department of Fish and Game). 1956. Unpublished stream surveys. CDFG, Yountville, California.

CDFG (California Department of Fish and Game). 1976. Memos on status of coastal steelhead project. Yountville, California.

CDFG (California Department of Fish and Game). 1977. Unpublished stream surveys. CDFG, Yountville, California.

CDFG (California Department of Fish and Game). 1984. Unpublished stream surveys. CDFG, Yountville, California.

CDFG. 2002. Status Review of California Coho Salmon North of San Francisco. Report to the California Fish and Game Commission. Prepared by The California Department of Fish and Game Candidate Species Status Review Report 2002-3. April http://www.dfg.ca.gov/nafwb/pubs/2002/2002_04_coho_status.pdf

CNDDB (California Natural Diversity Database). 2002. List of California terrestrial natural communities recognized by the California Natural Diversity Database, May 2002 Edition. California Department of Fish and Game, Sacramento, CA.

Confer, J. L., and P. I. Blades, 1975. Omnivorous zooplankton and planktivorous fish. Limnology and Oceanography 20: 571-579.

Cook, D. 1998. California red-legged frog and bullfrog – tadpole trapping, egg mass, and frog surveys: Golden Gate National Recreation Area, Marin County, CA, Spring/summer 1998. Prepared for D. Fong, GGNRA. August 31, 1998 (revised January 3, 2003 by Darren Fong to correct tables).

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe, 1979. Classification of wetlands and deepwater habitats of the United States, Biological Services Program Report FWS/OBS-79/31. Prepared for U. S. Fish and Wildlife Service, Office of Biological Services, Washington, D. C.

Cowen, R., 1991. Vanishing amphibians: Why they're croaking. Science News. 137:116.

Duncan, F. L., 1989. An Overview of the Prehistory and History of the Marin County Area.

Duncan, F. L., Unknown date. *The History of Two Valleys: Frank's and Homestead Valley, Marin County, California*.

Dybala, K. 2002. Golden Gate National Recreation Area, Winter 2001–2002 Waterbird Survey Results. Prepared for the National Park Service, Golden Gate National Recreation Area, Division of Resource Management. April.

Ely, E., 1993. Sensitive Species Herpetological Survey, Golden Gate National Recreation Area 1993. Prepared for the Golden Gate National Parks Association, San Francisco, CA.

Faden, M. 2002. Rare plant inventory report, Golden Gate National Recreation Area. Prepared for the National Park Service, GGNRA, San Francisco, CA.

Federal Register. Tuesday, March 13, 2001. Rules and Regulations, Vol. 66, No. 49. *As cited in* Fellers and Guscio 2003.

Fellers, G., and G. Guscio, 2003. California red-legged frog surveys of Lower Redwood Creek restoration project area, Golden Gate National Recreation Area – Draft report. Prepared by Western Ecological Research Center, US Geological Survey, Point Reyes, California.

Fellers, G., and P. Kleeman. 2003. California red-legged frog (Rana aurora draytonii) movement and habitat use. Prepared by Western Ecological Research Center, US Geological Survey, Point Reyes, California.

Fisher, A., M. Alvarez, and D. Fong, 1997. The effects of *Senecio mikanioides* on riparian invertebrate populations in Redwood Creek and Elk Creek in the Golden Gate National Recreation Area. Golden Gate National Recreation Area, San Francisco, CA.

Fong, D., 1996. Usage of Lower Redwood Creek and Big Lagoon by Juvenile Coho Salmon and Steelhead. Ecology Program 1995 Annual Report. National Park Service, Golden Gate National Recreation Area.

Fong, D., 1997a. 1996 Outmigrant trapping program Redwood Creek, Marin County. National Park Service, San Francisco, CA.

Fong, D., 1997b. 1996 California Freshwater Shrimp (*Syncaris pacifica*) Surveys within Point Reyes National Seashore and Golden Gate National Recreation Area. Prepared for the National Park Service, Golden Gate National Recreation Area. Division of Natural Resource Management. San Francisco, CA.

Fong, D., 1997c. 1996-1997 Redwood Creek spawner and carcass survey. Golden Gate National Recreation Area, San Francisco, CA.

Fong, D., 1999. 1997 California Freshwater Shrimp (*Syncaris pacifica*) Suveys Within Point Reyes National Seashore and Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area Division of Resource Management and Planning.

Fong, D., 2000. Winter 1998-2000 Frog Breeding Survey, Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area, Division of Resource Management.

Fong, D. 2002a. Summer 1995 stream habitat and benthic macroinvertebrate inventory, Redwood Creek, Marin County, California. Prepared for the National Park Service, Golden Gate National Recreation Area. Division of Natural Resource Management and Science. San Francisco, CA. 70 pp.

Fong, D,. 2002b. Western Pond Turtle (*Clemmys marmorata*) Inventory, Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area, Division of Resource Management.

Fong, D., J. Lee, and T. Muffoletto. 2003. Invertebrate inventory of seasonally and perennially inundated sites at Muir Beach, California. Prepared for the Golden Gate National Recreation Area, Division of Resource Management and Science.

Gardali, T., and G. R. Geupel, 1997. Songbird inventory and monitoring at Golden Gate National Recreation Area.

Gardali, T., C. Shoulders, D. Hatch, A. L. Holmes, S. E. Scoggin, and G. R. Geupel, 2001. Songbird monitoring in the Golden Gate National Recreation Area: a multifaceted tool for guiding the restoration of Redwood Creek. Park Science 21: 28-32.

Gardali, T., S. E. Scoggin, and G. R. Geupel, 1999. Songbird use of Redwood and Lagunitas creeks: management and restoration recommendations.

Godbe Research and Analysis (Godbe), 2002. Comprenhensive Transporation and Management Plan, Intercept Interviews. Prepared for National Park Service and Marin County. Godbe Research & Analysis. June 14, 2002.

Haux, S. and D. Anderson. 1992. Redwood Creek basin spawning and carcass survey protocol (draft). Redwood National Park, Fish and Wildlife Branch, Research and Resource Management Division.

Hayes, M. P., and M. R. Jennings, 1986. Decline of ranid frog species in western North America: Are bullfrogs (*Rana catesbeiana*) responsible? J. Herp. 20:490-509.

Hayes, M. P., and M. R. Jennings, 1989. Habitat correlates of distribution of the California red-legged frog (*Rana aurora draytonii*) and the foothill yellow-legged frog (*Rana boyleii*): Implication for management. In: Robert E. Sarzo, Keith E. Severson, and David R. Patton (technical coordinators): Management of amphibians, reptiles, and small mammals in North America, Proceedings of the symposium on the (July 19-21, 1988, Flagstaff, AZ). USDA General Technical Report RM-166:1-458.

Heard, M., 1904. A California frog ranch. Out West 21: 20-27.

Henley, W. E., M. A. Patterson, R. J. Neves, and A. D. Lemly, 2000. Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resource Managers. Reviews in Fisheries Science, 8(21): 125-139

Hilton-Taylor, C., (compiler), 2000. 2000 IUCN Red List of threatened species. IUCN, Gland, Switzerland, and Cambridge, UK (http://www.redlist.org/).

Holland, R., 1986. Preliminary descriptions of the terrestrial natural communities of California. Non-game heritage program. Calif. Dept. Fish Game, Sacramento, CA. unpub. m.s. 156 p.

Holland, R., 1990. Natural communities. Natural diversity data base. Calif. Dept. Fish Game, Sacramento, CA. unpub. m.s. 9 p.

Holmes, A. L., D. L. Humple, T. Gardali, and G. R. Geupel, 1999. Songbird habitat associations and response to disturbance in the Point Reyes National Seashore and Golden Gate National Recreation Area.

Horne, A., and C. Goldman, 1994. Limnology, McGraw-Hill, New York.

Jebens, B.S., 2001. A historical geography of disturbances within Redwood Creek Watershed, Marin County, California. Masters Thesis: San Francisco State University, San Francisco, CA.

Jennings, C. W., 1977. Geologic Map of California. California Department of Conservation, Division of Mines and Geology and the U.S. Geological Survey.

Jennings, M. R., 1991. Status of the California red-legged frog (*Rana aurora draytonii*) in Moore Creek on the University of California at Santa Cruz campus. unpubl. tech. rep.

Jennings, M.R., and M. P. Hayes, 1985. Pre-1900 overharvest of California red-legged frogs (*Rana aurora draytonii*): The inducement for bullfrog (*Rana catesbeiana*) introduction.

Johns, Alice. 1993. Redwood Creek Water Rights Assessment. Technical Report NPS/NRWRD/NRTR-93/16. National Park Service Water Rousers Division, Denver, CO.

Johnson, J. W., 1973. Characteristics and Behavior of Pacific Coast Tidal Inlets. *Journal of Waterways, Harbors, and Coastal Engineering Division*. ASCE, Vol. 99, No. WWE p. 325-339.

Kashiwagi, J. H., 1985. Soil survey of Marin County, California. United States Department of Agriculture, Soil Conservation Service.

Klein, R., G. Smillie, and J. Vick, 2002. Potential Interim Actions to Reduce Flooding adjacent to Lower Redwood Creek, Marin County, California. Prepared for the Golden Gate National Recreation Area, San Francisco, CA.

Komar, P. D., 1998. *Beach Processes and Sedimentation*. Prentice Hall, New Jersey. 544p.

Laidig, T., 2003. 2001-2002 salmonid estuary study. National Marine Fisheries Service, Santa Cruz Laboratory, Santa Cruz, CA. May 9, 2003. 8 pp. Draft.

Laudon, J., 1988. Redwood Creek Underflow, Marin County. Memorandum to files, Division of Water Rights, State Water Resources Control Board. 9p.

Leach, P. S., M. Podlech,. and R. J. Brown, 1997. Rodeo Valley/Tennessee Valley/Redwood Creek Water Quality Monitoring Report. October 1996-March 1997. Institute of Chemical Biology, University of San Francisco, San Francisco, CA. Prepared for the National Park Service, Golden Gate National Recreation Area.

Loomis, W. F., 1954. Environmental factors controlling growth in hydra. J. Exp. Zool. 126:223-234.

Madej, M., 1989. Analysis of USGS Water Quality Data Marin Headlands GGNRA 1986-1988. Redwood National Park, Arcata, CA. Prepared for National Park Service, Golden Gate National Recreation Area.

Marin Municipal Water Department (MMWD), 1995. Mount Tamalpais Area Vegetation Management Plan. Prepared by Leonard Charles and Associates for the Marin Municipal Water District, Corte Madera, CA.

Martin, L. 2000. Hydrogeology of the Muir Beach Community Services District Well Site Frank Valley, Redwood Creek, California, Golden Gate National Recreation Area. National Park Services Water Resources Division Technical Report NPS/NRWRD/NRTR-2000/265, Ft. Collins, CO.

Martin, T. E., C. R. Paine, C. J. Conway, W. M. Hochachka, P. Allen, and W. Jenkins, 1997. BIRD Field Protocol. Montana Cooperative Wildlife Research Unit, University of Montana, Missoula, Montana, USA.

Meyer, J., 2003. Preliminary Findings of the Big Lagoon Geoarchaeological Coring Program, Lower Redwood Creek, Marin County, California. Prepared for the Golden Gate National Recreation Area, San Francisco, CA.

Meyers, R., 1990. Redwood Creek Water Balance, Hydrologic Year 1985-86. Muir Woods National Monument.

MMWD (Marin Municipal Water District). 1995. Mount Tamalpais Area Vegetation Management Plan. Prepared by Leonard Charles and Associates for the Marin Municipal Water District, Corte Madera, CA.

Monroe, M. 2003. Monarch Butterflies at Muir Beach, Marin County, CA. Muir Woods National Monument.

Montgomery, J. M., Consulting Engineers, 1985. Water Treatment Principles and Design, John Wiley and Sons.

Moyle, P. B., 1973. Effects of introduced bullfrogs, *Rana catesbeiana*, on the native frogs of the San Joaquin Valley, California. Copeia. 1: 18-22.

Munro-Fraser, J. P., 1880. *The History of Marin County, California*. Alley, Bowen and Company Publishers, San Francisco.

National Geographic Society, 1983. Field Guide to the birds of North America. National Geographic Society, Washington, D.C.

National Park Service (NPS), 1980. Golden Gate National Recreation Area General Management Plan.

National Park Service (NPS), 1999. Hydrogeology of the Muir Beach Community Services District Well Site, Frank Valley, Redwood Creek, California. Preliminary report to Golden Gate National Recreation Area, San Francisco.

National Park Service (NPS), 2002a. Biological Monitoring Report for the Flood Control and Habitat Enhancement Projects on Redwood Creek in Marin County, California. Prepared by National Park Service for the National Marine Fisheries Service. December 26, 2002.

National Park Service (NPS) Technical Scoping Notes. 2002b. Lower Redwood Creek Restoration Planning: Dunes and riparian birds technical scoping. Field Meeting Notes, Dunes and Riparian Birds Technical Scoping Meeting conducted at the Big Lagoon Restoration site on August 2, 2002.

National Park Service (NPS), 2003. Personal communication between Carolyn Shoulders (NPS) and Noah Hume (Stillwater Sciences), 6/27/2003.

NatureServe, 2001. NatureServe Explorer: an online encyclopedia of life. Version 1.6. Association for Biodiversity Information, Arlington, VA (http://www.natureserve.org/explorer/).

Odum, H. T., 1956. Primary production in flowing waters: Limnology and Oceanography, v. 1, no. 2, p. 102-117.

Robert Peccia and Associates (Peccia), 2002. Draft Comprehensive Transportation Management Plan (CTMP) for Parklands in Southwestern Marin, Existing Condition Technical Memorandum. Prepared for Marin Parklands Task Force. Prepared by Robert Peccia and Associates. August 2002.

Pechmann, J. H. K., D. E. Scott, R. D. Semlitsch, J. P. Caldwell, L. J. Vitt, and J. W. Gibbons, 1991. Declining amphibian populations: The problem of separating human impacts from natural fluctuations. Science. 253: 892-895.

Philip Williams & Associates, Ltd. (PWA), 1993. Summary of Water Quality Data for Redwood Creek and Green Gulch. 1986-1993. Prepared for the National Park Service, Golden Gate National Recreation Area.

Philip Williams & Associates, Ltd. (PWA), 1995. Analysis of Land Use Impacts on Water Quality and Quantity in Redwood Creek. Prepared for The National Park Service, Golden Gate National Recreation Area. January.

Philip Williams & Associates, Ltd. (PWA), 2000. The Feasibility of Restoring Floodplain and Riparian Ecosystem Processes on the Banducci Site, Redwood Creek. Prepared for the Golden Gate National Recreation Area, San Francisco, CA.

Philip Williams & Associates, Ltd. (PWA), Moss Landing Marine Laboratories, Dr. Jerry Smith, San Jose State University, John Northmore Roberts and Associates, Nancy Horner, Golden Gate National Recreation Area, 1994 (PWA et al. 1994). A Preliminary Environmental Assessment of Wetland Restoration Alternatives for Big Lagoon At Muir Beach, Marin County. Prepared for The California Department of Transportation, District IV. April.

Phillips, K., 1990. Where have all the frogs and toads gone? Bioscience. 40: 1-6.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante, 1993. Field methods for monitoring landbirds. USDA Forest Service Publication, PSW-GTR 144. Albany, CA.

Redfield, A. C., 1958. The Biological Control of Chemical Factors in the Environment. American Scientist 46(3): 205-221.

RHJV (Riparian Habitat Joint Venture), 2000. Version 1.0. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight. http://www.prbo.org/calpif/plans.html.

Rosenberg, D. M., and V. H. Resh, eds, 1993. Freshwater biomonitoring and benthic macroinvertebrates: New York, Chapman and Hall.

San Francisco Regional Water Quality Control Board (SFRWQCB), 1995. San Francisco Bay Basin (Region 2) Water Quality Control Plan. Oakland, CA.

Sawyer, J.O., and T. Keeler-Wolf. 1995. A Manual of California Vegetation. California Native Plant Society, Sacramento, CA.

Scoggin, S. E., T. Gardali, and G. R. Geupel, 2000. Assessment of songbird response to cape ivy removal in the Redwood creek watershed: a progress report to the Golden Gate National Recreation Area.

Shapovalov, L., and A. C. Taft, 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. California Department of Fish and Game.

Shoulders, C., 2003. Notes on dune restoration activities/dune characterization at Muir Beach. National Park Service, March 5, 2003.

Shuford, W. D., 1993. The Marin County Breeding Bird Atlas: a distributional and natural history of coastal California birds. California Avifauna Series 1. Bushtit Books, Bolinas, CA.

Shuford, W. D., and T. Gardali. In review. California bird species of special concern 2003: Revised draft report to California Department of Fish and Game. Western Birds Monograph Series.

Shuford, W., G. Page, J. Evens, and L. Stenzel, 1989. Seasonal abundance of waterbirds at Point Reyes: a coastal California perspective. Western Birds 20(4): 137-265.

Small, A., 1974. The birds of California.

Smith, J. J., 1994a. Effects of streamflow reductions on fish habitat quality in Redwood Creek and lagoon. Prepared for the National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 4 pp.

Smith, J. J., 1994b. Abundance of coho and steelhead in Redwood Creek in 1994. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 10 pp.

Smith, J. J., 1994c. The effect of drought and pumping on steelhead and coho in Redwood Creek from July to October 1994. Prepared for the National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 6 pp.

Smith, J.J., 1995. Distribution and Abundance of Coho and Steelhead in Redwood Creek in Fall 1995. Dept. of Biol. Sciences, San Jose State Univ.

Smith, J. J., 1996. Distribution and abundance of coho and steelhead in Redwood Creek in November 1996. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Smith, J. J., 1997. Distribution and abundance of coho and steelhead in Redwood Creek in Fall 1997. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Smith, J. J., 1998. Distribution and abundance of coho and steelhead in Redwood Creek in Fall 1998. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 12 pp.

Smith, J. J., 2000. Distribution and abundance of juvenile coho and steelhead in Redwood Creek in Fall 2000. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 8 pp.

Smith, J. J., 2001. Distribution and abundance of juvenile coho and steelhead in Redwood Creek in Fall 2001. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Smith, J., and K. Berg, 1988. Inventory of rare and endangered vascular plants of California. Calif. Native Plant Soc. Sacramento, CA. Spec. Publ. 1 (4th edition), 246 p.

Snider, W., 1984. An assessment of coho salmon and steelhead resource requirements in Redwood Creek, Marin County. California Department of Fish and Game, Environmental Services Branch, Adm. Report 84-1.

Stallcup, R., 1995. Muir Beach native birds survey May 1994 to April 1995. Unpubl. report prepared for The Golden Gate National Recreation Area, U.S. National Park Service.

Stebbins, R. C., 1954. Amphibians and Reptiles of Western North America. McGraw-Hill Book Company, Inc. New York, New York. 536p.

Stillwater Sciences, 2003. Sediment Budget for Redwood Creek Watershed, Marin County, California. Prepared for Golden Gate National Parks Association.

Storlazzi, C. D., C. M. Willis, and G. B., Griggs, 2000. Comparative impacts of the 1982-83 and 1997-98 El Nino winters on the central California coast. Journal of Coastal Research. Vol. 16, No. 4: 1022-1036.

Takekawa, J. Y., M. A. Bias, I. Woo, S. A. Demers, and E. E. Boydston, 2003. Small mammal survey at Big Lagoon. Unpubl. Progr. Rep., U.S. Geological Survey, Vallejo, CA. 25pp.

Tamalpais Land and Water Company, 1892. Map of Big Lagoon.

U.S. Army Corps of Engineers (USACE), 1987. Corps of Engineers Wetland Delineation Manual, Department of the Army Technical Report Y-87-1.

U.S. Coast and Geodetic Survey (USCS), 1853. Pacific Coast, North of the Entrance to San Francisco Bay. Topographic Sheet 400.

U.S. Fish and Wildlife Service, 1996. Endangered and threatened wildlife and plants; review of plant and animal taxa that are candidates for listing as endangered or threatened. Federal Register 61:7596-7693.

Vick, J. 2002. Review of Big Lagoon historical aerial photographs. Conducted by Jennifer Vick, Golden Gate National Recreation Area, NPS, May 29, 2002.

Vore, D., 1996. Memorandum re Woody Debris Recruitment - Redwood Creek, 1994 AND 1995 AND 1996.

Wahrhaftig, C., 1994. Notes for the Green Gulch - Muir Beach Field Trip. From IGC Guidebook T105.

Wells, L., 1994. Memorandum to Philip Williams & Associates, Ltd. Describing analysis of soil cores taken at the restoration site. In: Philip Williams & Associates, Ltd. *et al*., 1994, as Appendix A.

Williamson, A. K., M. D. Munn, S. J. Ryker, R. J. Wagner, J. C. Ebbert, and A. M. Vanderpool, 1998, Water Quality in the Central Columbia Plateau, Washington and Idaho, 1992-95: U.S. Geological Survey Circular 1144.

Willis, C.M., 2002. Assessing Natural and Human Alterations to the Coastal Sediment Supply and the Impacts on Regional Beach Sustainability. Ph.D. dissertation. University of California, Santa Cruz. 141p.

Zervas, C., 2001. Sea Level Variations of the United States: 1854-1999. National Oceanic and Atmospheric Administration Technical Report NOS CO-OPS 36. 80p.

APPENDIX A
GROUNDWATER MONITORING DATA

APPENDIX B
WATER QUALITY

APPENDIX C
BIG LAGOON COMPILATION OF VEGETATION

APPENDIX D
BIOLOGICAL SAMPLING METHODS

APPENDIX E
PLANT SPECIES LIST BY WETLAND POLYGON NUMBER

APPENDIX F
AQUATIC INVERTEBRATE

APPENDIX G
BIRD SURVEYS

APPENDIX H
TERRESTRIAL MAMMALS

APPENDIX I
FISH SURVEYS

APPENDIX J
SPECIAL STATUS SPECIES

APPENDIX K
LIST OF PREVIOUS STUDIES

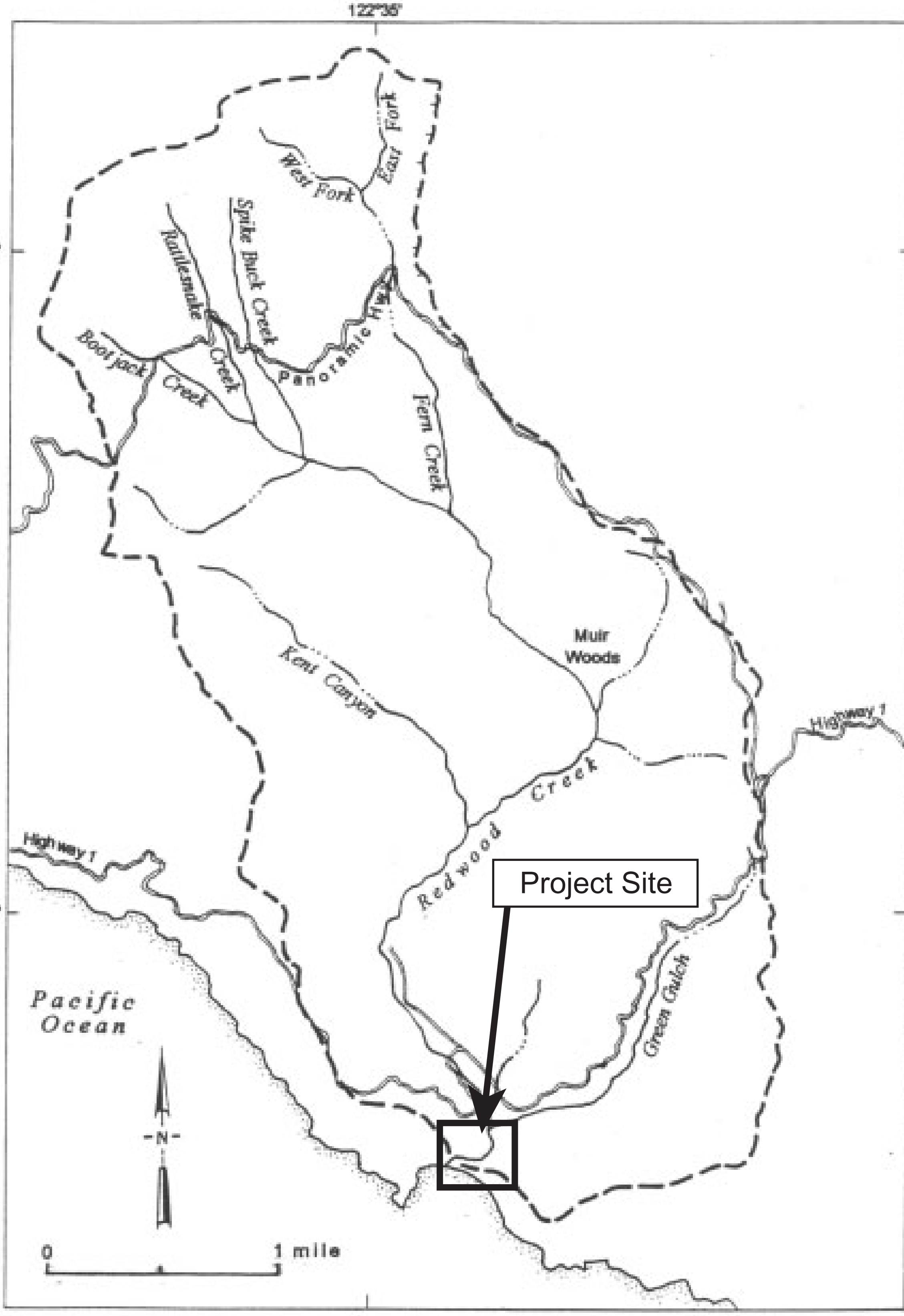

figure **1**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Redwood Creek Watershed and Project Site Location

PWA#1664.02

PWA

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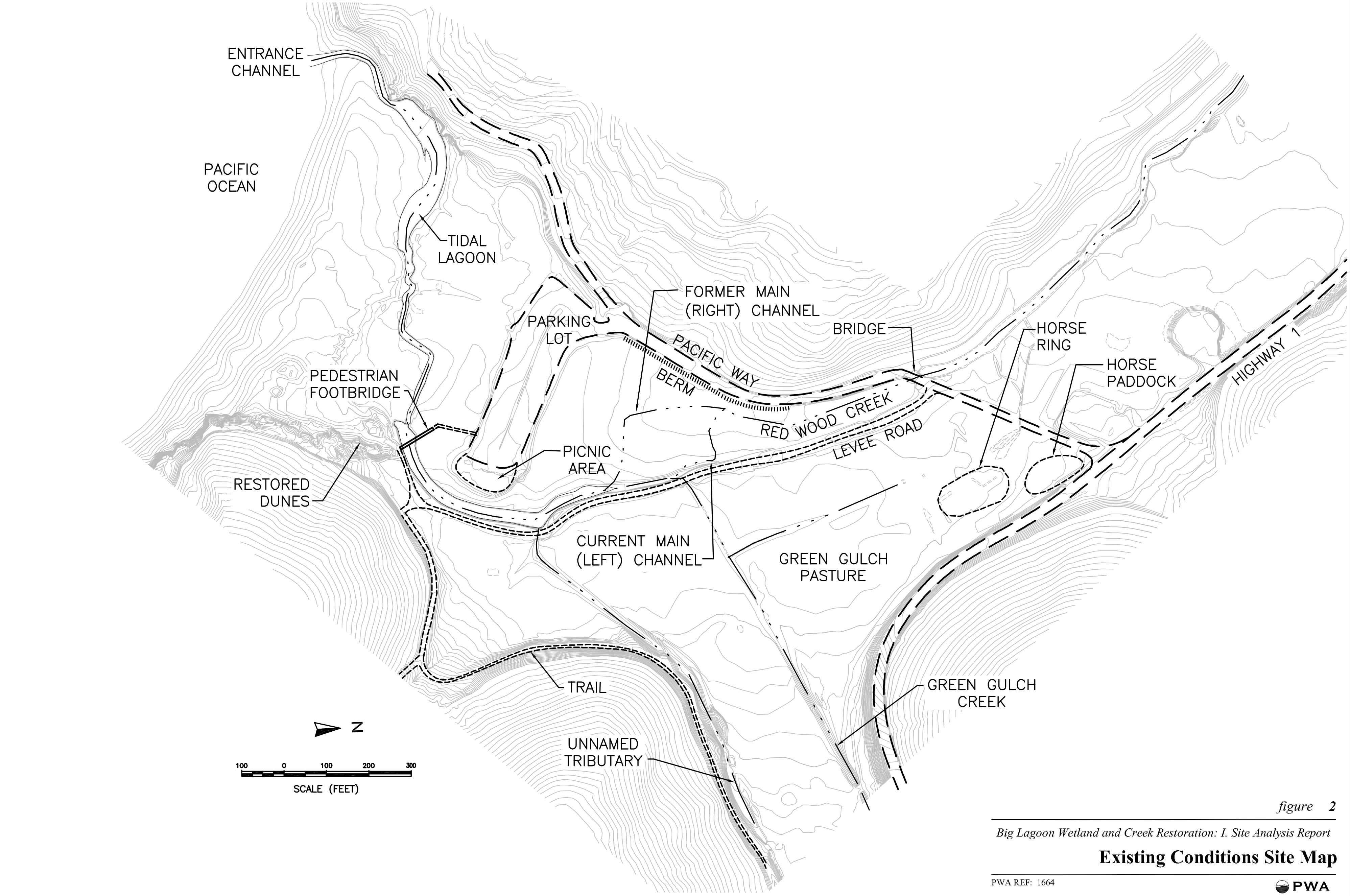


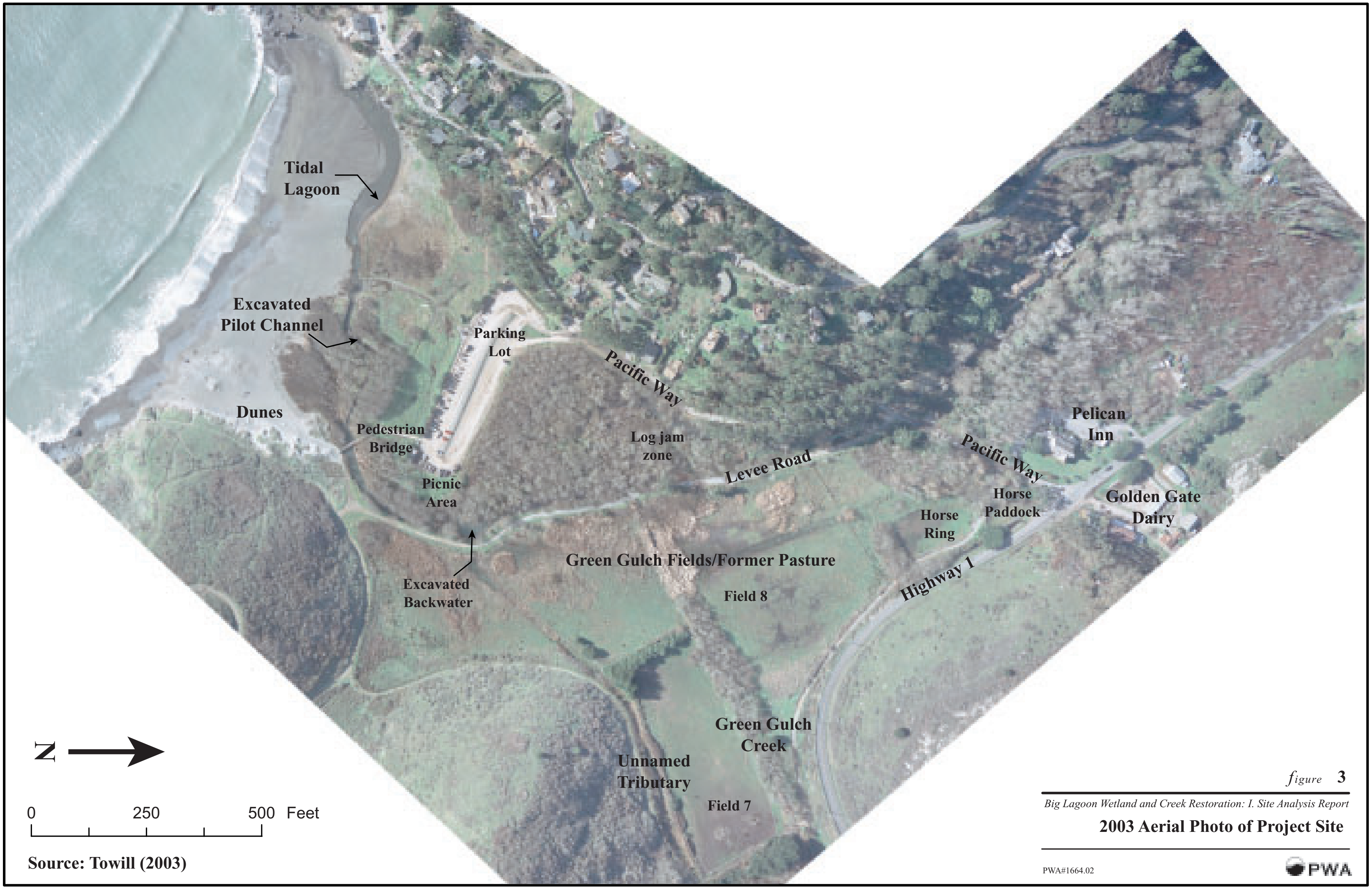
figure **2**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Existing Conditions Site Map

PWA REF: 1664

PWA



Source: Towill (2003)

figure 3

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

2003 Aerial Photo of Project Site

PWA#1664.02

PWA

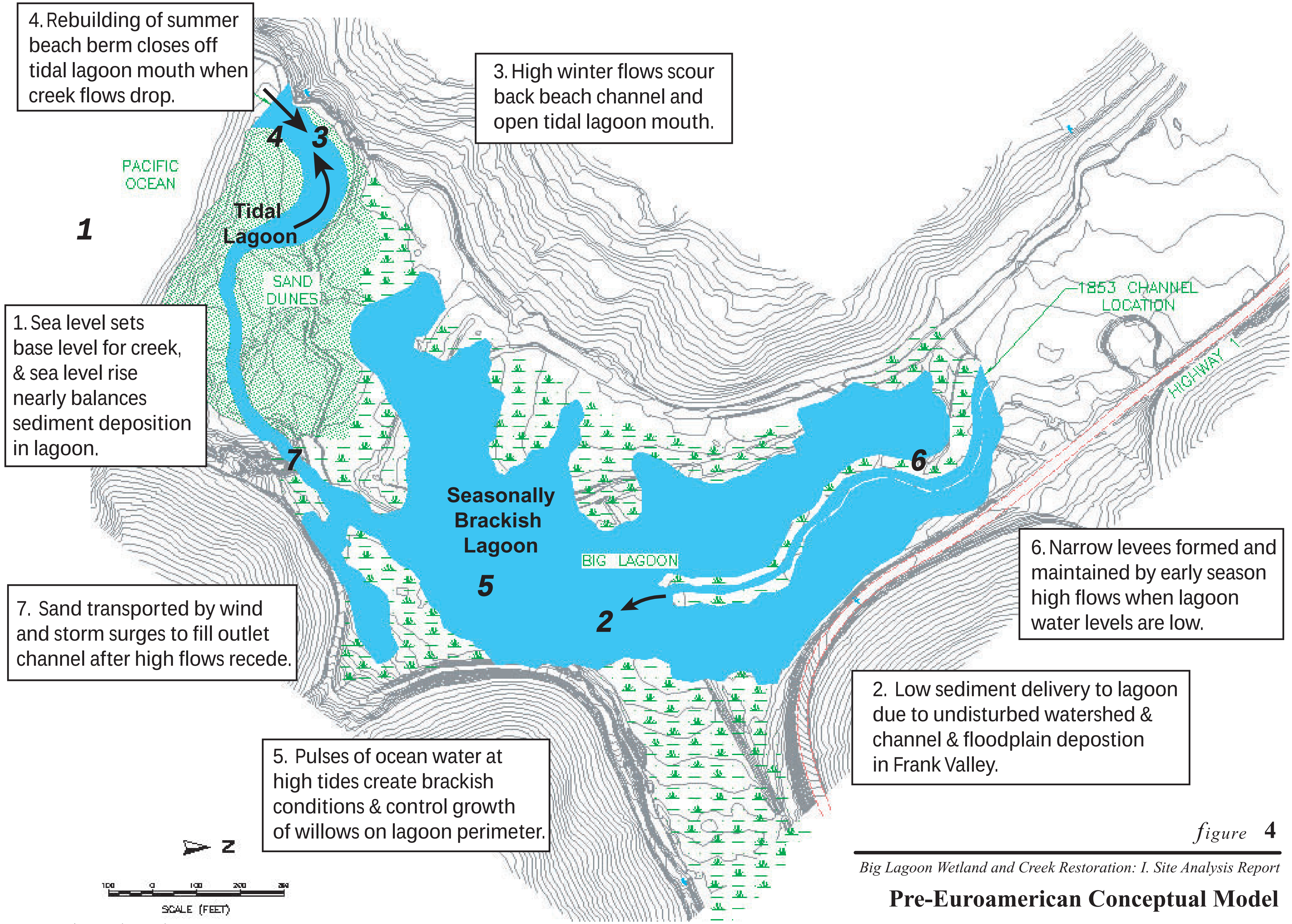


Figure based on USCS 1853 map

figure 4

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Pre-Euroamerican Conceptual Model

PWA#1664.02

PWA

Source:
Stillwater (2003)

f igure **5**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Sediment Discharge History into Big Lagoon

PWA Ref #1664.02

PWA

Fig05_Sed_History.doc

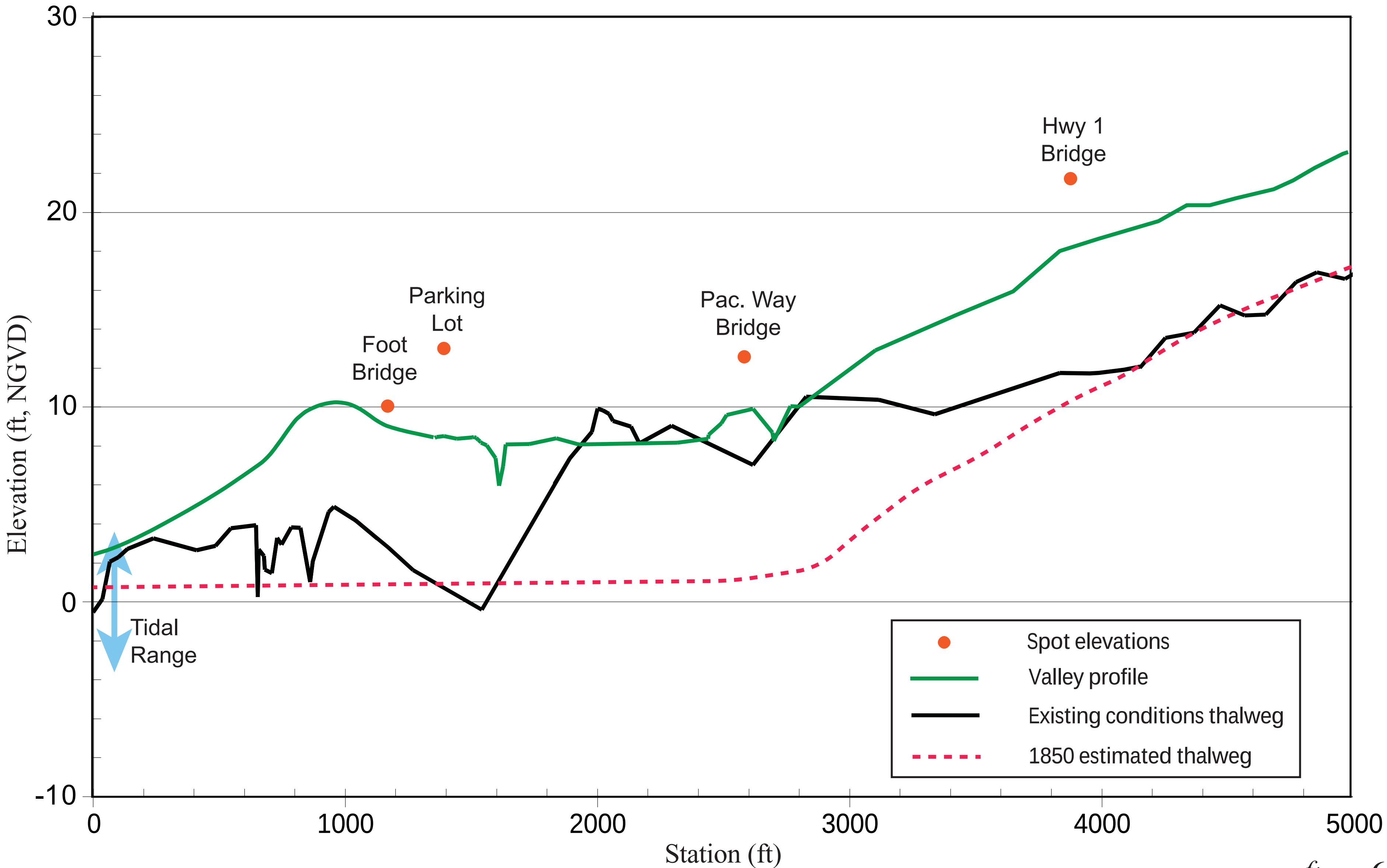


figure **6**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Existing Conditions vs. 1850 Profile

PWA#1664.02

PWA

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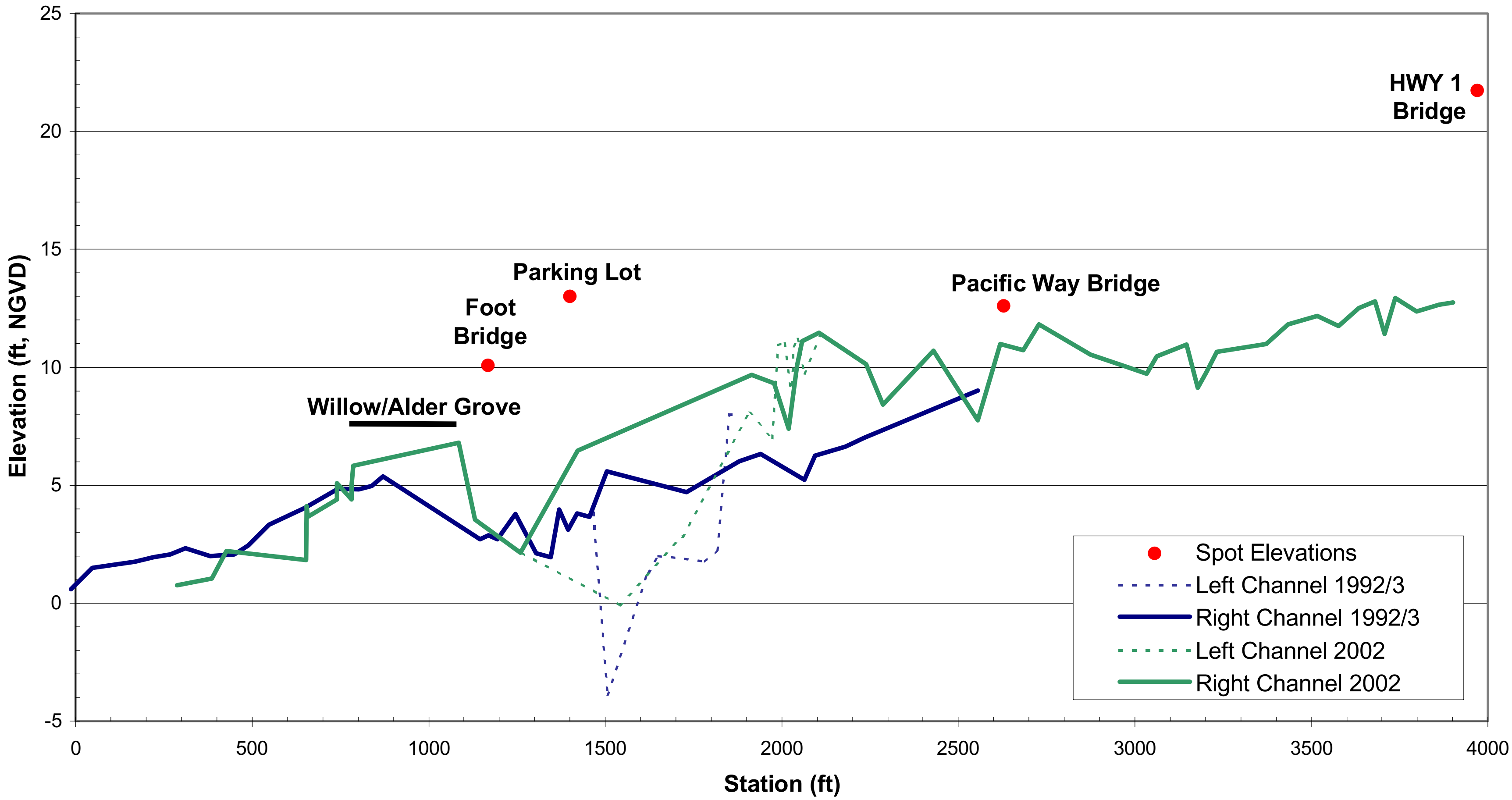


Sources:
1992 Survey, (PWA, 1994)
2002 Survey, (NPS, 2002)
Note:
Between stations 1300 and 2000, Redwood Creek is a two channel system.

f igure **7**

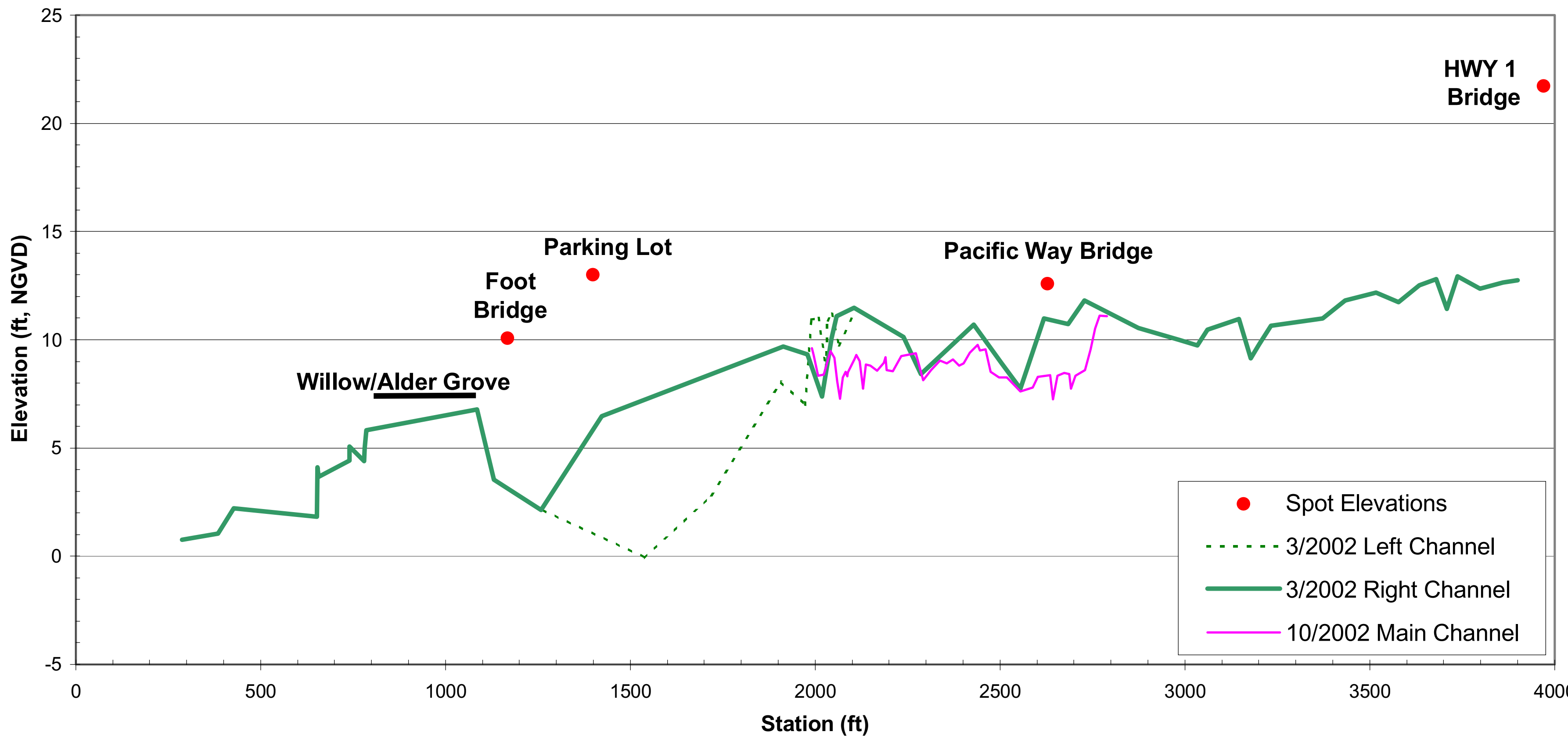
Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Redwood Creek Thalweg: 1992 vs. 2002

PWA Ref #1664.02

PWA

Fig07_1992vs2002.doc



Sources:
NPS (2002)

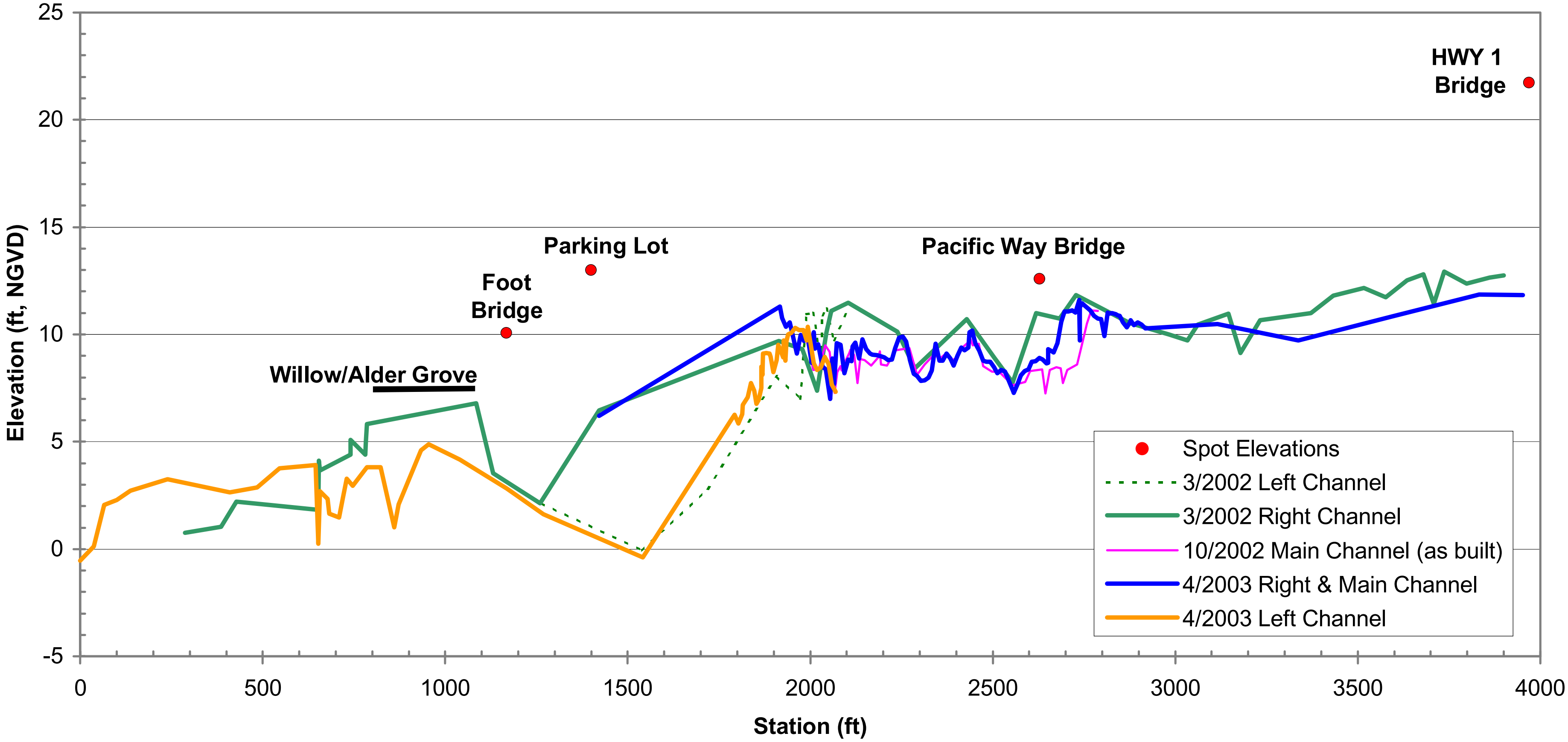
f igure **8**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Redwood Creek Thalweg: 3-2002 vs. 10-2002

PWA Ref #1664.02

PWA



Sources:
2002 surveys, NPS (2002)
2003 survey, EDS (2003)

f igure **9**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Redwood Creek Thalweg: 3-02, 10-02, & 4-03

PWA Ref #1664.02

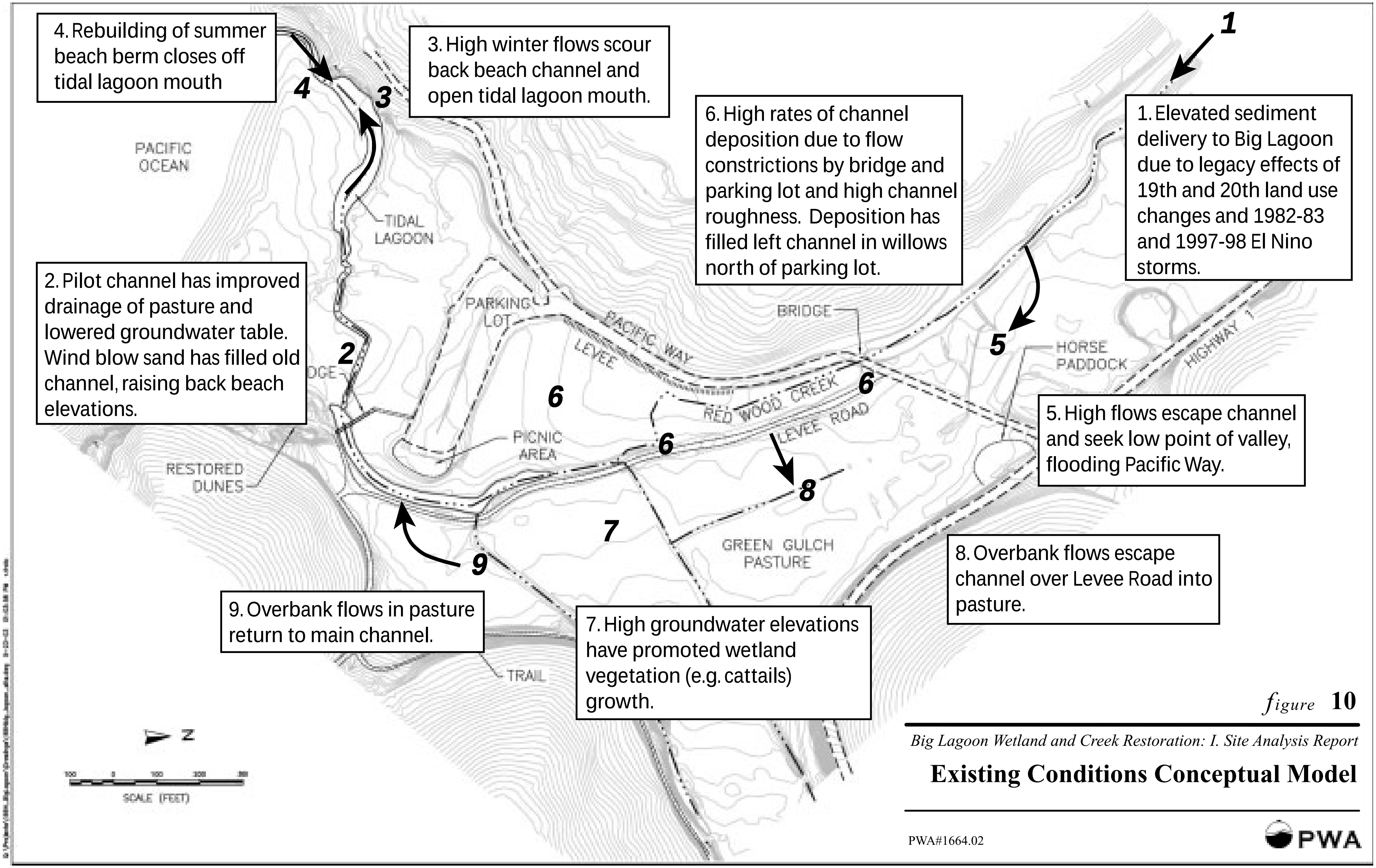


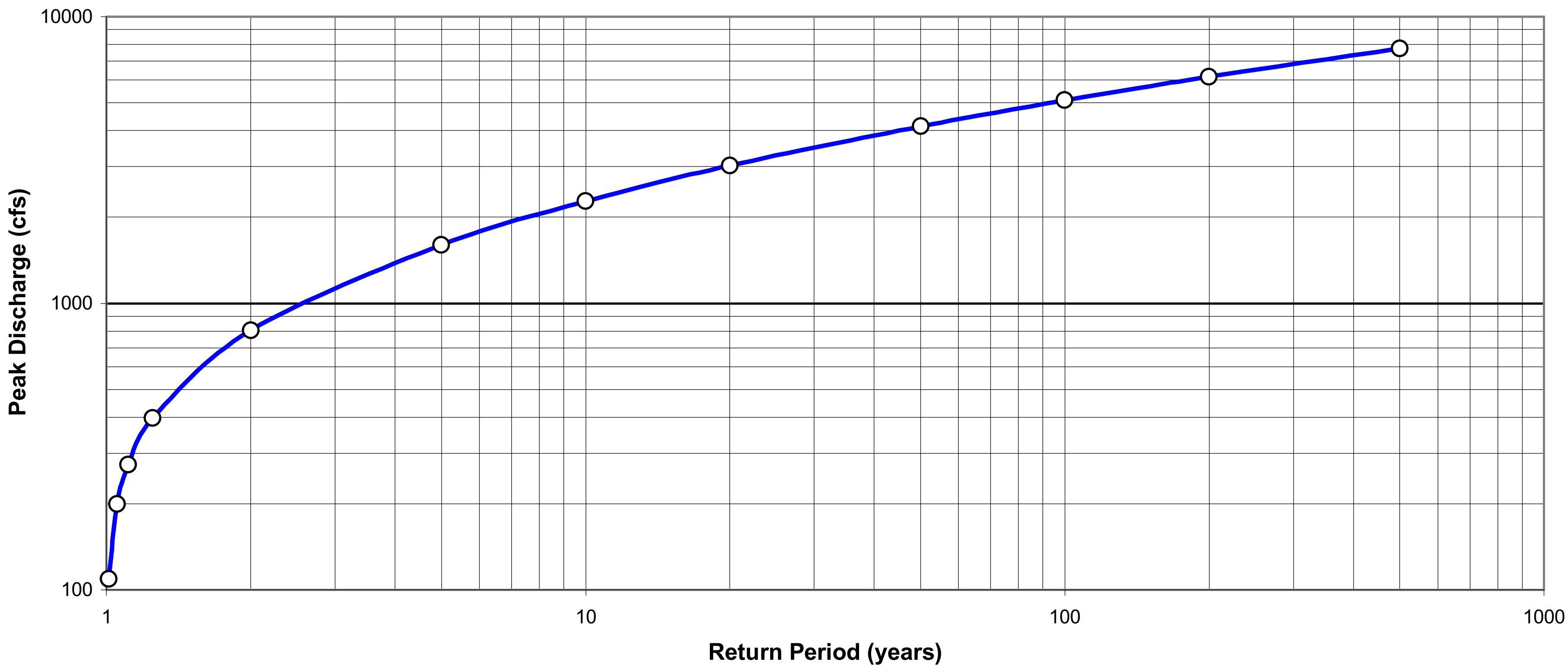
figure **10**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Existing Conditions Conceptual Model

PWA#1664.02

PWA



Source:
PWA (2000)

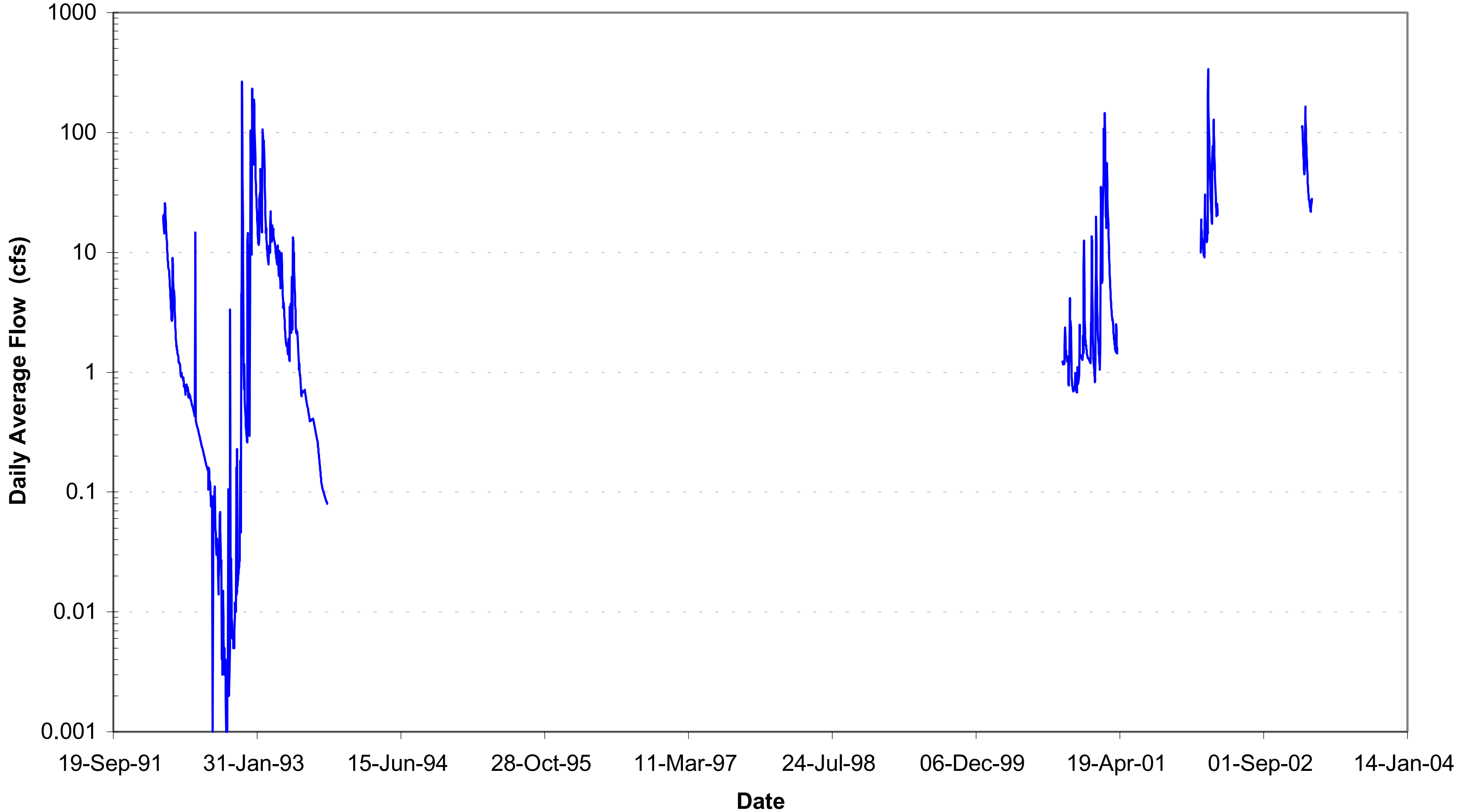
f igure **11**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Flow Frequency Curve at Hwy 1 Bridge

PWA Ref #1664.02

PWA



Source:
1992-93 data measured at Pacific Way Bridge, PWA (1994)
2001-2003 data measured at Highway 1 Bridge, NPS (2003)

f igure **12**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Redwood Creek Average Daily Flows: 1992-2003

PWA Ref #1664.02

PWA

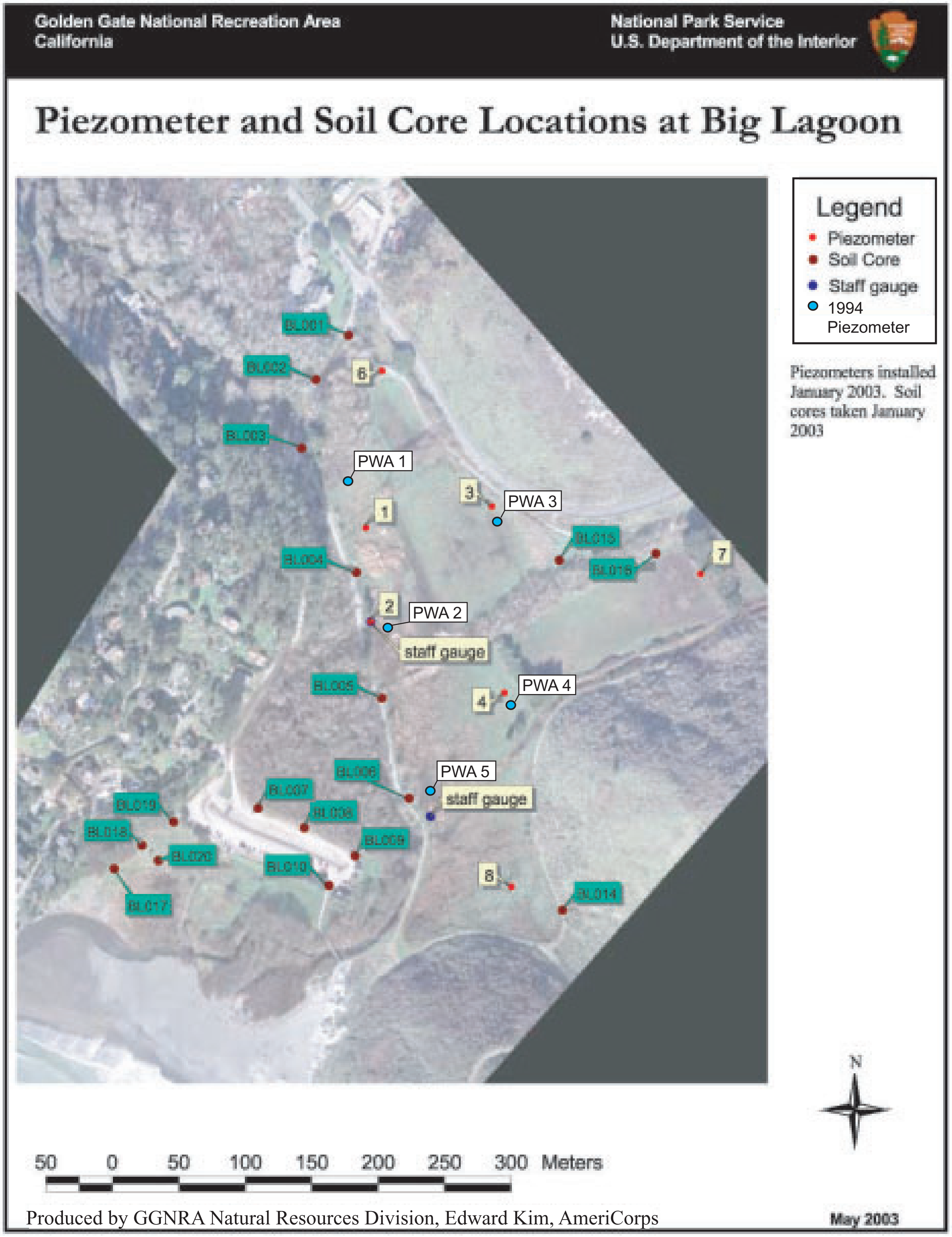


figure **13**

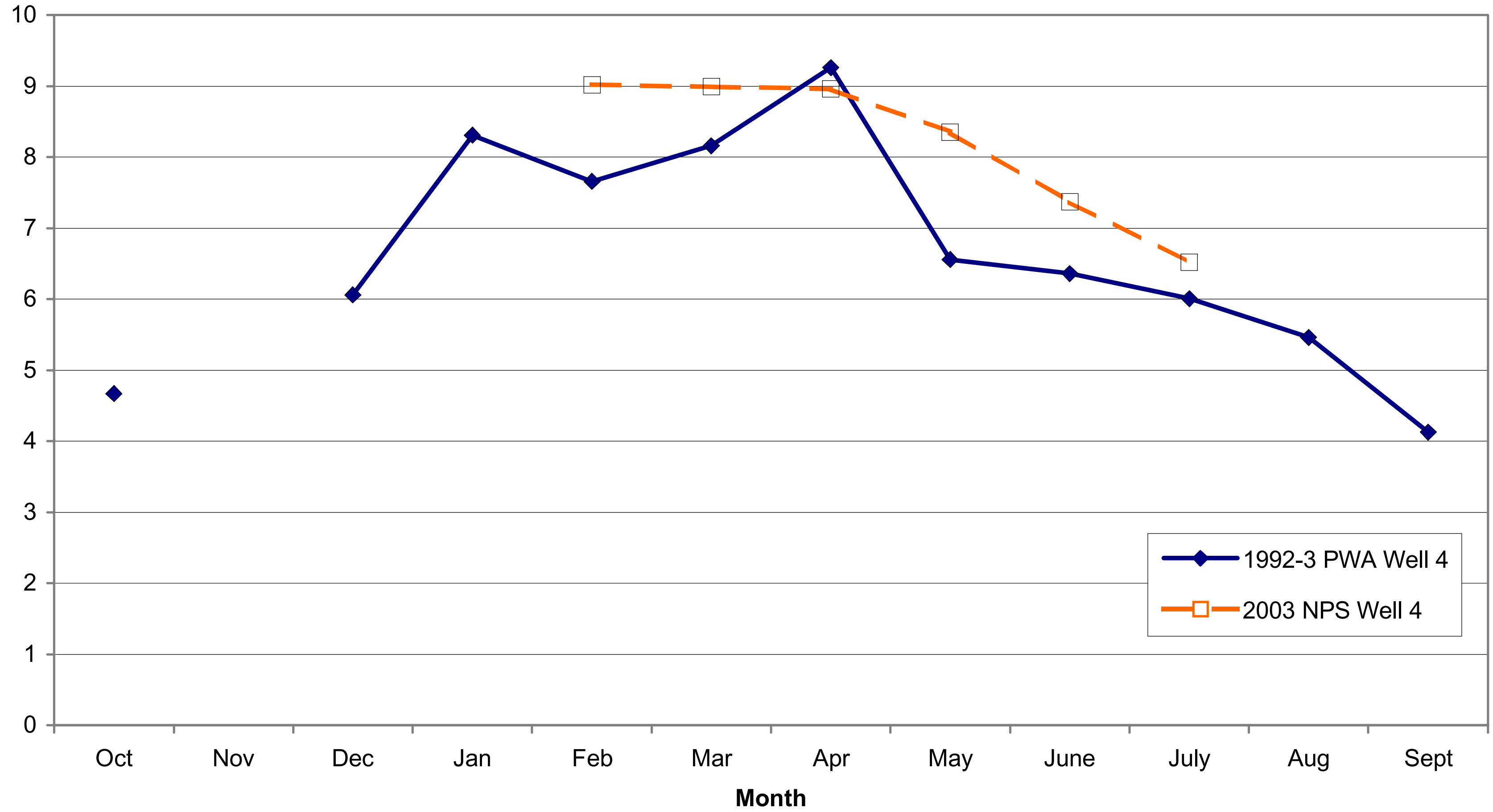
Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Piezometer and Soil Core Locations

Source: NPS

PWA#1664.02

PWA



Source:
Groundwater data for NPS (2003) and PWA (1994) well #4. Location of well shown in Figure 13.

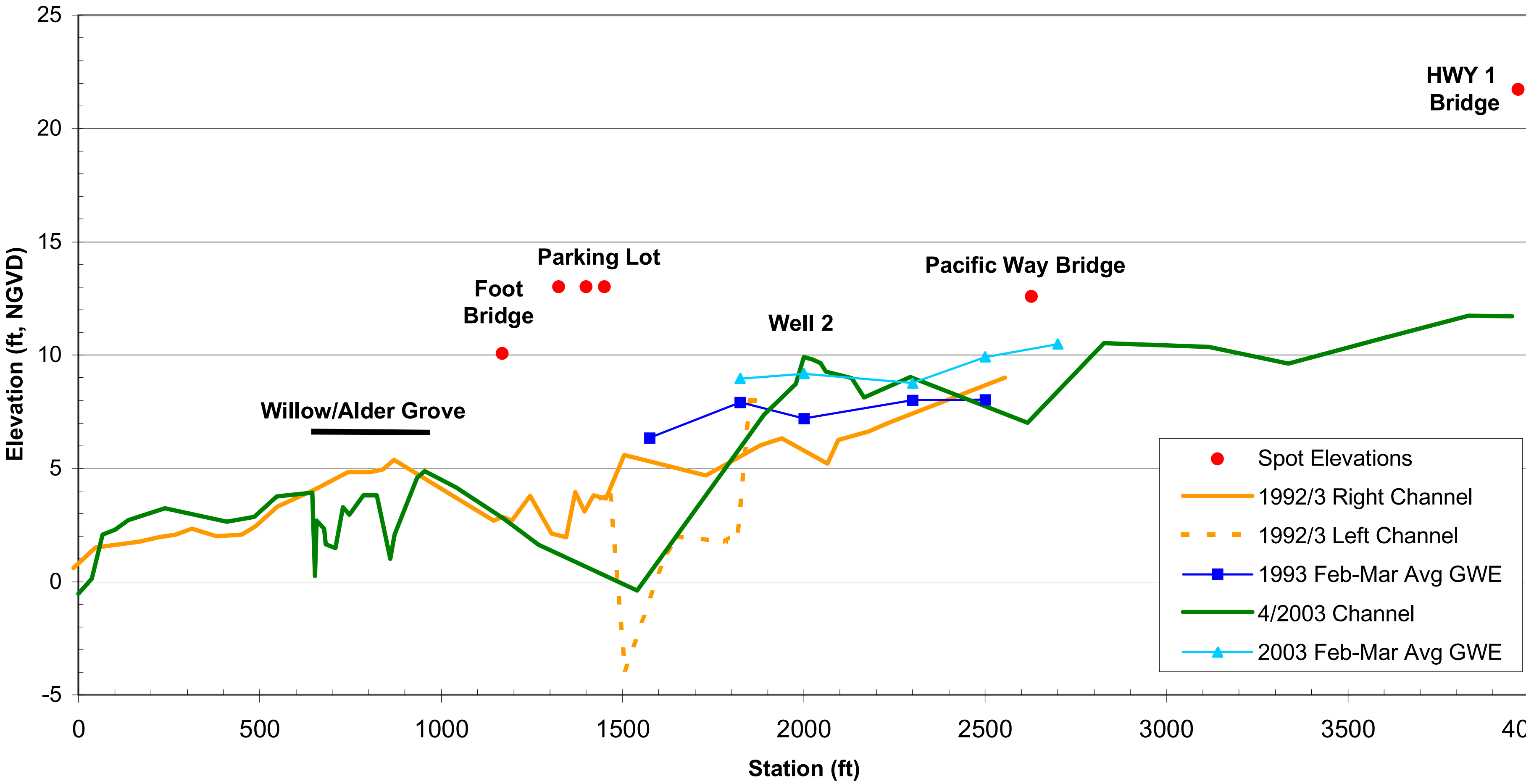
f igure **14**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Monthly Groundwater Elevations: 1992/3 vs 2003

PWA Ref #1664.02

PWA



Sources:
1992 survey and groundwater data, PWA (1994)
2003 survey, EDS (2003)
2003 groundwater data, NPS (2003)

figure **15**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

1992 vs. 2003 Groundwater Elevations

PWA Ref #1664.02

PWA

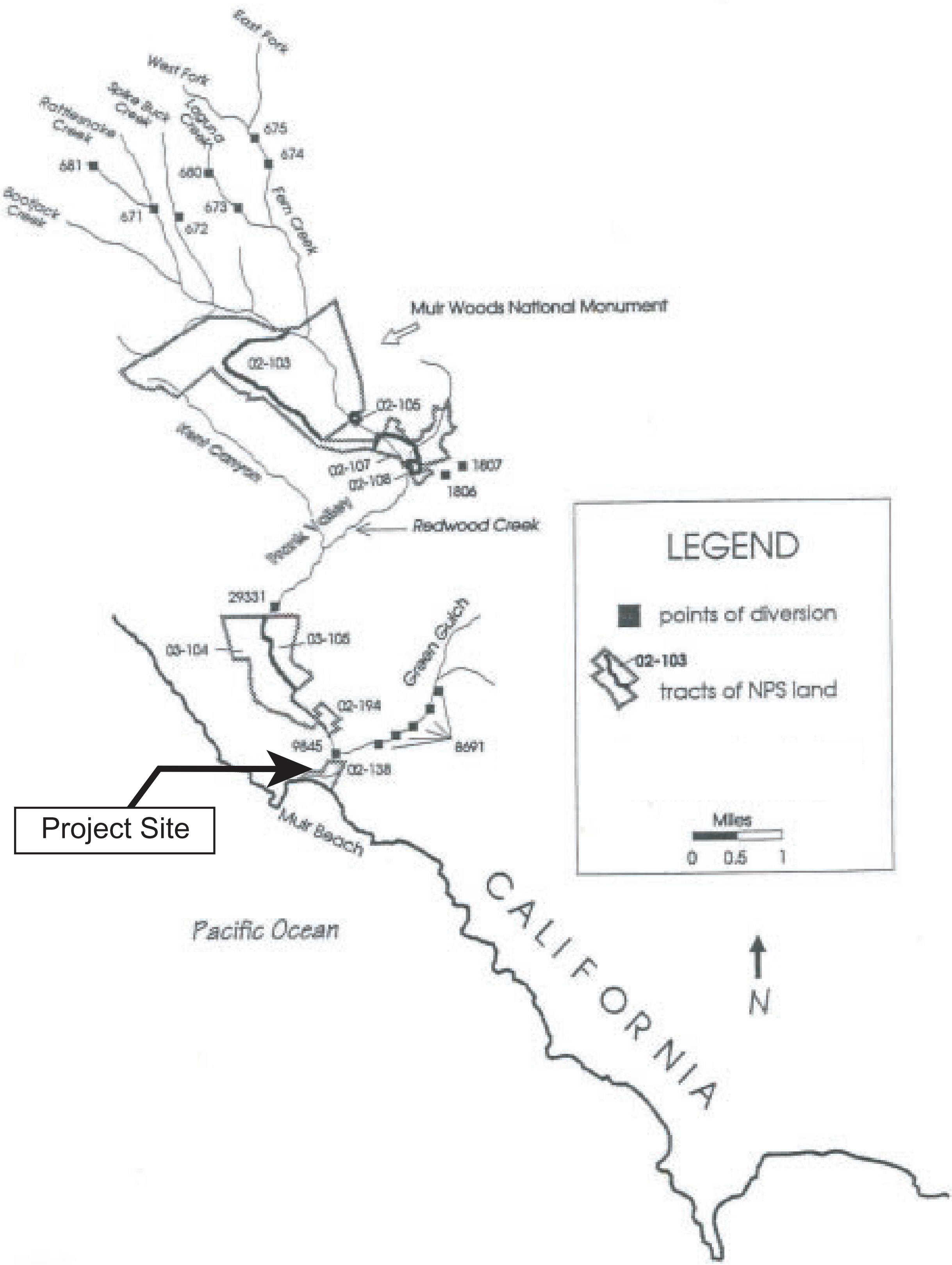


figure **16**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Water Rights Claims in Redwood Creek Watershed

Source: Johns (1993)

PWA#1664.02

PWA

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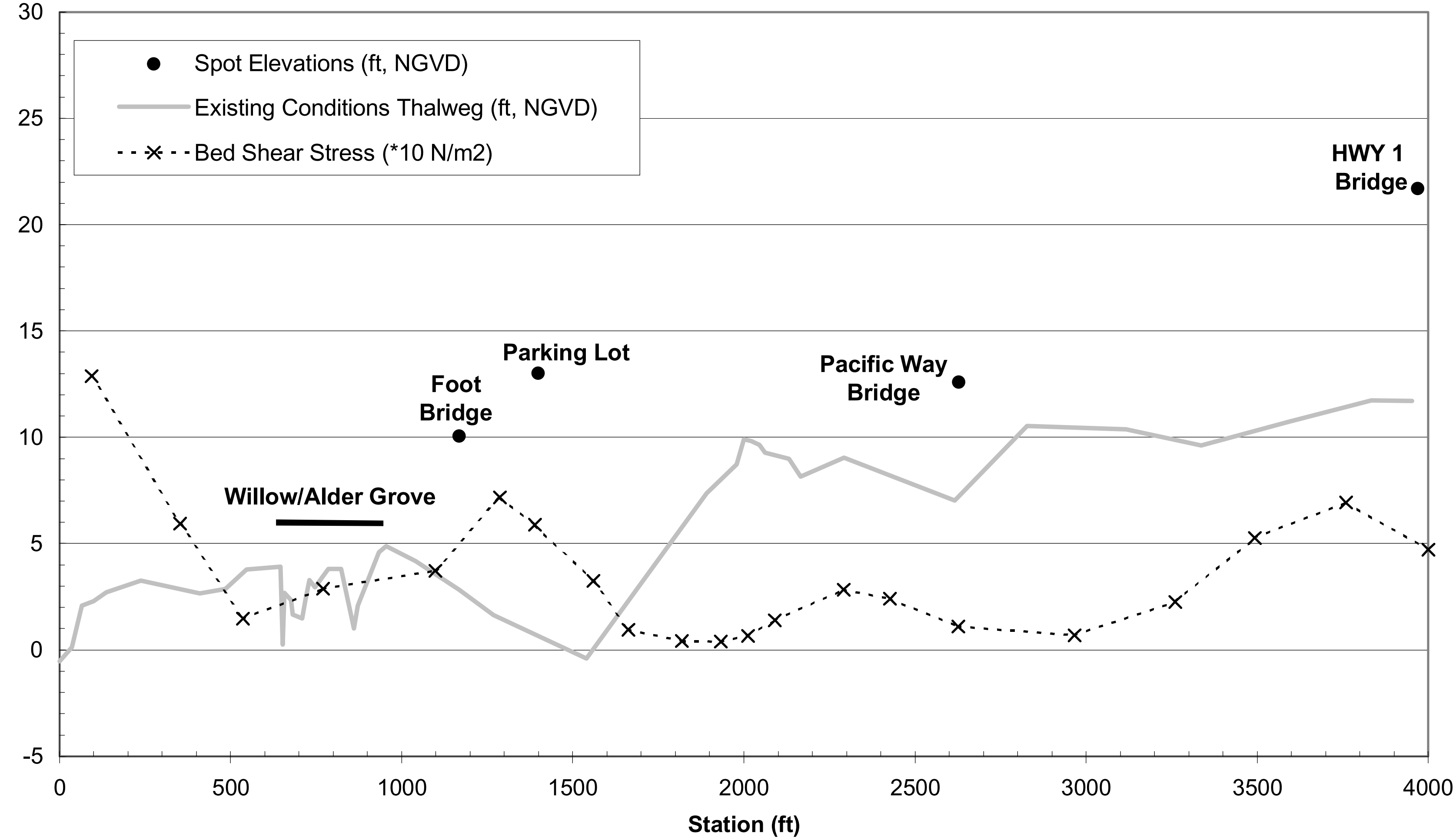


Notes:
Y-axis scale is labeled in plot legend.
Sources:
Existing conditions thalweg surveyed 4-2003 by EDS (2003)
Basal shear stress calculated from MIKE 11 hydraulic model of Redwood Creek (this report)

figure **17**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Channel Bed Shear Stress Distribution

PWA Ref #1664.02

PWA

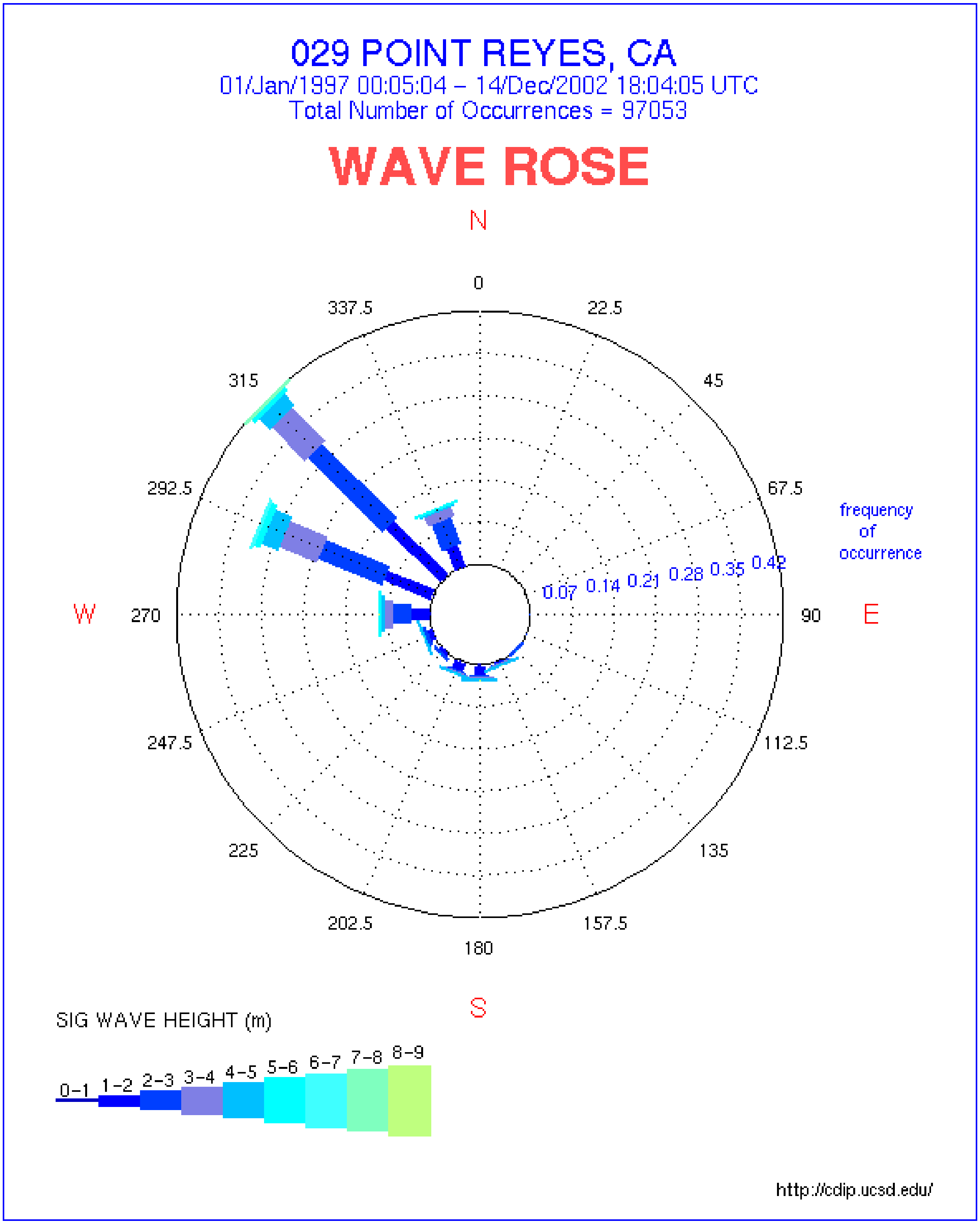
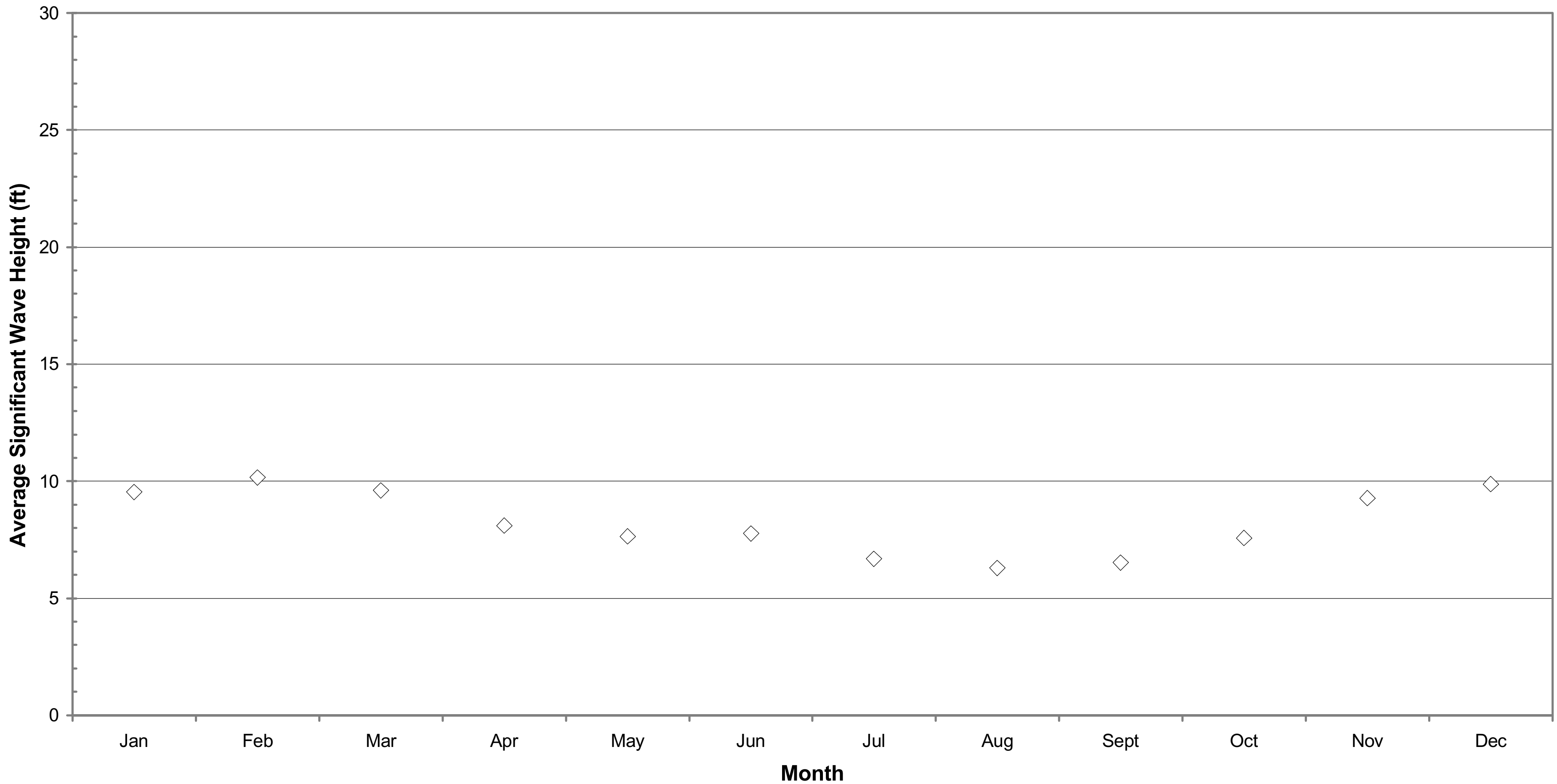


figure **18**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Frequencies of Wave Height and Direction: 1997-2002



Source:
Pt. Reyes Buoy
CDIP (2003a)

f igure **19**

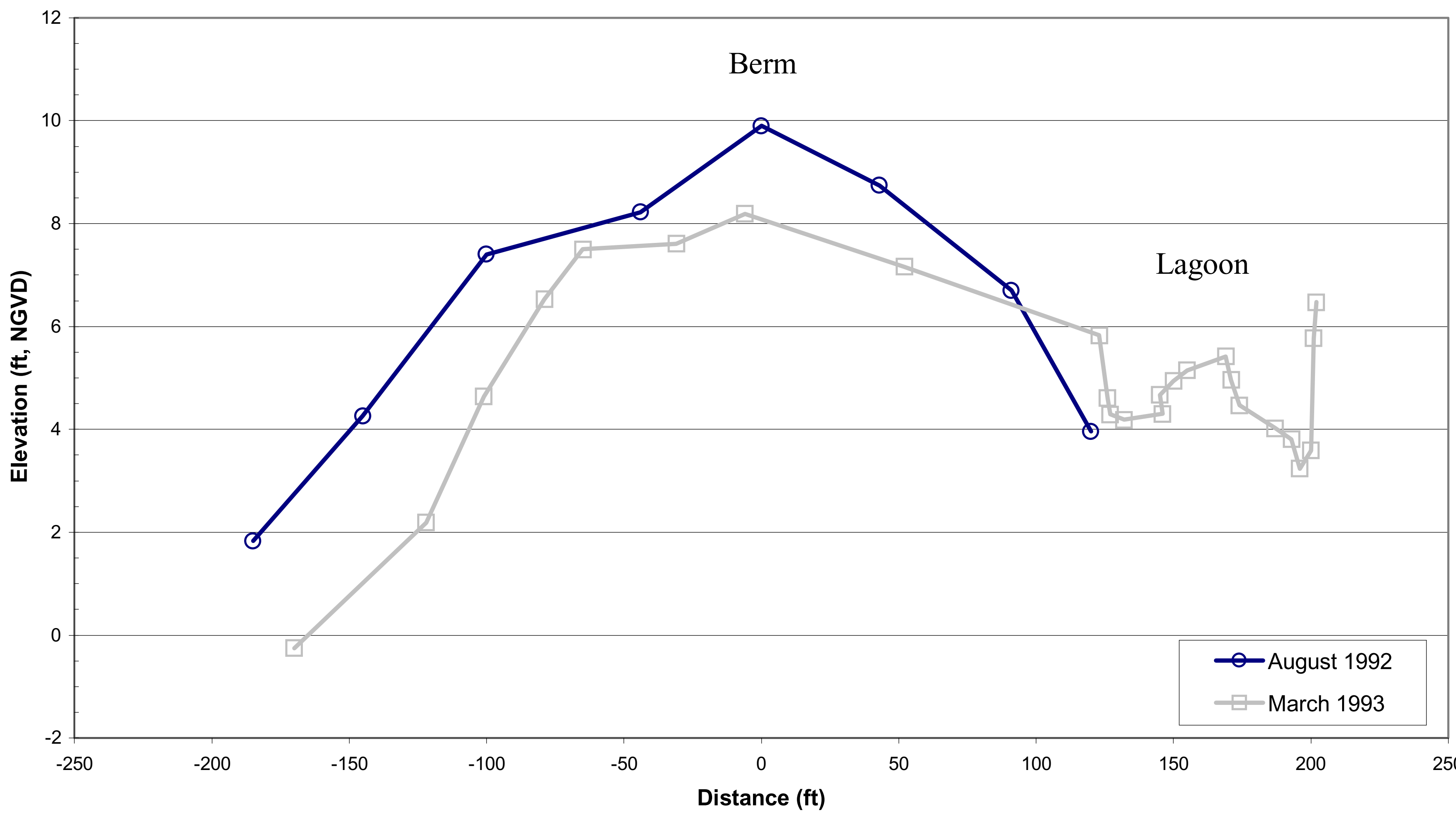
Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Avg., Max., and Min. Monthly Sig. Wave Heights: 1997-2002

PWA Ref #1664.02

PWA

Fig19_Monthly_Hs.doc



Source:
PWA (1994)

f igure **20**

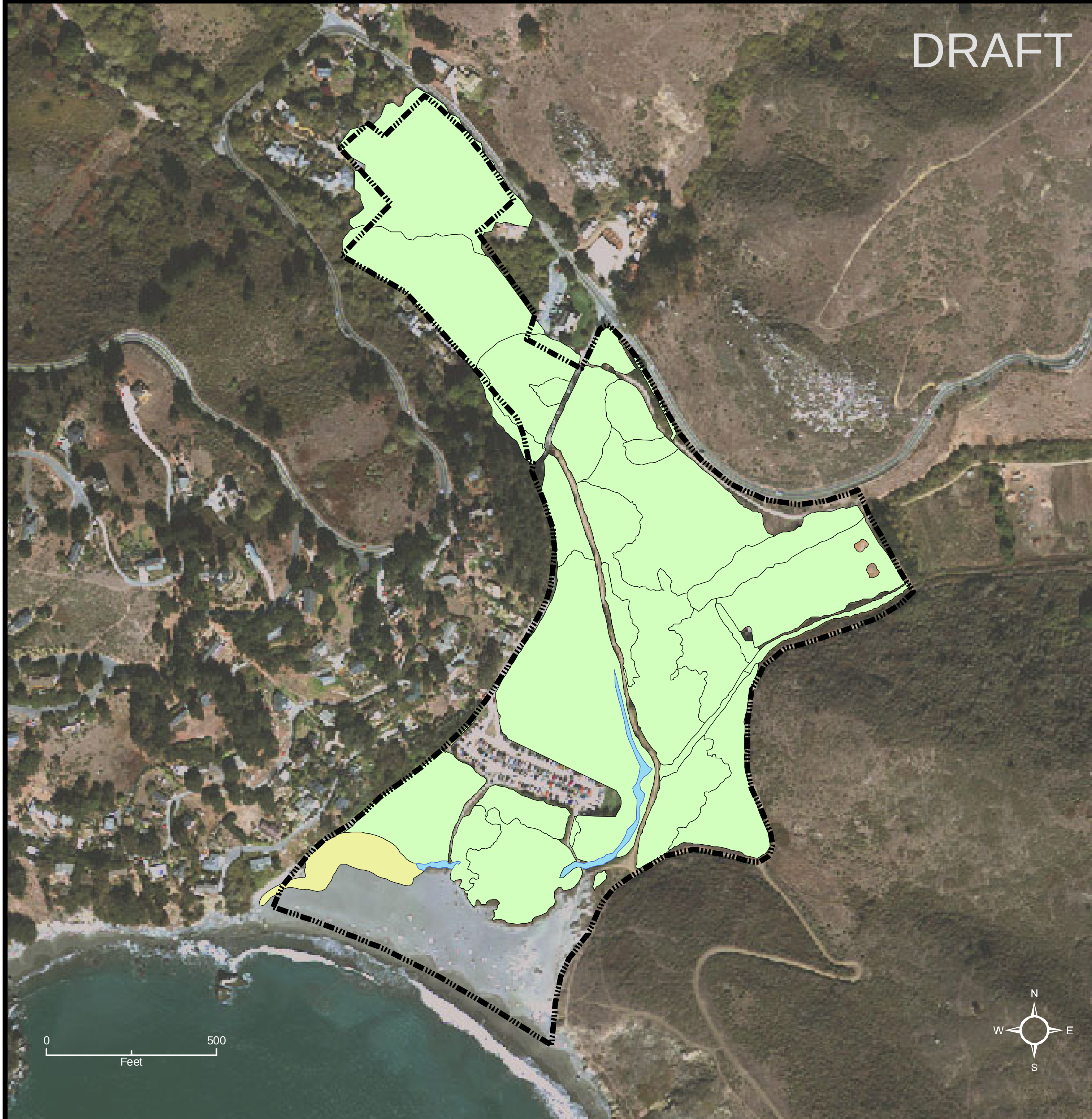
Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Summer vs. Winter Beach Profile

PWA Ref #1664.02

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior



Big Lagoon Project Area (41.0 acres)

Cowardin System

- Estuarine
- Palustrine
- Riverine

See Figures 21b-21d for additional detail.

Figure 21a: Cowardin Wetland Classification

Big Lagoon Wetland and Creek Restoration Project Area
Muir Beach, CA

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

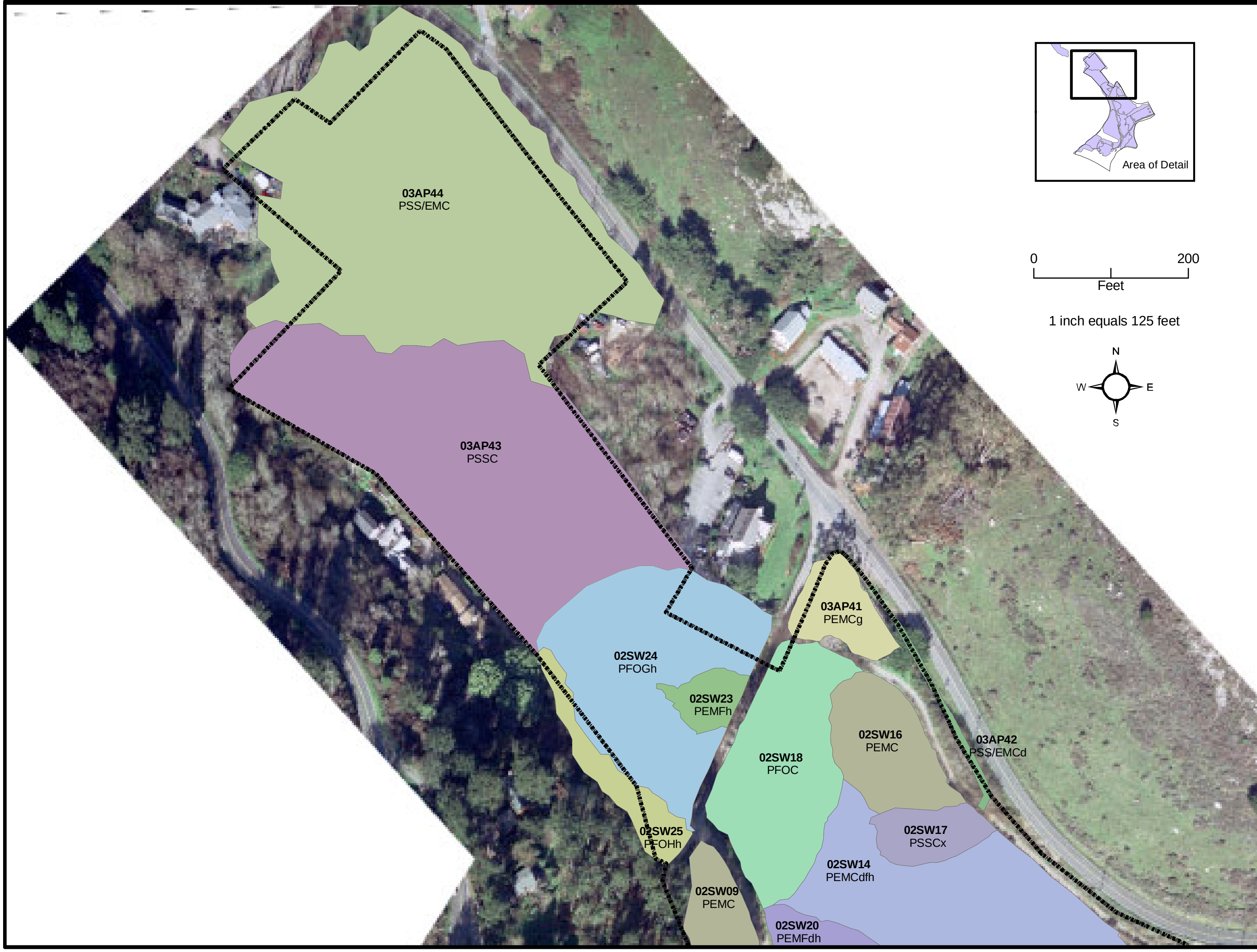


Figure 21b: Cowardin Wetland Classification - North Area

Big Lagoon Wetland and Creek
Restoration Project Area,
Muir Beach, CA

Project Area Boundary

USFWS Cowardin Classification

Palustrine Emergent:

PEMC	Seasonally flooded
PEMCdfh	Seasonally flooded, partially drained/ ditched, farmed, diked/impounded
PEMCg	Seasonally flooded, grazed
PEMFdh	Semi-permanently flooded, partially drained/ditched, diked/impounded
PEMFh	Semi-permanently flooded, diked/impounded

Palustrine Scrub-Shrub:

PSSC	Seasonally flooded
PSSCx	Seasonally flooded, excavated

Palustrine Scrub-Shrub/ Emergent Mix:

PSS/EMCd	Seasonally flooded, partially drained/ditched
PSS/EMC	Seasonally flooded

Palustrine Forested:

PFOC	Seasonally flooded
PFOGh	Intermittently exposed, diked/impounded
PFOHh	Permanently flooded, diked/impounded

02SW42: Wetland Polygon Code

USFWS wetland habitat classified according to the "Classification of Wetlands and Deepwater Habitats of the United States", Cowardin, et. al., 1979.

Wetland surveys conducted by Amy Parravano, Scott Willis, and Laura Castellini, 2002.

Aerial photo by Towill Mapping and Surveying, January 2003.

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

Figure 21c: Cowardin Wetland Classification - Central Area

Big Lagoon Wetland and Creek Restoration Project Area, Muir Beach, CA

Project Area Boundary

<u>USFWS Cowardin Classification</u>

Palustrine Emergent:

PEMC	Seasonally flooded
PEMCdfh	Seasonally flooded, partially drained/ ditched, farmed, diked/impounded
PEMCdh	Seasonally flooded, partially drained/ ditched, diked/impounded
PEMFdh	Semi-permanently flooded, partially drained/ditched, diked/impounded
PEMCdx	Seasonally flooded, partially drained/ ditched, excavated
PEMDg	Seasonally saturated, grazed
PEMGdx	Intermittantly exposed, partially drained/ditched, excavated

Palustrine Scrub-Shrub:

PSSF	Semi-permanently flooded
PSSCd	Seasonally flooded, partially drained/ditched

Palustrine Scrub-Shrub/ Emergent Mix:

PSS/EMBh	Saturated, diked/impounded

Palustrine Forested:

PFOB	Saturated
PFOC	Seasonally flooded

Riverine Lower Perennial

R2UBHh	Unconsolidated bottom, permanently flooded, diked/impounded

02SW42: Wetland Polygon Code

USFWS wetland habitat classified according to the "Classification of Wetlands and Deepwater Habitats of the United States", Cowardin, et. al., 1979.

Wetland surveys conducted by Amy Parravano, Scott Willis, and Laura Castellini, 2002.

Aerial photo by Towill Mapping and Surveying, January 2003.

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

Figure 21d: Cowardin Wetland Classification - Southern Area

Big Lagoon Wetland and Creek Restoration Project Area, Muir Beach, CA

Project Area Boundary

USFWS Cowardin Classification

Palustrine Emergent:

PEMBd	Saturated, partially drained/ditched
PEMBh	Saturated, diked/impounded
PEMC	Seasonally flooded
PEMCh	Seasonally flooded, diked/impounded
PEMCdh	Seasonally flooded, partially drained/ ditched, diked/impounded
PEMFdh	Semi-permanently flooded, partially drained/ditched, diked/impounded
PEMGdx	Intermittantly exposed, partially drained/ditched, excavated

Palustrine Scrub-Shrub:

PSSH	Permanently flooded

Palustrine Scrub-Shrub/ Emergent Mix:

PSS/EMBh	Saturated, diked/impounded

Palustrine Unconsolidated Bottom:

PUBCd	Seasonally flooded, partially drained/ditched

Riverine:

R1UBV	Tidal, unconsolidated bottom, permanent tidal
R2UBHh	Lower perennial, unconsolidated bottom, permanently flooded, diked/impounded

Estuarine:

E1UBL	Subtidal, unconsolidated bottom

02SW42: Wetland Polygon Code

USFWS wetland habitat classified according to the "Classification of Wetlands and Deepwater Habitats of the United States", Cowardin, et. al., 1979.

Wetland surveys conducted by Amy Parravano, Scott Willis, and Laura Castellini, 2002.

Aerial photo by Towill Mapping and Surveying, January 2003.

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

Big Lagoon Project Area (41.0 acres)

USACE Potential Jurisdictional Wetlands (26.6 acres)

USACE Potential Other Waters of the U.S. (3.5 acres)

note: Potential jurisdictional wetlands subject to Section 404 of the Clean Water Act. Wetland boundaries were not mapped outside of the project area.

Figure 22a

Potential USACE Jurisdictional Wetlands - Site Map

Big Lagoon Wetland and Creek Restoration Project Area
Muir Beach, CA

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

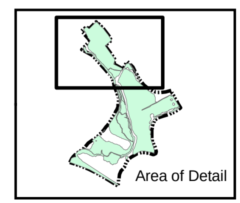
Figure 22b

Potential USACE Jurisdictional Wetlands - Northern Area

- Delineation Study Area Boundary
- USACE Potential Jurisdictional Wetland
- USACE Potential Jurisdictional "Other Waters of the U.S." (non-tidal)
- Wetland test pits

Contour Intervals

- 1-ft.
- 5-ft.



Wetland delineations conducted by Laura Castellini, Amy Parravano, and Carolyn Shoulders, March - May 2003.

Delineation report in preparation (August 2003).

Wetland boundaries were not mapped outside of the project area.

Aerial photo and topography by Towill Mapping and Surveying, January 2003.

Horizontal Datum and projection: UTM NAD83, Zone 10 North
Vertical Datum: NGVD 29

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

Figure 22c

Potential USACE Jurisdictional Wetlands - Central Area

Delineation Study Area Boundary

USACE Potential Jurisdictional Wetland

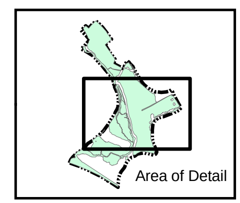
USACE Potential Jurisdictional "Other Waters of the U.S." (non-tidal)

Wetland test pits

Contour Intervals

1-ft.

5-ft.



Wetland delineations conducted by Laura Castellini, Amy Parravano, and Carolyn Shoulders, March - May 2003.

Delineation report in preparation (August 2003).

Wetland boundaries were not mapped outside of the project area.

Aerial photo and topography by Towill Mapping and Surveying, January 2003.

Horizontal Datum and projection: UTM NAD83, Zone 10 North
Vertical Datum: NGVD 29

Golden Gate National Recreation Area
Marin County, California

National Park Service
U.S. Department of the Interior

Figure 22d

Potential USACE Jurisdictional Wetlands - Southern Area

Delineation Study Area Boundary

USACE Potential Jurisdictional Wetland

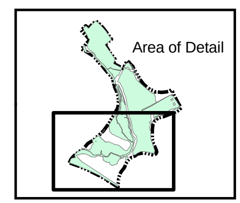
USACE Potential Jurisdictional "Other Waters of the U.S." (includes tidal and non-tidal waters)

Wetland test pits

Contour Intervals

1-ft.

5-ft.



N
W E
S

1 inch equals 125 feet

0 200
Feet

Wetland delineations conducted by Laura Castellini, Amy Parravano, and Carolyn Shoulders, March - May 2003.

Delineation report in preparation (August 2003).

Wetland boundaries were not mapped outside of the project area.

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Horizontal Datum and projection: UTM NAD83, Zone 10 North
Vertical Datum: NGVD 29

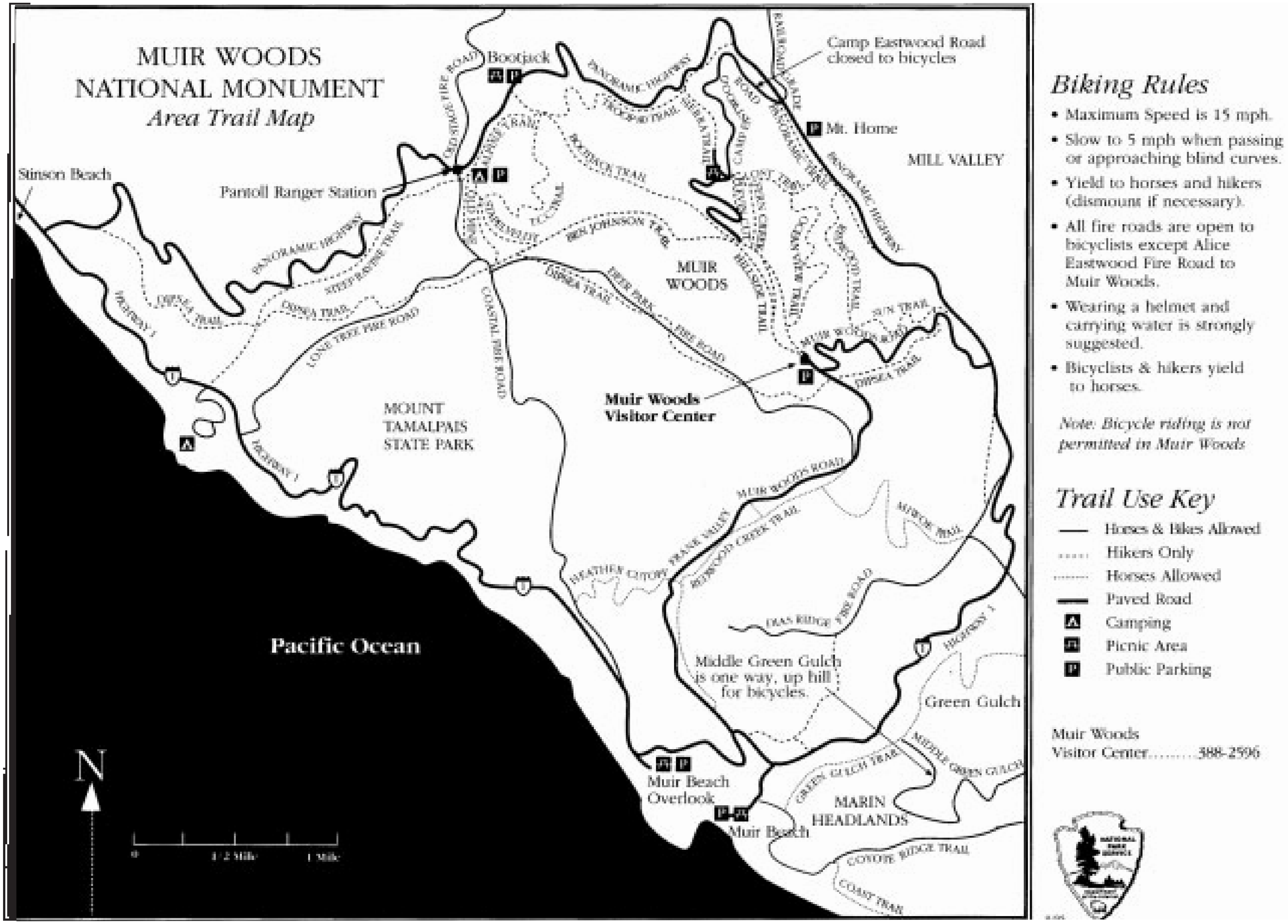


figure 23

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Area Trail Map

PWA#1664.02

PWA

P:\Projects\1664\Task2\FinalSept26\Figures\NewFig23_AreaTrailMap.ai

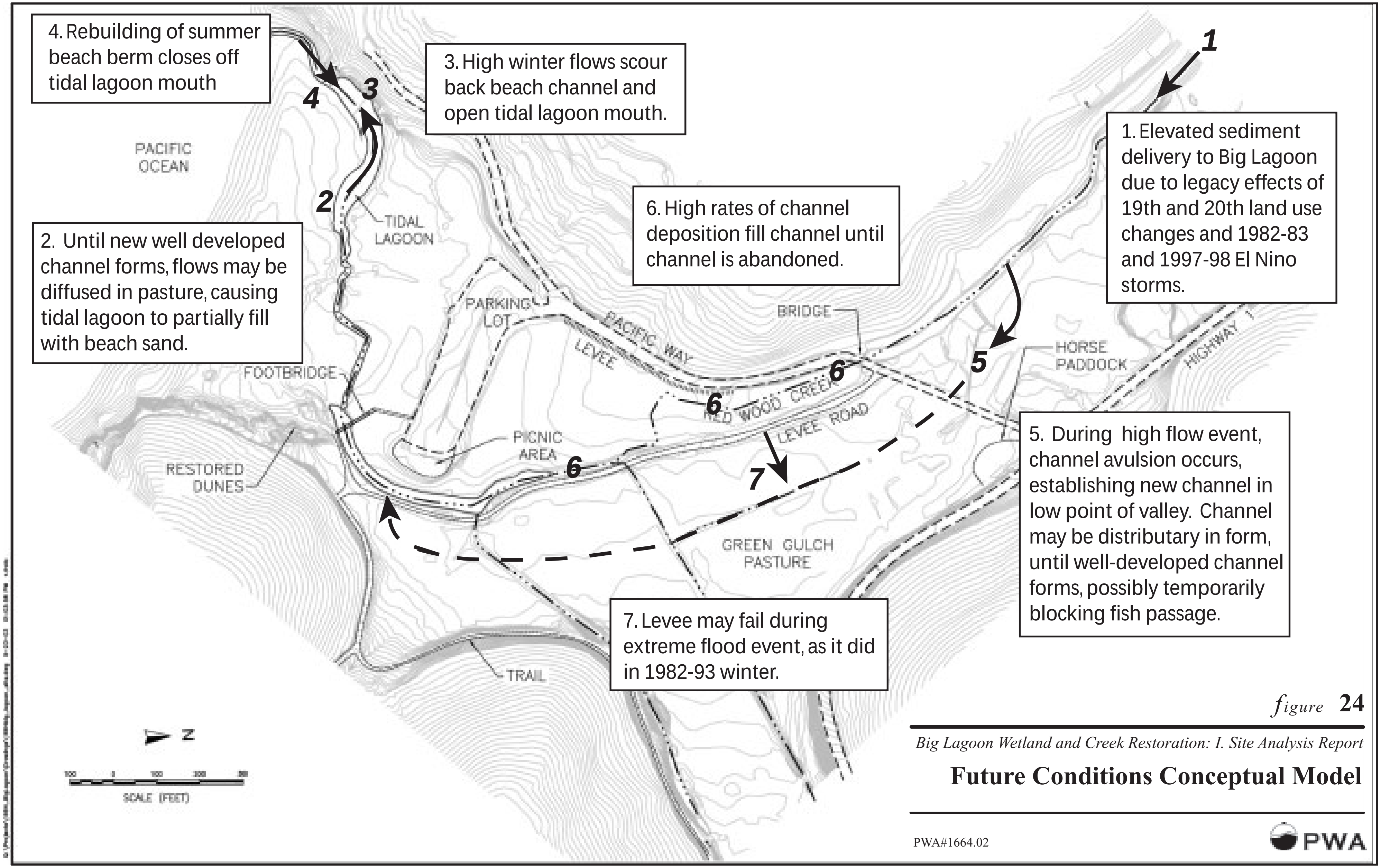


figure **24**

Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report

Future Conditions Conceptual Model

PWA#1664.02

PWA

APPENDIX A
GROUNDWATER MONITORING DATA

APPENDIX A

Groundwater Monitoring Data

Table A-1. 1992-93 Groundwater Monitoring Data (PWA *et al*., 1994)

	Depth to Groundwater from Existing Grade (ft)[1]				
Date (Elev, ft NGVD)	**Well 1** (9.3)	**Well 2** (8.59)	**Well 3** (9.07)	**Well 4** (9.46)	**Well 5** (7.58)
09/02/92	3.00	3.30	4.70	5.20	3.60
09/17/92	3.00	3.60	4.85	5.40	4.00
09/29/92	2.90	3.50	4.90	5.40	4.10
12/01/92	2.10	2.25	2.60	3.40	2.10
01/04/93	1.00	0.08	0.50	1.15	0.75
02/03/93	1.20	1.40	0.70	1.80	1.20
03/02/93	1.00	0.95	0.60	1.30	0.75
04/02/93	1.00	1.03	0.65	0.20	0.74
05/06/93	1.90	2.20	2.30	2.90	2.25
06/03/93	N/A	1.90	2.50	3.10	1.98
07/02/93	N/A	2.90	3.25	3.45	N/A
08/12/93	2.80	2.90	4.00	4.00	3.00

[1]Existing grade for each well shown in parenthesis below well number in feet NGVD
See Figure 13 for well locations.

Table A-2. 2003 Groundwater Monitoring Data

	Depth to Groundwater from Existing Grade (ft)[2]						
Date (Elev, ft NGVD)	**Well 1** (9.17)	**Well 2** (9.21)	**Well 3** (9.03)	**Well 4** (9.23)	**Well 6** (11.04)	**Well 7** (17.52)	**Well 8** (11.3)
02/12/03	-0.78	-0.05	0.32	0.32	0.59	1.40	-0.13
02/27/03	-0.77	-0.05	0.10	0.10	0.41	0.98	-0.59
03/11/03	-0.74	0.08	0.30	0.30	0.57	1.44	-0.12
03/18/03	-0.76	0.03	0.18	0.18	0.50	1.02	-0.37
04/01/03	-0.74	0.10	0.34	0.34	0.60	1.57	-0.05
04/15/03	-0.71	0.03	0.18	0.18	0.46	0.99	-0.28
04/29/03	-0.76	0.04	0.29	0.29	0.57	1.48	0.09
05/13/03	-0.73	0.09	0.39	0.39	0.71	1.81	0.18
05/27/03	-0.12	0.30	0.88	1.36	1.08	2.27	1.34
06/17/03	0.00	0.57	1.66	1.74	1.76	2.58	2.54
07/01/03	0.08	0.72	2.13	2.44	2.23	2.78	3.44
07/15/03	0.18	1.04	3.49	2.98	2.55	4.05	3.87

[2]Existing grade for each well shown in parenthesis below well number in feet NGVD.See Figure 13 for well locations.

APPENDIX B
WATER QUALITY

APPENDIX B

Water Quality - Existing Conditions

Water Quality Data Sources

The USGS sampled water quality twice per year from 1986 through 1988 at several locations in the Redwood Creek watershed (Figure B.1). Harding-Lawson and Associates collected samples from November through March 1991 near the Muir Beach Community Services Wells (Harding-Lawson and Associates, 1991). Philip Williams and Associates sampled water quality at various locations during the summer of 1993 and a December 1993 storm to identify potential pollutant sources under a separate contract for the NPS. Between 1996 and 1998, researchers at San Francisco State University and the University of California at Berkeley have monitored storm conditions. Beginning in 2001, NPS has continued to occupy sampling locations on a seasonal basis at the Golden Gate Dairy and lower Redwood Creek near the Green Gulch tributary.

Water Quality Objectives

The goal for the water quality evaluation below are common with Regional Water Quality Control Board Basin Plan (Basin Plan) objectives for the San Francisco Bay Region are(SFRWQCB 1995): to ensure the protection and maintenance of thriving aquatic ecosystems and the resources those systems provide to society and to accomplish these in an economically and socially sound manner. There are two types of objectives that are relevant to the existing conditions within the Big Lagoon project area: narrative and numerical. Narrative objectives present general descriptions of water quality that must be attained through pollutant control measures and watershed management. Perhaps the most important narrative objective outlined in the Basin Plan is that:

> " … all waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce significant alterations in population or community ecology or receiving water biota. In addition, the health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors."

Narrative water quality objectives also serve as the basis for the development of detailed numerical objectives. Published water quality objectives for designated beneficial uses within the Redwood Creek watershed are shown in Table B.1.

Temperature

Water temperatures within the Big Lagoon study area, generally range from 11–15 ^{o}C (Table B.2), with occasionally higher temperatures up to 18–19^{o}C in late summer and early fall (September–October). Although these temperatures are within the tolerance of many aquatic organisms, peak summertime temperatures within un-shaded areas downstream of Pacific Way have been reported to exceed 20°C (Table B.2).

Virtually all biological and ecological processes are affected by temperature. Beyond well-known effects on salmonids (Spence et al., 1996), temperature may have subtler effects on water quality equilibria (e.g., ammonia, pH) and other aquatic organisms. This in turn, may affect life history timing, habitat suitability, growth rates, rates of infection and mortality from disease and toxic chemicals, and exposure to predators better adapted to warm water temperatures.

In addition, salt water stratification in the brackish lagoon can apparently create a large enough density difference to prevent water and heat exchanges during night-time cooling of the fresher surface water. For example, the highest water temperatures in 1992 and 1993 reached 20-23°C, but cooled off substantially (15–18°C) over night and during overcast periods (PWA et al., 1994). However, when the lagoon was stratified for salinity, the highest water temperatures were within the salt water lens near the bottom (August 19, 1993) (PWA et al., 1994). The lack of shading, shallow water and salt water stratification combine to create extraordinarily unfavorable conditions for fish in summer and fall, since no deeper predator refuge or cool water refuge is available.

Salinity

Salinity represents the accumulations of anions such as carbonates, chlorides, and sulfates, and cations such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). Two general measures are used to assess salinity in water, electrical conductivity (EC) and total dissolved solids (TDS). EC measures the transmission of electricity between known electrode areas and path lengths (units µS/cm), whereas TDS is measured in mg/L by gravimetric analysis after drying with 0.65 used as a typical multiplier to convert from EC to TDS (APHA, 1998).

Salinity within the backwater area that corresponds to the location of the former lagoon is generally at or near the levels in Redwood Creek (Beutel, 1998) from the first winter rains until beach closure by the annual sand bar formation in early summer of each year (PWA et al., 1994). Although Table B.3 shows high salinity levels in the downstream backwater area exposed to tidal intrusion in the summer months, salinity levels are relatively low throughout the upstream portions of the study area.

Prior studies (Madej, 1989) suggested potential linkages between increased sodium and alkalinity to irrigation practices at Green Gulch. The relationship between salinity and stream discharge (Leach et al., 1997) suggests a higher salt content in the soils. For the above reasons, depending on the water year type, storm and tidal effects, late season increases in salinity in the lower reaches of Redwood Creek and deeper pools of Backwater area may potentially be slightly elevated by irrigation return flows as well as septic leachate from the community of Muir Beach. These influences are minor when compared to periodic salt-water inflow events that naturally occur during storm surges to the lower portions of the study area.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations within the Big Lagoon study area generally range between 8–11 mg/L, near saturation conditions (Table B.4). Although samples collected in summer and early fall had DO levels above those necessary for fish (5–7 mg/L shown in Table B.1), sampling is generally conducted in daylight hours, so low oxygen levels may still occur in the night time and early morning as the result of plant, algal and bacterial respiration.

During the 1992 and 1993 surveys, although creek samples remained high in dissolved oxygen, samples taken near the foot bridge at the tail of the large mid-channel pool had very low oxygen levels near the bottom, even in the afternoon. During September 19, 1992 sampling, the dissolved oxygen levels ranged between 2.0 and 4.3 mg/l in the morning (PWA et al., 1994), and because of overcast conditions, they increased little from photosynthesis during the day. It was noted in these surveys that steelhead juveniles were observed in the morning gulping at the surface to force more highly oxygenated boundary water over their gills.

DO is a very important indicator of a water body's ability to support aquatic invertebrates and fish. The majority of oxygen enters surface waters through absorption directly from the atmosphere, with typical natural water concentrations between 7–12 mg/L (Horne and Goldman, 1994). Small amounts of DO may be produced by aquatic plant and algal photosynthesis, but much of this oxygen is removed during "dark" respiration and bacterial decomposition of organic matter. Dissolved oxygen concentrations in water depend on several factors, including temperature (i.e., colder water absorbs more oxygen), the volume and velocity of water flowing in the water body (re-aeration), salinity, and the amount of organisms using oxygen for respiration. This last factor (respiratory consumption) is, in turn, strongly influenced by the availability of eutrophic nutrients (N and P), naturally derived from allochthonous sources (e.g., leaf litter), but more commonly arriving in runoff from fertilized agriculture, human and animal wastes. Although conditions appear to have improved in recent years, there is some evidence for eutrophic conditions from historical reports of diurnal fluctuations in pH and DO concentrations in the downstream study sites in the Big Lagoon study area (PWA et al., 1994).

Biostimulatory Substances

The basin plan narrative standards limit concentrations biostimulatory substances, or nutrients, below levels that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses. Nutrient concentrations vary throughout the year, largely in response to changes in precipitation and streamflow and to differences in time since fertilizer application. Nutrient concentrations in streams typically are elevated during higher streamflows in late winter or early spring following fertilizer application. Prior observations of biostimulatory, or eutrophic, conditions (Madej, 1989; Leach, 1997; Beutel, 1998) suggest potential future water quality issues for planned restoration design are related to three primary nutrients: ammonia, nitrate, and phosphates. These are discussed separately below.

Ammonia. The EPA has established criteria for maximum ammonia concentrations in surface water based on the potential threat to the health of aquatic organisms. These criteria vary with acidity and water temperature, which affect both the toxicity of ammonia and the form in which it occurs. In most natural surface waters, total ammonia concentrations greater than about 1 mg/L exceed the chronic exposure criteria for fish, with primary effects related to impaired gill function (Horne and Goldman, 1994). The Basin Plan objectives for unionized ammonia (NH_3) are to prevent receiving water to contain concentrations in excess of 0.025 mg/l as N as an annual median (Table B.1). For the entire period of record and all locations, Tables B.5a and B.5b show that ammonia concentrations have fluctuated between 0.02–0.2 mg/L (as N). Although historical ammonia levels in lower Redwood Creek are generally below acute levels for fish, acute toxicity can occur at levels as low as 0.1 mg/L as N in alkaline waters at higher temperatures (Horne and Goldman, 1994). Because several samples within the record were in excess of Basin Plan objectives, changes in horse management practices in the vicinity of Golden Gate Dairy were implemented in 1997. To determine the effectiveness of these measures, spatial and temporal variations of ammonia concentrations is discussed further, below.

Longitudinal and temporal variations in ammonia that are summarized in Tables B.5a and B.5b are shown graphically in Figures B.2 and B.3. For the entire period of record, higher ammonia levels are generally associated with downstream sites below the Highway 1 bridge (Figure B.2). Using Figure B.3 to examine temporal variations in ammonia, historical ammonia levels appear to have declined to near non-detect levels in 2003 at all locations sampled. Based upon these results, the downstream portions of the study area appear to meet Basin Plan objectives for ammonia levels. Depending upon ongoing management efforts, ammonia is not likely to affect planned restoration actions within the Big Lagoon study area.

Nitrite and Nitrate. For the entire period of record and all locations, Tables B.5a and B.5b show that nitrate concentrations have fluctuated between 0.01–2 mg/L (as N) with the exception of one water sample containing nitrate at 9.5 mg/L as N below Green Gulch (Table B.5b). Nitrite and nitrate are dissolved nutrients resulting from the oxidation of proteins and ammonia, with Nitrate representing the major from of dissolved nitrogen in natural waters. In natural waters, nitrate causes eutrophication, algal and plant growth, and subsequent water quality problems such as DO depletion (Horne and Goldman, 1994). The Basin Plan objective in Table B.1 was set by the EPA and RWQCB as a drinking water protection. Other than its biostimulatory effects on plant life, nitrate by itself is generally not a health problem; when ingested by humans it is converted into nitrite by enteric bacteria. In humans lacking a key enzyme, however, nitrite can lead to “blue baby syndrome” (methemoglobinemia), blocking hemoglobin binding of oxygen, which can be fatal to infants during the first three months of life.

Longitudinal and temporal variations in nitrates that are summarized in Tables B.5a and B.5b are shown graphically in Figures B.4 and B.5. Following the ammonia trends discussed above, Figure B.4 shows that higher nitrate levels are generally associated with downstream sites below the Highway 1 bridge. However, unlike ammonia Figure B.5 shows that recent (2003) nitrate levels below the Highway 1 bridge continue to be elevated over natural background levels (0.01–1.0 mg/L as N) reported in the literature (Horne and Goldman, 1994). It is apparent from these results that changes in horse management practices that have been successful in reducing ammonia levels in the lower portions of the study site have been less successful in reducing nitrates. Without further changes in the management of agricultural fertilizer, and animal and human wastes in the Redwood Creek watershed elevated nitrate levels (i.e., > 1–5 mg/L) may be expected to continue into the future. Depending on the design of the planned restoration alternative, tidal mixing, sunlight and other conditions, the expected nitrate concentrations may contribute to episodic algal blooms in the downstream open water lagoon areas. This may be no more than a nuisance during the first year or two following construction, or may represent a long-term influence on DO depletion and pH fluctuation in the lower portions of the study area. Although daily fluctuations in DO and pH from excess nutrients may limit the distribution of many aquatic species (Odum, 1956), it is unclear whether the conditions in the Big Lagoon study area have pH variations great enough (approx pH 9.4 for the release of free ammonia) to create chronic or acute effects.

Phosphorus. For the entire period of record and all locations, Tables B.5a and B.5b show that nitrate concentrations have fluctuated between 0.01–0.02 mg/L). On examination of the data record, it is unclear which historical samples are reported on a phosphorous basis, and which are reported on an orthophosphate basis (i.e., differ by 3:1 on molecular weight basis). Because of these discrepancies, there is no basis to confidently assess the impacts of phosphorus loadings to the Big Lagoon study area.

Despite this, phosphorus is often a limiting nutrient in natural waters and contributes to eutrophication (Horne and Goldman, 1994). Phosphorus may be found in low levels in natural waters and in wastewaters almost solely as phosphates. The principally bioavailable form includes several classes of phosphates: orthophosphates, condensed phosphates and organically bound phosphates. These compounds are found in solution (by natural weathering or fertilizer application), in detritus, and in tissues of aquatic organisms (organic phosphates). Examination of the Table B.5 values for phosphorus and nitrate suggest that upstream sites generally produce low N:P ratios upstream, with higher ratios downstream. Using the Redfield ratio (Redfield, 1958) as a guide, this suggests that incremental additions in N and P will have a differing biostimulatory effect in these two environments (i.e., upstream starved of nitrogen, downstream of phosphorus). Further sampling will be required before any detailed conclusions can be made regarding water quality implications for planned restoration activities.

Suspended Sediment and Turbidity

Although sediment transport is the subject of a separate study in progress by Stillwater Sciences, sediment loading to the Big Lagoon area may result in the major water quality limiting factor in the planned restoration designs. Very fine (colloidal) suspended matter such as clay, silt, organic matter, plankton and other microscopic organisms causes turbidity in water.

Turbidity is an optical property (light scattering) that is closely related to total suspended solids, where 1 mg/L is approximately equivalent to nephelometric turbidity unit (Montgomery, 1985). Sediment sources to the Redwood Creek and the Big Lagoon study area include suspended sediment from inflows and bank erosion and resuspension of local sediments from tidal mixing, high flows, and wind-generated wave fetch in the lower portion of the study area. Although turbidity itself is not a major health concern, high turbidity can interfere with temperature, DO, and is also associated with total metals loadings and sorption of contaminants from the water column (e.g., polar organics and cationic metal forms). In addition to the potential for fish habitat impairment from DO depletion and salinity, increased turbidity and light absorption by algae may reduce water clarity, interfering with fish foraging and lead to decreased growth rates. Turbidity works to reduce the reaction distance of a predator to its prey, greatly reducing the volume a fish can search in a given time. By dimensional arguments, a 50 percent reduction in reaction distance can reduce the volume searched by a factor of four.

Bacteria

A number of bacterial indices have been used in Redwood Creek and also led to a large number of water quality objectives for bacteria (Table B.1). Briefly, total coliform is generally only used as an index of overall bacterial density, whereas fecal coliform bacteria has been traditionally used as indicators of the sanitary quality of the water. In 1986, the USEPA recommended that Escherichia coli (E. coli) be used in place of fecal-coliform bacteria in State recreational water-quality standards as an indicator of fecal contamination. E.coli is a member species of the fecal coliform group of indicator bacteria. Subsequently, the EPA recommended the use of Enterococcus bacteria as an indicator of bacterial contamination in salt water areas such as Muir Beach. Although some strains are ubiquitous and not related to fecal pollution, the presence of enterococci in water is an indication of fecal pollution and the possible presence of enteric pathogens.

Bacterial contamination of the water supply of Muir Beach as well as the backwater and beach areas have been an ongoing water quality concern (PWA et al., 1994). Tables B.6a and B.6b show that bacterial levels are variable and sometimes quite high in the lower Redwood Creek watershed. With the exception of reported overflows in the Muir Woods bathrooms in the 1980s (Figure B.6), higher bacterial concentrations generally occur in the lower portions of the site. Recent sampling shows the coliform levels in lower Redwood Creek appear to be lower than historical levels (Beutel, 1998; NPS, 2003). Although there are NPS WQ data for the Golden Gate Dairy and the Green Gulch tributary for the period between 1998 and 2002, the most recent data shows the impacts of recent land use changes discussed below.

Prior to 1997, horses freely roamed Diaz Ridge (behind the dairy), and extensive areas were denuded (NPS, 2003). There were horse paddocks that backed up to the un-named creek tributary at the Golden Gate Dairy, and manure was never swept out of those paddocks. In November 1997, the paddocks adjacent to the tributary were moved away, and that area was established as a buffer zone. Horses were removed from the back paddock, and a layer of the top soil, heavily laden with manure, was scraped and hauled away. The tributary was re-contoured at the two primary crossings and erosion control material was placed there. The highly eroded hillside which once had been the primary horse passage up to Diaz Ridge was also closed off to horses and erosion control treatments were also applied there.

While the implementation of horse management practices have led to a decrease in fecal coliform concentrations in the Golden Gate Dairy tributary (Figure B.7) and lower Redwood Creek (Figure B.6), bacterial water quality violations have continued to occur in the ocean at Muir Beach, leading to a 30 day beach postings in June 2003. Although bacterial loadings shown in the data record to date will not likely affect beneficial uses for fish and wildlife, beach closures will have a direct effect on recreational uses of the beach area. A more thorough investigation of bacterial sources and loadings to the study area would be required before the implementation of any sources control measures.

References Cited

APHA, Eds. 1998. Standard Methods for the Examination of Water and Wastewater. Washington, DC, American Public Health Association.

Beutel, M. 1998. Golden Gate National Recreation Area Stormwater Monitoring Program 1997/1998. Prepared by Beutel Environmental. Submitted to National Park Service, Division of Resource Management and Planning, Golden Gate National Recreation Area, San Francisco, CA. Final Report. June 1998.

Regional Water Quality Control Board SF Bay Region (SFRWQCB) 1995. San Francisco Bay Basin (Region 2) Water Quality Control Plan. Oakland, CA.

Fong, D. 2003. Personal communication. National Park Service, Golden Gate National Recreation Area. Files received: *RW1999\Rwdwqall99.xls* (DO and temperature data from Fall 1999 at three sites: below MBCSD Well, at MBCSD, and Above Highway 1); *RW1999\Rwd WQ-gageH-98.xls* (DO data from October/November 1998 at three sites: below MBCSD Well, at MBCSD, and Above Highway 1); *RW2001\rw010912wq0.xls* (MiniSonde 34862 DO and Temp data below MBCSD bridge and below gages from Sept-Nov 2001); *RW2002\DO data Oct 02.xls* (DO data from Oct 2002). July 2003.

Francy, D.S., D.Myers, and K. Metzker. 1993. Escherichia Coli and Fecal-Coliform Bacteria as Indicators of Recreational Water Quality. U.S.G.S. Water-Resources Investigations Report 93-4083.

Harding-Lawson and Associates. 1991. Water Quality Sampling In Redwood Creek. Letter Report prepared for the Muir Beach Community Services District. Muir Beach, CA.

Horne, A.J. and C. Goldman. 1994. Limnology. New York, McGraw-Hill.

Leach, P.S., Podlech, M. and R.J. Brown. 1997. Rodeo Valley/Tennessee Valley/Redwood Creek Water Quality Monitoring Report. October 1996-March 1997. Institute of Chemical Biology, University of San Francisco, San Francisco, CA. Prepared for the National Park Service, Golden Gate National Recreation Area.

Madej, M. 1989. Analysis of USGS Water Quality Data Marin Headlands GGNRA 1986-1988. Redwood National Park, Arcata, CA. Prepared for National Park Service, Golden Gate National Recreation Area.

Marin County Department of Health Services (DHS). 2003. Muir Beach 2003 data. Contact: Robert Turner. File: *Beach Monitoring Data 2003 Final.xls.*

Montgomery, J. M., 1985. Water treatment principles and design. John Wiley and Sons.

National Park Service (NPS). 2003. Muir Beach bacterial WQ data (NPS). Samples collected by GGNRA maintenance division (Pat Reischl). Samples processed at Brelje and Race Laboratories, Santa Rosa, CA. File: *2001-2002 Beach WQ data.xls*.

National Park Service (NPS). 2002. Draft Winter 2001-2002 Water Quality Monitoring at Golden Gate National Recreation Area Stables. August 2002. Prepared by National Park Service, Golden Gate National Recreation Area, Division of Resource Management and Planning. Files: *docs\WaterQuality01\01wqrprt.doc* and *docs\WaterQuality01\01finaldata.xls*.

Odum, H. T. 1956. Primary Production in Flowing Waters. Limnol. Oceanogr. 1(2), 102-117.

Philip Williams and Associates (PWA). 1993. Summary of Water Quality Data for Redwood Creek and Green Gulch. 1986-1993. Prepared for the National Park Service, Golden Gate National Recreation Area.

PWA et al. 1994. A preliminary environmental assessment for wetland restoration alternatives for Big Lagoon at Muir Beach. Marin County, CA. Prepared for the National Park Service, Golden Gate National Recreation Area.

Redfield, A.C. 1958. The Biological Control of Chemical Factors in the Environment. American Scientist 46(3): 205-221.

Shoulders, C. 2003. Personal communication. National Park Service, Golden Gate National Recreation Area. Files received: *\docs\WTRQUAL\WQGRF.XLS* (Redwood Creek Water Quality Data Water Quality Monitoring Summary) and *wq97.mdb* (water quality monitoring database, with data through 1999). July 2003.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Table B.1. Applicable Surface Water Quality Objectives and Criteria for the Big Lagoon study area.

Parameter	Criteria/limit	Comments	Source
Temperature	The temperature of any cold or warm freshwater habitat shall not be increased by more than 5ºF (2.8ºC) above natural receiving water temperature.		SFWQCB 1995
Dissolved oxygen	7.0 mg/l minimum	Cold water habitat; for nontidal waters	SFWQCB 1995
	5.0 mg/l minimum	Warm water habitat; for nontidal waters	
	The median dissolved oxygen concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation		
Un-ionized ammonia	The discharge of wastes shall not cause receiving water to contain concentrations of un-ionized ammonia in excess of 0.025 (annual median, mg/l as N)		SFWQCB 1995
Nitrate + Nitrite	10.0 mg/l as N	Maximum Contaminant Level as specified in Table 64431-A (Inorganic Chemicals) of Section 64431, Title 22 of the California Code of Regulations, as of June 19, 1995.	SFWQCB 1995
Total coliform	Marine and Fresh Water < 10,000 per 100 ml	Water contact recreation, Single Day Sample	SFWQCB 1995
	Marine and Fresh Water Median <240 per 100 ml	Water contact recreation, 30 Day Average	SFWQCB 1995
	Marine and Fresh Water Median <1000 per 100 ml	Water contact recreation, 30 Day Average	Marin DHS 2003
	log mean <100 per 100 ml	Municipal Supply, 30 Day Average	SFWQCB 1995
	log mean <20 per 100 ml	Municipal Supply, 30 Day Average	SFWQCB 1995
Fecal coliform	90th percentile <400 per 100 ml	Water contact recreation, Single Day Sample	SFWQCB 1995
	log mean <200 per 100 ml	Water contact recreation, 30 Day Average	
	Marine and Fresh Water log mean <2000 per 100 ml	Non-contact recreation, Single Day Sample	SFWQCB 1995
	Marine and Fresh Water 90th percentile <4000 per 100 ml	Non-contact recreation, 30 Day Average	
	log mean <20 per 100 ml	Municipal Supply, 30 Day Average	
Escherichia coli	Marine water and fresh water 235 per 100 ml	Water contact recreation, Single Day Sample	Marin DHS 2003
	Marine water and fresh water 126 per 100 ml	Water contact recreation, 30 Day Average	Marin DHS 2003
Enterococcus	Marine water 104 per 100 ml; Fresh water 61 per 100 ml	Water contact recreation, Single Day Sample	Marin DHS 2003
	Marine water 35 per 100 ml; Fresh water 33 per 100 ml	Water contact recreation, 30 Day Average	Marin DHS 2003

Table B.2. Monthly Stream Temperatures (oC) for all sites for entire period of record.

Location	Period of Record	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
		October			November			December			January			February			March		
Redwood Creek																			
Muir Woods Bridge	1986-1998	13.6	3	1.7	12.9	2	0.2	11.9	2	0.1	11.6	3	1.0	12.2	2	0.9	10.9	1	n/a
Banducci (at MBCSD well)	1990-1993	13.4	3	0.5	10.7	2	2.3	9.0	1	n/a	6.0	1	n/a	9.5	2	0.7	9.3	3	0.6
Banducci tributary	1997-1998							9.5	2	0.7	11.5	2	0.7	13.0	2	1.4	11.0	1	n/a
Hwy 1 Bridge	1993-2003	13.2	23	0.8	12.8	1	n/a				11.1	2	1.6				11.9	2	2.2
Pacific Way Bridge	1986-2003	14.0	3	1.1	12.2	3	1.0	10.9	4	1.8	12.4	3	0.5	13.4	2	0.8	12.0	2	1.8
Backwater	1992-2003	16.0	1	n/a	14.0	1	n/a	12.5	1	n/a				12.9	1	n/a	13.6	1	n/a
Pedestrian Bridge	1992-2003																12.9	1	n/a
Green Gulch																			
Upper Green Gulch	1986-2002	15.5	1	n/a				12.1	1	n/a	9.3	4	2.5	11.0	7	1.5	13.2	3	1.2
Lower Green Gulch	1992-2003							11.7	2	0.5	7.8	2	0.1	11.5	7	2.8	14.0	3	1.0
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002				12.0	1	n/a	9.5	2	0.7	9.9	4	2.4	10.6	7	1.9	10.2	4	5.0
Golden Gate Dairy	1995-2002				12.3	2	0.4	10.0	2	1.4	12.5	2	0.7	11.3	5	1.9	9.6	4	4.4
Golden Gate Dairy below Hwy 1	1994-2002				12.0	1	n/a	11.8	5	1.9	10.6	4	1.9	11.2	9	1.7	10.2	4	4.1
		April			May			June			July			August			September		
Redwood Creek																			
Muir Woods Bridge	1986-1998							13.0	2	0.7				16.0	1	n/a	18.0	1	n/a
Banducci (at MBCSD well)	1990-1993							14.3	2	0.3	13.4	2	0.1	14.1	2	0.1	13.6	3	0.24
Banducci tributary	1997-1998																		
Hwy 1 Bridge	1993-2003							14.0	2	0.1	13.3	1	n/a	14.0	1	n/a	13.7	1	n/a
Pacific Way Bridge	1986-2003							13.4	3	1.4							19.3	1	n/a
Backwater	1992-2003							13.8	1	n/a							24.5	1	n/a
Pedestrian Bridge	1992-2003							14.1	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							13.5	2	0.7									
Lower Green Gulch	1992-2003							13.7	1	n/a				14.5	1	n/a			
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002																		
Golden Gate Dairy	1995-2002																		
Golden Gate Dairy below Hwy 1	1994-2002																		

Notes:

* Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.3. Conductivity (uS/cm) values for all sites for entire period of record (updated 8/19/03)

Location	Period of Record	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
		October			November			December			January			February			March		
Redwood Creek																			
Muir Woods Bridge	1986-1998	197	3	24	125	2	85	145	1	n/a	131	3	48	131	4	32	130	1	n/a
Kent Canyon	1996																		
Banducci (at MBCSD well)	1990-1993																		
Banducci tributary	1997-1998							255	2	35	140	2	14	120	2	14			
Hwy 1 Bridge	1993-2003	180	1	n/a	180	1	n/a				90	1	n/a				158	2	26
Pacific Way Bridge	1986-2003	242	3	24	183	3	15	190	3	26	116	3	34	146	5	65	158	2	26
Backwater	1992-2003	30,500	1	n/a	18,000	1	n/a	310	1	n/a				145	2	7	193	1	n/a
Pedestrian Bridge	1992-2003																193	1	n/a
Green Gulch																			
Upper Green Gulch	1986-2002	463	1	n/a				134	1	n/a	216	4	52	170	8	62	285	3	181
Lower Green Gulch	1992-2003				215	1	n/a	240	1	n/a	321	2	6	229	7	67	280	3	148
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002				505	2	177	310	2	71	191	4	115	163	7	144	238	1	n/a
Golden Gate Dairy	1995-2002				553	2	145	335	2	78	140	2	71	231	5	112	301	2	86
Golden Gate Dairy below Hwy 1	1994-2002				437	3	210	297	3	95	238	4	120	221	9	110	323	2	113
		April			May			June			July			August			September		
Redwood Creek																			
Muir Woods Bridge	1986-1998							227	2	2							225	1	n/a
Kent Canyon	1996																		
Banducci (at MBCSD well)	1990-1993																		
Banducci tributary	1997-1998				160	1	n/a												
Hwy 1 Bridge	1993-2003							177	1	n/a									
Pacific Way Bridge	1986-2003							187	2	15							260	1	n/a
Backwater	1992-2003							193	1	n/a							14500	1	n/a
Pedestrian Bridge	1992-2003							193	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							338	2	174									
Lower Green Gulch	1992-2003							276	1	n/a									
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002										208	2	12						
Golden Gate Dairy	1995-2002													210	2	14			
Golden Gate Dairy below Hwy 1	1994-2002																198	2	26

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "greater than" values are reported as that value.

For fields with multiple values, an average was taken.

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.4. Monthly DO Values (mg/l) for all sites for entire period of record

Location	Period of Record	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
		October			November			December			January			February			March		
Redwood Creek																			
Muir Woods Bridge	1986-1998	9.4	3	1.2	9.3	2	1.1	10.0	1	n/a	10.6	3	0.2	10.4	2	0.5	10.7	1	n/a
Banducci (at MBCSD well)	1990-1993	6.5	5	1.1	7.6	3	0.9												
Banducci tributary	1997-1998							8.7	2	0.4	10.5	2	0.1	10.4	1	n/a	10.4	1	n/a
Hwy 1 Bridge	1993-2003	5.6	24	2.9	8.3	2	1.6				10.8	1	n/a				10.6	2	0.6
Pacific Way Bridge	1986-2003	7.5	3	1.4	8.4	3	1.0	9.2	3	4.6	10.3	3	0.3	10.0	2	0.3	10.7	2	0.7
Backwater	1992-2003																9.6	1	n/a
Pedestrian Bridge	1992-2003																9.1	1	n/a
Green Gulch																			
Upper Green Gulch	1986-2002	7.4	1	n/a				9.9	1	n/a	11.3	4	0.9	11.4	7	1.0	10.0	3	2.3
Lower Green Gulch	1992-2003							10.3	1	n/a	12.6	2	0.4	11.3	6	4.4	11.0	3	1.3
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002				9.2	2	0.0	9.6	2	0.0	10.7	4	0.7	10.8	6	4.1	9.0	4	2.4
Golden Gate Dairy	1995-2002				6.7	2	3.0	6.0	2	2.3	10.2	2	0.3	10.9	4	5.1	8.8	4	4.7
Golden Gate Dairy below Hwy 1	1994-2002				8.0	3	0.6	8.3	3	4.6	8.3	4	2.7	8.2	7	5.1	8.6	4	5.2
		April			May			June			July			August			September		
Redwood Creek																			
Muir Woods Bridge	1986-1998							8.9	2	0.4							7.5	1	n/a
Banducci (at MBCSD well)	1990-1993							8.3	2	0.3	8.1	2	0.2	7.2	2	0.7	6.4	3	0.6
Banducci tributary	1997-1998																		
Hwy 1 Bridge	1993-2003							8.3	2	1.0	7.2	1	n/a	5.8	1	n/a	5.5	1	n/a
Pacific Way Bridge	1986-2003							9.4	3	3.1							6.6	1	n/a
Backwater	1992-2003							8.5	1	n/a									
Pedestrian Bridge	1992-2003							7.7	1	n/a									
Green Gulch																			
Upper Green Gulch	1986-2002							7.5	2	1.7									
Lower Green Gulch	1992-2003							9.8	1	n/a									
Golden Gate Dairy																			
Golden Gate Dairy control	1997-2002																		
Golden Gate Dairy	1995-2002																		
Golden Gate Dairy below Hwy 1	1994-2002																		

Notes:

* Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.5a. Summary of existing water quality data in the Big Lagoon study area (pre 1997)

Location	Period of Record	Phos (mg/l)			NH_3 (mg N/l)			NO_2 & NO_3 (mg/l)		
		mean	n	SD	mean	n	SD	mean	n	SD
		October - March								
Redwood Creek										
Muir Woods Bridge	1986-1996	0.01	4	0.01	0.02	2	0.01	0.22	4	0.19
Kent Canyon	1996									
Above Banducci	1990-1993							0.25	8	0.17
Banducci tributary	1997-1998									
Hwy 1 Bridge	1993-1996				0.02	2	0.01			
Pacific Way Bridge	1986-1996	0.01	3	0.01	0.02	2	0.01	0.32	3	0.24
Backwater	1992-1993									
Pedestrian Bridge	1992-1993									
Green Gulch										
Upper Green Gulch	1986-1988	0.03	5	0.03				0.46	5	0.42
Lower Green Gulch	1992-1995									
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002									
Golden Gate Dairy	1995									
Golden Gate Dairy below Hwy 1	1994-1996									
		April - September								
Redwood Creek										
Muir Woods Bridge	1986-1996	0.06	2	0.04				0.10	2	0.05
Kent Canyon	1996									
Above Banducci	1990-1993	0.01	3	0.00	0.05	3	0.00	0.01	3	0.00
Banducci tributary	1997-1998									
Hwy 1 Bridge	1993-1996	0.04	3	0.04	0.05	3	0.03	0.01	3	0.01
Pacific Way Bridge	1986-1996	0.19	11	0.41	0.13	5	0.10	0.59	10	0.63
Backwater	1992-1993	0.12	5	0.04	0.20	3	0.11	1.40	3	1.08
Pedestrian Bridge	1992-1993	0.12	7	0.04	0.25	2	0.13	0.88	5	0.58
Green Gulch										
Upper Green Gulch	1986-1988	0.06	2	0.06				0.10	2	0.00
Lower Green Gulch	1992-1995	0.11	9	0.10	0.19	6	0.19	0.64	6	0.62
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002									
Golden Gate Dairy	1995									
Golden Gate Dairy below Hwy 1	1994-1996									

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken.

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Note phosphorus form may be either as P or PO4 (unknown)

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.5b. Summary of existing water quality data in the Big Lagoon study area (Post 1997)

Location	Period of Record	Phos (mg/l)			NH_3 (mg N/l)			NO_2 & NO_3 (mg/l)		
		mean	n	SD	mean	n	SD	mean	n	SD
		October - March								
Redwood Creek										
Muir Woods Bridge	1997-1998				0.08	8	0.04			
Kent Canyon	1996									
Above Banducci	1990-1993									
Banducci tributary	1997-1998									
Hwy 1 Bridge	1997-2003				0.02	2	0.01			
Pacific Way Bridge	1997-2003				0.08	9	0.04	0.8	1	n/a
Backwater/Big Lagoon	1997-2003				0.10	5	0.04			
Pedestrian Bridge	2003							2.5	1	n/a
Green Gulch										
Upper Green Gulch	1997-2002	0.17	11	0.16	0.05	14	0.08			
Lower Green Gulch	1997-2003	0.14	11	0.12	0.04	15	0.05	9.4	1	n/a
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002	0.12	10	0.08	0.01	10	0.04			
Golden Gate Dairy	1997-2002	0.20	7	0.08	0.03	7	0.02			
Golden Gate Dairy below Hwy 1	1997-2002	0.24	10	0.10	0.05	14	0.04			
		April - September								
Redwood Creek										
Muir Woods Bridge	1997-1998				0.10	1	n/a			
Kent Canyon	1996									
Above Banducci	1990-1993									
Banducci tributary	1997-1998									
Hwy 1 Bridge	1997-2003	0.01	1	n/a						
Pacific Way Bridge @ Muir Beach	1997-2003	0.01	1	n/a	0.10	1	n/a			
Backwater/Big Lagoon	1997-2003	0.02	1	n/a	0.10	1	0.0			
Pedestrian Bridge	2003	0.02	1	n/a						
Green Gulch										
Upper Green Gulch	1997-2002									
Lower Green Gulch	1997-2003	0.12	1	n/a						
Golden Gate Dairy										
Golden Gate Dairy control site	1997-2002									
Golden Gate Dairy	1997-2002									
Golden Gate Dairy below Hwy 1	1997-2002									

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken.

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Note phosphorus form may be either as P or PO4 (unknown)

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.6a. Summary of existing water quality data (bacteria) in the Big Lagoon study area (pre 1997)

Location	Period of Record	Bacterial Concentration (MPN/100 ml)									
		Enterococcus			E. coli			Fecal			Total
		mean	n	SD	mean	n	SD	mean	n	SD	mean
		October - March									
Redwood Creek											
Muir Woods Bridge	1986-1996							1021.55	11	2331.10	660.00
Kent Canyon	1996										
Above Banducci	1990-1993							51.00	7	48.28	
Banducci tributary	1997-1998										
Hwy 1 Bridge	1993-1996							456.67	6	351.26	1533.33
Pacific Way Bridge	1986-1996							974.55	11	798.83	1983.33
Backwater	1992-1993										
Pedestrian Bridge	1992-1993										
Green Gulch											
Upper Green Gulch	1986-1988							93.20	5	155.39	
Lower Green Gulch	1992-1995							7602.50	4	8542.33	5100.00
Golden Gate Dairy											
Golden Gate Dairy control site	1997-2002										
Golden Gate Dairy	1995							130.00	2	0.00	130.00
Golden Gate Dairy below Hwy 1	1994-1996							3045.45	11	3752.13	2114.44
		April - September									
Redwood Creek											
Muir Woods Bridge	1986-1996							89.40	5	106.87	210.00
Kent Canyon	1996							27.00	2	0.00	27.00
Above Banducci	1990-1993							35.00	3	13.11	
Banducci tributary	1997-1998										
Hwy 1 Bridge	1993-1996							197.80	5	209.75	245.00
Pacific Way Bridge	1986-1996							858.86	7	1097.59	1310.00
Backwater	1992-1993										
Pedestrian Bridge	1992-1993										
Green Gulch											
Upper Green Gulch	1986-1988							4.00	2	1.41	
Lower Green Gulch	1992-1995							121.25	4	96.30	34.00
Golden Gate Dairy											
Golden Gate Dairy control site	1997-2002										
Golden Gate Dairy	1995										
Golden Gate Dairy below Hwy 1	1994-1996										

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken.

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Table B.6b. Summary of existing water quality data (bacteria) in the Big Lagoon study area (Post 1997)

Location	Period of Record	Bacterial Concentration (MPN/100 ml)									
		Enterococcus			E. coli			Fecal			Tota
		mean	n	SD	mean	n	SD	mean	n	SD	mean
		October - March									
Redwood Creek											
Muir Woods Bridge	1997-1998							448.20	5	680.44	1469.80
Kent Canyon	1996										
Kent Canyon	1996										
Above Banducci	1990-1993										
Banducci tributary	1997-1998										
Hwy 1 Bridge	1997-2003							2.00	1	n/a	
Pacific Way Bridge	1997-2003							1093.33	6	954.51	2523.80
Backwater/Big Lagoon	1997-2003							1363.67	6	809.53	4643.80
Pedestrian Bridge	2003							13.00	1	n/a	
Muir Beach											
Muir Beach North	2000-2003	286.93	20	608.22	4.00	1	0.00				4.00
Muir Beach Middle	2000-2003	92.53	20	194.80	2.00	1	0.00				2.00
Muir Beach South	2000-2003	57.96	20	98.57	2.00	1	0.00				7.00
Green Gulch											
Upper Green Gulch	1997-2002							249.71	14	452.58	1800.00
Lower Green Gulch	1997-2003							148.50	15	173.75	1260.00
Golden Gate Dairy											
Golden Gate Dairy control site	1997-2002							55.36	11	77.45	
Golden Gate Dairy	1997-2002							138.43	7	185.57	
Golden Gate Dairy below Hwy 1	1997-2002							443.29	14	635.85	5200.00
		April - September									
Redwood Creek											
Muir Woods Bridge	1997-1998							8.00	1	n/a	350.00
Kent Canyon	1996										
Above Banducci	1990-1993										
Banducci tributary	1997-1998										
Hwy 1 Bridge	1997-2003							30.00	1	n/a	
Pacific Way Bridge @ Muir Beach	1997-2003							18.00	2	n/a	1600.00
Backwater/Big Lagoon	1997-2003							27.50	2	31.82	110.00
Pedestrian Bridge	2003							70.00	1	n/a	
Muir Beach											
Muir Beach North	2000-2003	54.67	60	140.96	466.38	16	1515.11				1688.63
Muir Beach Middle	2000-2003	13.55	51	17.94	14.11	9	14.22				144.56
Muir Beach South	2000-2003	21.14	50	46.85	9.10	10	0.32				17.90
Green Gulch											
Upper Green Gulch	1997-2002										
Lower Green Gulch	1997-2003							300	1	n/a	
Golden Gate Dairy											
Golden Gate Dairy control site	1997-2002										
Golden Gate Dairy	1997-2002										
Golden Gate Dairy below Hwy 1	1997-2002										

Notes:

Data are organized by season (October-March [Wet], April-Sept [Dry])

All "less than" or "greater than" values reported as that value.

For fields with multiple values, an average was taken.

Period of record is not necessarily inclusive for all years, and is for all water quality parameters.

Sources:

Beutel 1998, Fong, D. 2003. Pers. comm., Leach et al 1997, Madej 1989, Marin County DHS 2003, NPS 2003, NPS 2002, PWA 1993, Shoulders, C. 2003. Pers. comm.

Figure B 1
Water Quality Sampling Sites
Redwood Creek and Tibutaries, Marin, CA

Figure B.2
Longitudinal Variation in Ammonia Concentrations
Redwood Creek, Marin, CA

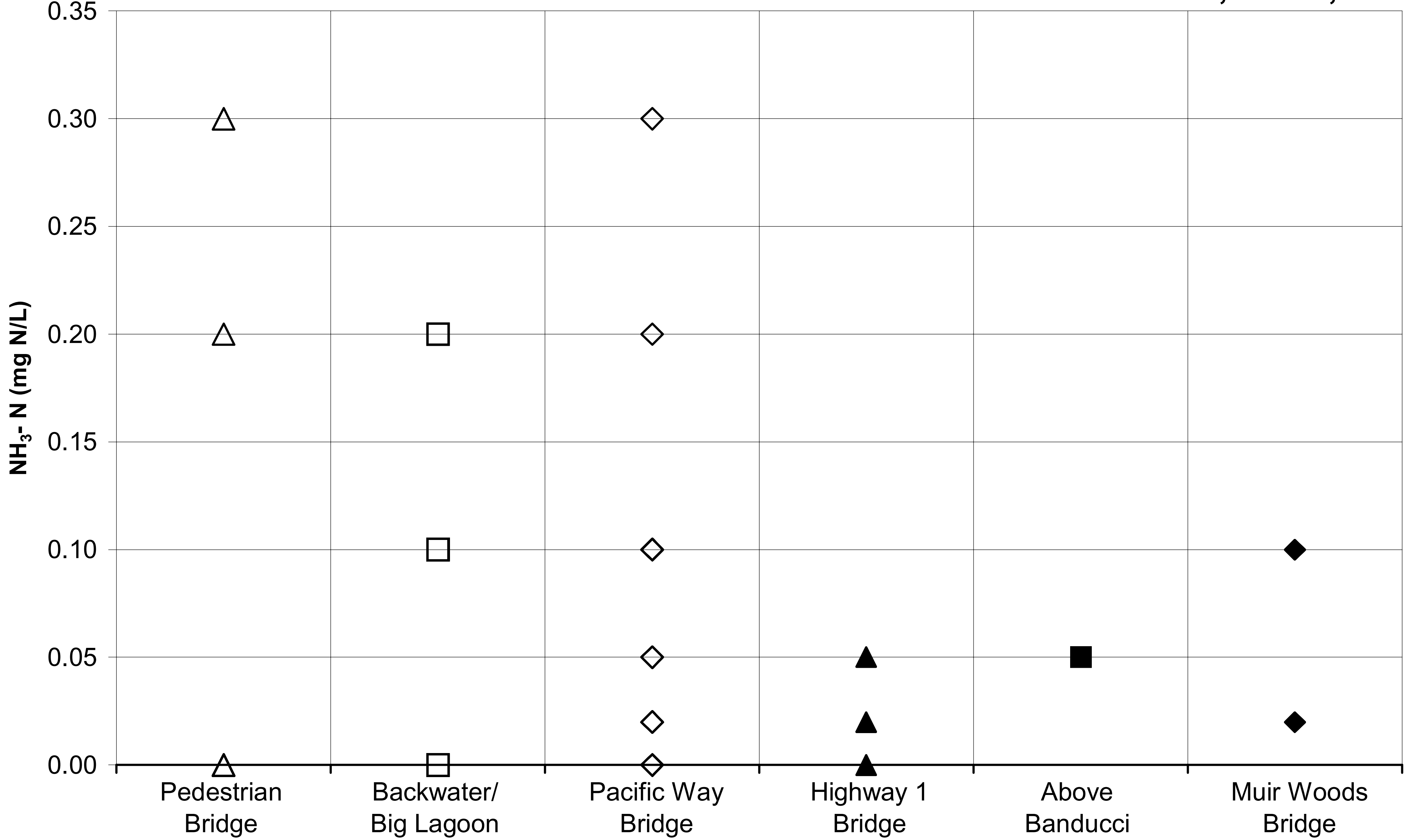


Figure B.3
Temporal Variation in Ammonia Concentrations
Redwood Creek, Marin, CA

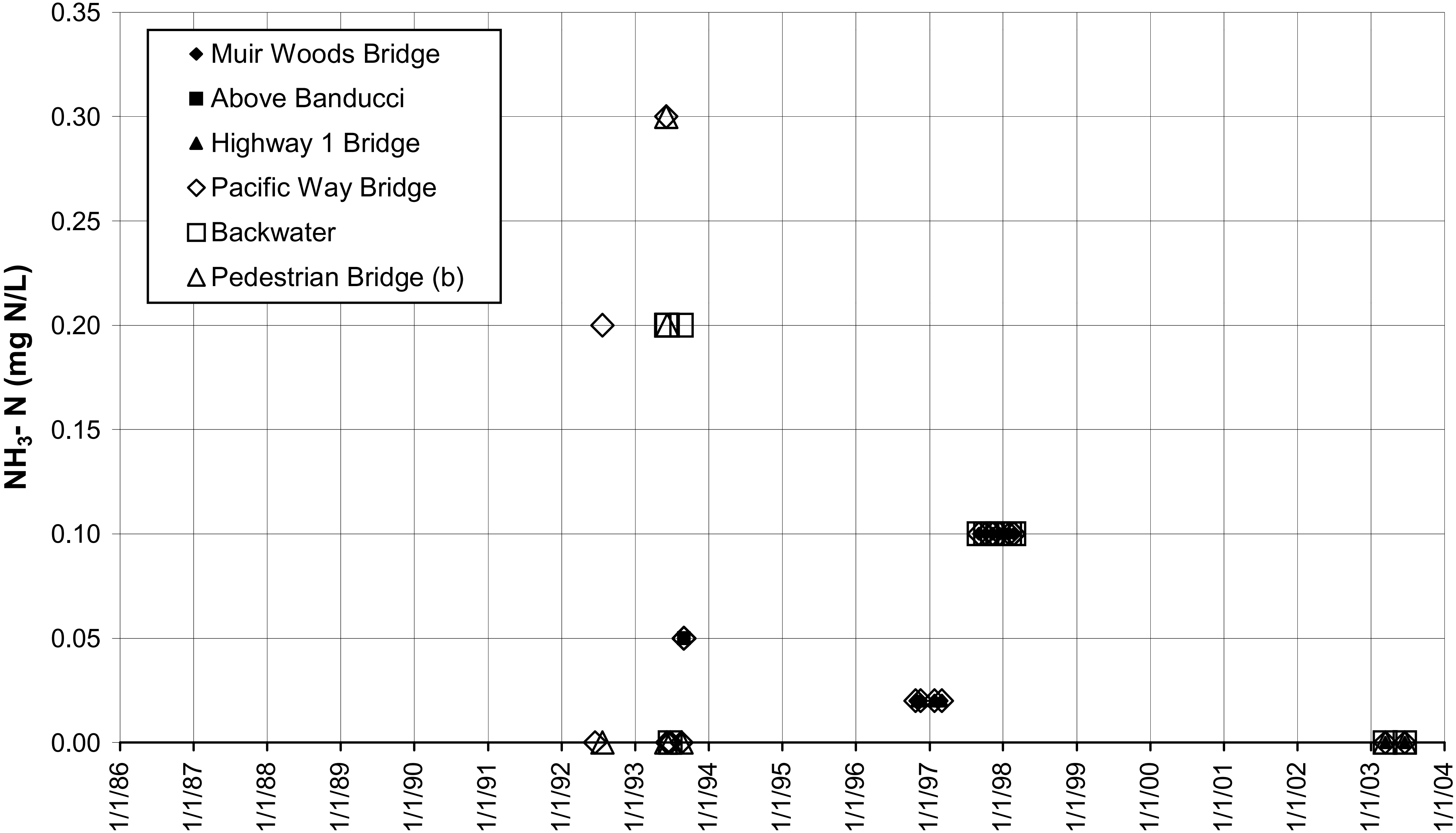


Figure B.4
Longitudinal Variation in Nitrite + Nitrate Concentrations
Redwood Creek, Marin, CA

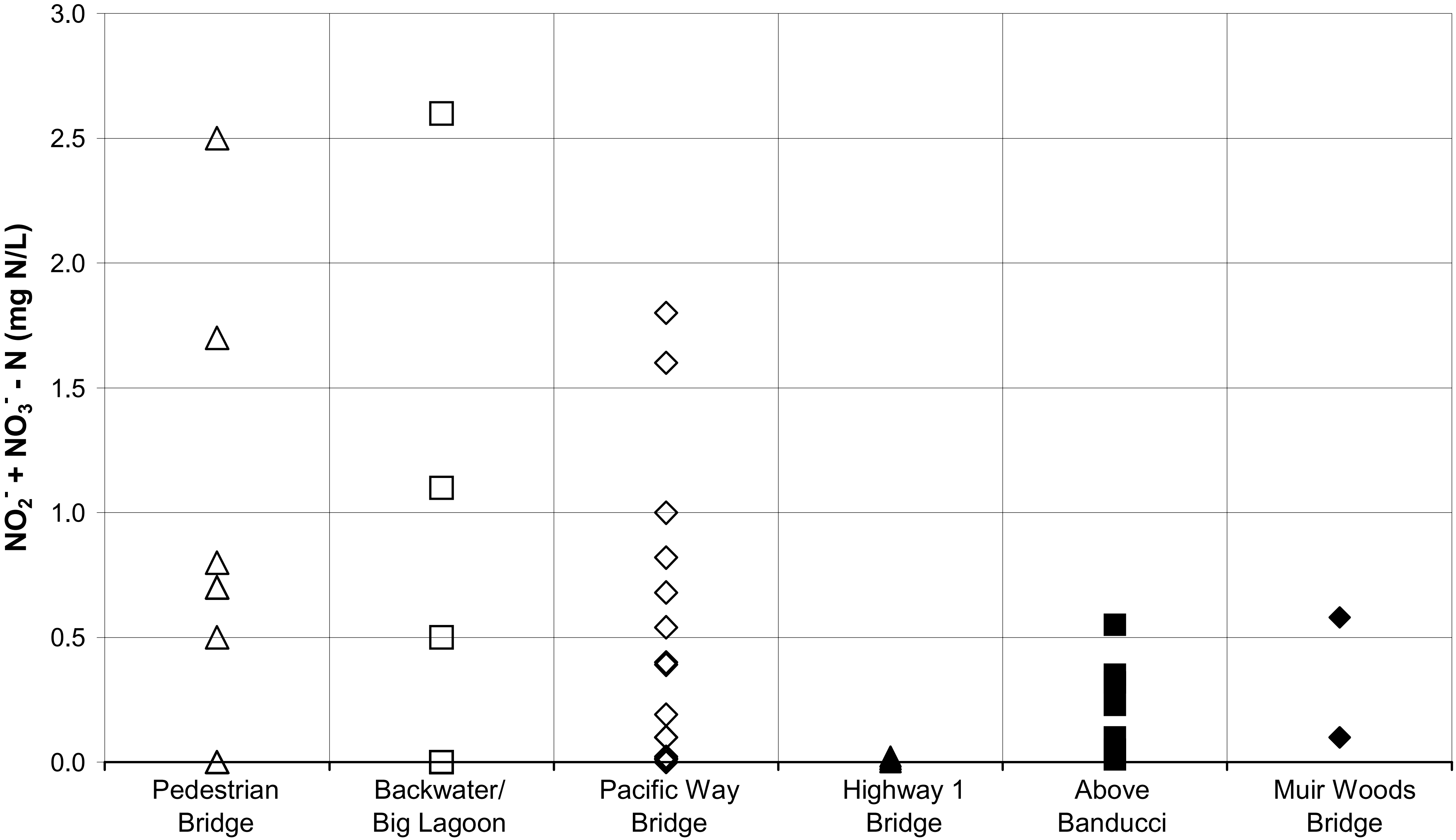


Figure B.5
Temporal Variation in Nitrite + Nitrate Concentrations
Redwood Creek, Marin, CA

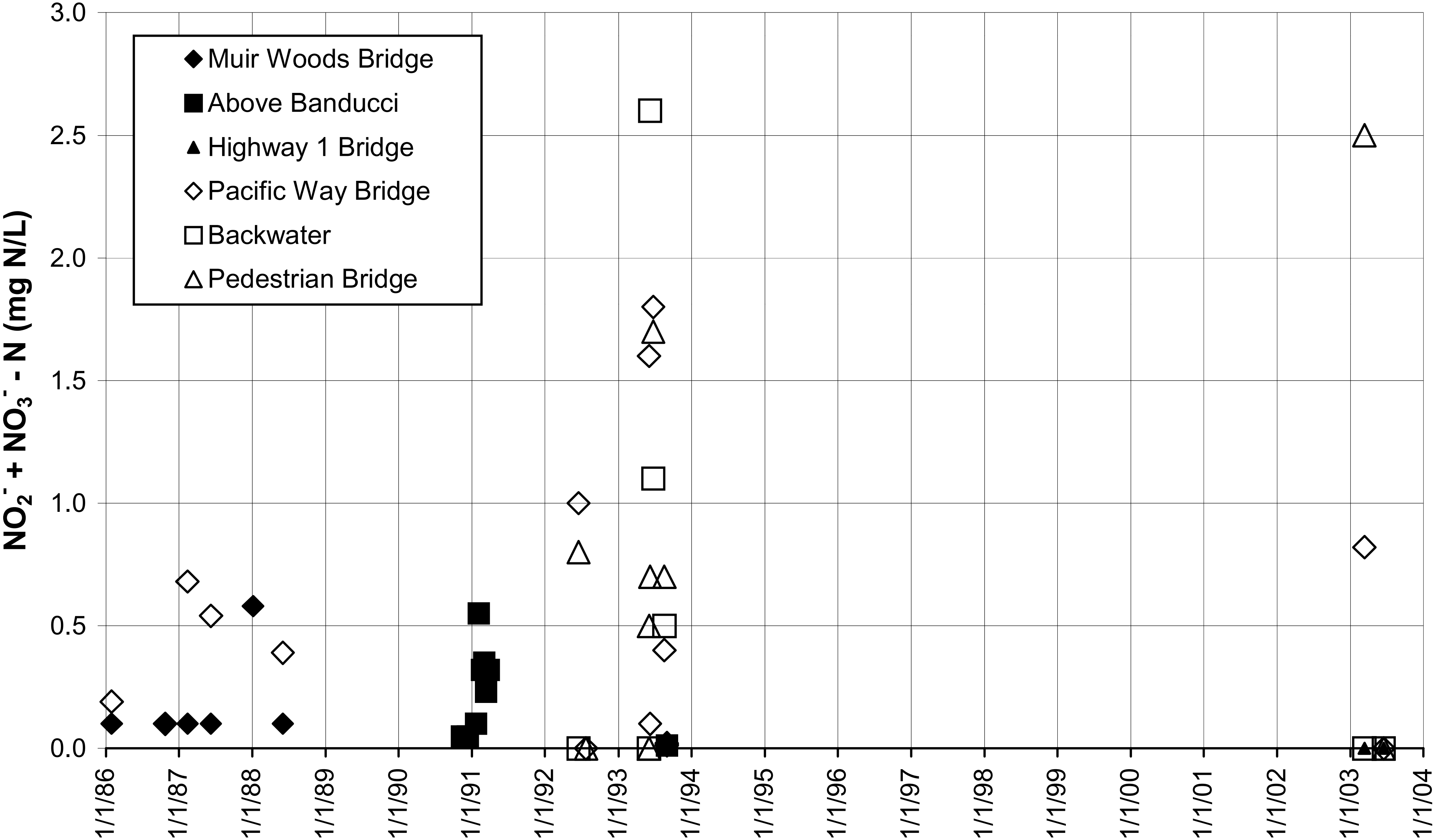


Figure B.6
Temporal Variation in Fecal Coliform Concentrations
Redwood Creek, Marin, CA

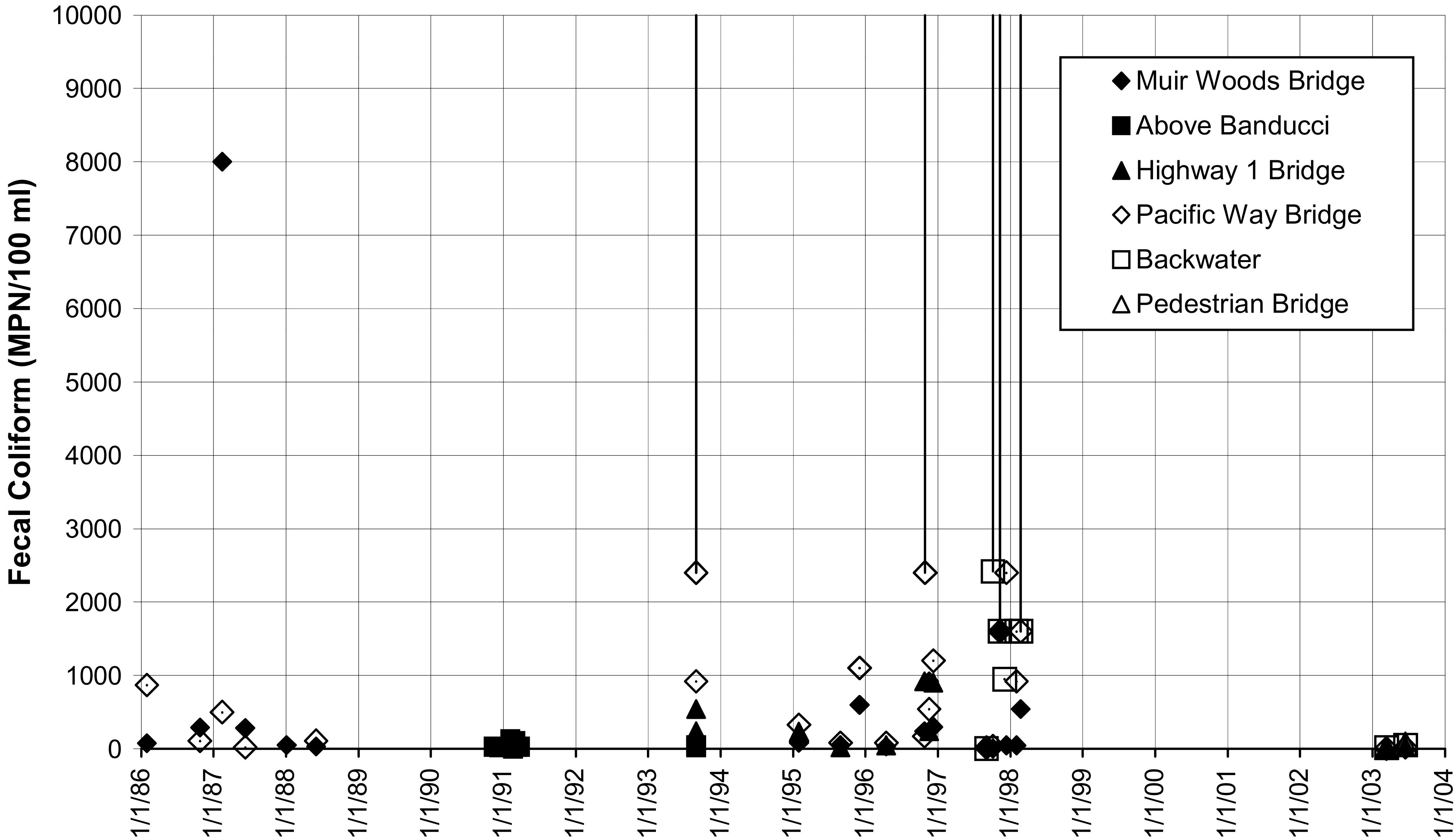
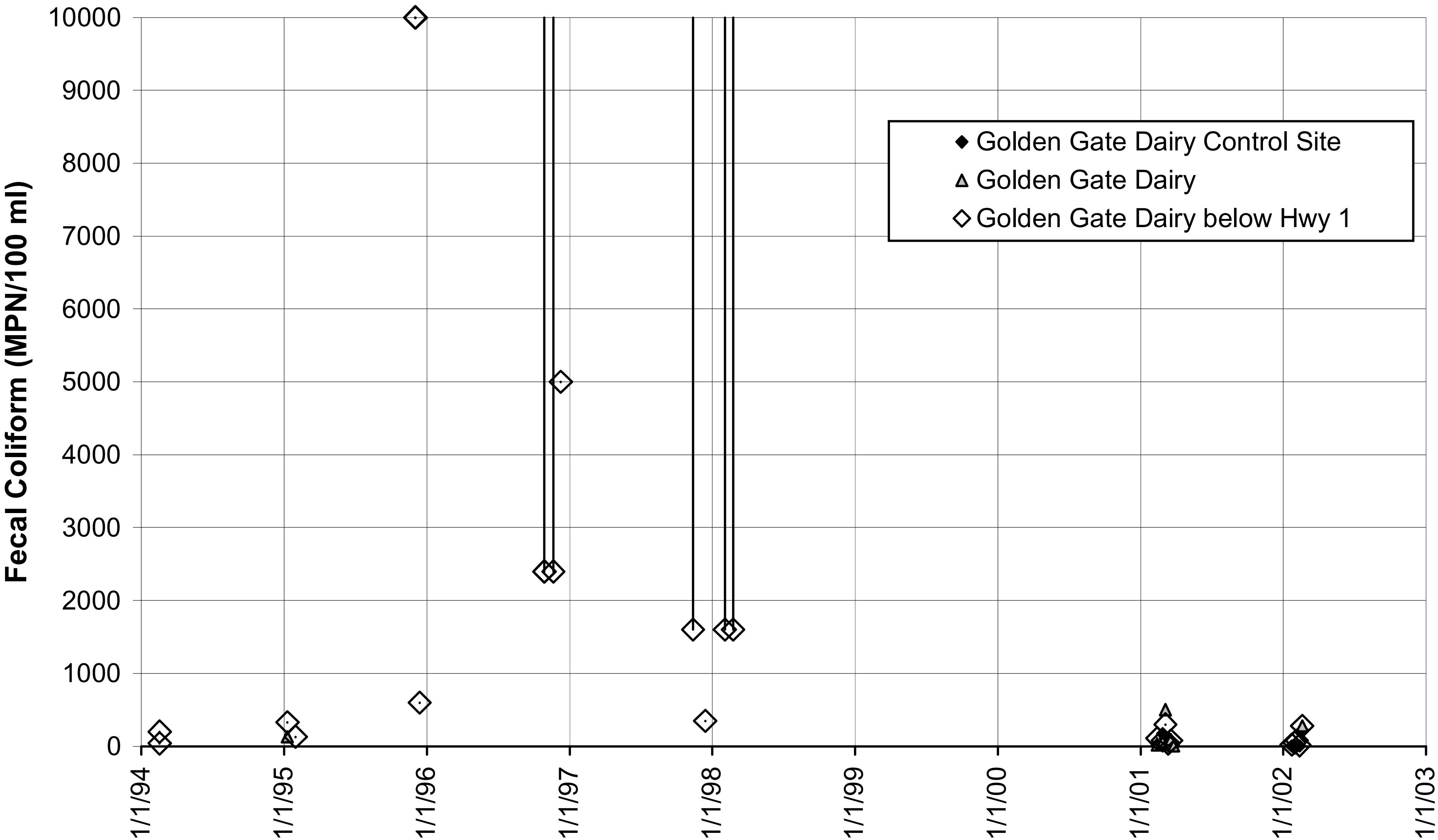


Figure B.7
Temporal Variation in Fecal Coliform Concentrations
Golden Gate Dairy Tributary, Redwood Creek, Marin, CA



APPENDIX C
BIG LAGOON COMPILATION OF VEGETATION

Appendix C - Compilation of Vegetation in Big Lagoon Study Area

Jepson Herb. Query	1970 Marin Flora	1979 Wildflowers of Marin	1989 flora of GGNRA	1994 MuWo flora	1994 PWA Report	2003 PORE Survey	Scientific Name	Common Name	Wetland indicator status	lifestage	Non-native	riparian	aquatic	disturbed	pasture	marsh	dune	upland	comments
		X			X		*Abronia latifolia*	Sand verbena		p				O			A		
			X		X		*Achillea millefolium*	Common yarrow		p				O				A	
					X		*Aesculus californica*	CA buckeye		t				O					
1957							*Agrostis hallii*	bent grass		p									1.3 mi. north on hwy 1
					X		*Agrostis pallens*	Leafy bent grass		p					O			O	
					X	X	*Agrostis stolonifera*	Creeping bent	FACW	p			O		O				
					X		*Aira caryophyllea*	European hair grass		a	Y							O	
					X	X	*Alisma plantago-aquatica*	Water plantain		p		O	O		O				
					X	X	*Alnus rubra*	Red alder	FACW	t		D	D			A			
					X		*Alopecurus pratensis*	Meadow foxtail		p	Y			O	A				
					X	X	*Ambrosia chamissonis*	Beach bur		p						O	D		
					X		*Ammophila arenaria*	European beach grass		p	Y						A		
			X		X		*Anagallis arvensis*	Scarlet pimpernel		a	Y		O	O	O	O			
			X				*Anaphalis margaritacea*	Pearly everlasting		p									
					X		*Arctotheca calendula*	Capeweed		p	Y							O	
			X				*Artemisisa californica*	CA sagebrush		p									
					X		*Artemisisa douglasiana*	CA mugwort		p		O		O			A	A	
					X	X	*Athyrium felix-femina*	Lady fern	FACW	p		A							
					X		*Atriplex triangularis = A. patula*	Spear oracle = fat hen		a						O			
					X		*Avena barbata*	Slender wild oat		a	Y			A		O		O	
					X		*Avena fatua*	Wild oat		a	Y			O					
					X		*Azolla filiculoides*	American water fern		a			O		O				
			X		X		*Baccharis pilularis*	Coyote brush		p				O		O		D	
			X	X	X		*Brassica rapa = B. campestris*	Field mustard		a	Y			A					
					X		*Brassica nigra*	Black mustard		a	Y	O		A	O	O	O	O	
			X				*Briza maxima*	Quaking grass		a	Y								
					X		*Briza minor*	Little quaking grass		a	Y							O	
			X		X		*Bromus carinatus var. maritimus*	CA brome		p									
					X		*Bromus catharticus*	Rescue grass		p	Y			O					
					X		*Bromus diandrus*	Ripgut brome		p	Y			C	O	O	O		
					X		*Bromus hordeaceous = B. mollis*	Soft chess		a	Y		O	O	O			O	
					X		*Bromus vulgaris*	Brome		p		O							
1943		X			X		*Cakile maritima*	Sea rocket		p	Y					O	A		just above high tide line
						X	*Callitriche heterophylla var. bolanderi*		OBL										
				X	X	X	*Calystegia occidentalis spp. O.*	Bush morning glory		v		O							
					X	X	*Calystegia purpurata ssp. P*	morning glory		v		O							
					X	X	*Calystegia sepium*	Hedge bindweed		v		O		O					
						X	*Carex deweyana ssp. Leptopoda*												
					X		*Carex sp.*	sedge		p		O							
					X		*Carpobrotus edulus*	Hottentot fig		p	Y						O		

Appendix C - Compilation of Vegetation in Big Lagoon Study Area

Jepson Herb. Query	1970 Marin Flora	1979 Wildflowers of Marin	1989 flora of GGNRA	1994 MuWo flora	1994 PWA Report	2003 PORE Survey	Scientific Name	Common Name	Wetland indicator status	lifestage	Non-native	riparian	aquatic	disturbed	pasture	marsh	dune	upland	comments
1968 1969 1991							*Castilleja subinclusa ssp. Franciscana*	indian paintbrush		p								O	1.5 mi e; 1.2 mi west on hwy 1, hwy 1 junct. W/rd to mube, .5 mi n on hwy1, .75 mi north on hwy 1, 1.3 mi se on hwy 1
1963							*Castilleja wightii*	indian paintbrush		p						O			600 ft from shoreline in april
					X		*Cerastiym arvense*	Meadow chickweed		p								O	
					X		*Chamomilla suaveolens*	Pineapple weed		p	Y			O	O				
					X		*Chloragalum pomeridianum*	Soap plant		p								O	
					X		*Cirsium arvense*	Canada thistle		b	Y			O	O			O	
					X		*Cirsium vulgare*	Bull thistle		a				A	O			O	
					X		*Claytonia perfoliata*	Miner's lettuce		a			O						
			X		X	X	*Conium maculatum*	Hemlock	FAC	a	Y			D	O	O		A	
					X		*Conyza canadensis*	Horseweed		a				O					
		X	X		X	X	*Cornus sericia ssp. Sericia = C. californica*	American dogwood	FACW	s				O					
				X	X	X	*Cortaderia jubata*	Jubata grass		p				O		O			
					X	X	*Cotula coronopifolia*	Brass buttons	FACW	p	Y		O		O	O			
						X	*Croton californicus*	Californa croton											
					X		*Cynodon dactylon*	Bermuda grass		p	Y				O				
			X		X		*Cynosurus echinatus*	Hedgehog dogtail		p	Y			O				O	
					X	X	*Cyperus eragrostis*	Tall cyperus	FACW	p			A		O	O			
					X		*Dactylis glomerata*	Orchard grass		p	Y				O			O	
				X	X		*Delairea odorata*	Cape ivy		v	Y	A		A					
						X	*Delairea odorata*	Cape Ivy		p									
1946							*Delphinium californicum*	larkspur		p									
					X		*Dichelostemma capitatum*	Blue dicks		p								O	
						X	*Digitaria sanguinalis*	Hairy crabgrass	FACU										
						X	*Dipsacus sp.*	Teasel											
					X		*Distichlis spicata*	Salt grass		p				O		O	A	O	
					X	X	*Eleocharis macrostachya*	Creeping spike rush	OBL	p			A		A				
1957			X		X		*Elymus glaucus*	Blue wild rye		p								A	just s. on slopes and bluffs above sea
					X	X	*Epilobium ciliatum ssp. Watsonii*	Fringed willowherb	FACW	p			O	O					
						X	*Equisetum arvense*	Horsetail	FAC										
					X	X	*Equisetum telmateia sso, braybuu*	Giant horsetail	OBL	p			O	O					
			X				*Erigonum latifolium*	Wild buckwheat		p									
					X		*Eriophyllum staechadifoliym*	Lizard tail		p							O	O	
					X		*Erodium moschatum*	White-stemmed filaree		a	Y			A				O	
				X			*Eucalyptus globulus*	Blue gum eucalyptus		t	Y								
					X	X	*Festuca arundinaceae*	Tall fescue	FAC-	p	Y		O	O		O			
1957							*Festuca rubra*	Red fescue		p								O	1.2 mi north along hwy 1
			X	X	X		*Foeniculum vulgare*	Fennel		p	Y			O		O			

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		X					*Fragaria chiloensis*	Beach strawberry		p							X		
					X		*Frankenia salina = F. grandifolia*	Alkali heath		p						O			
						X	*Galium aparine*	Stickywillow	FACU										
					X		*Galium triflorum*	Sweet-scented bedstraw		p	Y	O							
				X	X	X	*Genista monspessulana*	French broom		s	Y	O		O					
					X		*Geranium dissectum*	Cut-leaved geranium		a	Y		O					A	
					X		*Glyceria leptostachya*	Davy's manna grass		p			O						
						X	*Glyceria sp.*	manna grass	OBL										
					X		*Gnaphalium luteo-album*	Weedy cudweed		a	Y				O				
					X		*Grindelia stricta*	Pacific grindelia		p						O			
1957							*Hainardia cylindrica*				Y								found in coastal salt marshes, alkaline soils
			X		X		*Hedera helix*	English ivy		v	Y	A							
					X	X	*Helenium puberulum*	Sneezeweed	FACW	p			O						
					X		*Heracleum lanatum*	Cow parsnip		p				O					
						X	*Hirschfeldia incana*	Shortpod mustard	UPL										
					X	X	*Holcus lanatus*	Purple velvet grass	FAC	p	Y		O	O	O	O			
					X		*Hordeum brachyantherum*	Meadow barley		p					O				
					X		*Hordeum depressum*	Low barley		a					O				
					X		*Hordeum murinum ssp. Leporinum*	Farmer's foxtail		a	Y			A	O	O			
1946					X		*Horkelia californica ssp. C.*	CA horkelia		p								O	
					X	X	*Hydrocotyle rannunculoides*	Marsh pennywort	OBL	p		A			O				
					X		*Hypochaeris glabra*	Smooth cat's ear		a	Y			O					
					X		*Hypochaeris radicata*	Rough cat's ear		p	Y	O		O		O		O	
					X		*Jaumea carnosa*	Jaumea		p						O			
						X	*Juncus balticus*	Baltic rush	FACW+	p									
					X	X	*Juncus bufonius*	Toad Rush	FACW+	a		O	O		A				
					X	X	*Juncus effusus var. brunneus*	Bog rush		p		O	O		O				
					X		*Juncus leseurii*	Salt rush		p		O	O	O		D			
					X	X	*Juncus patens*	Common rush	FAC	p		O							
					X	X	*Juncus xiphioides*	Iris-leaved rush	OBL	p			O						
						X	*Kniphofia uvaria*	Redhot poker											
			X				*Koeleria macrantha*	June grass		p									
1935							*Layia gaillardioides*												1 mi east of mube
					X		*Lemna minor*	Smaller duckweed		p			A						
					X		*Leymus mollis*	American dune grass		p							D		
						X	*Leymus sp.*												
					X		*Leymus triticoides*	Alkali rye grass		p				O		O			
					X	X	*Lolium multiflorum*	Italian ryegrass		a	Y		O	O	D	O		O	
						X	*Lolium perenne*	Perrenial ryegrass	FAC*										
						X	*Lonicera involucrata var. ledebourii*	Twinberry	FAC										

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					X	X	*Lotus corniculatus*	Birdfoot treefoil	FAC	p	Y			A					
1957							*Lotus scoparius*			p									6 mi. north
					X		*Lupinus arboreus*	Yellow bush lupine		s				O				O	
		X			X		*Lupinus microcarpus var. m*	Chick lupine		a				O					
					X		*Lupinus rivularis*	Lupine		s				O					
					X	X	*Lythrum hyssopifloliym*	Hyssop loosestrife	FACW	a	Y		O		O				
1935							*Madia gracillis*			a									2 mi. east
1935					X		*Madia sativa*	Coast tarweed		a				O	A				2 mi. east
					X		*Malva nicaeensis*	Bull mallow		ap	Y			O					
					X		*Malva parviflora*	cheeseweed		a	Y			O					
					X		*Marah fabaceus*	CA man-root		p		O							
					X		*Medicago luplina*	yellow treefoil		a	Y			O				O	
					X		*Medicago polymorpha = M. hispida*	CA burclover		a			O	A	O			O	
					X		*Melica sp.*	Melic		p								O	
1957							*Melica torreyana*	melic grass		p									1.3 mi north
					X		*Melilotus alba*	White sweetclover		ab	Y			O					
					X	X	*Melilotus indica*	Sourclover	FAC	a	Y		O	A		O			
						X	*Mentha arvensis*	Wild mint	FACW										
				X	X	X	*Mentha pulegium*	Pennyroyal	OBL	p	Y	O	O	O	A				
					X	X	*Mimulus guttatus*	Seep monkey flower	FACW+	a, p			O		O	O			
					X		*Myoporum laetum*	Myoporum		t	Y			O					
					X		*Myosotis latifolia*	Forget-me-not		p	Y	O							
			X		X		*Nassella pulchra*	Purple needle grass		p								A	was N. lepida in PWA report--seemed unlikely.
					X	X	*Oenanthe sarmentosa*	Water parsley	OBL	p		O	A		O	O			
					X		*Oxalis oregana*	Redwood sorrel		p		O							
					X	X	*Paspalum dilatatum*	Dallis grass	FAC	p	Y			O					
					X		*Paspalum distichum*	Knotgrass		p			D		O				
			X		X	X	*Pennisetum clandestinum*	Kikuyu grass	FACU+	p	Y	O	O	D	O	D	O		
						X	*Petasites frigidus var. palmatus*	Coltsfoot	FACW*										
1963							*Phacelia divaricata*			a									rocky slope facing pacific ocean, 600 ft from shore
					X		*Phacelia malvifolia*	Stinging phacelia		a								O	
					X		*Phalaris aquatica = p. tuberosa*	Harding grass		p	Y			O	O				
					X	X	*Phalaris californica*	CA canary grass		p				O					
					X	X	*Picris echioides*	Bristly ox-tongue	FAC	ab	Y		O	O		A		O	
					X		*Pinus contorta var. c*	Shore pine		t				O					
				X	X		*Pinus radiata*	Monterey pine		t	Y	O		O					
					X		*Plantago coronopus*	Cut-leaved plantain		ab			O	O					
					X		*Plantago lanceolaata*	English plantain		p	Y		O					D	
					X	X	*Plantago major*	Common plantain	FAC	p	Y		O		A	O			

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						X	*Plantago maritima*	goose tongue	FACW+										
					X		*Poa annua*	Annual bluegrass		a	Y				O				
					X		*Poa sp.*	Bluegrass		p					O			O	
						X	*Polygonum arenastrum*	Oval-leaf knotweed	FAC										
					X		*Polygonum hydropiperoides*	Waterpepper		p		O	O						
						X	*Polygonum punctatum*	dotted smartweed/ water	OBL	a, p		O	O			O			
					X	X	*Polypogon monspeliensis*	Rabbits foot grass	FACW+	a	Y			A	D	A			
					X		*Polystichum munitum*	Western sword fern		p		A							
					X		*Populus balsamifera var. trichocarpa*	Black cottonwood		t				O					
				X	X	X	*Potentilla ansserina ssp. Pacifica = P. eggedii*	Pacific silverweed	OBL	p			O		O	D			
					X		*Pteridium aquilinum*	Bracken fern		p								O	
					X		*Ranunculus aquatilus*	Water buttercup		p		O			O				
					X		*Ranunculus muricatus*	Pickle-fruited buttercup		ab	Y				O			O	
				X	X	X	*Raphanus sativus*	Cultivated radish	UPL		Y					D			
					X	X	*Rorippa naasturtium-aquacitcum*	Watercress	OBL	p		O	A						
1938				X	X	X	*Rubus discolor*	Himalayan blackberry	FAC+	s	Y			C					
					X		*Rubus parviflorus*	Thimbleberry		s		O		O					
					X	X	*Rubus ursinus*	California blackberry	FAC+	s		O		O	O			O	
					X		*Rumex acetosella*	Sheep sorrel		p	Y			O				O	
					X	X	*Rumex conglomeratus*	clustered dock	FACW-	p	Y		O	O	A	O			
					X	X	*Rumex crispus*	Curly dock	FACW-	p	Y		O	O	A	O			
1943							*Ruppia cirrhosa*												marshes, ponds, sloughs
					X	X	*Salix lasiolepis*	Arroyo willow	FACW	t		A							
					X	X	*Salix lucida ssp. Lasiandra*	Shining/yellow willow	OBL	t		D			O	O			
					X	X	*Sambucus racemosa var. r.*	Red elderberry	FACU	s		O		O					
					X		*Sanicula crassicaulis*	Pacific sannicle		p								O	
					X		*Scirpus acutus*	Common tule		p			O						
					X		*Scirpus americanus*	Three square		p			D		O	O			
						X	*Scirpus californicus*	CA tule											
					X		*Scirpus cernuus*	Low club rush		a			A						
					X	X	*Scirpus microcarpus*	Small-fruited bulrush	OBL	p		O	O						
						X	*Scirpus pungens*		OBL										
					X		*Scirpus robustus*	Prairie bulrush		p			A						
					X		*Scrophularia californica*	CA figwort		p		O	O	O		O	O		
					X		*Senecio sylvaticus*	Wood groundsel		a	Y	O		O	O				
					X		*Silybum marianum*	Milk thistle		ab	Y			O				O	
					X		*Sinapsis kaber*	Charlock		a	Y			O					
					X		*Solanum sarrachoides*	Nightshade		a	Y	O							
					X	X	*Sonchus asper*	Prickly sow thistle	FAC	a	Y			O	O	O			
			X		X		*Sonchus oleraceus*	Common sow thistle		a	Y			O		O			
					X		*Spergularia marina*	Salt marsh sand spurry		a							O		

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					X		*Spergularia rubra*	Purple sand spurry		ap	Y			O	O				
						X	*Stachys adjugoides*		OBL										most likely STCH
		X			X		*Stachys chamissonis*	Coast hedge nettle		p		O				O		O	
			X		X		*Symphoricarpus albus*	Common snowberry		s		O							
					X		*Sysrinchium bellum*	Blue-eyed grass		a								O	
					X		*Tetragonia tertragonioides*	New Zeeland spinach		a	Y			O					
					X		*Toxicodendron diversilobum*	Poison oak		s				O				A	
					X		*Tragopogon porrifolius*	Salsify		b	Y	O		O		O			
					X	X	*Trifolium repens*	White clover	FAC	p	Y		A	O	D				
					X		*Trifolium wormskioldii*	Coast clover		p			A	A	A				
1957							*Trisetum canescens*			p									1.3 mi n along hwy 1
				X	X		*Tropaeolum majus*	Garden nasturtium		ap	Y		O						
					X	X	*Typha latifolia*	Broad-leaved cat-tail	OBL	p		D		O	O				
					X	X	*Urtica dioica ssp. Holosericea*	Hoary nettle	FACW	a		A							
						X	*Verbena lasiostachys*	western vervain	FAC-										
					X	X	*Veronica americana*	American brooklime	OBL	p		O	O		O				
					X	X	*Vicia sativa*	Common vetch	FACU	a	Y	O	O	A	O			O	
					X		*Vulipa bromoides*	6-week's fescue		a	Y			O				O	
					X		*Vulpia myuros var. m*	Fescue		a	Y							O	
			X				*Wyethia angustifolia*	Narrow-leaf mules-ears		p									
				X	X	X	*Zantedeschia aethiopica*	Calla lily	OBL	p	Y	O				O			
									TOTAL	**218**		**49**	**52**	**84**	**56**	**46**	**15**	**49**	
									Number of non-native species	**78**		**15**	**19**	**52**	**30**	**24**	**6**	**23**	
									Percent non-native	**36%**		**31%**	**37%**	**62%**	**54%**	**52%**	**40%**	**47%**	

lifestage: annual (a), biennial (b), perennial (p), shrub (s), tree (t), vine (v).

Habitat: Dominant (D), Abundant (A), Common [C], Occasional (O), Present (X).

APPENDIX D
BIOLOGICAL SAMPLING METHODS

APPENDIX D

Biological Sampling Methods

The following biological sampling methods and survey locations presented in Appendix D were used during the 1992 – 1993 surveys by PWA et al. (1994).

XII. APPENDIX- METHODS

A. Methods

Physical

Grain Size

Field Methods:

Sediment samples for grain size analysis were collected from three stations within the lower lagoon. Lagoon stations were roughly equally spaced, with station one near the lower end (the "mouth", when open to tidal flow), station two in the middle, and station three near the upstream end of the lagoon. Samples were collected using stainless steel implements. An approximately 80g subsample from the top 2cm of the sediment surface was placed in a zip-lock bag for grain-size analysis. Samples were labeled with an external label on the bag with an additional internal label.

Laboratory methods:

Sample Preparation

The samples were analyzed whole; no subsampling or splitting was performed. All weights in all analyses were read and recorded to the nearest 0.01g. The samples were placed into numbered pre-weighed beakers and were dried at less than 55°C to prevent collapse of the clays. Samples were allowed to cool for at least one hour to equilibrate to the atmosphere, then weighed. After the sample was dried, the debris was removed, with any sediment adhering to the debris being washed into the sample container. The debris/shell fragments were dried, weighed, and listed on the data sheet, but not included in the computation of sediment size statistics. The stock container (50g/l) of 'Calgon' dispersant was stirred to ensure homogeneity, and 100 ml added to each beaker to prevent flocculating. Lumps were broken up using a rubber-tipped probe, then the sample beakers placed in an ultrasonic cleaner for 15 minutes for disaggregation. Samples were then wet-sieved through a No. 230 4 phi (0.0625 mm) stainless-steel sieve. Silts, clays, and colloidal material passing through the sieve were not retained and were allowed to flow down the drain. The coarse fraction was placed into a pre-weighed beaker, dried at 55°C, allowed to acclimate, then weighed. Analysis of March 1993 sediments was limited to this rough percent fine/percent coarse characterization. The preponderance of coarse sediments in samples from all three stations (see below) suggested that further analysis of the coarse fraction was necessary. In accordance, the coarse fraction from the May and September 1993 sampling dates were analyzed by sieve analysis using a mechanical shaker for 15 minutes and the following sieves: No. 10 (2.0 mm), 18 ((1.0 mm), 60 (0.25 mm), 80 (0.177 mm), 120 (0.125 mm), and 170 (0.088 mm). After shaking, each sieve was inverted onto a large piece of paper and tapped 5 times to free stuck particles. The sieve fractions were added cumulatively to a pre-tared weighing dish, and the cumulative weight after each addition determined to 0.01g. Each sample was returned to its original beaker and saved until the sample computations were completed and checked for errors.

Data Analysis

Fractional weights and percentages of fine (silt, clay, and colloidal, particle size < 63 µm) and coarse (coarse sand, medium/fine sand, and pebbles/gravel, particle sizes ≥ 63 µm) fractions, as well as Folk & Ward parameters (mean and median grainsize, sorting coefficient, skewness, and kurtosis were calculated using custom software on a Macintosh 2 computer.

Ecological Methods

Vegetation

Five major plant associations were recognized on the lowlands. They were identified by visual survey of the site from the ground and by a supplemental overview inspection looking down from the adjacent hills. They were pasture, marsh, disturbed, riparian and dune. Upland habitat of modified coastal scrub grew adjacent to the site on the surrounding hills. Eight permanent transects were established for quantitative sampling (Figure D-1).

Vegetation was also assessed qualitatively and semiquantitatively. Regional distribution of species and approximate cover were noted by walking over the entire study site. The whole area was generally searched to locate all species, including those of the dense riparian woodland. Since the upland was peripheral to the study it was not surveyed thoroughly and only species that occurred along the transect or were important components were included in the species list. Seasonal changes in species composition and reproductive state of plants were noted. Aerial photographs were used to assess general seasonal trends in plant composition and cover over the area. Aerial photographs and recorded oral histories provided the basis for review of probable historical conditions and subsequent changes.

Quantitative plant surveys to measure per cent cover by species were conducted a total of 5 times, approximately quarterly, along 20 m transects (Figure D-1) . An additional transect was put in the upland. Transects were positioned through the most typical, homogenous, sections of each habitat. Transects were marked by a small pvc stake at each end and visual lineups were established to facilitate finding the stakes. Generally the habitats were small relative to the length of the transect consequently, transects generally ran through the middle of each area. Lists of species in each habitat type were generated from quantitative transect surveys as well as qualitative evaluations. Habitat types graded into each other or were bordered by disturbed areas with many weeds, and species were often recorded from the edges of habitat types. Dune habitat was sampled by semiquantitative assessment of the community remnants on individual sand mounds.

Quantitative sampling was carried out by stretching a 20m tape between each pair of stakes and placing a quadrat of a quarter meter square area at each of ten points along the tape. The points had been selected each sampling period using a table of random numbers. The random point-quadrat method was employed. The quadrat was covered with a grid dividing it into 100 equally spaced intersects and it defined the sampling area. Ten intersects were chosen each sampling period using a table of random numbers. Data were obtained by recording the species which occurred under each of the ten selected intersect points. The raw quantitative data are archived at Moss Landing Marine Laboratories and may be used for long-term comparisons.

Scientific and common names are the most current according to Hickman (1993). Long-recognized common and scientific names that have been replaced are noted in parentheses in Table 3.

Freshwater Aquatic Invertebrates

Although we initially sampled insect fauna at 17 stations in seven habitat types (Figure D-2) we have refined our study to concentrate on aquatic species because they will be most profoundly affected by the proposed mitigation. Our approach, therefore, has been to compare and contrast insect families found in the ditches with those associated with Redwood Creek as a means of evaluating how increasing pond habitat at Muir Beach will influence the relative abundance and composition of aquatic insect and crustacean fauna.

We have adopted this approach because it is in the horse pasture stations that the most dramatic changes will occur following the creation of the proposed freshwater pond. Sampling of the existing stations and new stations to be established after the creation of the mitigation pond, will enable us to compare the stream habitats with the more stagnant ditch wetlands, and to document the insect colonization sequence in the pond when created.

We have also entered into an informal collaboration with Ray Peterson, an entomologist and resident naturalist at the Audubon Canyon Ranch (ACR), a few miles from the Muir Beach restoration site. Ray has been documenting aquatic insect recolonization patterns following the creation of a small pond at ACR, and has agreed to share his data, technology, species lists and taxonomic expertise with us if the mitigation pond is created. Our ultimate goal will be to evaluate the success of the Muir Beach restoration project by comparing the recolonization sequence and temporal insect community patterns in the newly created pond with those of the more "natural" and already established pond at ACR. This inter-study comparison will be possible because we have adopted Ray's highly effective nocturnal trapping technique for the remainder of the Muir Beach project.

Seasonal changes were tracked via quarterly, qualitative and quantitative sampling at these sites. Qualitative sampling was done during the day by sweeping through the water with a $0.01m^2$ insect net at 7 aquatic stations (Figure D-2). Quantitative sampling was done using three replicate, lighted, nocturnal traps placed in Redwood Creek at station 14 and in Ditch 3 at station 15. These two stations used for quantitative sampling were chosen because they offered the best comparison of a quiet stream habitat (#14) with the most persistent of the seasonal "ponds" at the Muir site (#15). Both sites supported emergent vegetation, but the #14 Redwood Creek Backwater site is more directly influenced by the physical dynamics and ecology of the creek than the ditch at #15 which is separated from the creek by a culvert. Insects were preserved in 75% isopropyl alcohol, sorted and identified to family (Powell and Hogue 1979, Borror and White 1970, Lehmkuhl 1979).

Qualitative monitoring only was done on 29 May and 24 September, 1992. Qualitative and quantitative monitoring were done in late winter (6 March 1993), spring (2 May, 1993), and summer (9 July, 1993).

Tidal Lagoon Invertebrates

Since there is a gradient of fresh and salt water mixing in lower Big Lagoon, we selected three stations along the salinity gradient from the mouth to the head of this lagoon area (Figure D-2). Quantitative samples were taken during three seasons from the three stations. Six replicate cores were collected from each station to describe the benthic infaunal communities in the lagoon. Sediment was sampled to measure changes in grain size. Cores were 0.0072 m^2 in area (the same standard core used in the Lone Tree marine monitoring). Cores were washed over a 0.5 mm screen. Screen residues were preserved in 4% formaldehyde solution and later transferred to 70% propanol. Animals were sorted from residues, identified to lowest taxon, and counted.

Amphibians and Reptiles

Visual encounter surveys were conducted on foot primarily at night and approximately twice a month from December 1992 to February 1993. Monthly surveys were conducted after that time. Surveys followed an established route designed to encounter the primary wetland and riparian habitats at Big Lagoon (Figure D-3). Surveys were scheduled during and immediately after rainfall to coincide with periods of greatest herpetological activity. Animals were located using flashlights, identified and counted. Locations of sightings were marked on topological maps. Larvae were identified by sampling with a dip-net and counted.

Qualitative observations on the species composition and relative abundance of reptiles were made on each monthly amphibian survey in the late afternoon. In addition, three longer morning surveys of the same amphibian survey route (Figure 10), as well as the major habitats for plant sampling (Figure 3), were made to look for reptiles.

Birds

Birds at Big Lagoon were quantitatively surveyed on eleven dates between 29 May 1992 and 9 August 1993 (Table D-1). Birds were originally surveyed by a primary observer and an occasional assistant observer every two months. Beginning April 93, a local birder and long-time Muir Beach resident was contracted to conduct monthly surveys[1].

Permanent stations were established in all wetland and former wetland habitats (Figure D-4); boundaries for each station were set using existing landmarks. Though most stations were visited on all sampling dates, some changes were made during the 11/4-year sampling period to enhance coverage of the most

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[1]Note that results are presented only through the end of the most recent full quarter completed prior to this report (June-August 93), but monthly surveys are continuing

important habitats (Table D-1). Surveys of the single upland station (Station 30) were discontinued after November as it was deemed far more useful to increase coverage of habitats in the lowland areas which might be impacted by restoration efforts. Station 9 was added in April 93 to sample a riparian area which a local birder had observed supporting large numbers of birds over several years of observations (O. Onorato, pers. comm.). Station 14 was created in response to the complete inundation of Station 13 in January 93. This station site included a 10 m swath to the north and east of Station 13. In January 93 it was heavily utilized by sitting and wading waterfowl, though the middle of the pond (i.e. Station 13) was devoid of birds. Station 14 will be used to enhance qualitative observations of bird wetland edge preferences when Station 13 is inundated; previous qualitative observations indicate nominal use (at best) of Station 14 during drier times of the year.

During surveys, each station was visited for 10 minutes. During this period, all birds were identified to species and counted; if possible, behavior was also recorded. At most stations, the observer consistently made all observations from a single location. However, due to the long, narrow shape of the riparian habitat being surveyed, Stations 6 and 7 were surveyed by slowly walking along the vehicle road from north to south.

Qualitative observations were made incidental to regular surveys to supplement the bird species list and to better document breeding use of areas within Big Lagoon. However, these were not the primary focus of the field work, and should therefore be considered supplementary to more comprehensive surveys conducted specifically for these purposes. All species names used in text and figures are accepted common names established by the American Ornithologists' Union (1983,1985).

Grainsize characteristics of sediments from three stations in the lower lagoon area of Muir Beach during March - September, 1993. Fractional percentages of four grainsize categories are shown. Due to type of analysis used, data for only the percentage of fine sediment (<0.063mm particle diameter) was obtained for March 1993 samples (see results discussion). n = 1 in all cases.

FRACTIONAL PERCENT

Date	Station	Pebbles/ Gravel (>1.0mm)	Coarse Sand (0.500mm)	Medium/ Fine Sand (0.063mm)	Medium/Coarse Fine Silt (<0.063mm)
March-4	1	-	-	-	0.54
	2	-	-	-	0.11
	3	-	-	-	0.51
May-13	1	0.04	1.02	98.66	0.29
	2	50.34	20.94	28.30	0.42
	3	69.56	8.52	21.59	0.33
September-3	1	10.30	18.15	71.11	0.43
	2	0.13	13.33	86.37	0.18
	3	10.51	5.10	84.07	0.32

Grainsize characteristics of sediments from three stations in the lower lagoon area of Muir Beach during March - September, 1993. Folk and Ward statistics are shown. Due to type of analysis used, no Folk and Ward statistics could be calculated for March 1993 samples (see results discussion). n = 1 in all cases.

FOLK & WARD STATISTICS (phi)

Date	Station	Mean	Median	Sorting
March-4	1	-	-	-
	2	-	-	-
	3	-	-	-
May-13	1	3.37	3.99	0.80
	2	0.14	-0.02	1.16
	3	-0.24	-1.05	1.15
September-3	1	1.42	1.69	0.89
	2	1.82	1.92	0.39
	3	1.78	2.01	0.78

Table D-1

Bird survey dates, times, and station coverage at Big Lagoon, May 29, 1992 to August 9, 1993.

Date	5/29/92	7/28/92	10/22/92	11/25/92	1/20/93	2/5/93	4/13/93	5/5/93	6/10/93	7/11/93	8/9/93
Time	1100-1410	0700-1030	0840-1205	0740-1110	0840-0930	0845-1100	0715-0935	0820-1115	0810-1115	0750-1100	0740-1030
STATION											
1	●	●	●	●		●	●	●	●	●	●
2	●	●	●	●		●	●	●	●	●	●
3		●	●	●		●	●	●	●	●	●
4	●	●	●	●		●	●	●	●	●	●
5	●	●	●	●		●	●	●	●	●	●
6	●	●	●	●		●	●	●	●	●	●
7		●	●	●		●	●	●	●	●	●
8	●	●	●	●	●	●	●	●	●	●	●
9							●	●	●	●	●
10	●	●	●	●		●	●	●	●	●	●
11		●	●	●		●	●	●	●	●	●
12	●	●	●	●	●	●	●	●	●	●	●
13	●	●	●	●	●	●	●	●	●	●	●
14					●						
20	●	●	●	●		●	●	●	●	●	●
30	●	●	●	●							

Source: PWA et al. (1994)

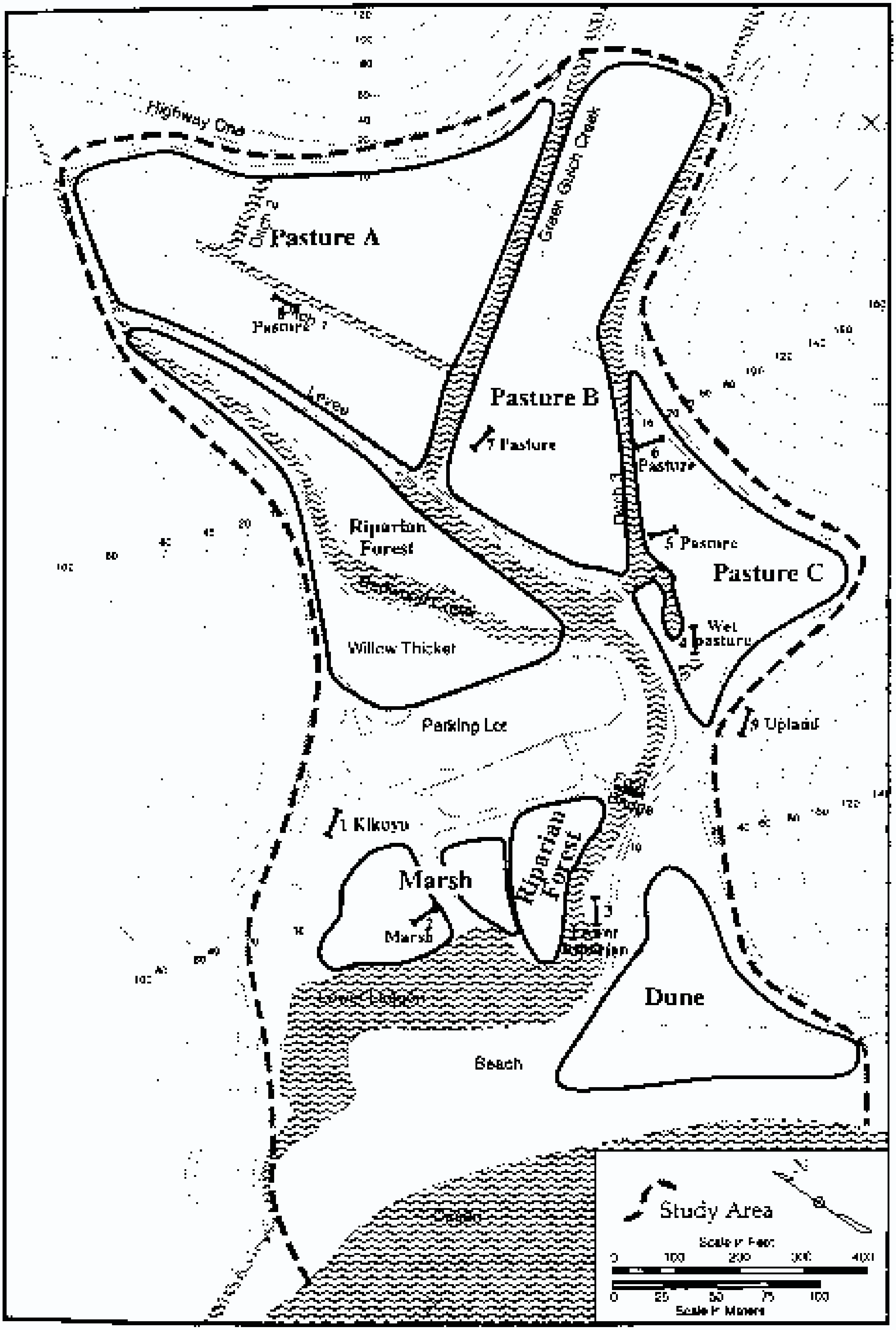
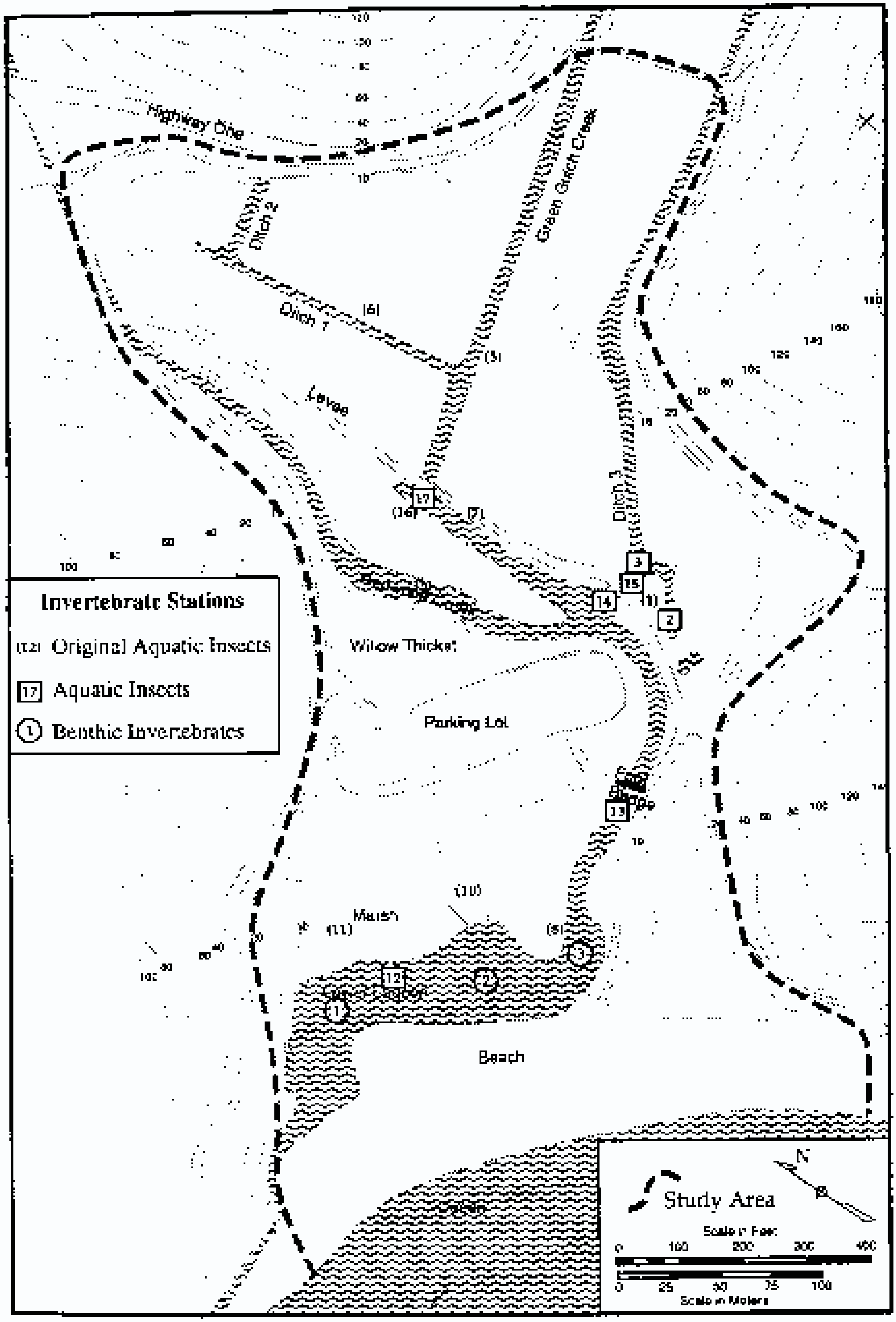


Figure D-1

Location of the nine vegetation transects.

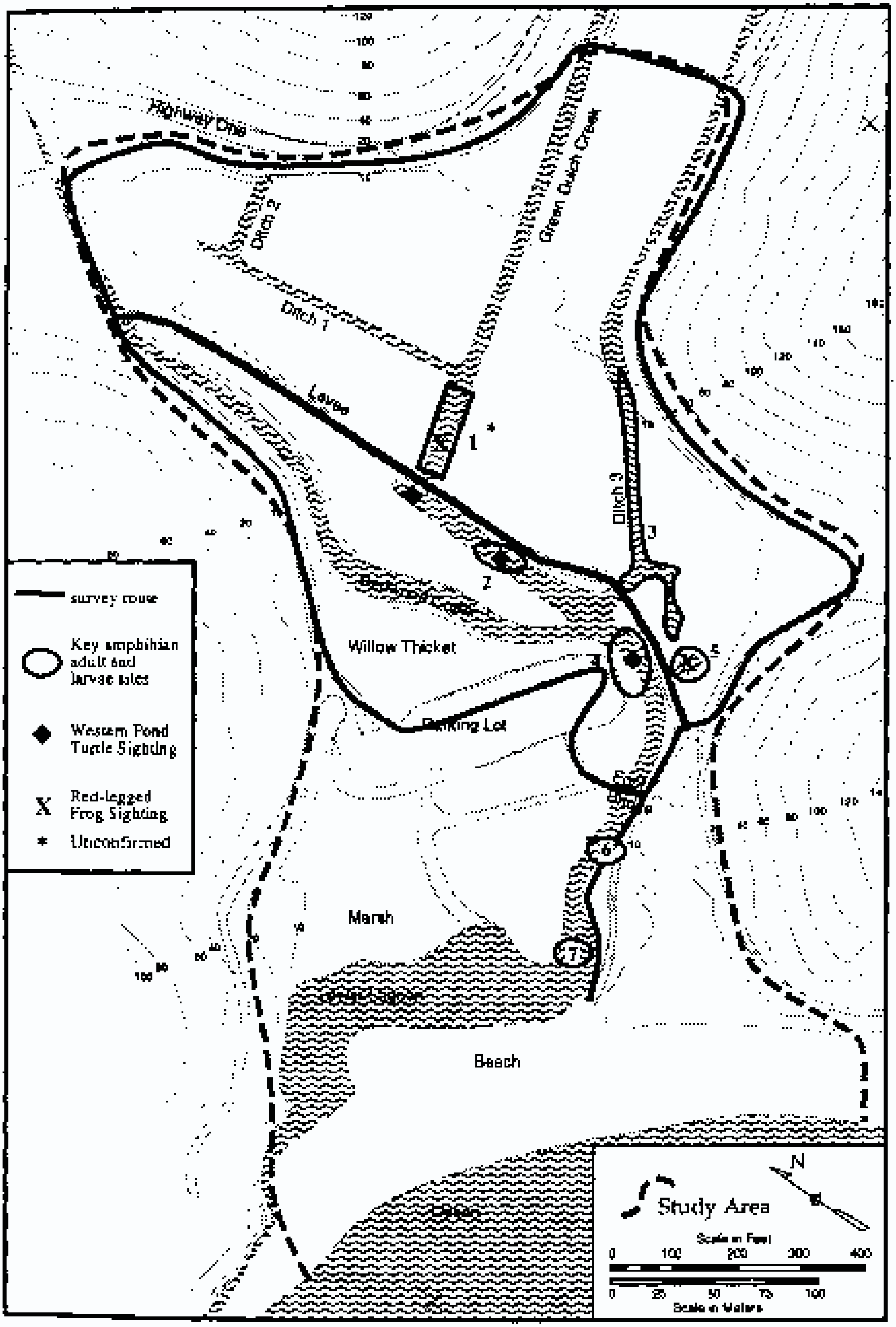
Source: PWA et al. (1994)



Locations of aquatic insect (boxed) and benthic invertebrate (dotted) survey stations in Big Lagoon.

Figure D-2

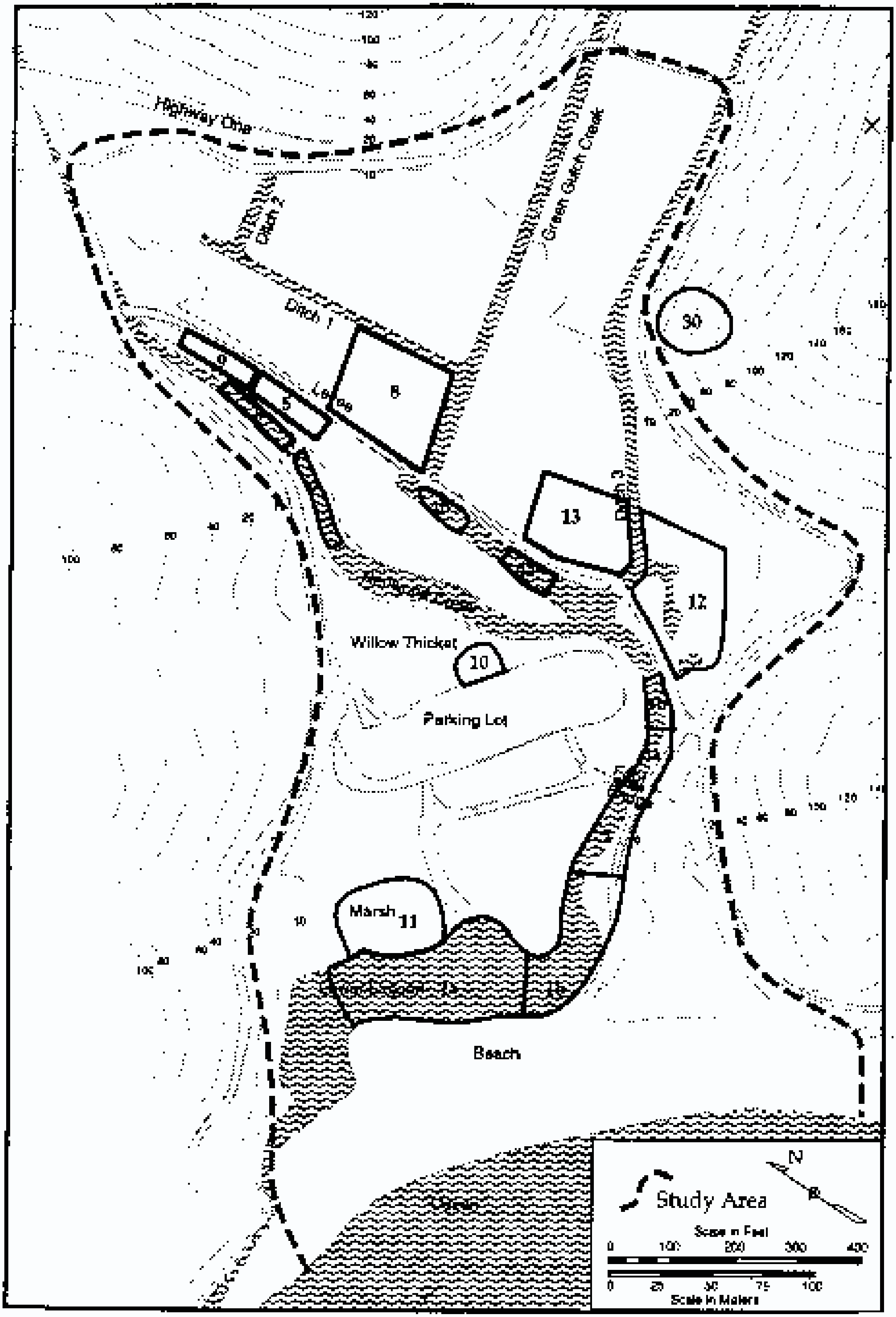
Source: PWA et al. (1994)



Survey route and locations of critical amphibian and reptile habitats in Big Lagoon.

Figure D-3

Source: PWA et al. (1994)



Locations of bird survey stations at Big Lagoon. Station areas are roughly delimited by polygons. See IV B.1. Methods and Appendix B Bird Methods.

Figure D-4

Source: PWA et al. (1994)

APPENDIX E
PLANT SPECIES LIST BY WETLAND POLYGON NUMBER

APPENDIX E

USFWS Wetland Plant List for Big Lagoon

Wetland mapping using the Cowardin classification system was conducted by the NPS during 2002, with additional area within the project boundary mapped in 2003. The numbered polygons identified on Figure 21 of the Site Analysis Report (2003 map) correspond to the "Polygon #" field in the following plant list table, indicating the presence of particular species in each polygon.

Polygon ID # **02SW01** ***NWI Classification:*** P EM C h

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Potentilla anserina ssp. pacifica		OBL	1	4
unknown grass			1	4
Rumex conglomeratus	clustered dock	FACW	2	3b
Polygonum punctatum	dotted smartweed	OBL	1	3a
unknown grass			1	3a
Festuca arundinacea		FAC-	2	2
Juncus balticus	Baltic rush	FACW+	1	2
Raphanus sativus	cultivated radish	UPL	2	2
Alisma plantago-aquatica			1	1
Eleocharis macrostachya		OBL	1	1
Equisetum arvense	field horsetail	FAC	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Mentha pulegium	penny royal	OBL	2	1
Picris echioides	bristly oxtongue	FAC	2	1
Rumex crispus	curly dock	FACW-	2	1
Scirpus pungens		OBL	1	1
Stachys ajugoides	hedgenettle	OBL	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID # **02SW02** ***NWI Classification:*** P EM B d

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Oenanthe sarmentosa	water parsely	OBL	1	4
Agrostis stolonifera	creeping bent	FACW	2	3a
Juncus balticus	Baltic rush	FACW+	1	3a
Polygonum punctatum	dotted smartweed	OBL	1	3a
Potentilla anserina ssp. pacifica		OBL	1	3a

Rumex conglomeratus	clustered dock	FACW	2	3a
Festuca arundinacea		FAC-	2	2
Veronica americana	American speedwell	OBL	1	2
Alnus rubra	red alder	FACW	1	1
Cotula coronopifolia	common brassbuttons	FACW+	2	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Lemna minor	common duckweed	OBL	1	1
Lolium multiflorum			2	1
Mentha pulegium	penny royal	OBL	2	1
Mimulus guttatus	seep monkeyflower	FACW+	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Plantago major	common plantain	FAC	2	1
Plantago maritima	goose tongue	FACW+	1	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rumex crispus	curly dock	FACW-	2	1
Salix lasiolepis	arroyo willow	FACW	1	1
Scirpus pungens		OBL	1	1
Typha latifolia	broadleaf cattail	OBL	1	1

Polygon ID #* 02SW03** ***NWI Classification: P SS H

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Alnus rubra	red alder	FACW	1	4
Oenanthe sarmentosa	water parsely	OBL	1	4
Salix lasiolepis	arroyo willow	FACW	1	4
Stachys ajugoides	hedgenettle	OBL	1	3b
Alnus rubra	red alder	FACW	1	3a
Alnus rubra	red alder	FACW	1	3a
Rumex conglomeratus	clustered dock	FACW	2	3a
Salix lasiolepis	arroyo willow	FACW	1	3a
Polygonum punctatum	dotted smartweed	OBL	1	2
Callitriche heterophylla var. bolanderi		OBL	1	1
Carex sp.			1	1

Delairea odorata (=Senecio mikanioides)	cape ivy		2	1
Holcus lanatus	common velvetgrass	FAC	2	1
Mimulus guttatus	seep monkeyflower	FACW+	1	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rubus discolor	Himalayan blackberry	FAC+	2	1
Rubus ursinus	California blackberry	FAC+	1	1
Sambucus racemosa var. racemosa	red elderberry	FACU	1	1
Scirpus microcarpus	panicled bulrush	OBL	1	1
Scirpus pungens		OBL	1	1
Sonchus asper	spiny sowthistle	FAC	2	1
Typha latifolia	broadleaf cattail	OBL	1	1
unknown herb			1	1
Urtica dioica		FACW	1	1
Zantedeschia aethiopica	calla lily	OBL	2	1

Polygon ID #* 02SW04** ***NWI Classification: P EM C

Full Species Name	***Common Name***	***California Wetland Indicator (1)***	***Native? (2)***	***Cover Class***
Potentilla anserina ssp. pacifica		OBL	1	5
Juncus balticus	Baltic rush	FACW+	1	4
Leymus triticoides	beardless wildrye	FAC+	1	3a
Agrostis sp.			1	2
Alnus rubra	red alder	FACW	1	2
Cyperus eragrostis	tall flatsedge	FACW	1	2
Festuca arundinacea		FAC-	2	2
Mentha pulegium	penny royal	OBL	2	2
Oenanthe sarmentosa	water parsely	OBL	1	2
Picris echioides	bristly oxtongue	FAC	2	2
Raphanus sativus	cultivated radish	UPL	2	2
Rumex conglomeratus	clustered dock	FACW	2	2
Scirpus pungens		OBL	1	2
Ambrosia chamissonis	beach-bur		1	1
Cortaderia jubata	purple pampas grass		2	1
Lolium multiflorum			2	1
Salix lasiolepis	arroyo willow	FACW	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID # 02SW05 **NWI Classification:** R UB V 1

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Scirpus pungens		OBL	1	3b
Agrostis stolonifera	creeping bent	FACW	2	3a
Potentilla anserina ssp. pacifica		OBL	1	3a
Alnus rubra	red alder	FACW	1	2
Cyperus eragrostis	tall flatsedge	FACW	1	2
Festuca arundinacea		FAC-	2	2
Juncus effusus var. brunneus	lamp rush	FACW+	1	2
Melilotus indica	annual yellow sweetclover	FAC	2	2
Picris echioides	bristly oxtongue	FAC	2	2
Callitriche heterophylla var. bolanderi		OBL	1	1
Cotula coronopifolia	common brassbuttons	FACW+	2	1
Helenium puberulum	rosilla	FACW	1	1
Lotus corniculatus	birdfoot deervetch	FAC	2	1
Mentha pulegium	penny royal	OBL	2	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rumex conglomeratus	clustered dock	FACW	2	1
Salix lasiolepis	arroyo willow	FACW	1	1
Trifolium repens	white clover	FAC	2	1

Polygon ID # 02SW06 **NWI Classification:** P SS/ B h EM

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lasiolepis	arroyo willow	FACW	1	5
Alnus rubra	red alder	FACW	1	4
Oenanthe sarmentosa	water parsely	OBL	1	3b
Polygonum punctatum	dotted smartweed	OBL	1	3a
Stachys ajugoides	hedgenettle	OBL	1	3a
Rubus ursinus	California blackberry	FAC+	1	2
Salix lasiolepis	arroyo willow	FACW	1	2
Scirpus microcarpus	panicled bulrush	OBL	1	2
unknown herb			1	2
Urtica dioica		FACW	1	2

Calystegia sp.	unk bindweed		1	1
Cornus sericea ssp. sericea	redosier dogwood	FACW	1	1
Genista monspessulana	French broom		2	1
Holcus lanatus	common velvetgrass	FAC	2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Mentha arvensis	wild mint	FACW	1	1
Mentha pulegium	penny royal	OBL	2	1
Petasites frigidus var. palmatus	arctic sweet coltsfoot	FACW*	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Rubus discolor	Himalayan blackberry	FAC+	2	1
Rumex conglomeratus	clustered dock	FACW	2	1
Typha latifolia	broadleaf cattail	OBL	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID #* 02SW07** ***NWI Classification: P EM C

Full Species Name	***Common Name***	***California Wetland Indicator (1)***	***Native? (2)***	***Cover Class***
Potentilla anserina ssp. pacifica		OBL	1	4
Agrostis sp.			1	3b
Lolium multiflorum			2	3b
Rumex conglomeratus	clustered dock	FACW	2	3a
Holcus lanatus	common velvetgrass	FAC	2	2
Oenanthe sarmentosa	water parsely	OBL	1	2
Polygonum punctatum	dotted smartweed	OBL	1	2
Rumex crispus	curly dock	FACW-	2	2
Cotula coronopifolia	common brassbuttons	FACW+	2	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Lythrum hyssopifolia	hyssop loosestrife	FACW	2	1
Mentha pulegium	penny royal	OBL	2	1
Pennisetum clandestinum	kikuyugrass	FACU+	2	1
Picris echioides	bristly oxtongue	FAC	2	1
Plantago major	common plantain	FAC	2	1
Plantago maritima	goose tongue	FACW+	1	1
Polygonum arenastrum	oval-leaf knotweed	FAC	2	1
Polypogon monspeliensis	annual rabbitsfoot grass	FACW+	2	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID # 02SW08 | **NWI Classification:** P EM B h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Juncus effusus var. brunneus	lamp rush	FACW+	1	4
Potentilla anserina ssp. pacifica		OBL	1	4
Juncus balticus	Baltic rush	FACW+	1	3b
Eleocharis macrostachya		OBL	1	3a
Polygonum punctatum	dotted smartweed	OBL	1	2
Scirpus pungens		OBL	1	2
Alnus rubra	red alder	FACW	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Lolium multiflorum			2	1
Mentha pulegium	penny royal	OBL	2	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Rumex conglomeratus	clustered dock	FACW	2	1
Vicia sativa	garden vetch	FACU	2	1

Polygon ID # 02SW09 | **NWI Classification:** P EM C

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Polygonum punctatum	dotted smartweed	OBL	1	5
Hydrocotyle ranunculoides	floating marshpennywort	OBL	1	4
Rorippa nasturtium-aquaticum	watercress	OBL	1	2
Stachys ajugoides	hedgenettle	OBL	1	2
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Rubus ursinus	California blackberry	FAC+	1	1
Rumex conglomeratus	clustered dock	FACW	2	1
Salix lasiolepis	arroyo willow	FACW	1	1

Polygon ID # 02SW10 | **NWI Classification:** E UB L 1

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Croton californicus	California croton		1	1
Juncus balticus	Baltic rush	FACW+	1	1
Scirpus pungens		OBL	1	1

Polygon ID # 02SW11

NWI Classification: R UB H h 2

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Alnus rubra	red alder	FACW	1	3a
Salix lasiolepis	arroyo willow	FACW	1	2
Alisma plantago-aquatica			1	1
Callitriche heterophylla var. bolanderi		OBL	1	1
Cotula coronopifolia	common brassbuttons	FACW+	2	1
Hydrocotyle ranunculoides	floating marshpennywort	OBL	1	1
Juncus balticus	Baltic rush	FACW+	1	1
Mimulus guttatus	seep monkeyflower	FACW+	1	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Polygonum punctatum	dotted smartweed	OBL	1	1
Potentilla anserina ssp. pacifica		OBL	1	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Scirpus microcarpus	panicled bulrush	OBL	1	1
Scirpus pungens		OBL	1	1
Typha latifolia	broadleaf cattail	OBL	1	1

Polygon ID # 02SW12

NWI Classification: P EM F d, h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Typha latifolia	broadleaf cattail	OBL	1	6
Eleocharis macrostachya		OBL	1	3b
Alisma plantago-aquatica			1	3a
Mentha pulegium	penny royal	OBL	2	3a
Scirpus pungens		OBL	1	3a
Hydrocotyle ranunculoides	floating marshpennywort	OBL	1	2
Juncus balticus	Baltic rush	FACW+	1	2
Paspalum dilatatum	dallisgrass	FAC	2	2
Potentilla anserina ssp. pacifica		OBL	1	2
Agrostis stolonifera	creeping bent	FACW	2	1
Callitriche heterophylla var. bolanderi		OBL	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Holcus lanatus	common velvetgrass	FAC	2	1

Oenanthe sarmentosa	water parsely	OBL	1	1
Polygonum punctatum	dotted smartweed	OBL	1	1
Rumex conglomeratus	clustered dock	FACW	2	1

Polygon ID # 02SW13 **NWI Classification:** P EM C d, h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Potentilla anserina ssp. pacifica		OBL	1	4
Rumex conglomeratus	clustered dock	FACW	2	4
Agrostis stolonifera	creeping bent	FACW	2	3b
Holcus lanatus	common velvetgrass	FAC	2	3a
Oenanthe sarmentosa	water parsely	OBL	1	3a
Lolium multiflorum			2	2
Mentha pulegium	penny royal	OBL	2	2
Phalaris sp.	canarygrass			2
Cyperus eragrostis	tall flatsedge	FACW	1	1
Dipsacus sp.	teasel		2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Rumex crispus	curly dock	FACW-	2	1

Polygon ID # 02SW14 **NWI Classification:** P EM C d, h, f

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Agrostis stolonifera	creeping bent	FACW	2	4
Eleocharis macrostachya		OBL	1	3a
Lolium multiflorum			2	3a
Mentha pulegium	penny royal	OBL	2	3a
Oenanthe sarmentosa	water parsely	OBL	1	3a
Potentilla anserina ssp. pacifica		OBL	1	3a
Rumex conglomeratus	clustered dock	FACW	2	3a
Rumex crispus	curly dock	FACW-	2	3a
Juncus effusus var. brunneus	lamp rush	FACW+	1	2
Plantago major	common plantain	FAC	2	2
Polygonum punctatum	dotted smartweed	OBL	1	2
Typha latifolia	broadleaf cattail	OBL	1	2
Alnus rubra	red alder	FACW	1	1
Cotula coronopifolia	common brassbuttons	FACW+	2	1

Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Mentha arvensis	wild mint	FACW	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Salix lucida ssp. lasiandra	Pacific willow	OBL	1	1
Urtica dioica		FACW	1	1

Polygon ID # **02SW15** **NWI Classification:** P SS C d

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lasiolepis	arroyo willow	FACW	1	6
Oenanthe sarmentosa	water parsely	OBL	1	3a
Stachys ajugoides	hedgenettle	OBL	1	3a
Urtica dioica		FACW	1	3a
Alnus rubra	red alder	FACW	1	2
Conium maculatum	poison hemlock	FAC	2	2
Equisetum arvense	field horsetail	FAC	1	2
Lonicera involucrata var. ledebourii	twinberry honeysuckle	FAC	1	2
Mentha pulegium	penny royal	OBL	2	2
Rubus ursinus	California blackberry	FAC+	1	2
Delairea odorata (=Senecio mikanioides)	cape ivy		2	1
Glyceria sp.	mannagrass	OBL	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Polygonum amphibium var. emersum	longroot smartweed	OBL	1	1
Potentilla anserina ssp. pacifica		OBL	1	1
Raphanus sativus	cultivated radish	UPL	2	1
Rubus discolor	Himalayan blackberry	FAC+	2	1
Scirpus microcarpus	panicled bulrush	OBL	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID # **02SW16** **NWI Classification:** P EM C

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Lolium perenne	perennial ryegrass	FAC*	2	3b
Trifolium sp.	unknown clover		1	3b
Cyperus eragrostis	tall flatsedge	FACW	1	3a

Eleocharis macrostachya		OBL	1	3a
Polypogon monspeliensis	annual rabbitsfoot grass	FACW+	2	3a
Equisetum arvense	field horsetail	FAC	1	2
Holcus lanatus	common velvetgrass	FAC	2	2
Juncus effusus var. brunneus	lamp rush	FACW+	1	2
Rumex crispus	curly dock	FACW-	2	2
Juncus bufonius	toad rush	FACW+	1	1
Mentha pulegium	penny royal	OBL	2	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Plantago major	common plantain	FAC	2	1
Potentilla anserina ssp. pacifica		OBL	1	1
Rumex conglomeratus	clustered dock	FACW	2	1
Stachys ajugoides	hedgenettle	OBL	1	

Polygon ID # 02SW17 **NWI Classification:** P SS C x

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lasiolepis	arroyo willow	FACW	1	6
Mentha pulegium	penny royal	OBL	2	2
Oenanthe sarmentosa	water parsely	OBL	1	2
Rumex conglomeratus	clustered dock	FACW	2	2
Conium maculatum	poison hemlock	FAC	2	1
Holcus lanatus	common velvetgrass	FAC	2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Picris echioides	bristly oxtongue	FAC	2	1

Polygon ID # 02SW18 **NWI Classification:** P FO C

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lasiolepis	arroyo willow	FACW	1	5
Salix lucida ssp. lasiandra	Pacific willow	OBL	1	4
Stachys ajugoides	hedgenettle	OBL	1	3b
Urtica dioica		FACW	1	3a
Equisetum arvense	field horsetail	FAC	1	2
Polygonum punctatum	dotted smartweed	OBL	1	2
Holcus lanatus	common velvetgrass	FAC	2	1

Picris echioides	bristly oxtongue	FAC	2	1
Rumex conglomeratus	clustered dock	FACW	2	1

Polygon ID # 02SW19 **NWI Classification:** P EM C d, h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Potentilla anserina ssp. pacifica		OBL	1	4
Rumex conglomeratus	clustered dock	FACW	2	4
Agrostis stolonifera	creeping bent	FACW	2	3b
Holcus lanatus	common velvetgrass	FAC	2	3a
Oenanthe sarmentosa	water parsely	OBL	1	3a
Lolium multiflorum			2	2
Mentha pulegium	penny royal	OBL	2	2
Phalaris sp.	canarygrass			2
Cyperus eragrostis	tall flatsedge	FACW	1	1
Dipsacus sp.	teasel		2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Rumex crispus	curly dock	FACW-	2	1

Polygon ID # 02SW20 **NWI Classification:** P EM F d, h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Typha latifolia	broadleaf cattail	OBL	1	6
Eleocharis macrostachya		OBL	1	3b
Alisma plantago-aquatica			1	3a
Mentha pulegium	penny royal	OBL	2	3a
Scirpus pungens		OBL	1	3a
Hydrocotyle ranunculoides	floating marshpennywort	OBL	1	2
Juncus balticus	Baltic rush	FACW+	1	2
Paspalum dilatatum	dallisgrass	FAC	2	2
Potentilla anserina ssp. pacifica		OBL	1	2
Agrostis stolonifera	creeping bent	FACW	2	1
Callitriche heterophylla var. bolanderi		OBL	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Polygonum punctatum	dotted smartweed	OBL	1	1

Rumex conglomeratus	clustered dock	FACW	2	1

Polygon ID # 02SW21 *NWI Classification:* P EM G d, x

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Alisma plantago-aquatica			1	4
Digitaria sanguinalis	hairy crabgrass	FACU	2	4
Mentha pulegium	penny royal	OBL	2	2
Polygonum punctatum	dotted smartweed	OBL	1	2
Scirpus pungens		OBL	1	2
Callitriche heterophylla var. bolanderi		OBL	1	1
Eleocharis macrostachya		OBL	1	1
Hydrocotyle ranunculoides	floating marshpennywort	OBL	1	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Rumex conglomeratus	clustered dock	FACW	2	1
Typha latifolia	broadleaf cattail	OBL	1	1

Polygon ID # 02SW22 *NWI Classification:* P EM C d, x

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Scirpus microcarpus	panicled bulrush	OBL	1	6
Oenanthe sarmentosa	water parsely	OBL	1	3b
Juncus effusus var. brunneus	lamp rush	FACW+	1	3a
Rumex conglomeratus	clustered dock	FACW	2	3a
Equisetum arvense	field horsetail	FAC	1	2
Rorippa nasturtium-aquaticum	watercress	OBL	1	2
Rubus ursinus	California blackberry	FAC+	1	2
Conium maculatum	poison hemlock	FAC	2	1
Festuca arundinacea		FAC-	2	1
Galium aparine	stickywilly	FACU	2	1
Hirschfeldia incana	shortpod mustard	UPL	2	1
Holcus lanatus	common velvetgrass	FAC	2	1
Mimulus guttatus	seep monkeyflower	FACW+	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Typha latifolia	broadleaf cattail	OBL	1	1

Polygon ID # **02SW23** **NWI Classification:** P EM F h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Rubus ursinus	California blackberry	FAC+	1	4
Stachys ajugoides	hedgenettle	OBL	1	4
Equisetum arvense	field horsetail	FAC	1	3b
Alnus rubra	red alder	FACW	1	3a
Delairea odorata (=Senecio mikanioides)	cape ivy		2	3a
Sambucus racemosa var. racemosa	red elderberry	FACU	1	3a
Oenanthe sarmentosa	water parsely	OBL	1	2
Polypogon monspeliensis	annual rabbitsfoot grass	FACW+	2	2
Scirpus microcarpus	panicled bulrush	OBL	1	2
Agrostis stolonifera	creeping bent	FACW	2	1
Athyrium filix-femina var. cyclosorum		FAC	1	1
Carex deweyana ssp. leptopoda			1	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Glyceria sp.	mannagrass	OBL	1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Juncus patens	spreading rush	FAC	1	1
Juncus xiphioides	irisleaf rush	OBL	1	1
Picris echioides	bristly oxtongue	FAC	2	1
Polygonum punctatum	dotted smartweed	OBL	1	1
Raphanus sativus	cultivated radish	UPL	2	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rumex conglomeratus	clustered dock	FACW	2	1
Veronica americana	American speedwell	OBL	1	1
Zantedeschia aethiopica	calla lily	OBL	2	1

Polygon ID # **02SW24** **NWI Classification:** P FO Y h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Alnus rubra	red alder	FACW	1	5
Stachys ajugoides	hedgenettle	OBL	1	5
Polygonum punctatum	dotted smartweed	OBL	1	3A
Rubus ursinus	California blackberry	FAC+	1	3A

Alnus rubra	red alder	FACW	1	2
Calystegia sp.	unk bindweed		1	2
Delairea odorata (=Senecio mikanioides)	cape ivy		2	2
Equisetum telmateia ssp. braunii		OBL	1	2
Oenanthe sarmentosa	water parsely	OBL	1	2
Rorippa nasturtium-aquaticum	watercress	OBL	1	2
Sambucus racemosa var. racemosa	red elderberry	FACU	1	2
Urtica dioica		FACW	1	2
Athyrium filix-femina var. cyclosorum		FAC	1	1
Conium maculatum	poison hemlock	FAC	2	1
Cornus sericea ssp. sericea	redosier dogwood	FACW	1	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Festuca sp.			1	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Scirpus microcarpus	panicled bulrush	OBL	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID # 02SW25 — NWI Classification: P FO H h

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lucida ssp. lasiandra	Pacific willow	OBL	1	5
Alnus rubra	red alder	FACW	1	2
Callitriche heterophylla var. bolanderi		OBL	1	2
Oenanthe sarmentosa	water parsely	OBL	1	2
Rorippa nasturtium-aquaticum	watercress	OBL	1	1

Polygon ID # 02SW26 — NWI Classification: P SS F

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Alnus rubra	red alder	FACW	1	3b
Oenanthe sarmentosa	water parsely	OBL	1	3b
Salix lasiolepis	arroyo willow	FACW	1	3b
Conium maculatum	poison hemlock	FAC	2	3a
Rubus discolor	Himalayan blackberry	FAC+	2	3a
Rubus ursinus	California blackberry	FAC+	1	3a

Rumex sp.	dock		1	3a
Typha latifolia	broadleaf cattail	OBL	1	3a
Alnus rubra	red alder	FACW	1	2
Cupressus macrocarpa	Monterey cypress		2	2
Delairea odorata (=Senecio mikanioides)	cape ivy		2	2
Mimulus guttatus	seep monkeyflower	FACW+	1	2
Stachys chamissonis	coastal hedgenettle	OBL	1	2
Urtica dioica		FACW	1	2
Cornus sericea ssp. sericea	redosier dogwood	FACW	1	1
Populus balsamifera trichocarpa	black cottonwood	FACW	1	1

Polygon ID #* 03AP41** ***NWI Classification: P EM C g

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Poa annua	annual bluegrass	FAC	2	4
Glyceria occidentalis	northwestern mannagrass	OBL	1	3a
Oenanthe sarmentosa	water parsely	OBL	1	3a
Rumex conglomeratus	clustered dock	FACW	2	3a
Delairea odorata (=Senecio mikanioides)	cape ivy		2	2
Rubus ursinus	California blackberry	FAC+	1	2
Salix lasiolepis	arroyo willow	FACW	1	2
Salix lasiolepis	arroyo willow	FACW	1	2
Salix lucida ssp. lasiandra	Pacific willow	OBL	1	2
Sambucus racemosa var. racemosa	red elderberry	FACU	1	2
Bromus carinatus			1	1
Cardamine oligosperma	little western bittercress	FACW	1	1
Cirsium vulgare	bull thistle	FAC	2	1
Conium maculatum	poison hemlock	FAC	2	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Foeniculum vulgare	sweet fennel	FACU-	2	1
Geranium dissectum	cutleaf geranium		2	1
Hedera helix	English ivy		2	1
Holcus lanatus	common velvetgrass	FAC	2	1
Juncus patens	spreading rush	FAC	1	1
Lolium multiflorum			2	1
Lonicera involucrata var. ledebourii	twinberry honeysuckle	FAC	1	1

Lythrum hyssopifolia	hyssop loosestrife	FACW	2	1
Mentha pulegium	penny royal	OBL	2	1
Oxalis pes-caprae	Bermuda buttercup		2	1
Picris echioides	bristly oxtongue	FAC	2	1
Raphanus sativus	cultivated radish	UPL	2	1
Rosa sp.	rose		1	1
Rubus discolor	Himalayan blackberry	FAC+	2	1
Scirpus californicus		OBL	1	1
Sidalcea sp.			1	1
Solanum nigrum	black nightshade	FACU	2	1
Trifolium repens	white clover	FAC	2	1
Urtica dioica		FACW	1	1
Veronica americana	American speedwell	OBL	1	1
Vicia gigantea			1	1

Polygon ID # 03AP42 **NWI Classification:** P SS/ C d EM

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Salix lasiolepis	arroyo willow	FACW	1	4
Polygonum amphibium var. emersum	longroot smartweed	OBL	1	3a
Cupressus macrocarpa	Monterey cypress		2	2
Rumex crispus	curly dock	FACW-	2	2
Scirpus microcarpus	panicled bulrush	OBL	1	2
Avena barbata	slender oat		2	1
Bromus diandrus	ripgut brome		2	1
Cirsium vulgare	bull thistle	FAC	2	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Genista monspessulana	French broom		2	1
Juncus effusus var. brunneus	lamp rush	FACW+	1	1
Mentha pulegium	penny royal	OBL	2	1
Typha latifolia	broadleaf cattail	OBL	1	1
Urtica dioica		FACW	1	1

Polygon ID # 03AP43 **NWI Classification:** P SS C

Full Species Name	Common Name	California Wetland Indicator (1)	Native? (2)	Cover Class
Rubus ursinus	California blackberry	FAC+	1	4

Salix lasiolepis	arroyo willow	FACW	1	4
Alnus rubra	red alder	FACW	1	3b
Sambucus racemosa var. racemosa	red elderberry	FACU	1	3b
Stachys chamissonis	coastal hedgenettle	OBL	1	3b
Urtica dioica		FACW	1	3b
Cornus sericea ssp. sericea	redosier dogwood	FACW	1	3a
Delairea odorata (=Senecio mikanioides)	cape ivy		2	3a
Oenanthe sarmentosa	water parsely	OBL	1	2
Athyrium filix-femina var. cyclosorum		FAC	1	1
Carex obnupta	slough sedge	OBL	1	1
Cirsium vulgare	bull thistle	FAC	2	1
Conium maculatum	poison hemlock	FAC	2	1
Cortaderia jubata	purple pampas grass		2	1
Cynoglossum grande	Pacific hound's tongue		1	1
Cyperus eragrostis	tall flatsedge	FACW	1	1
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Equisetum telmateia ssp. braunii		OBL	1	1
Hedera helix	English ivy		2	1
Heracleum lanatum			1	1
Holcus lanatus	common velvetgrass	FAC	2	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rumex crispus	curly dock	FACW-	2	1
Sonchus asper	spiny sowthistle	FAC	2	1
Umbellularia californica	California laurel	FAC	1	1
Veronica americana	American speedwell	OBL	1	1
Zantedeschia aethiopica	calla lily	OBL	2	1

Polygon ID #* 03AP44** ***NWI Classification: P SS/ C EM

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Oenanthe sarmentosa	water parsely	OBL	1	3b
Salix lasiolepis	arroyo willow	FACW	1	3b
Sambucus racemosa var. racemosa	red elderberry	FACU	1	3b
Stachys chamissonis	coastal hedgenettle	OBL	1	3b
Alnus rubra	red alder	FACW	1	3a
Carex obnupta	slough sedge	OBL	1	3a
Cornus sericea ssp. sericea	redosier dogwood	FACW	1	3a

Juncus effusus var. brunneus	lamp rush	FACW+	1	3a
Rubus ursinus	California blackberry	FAC+	1	3a
Urtica dioica		FACW	1	3a
Athyrium filix-femina var. cyclosorum		FAC	1	2
Delairea odorata (=Senecio mikanioides)	cape ivy		2	2
Hedera helix	English ivy		2	2
Veronica americana	American speedwell	OBL	1	2
Epilobium ciliatum ssp. watsonii	fringed willowherb	FACW	1	1
Heracleum lanatum			1	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Rumex crispus	curly dock	FACW-	2	1
Smilacina racemosa			1	1
Zantedeschia aethiopica	calla lily	OBL	2	1

Polygon ID #* 03AP45** ***NWI Classification: P UB C d

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Glyceria occidentalis	northwestern mannagrass	OBL	1	1
Oenanthe sarmentosa	water parsely	OBL	1	1
Rorippa nasturtium-aquaticum	watercress	OBL	1	1
Veronica americana	American speedwell	OBL	1	1

Polygon ID #* 03AP46** ***NWI Classification: P FO B

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Cupressus macrocarpa	Monterey cypress		2	6
Oenanthe sarmentosa	water parsely	OBL	1	3b
Rubus ursinus	California blackberry	FAC+	1	3b
Conium maculatum	poison hemlock	FAC	2	2
Sambucus racemosa var. racemosa	red elderberry	FACU	1	1

Polygon ID #* 03AP59** ***NWI Classification: P EM D g

Full Species Name	*Common Name*	*California Wetland Indicator (1)*	*Native? (2)*	*Cover Class*
Poa annua	annual bluegrass	FAC	2	4

Trifolium repens	white clover	FAC	2	3b
Trifolium subterraneum	subterranean clover		2	3b
Erodium cicutarium	redstem stork's bill		2	3a
Conium maculatum	poison hemlock	FAC	2	2
Malva parviflora	cheeseweed mallow		2	2
Picris echioides	bristly oxtongue	FAC	2	2
Plantago major	common plantain	FAC	2	2
Ranunculus californicus	California buttercup	FAC	1	2
unknown herb			1	2
Baccharis pilularis	coyotebrush		1	1
Cirsium vulgare	bull thistle	FAC	2	1
Dipsacus sp.	teasel		2	1
Plantago lanceolata	narrowleaf plantain	FAC-	2	1
Rumex crispus	curly dock	FACW-	2	1

1) Wetland indicators from 1996 USFWS list
2) Native = 1; Non-native = 2

Cover classes: (1) <1% (2) 1-5% (3a) 6-15% (3b) 16-25% (4) 26-50% (5) 51-75% (6) 76-100%

Height Classes: (1) <.5 m (2) .5-2 m (3) 2-5 m (4) 5-15 m (5) 15-35 m (6) 35-50 m (7) >50 m (9) Not Applicable

APPENDIX F

AQUATIC INVERTEBRATE

APPENDIX F

Aquatic Invertebrate – Existing Conditions

An inventory of benthic macroinvertebrates was conducted in August 1995 and November 1997 (Fong 2002a) in Redwood Creek. In April 2002, invertebrate sampling was conducted at seasonally and perennially inundated sites at Muir Beach (Fong et al. 2003). These two surveys are summarized briefly below, and a summary table of all invertebrates observed at Big Lagoon from 1992 – 2002 is provided in Tables F-1a–k. Surveys specifically for California freshwater shrimp (*Syncaris pacifica*) have also been conducted, and are discussed in the Special Status Species section in the main body of the document. Aquatic insects were sampled both qualitatively and quantitatively as part of the 1992–1993 survey efforts for the Preliminary Environmental Assessment (PWA et al. 1994). These 1992–1993 survey results are discussed below.

1995 and 1997 Benthic Macroinvertebrate Inventory

Qualitative surveys presented by Fong (2002a) were conducted in 1995 and 1997 at six sample locations to provide a taxa list of stream macroinvertebrates and some index of relative abundance and "health." Species observed at the Pacific Way Bridge station are listed in Table F-1. Additional species that were observed at more upstream stations in 1995 and 1997 include:

Insecta:

- Coleoptera (Dytiscidae *Oreodytes*, Psephenidae *Eubrianax*)
- Diptera (Chironomidae Chironominae *Stenochironomus*, Dixidae *Dixa,* Ephydridae, Ceratopogonidae *Atrichopogon*, Ceratopogonidae *Forcipomyia)*
- Ephemeroptera (Ephemerellidae *Drunella*, Heptageniidae *Cinygma,* Heptageniidae *Ironodes,* Heptageniidae *Epeorus*)
- Hemiptera (Veliidae *Microvelia*)
- Plecoptera (Chloroperlidae *Paraperla*, Leuctridae, Perlidae *Hesperoperla*)
- Trichoptera (Hydroptilidae *Hydroptila*, Hydroptilidae *Ochrotrichia*, Odontoceridae *Parthina,* Apataniidae *Apatania,* Brachycentridae *Micrasema*, Calamoceratidae *Heteroplectron,* Glossosomatidae *Glossosoma,* Limnephilidae *Psychoglypha,* Philopotamidae *Wormaldia*, Polycentropodidae *Polycentropus*)

Arachnida:

- Acarina (Aturidae *Aturus*, Aturidae *Kongsbergia*, Hydryphantidae *Protzia*, Hygrobatidae *Hygrobates*, Mideopoidae, Sperchonidae, Lebertiidae *Estelloxus*, Stygothrombiidae)

Hydrozoa:

- Hydroida (Hydridae *Hydra*)

Crustacea:

- Copepoda (Ergasilidae *Ergasilus*)

Turbellaria:

- Tricladida (Planariidae *Dugesia)*

Nemertea:

- Enopla (Tertastemmatidae *Prostoma)*

The sampled invertebrate community at the downstream-most station in the watershed, below the Pacific Way Bridge, had significantly different metric values than other stations (Fong 2002a). This station had significantly lower Shannon diversity than two out of sample location in 1995, and also had significantly higher proportion of dominant taxa when compared to the other sites (Fong 2002a). This dominance was associated with extremely large numbers of *Malenka* larvae, a stonefly (Fong 2002a).

2002 Invertebrate Inventory

The objectives of the 2002 study were to (Fong et al 2003):

1. Establish a baseline taxa list and reference collection of aquatic and semiaquatic macroinvertebrates from seasonally and permanently inundated sites within the project area.
2. Compare aquatic and semiaquatic macroinvertebrate fauna diversity and relative abundance between open water and emergent-open water interface habitats.

Samples were collected at six locations in April 2002 (Figure F-1). Freshwater wetland sites had higher invertebrate densities than other sites, which is similar to the results reported by PWA et al (1994). PWA et al (1994) reported higher production of zooplankton and insects in the late winter and spring for the pasture wetlands when compared to open water habitat in Redwood Creek.

At each wetland site, the sample near the vegetated edge had greater density and greater taxa richness than the open water samples, suggesting a more heterogeneous habitat and most likely greater food availability. However, samples obtained in more stream influenced sites had opposite results. Samples along Redwood Creek at the backwater and below the pedestrian footbridge had higher densities at open water rather than the vegetated margins (Fong et al 2003).

The majority of the taxa collected were still-water taxa; however, three typically stream taxa were collected at the Below Footbridge sample sites, including the baetid mayflies (Ephemeroptera) *Centroptilum* and *Diphetor*, and the brachycentrid caddisfly (Trichoptera) *Amiocentrus*. Appendix F, Table F-1 lists all the species that were observed during 2002 surveys. Relatively high dissolved oxygen concentration and relatively low temperatures were evident at this site indicating the influence of Redwood Creek. No sensitive invertebrate taxa were encountered in surveys (Fong et al 2003).

The brackish wetland sample sites (Big Lagoon Marsh and Parking Lot Wetland) had lower abundance of invertebrates than the freshwater wetland sites. The brackish wetlands likely had variable salinities throughout the prior winter and spring depending upon the frequency and amount of rain and overwash from the ocean. These sites also had water depths that were typically lower than other sample sites, which may imply a greater tendency towards fluctuating conditions (e.g., water temperature). Such dynamic conditions may be difficult for the production of invertebrates (Fong et al 2003).

1992–1993 Qualitative Surveys

Qualitative surveys in 1992–1993 were made to provide a broader perspective on the spatial and temporal changes in the fauna, and especially to locate representative habitats for more intense quantitative sampling. The location of original survey sites (only sampled once), and seasonal qualitative and quantitative survey sites are shown in Figure D-2. The details of sampling methods are provided in Appendix D. Since amphibian larvae were captured while sampling for aquatic invertebrates, they became a secondary focus of the surveys.

The seasonal patterns in quantitative nocturnal traps were similar to those from the more qualitative daytime sweep samples. Traps were set at two stations representing contrasting aquatic habitats, as indicated by sweep sampling. One was within a side channel of Redwood Creek and represents a quiet water pond in a fairly natural creek system (Figure D-2: Station 14). The other is in the main pond within a large drainage ditch south of Green Gulch Creek (Figure D-2: ditch 3, Station 15).

Late winter was a period of reduced abundance of aquatic invertebrates in Redwood Creek, coincident with a significant reduction in cover of emergent vegetation along the stream border after several episodes of flooding. There was a similar pattern in the pasture ponds, but less pronounced. In spite of the low numbers of insects, damsel fly larvae and water boatman nymphs were common at some sites, and ephemeroptera larvae were very diverse and common. Beetles, however, were scarce, although some larvae of predatory beetles were present. In all cases, the highest numbers of insects were collected at those sites with the highest vegetation cover.

Insect abundance and species richness were substantially higher by the spring sampling compared to the late winter. Most numerous were water boatman nymphs and adults. Mayfly nymphs, beetle adults and larvae, backswimmer nymphs, fly larvae, giant waterbugs, and damsel fly larvae were also common. The insects were clearly more abundant and diverse than in early March, with more species and individuals found in the pasture ponds than in the river. This pattern was most likely due to the much greater cover of emergent vegetation in the ponds versus the stream. During the March sampling, the pasture ponds had been turned into mud holes by the horses, and had even less emergent vegetation than the stream. By May, however, sufficient forage was available in the dry pastures so that the horses were no longer trampling the marsh vegetation, which was lush and supported a rich insect assemblage. Thus, insect abundance and diversity were correlated, as during March, with vegetation cover (PWA et al. 1994).

With the onset of the summer dry season, standing water was much reduced in the pasture and marsh areas. Emergent vegetation was well developed in the remaining wet habitats, but still less abundant in Redwood Creek than at the pasture pond sites. Insect abundance was similar to the spring sampling, but with proportionately more adults, and fewer juvenile and larval stages than in May. This pattern was especially true for the beetles, backswimmers, and water boatmen. Giant water bugs, mayfly nymphs, and damsel fly larvae, were all less common in July than during the spring, and damsel fly larvae were still generally found only in Redwood Creek net samples. Diptera larvae, however, were more abundant and diverse than in May at all sites. These larvae were especially common in Redwood Creek.

The largest individuals, and the highest densities were found in the remains of the temporary pond among the cattail stand at the extreme southwest end of the pasture (Figure D-2: station 2, square symbol). Here, not only was the insect fauna well developed and mature, but this was also the only site where amphibian larvae (Pacific tree frog [*Hyla regilla*] and California newt [*Taricha torosa*]) were taken. Interestingly, there were no adult or larval beetles (predaceous or otherwise) taken at this site.

Planktonic crustaceans (amphipods, daphnia, and copepods) were generally more abundant in the pasture ponds than in Redwood Creek.

1992–1993 Quantitative Surveys

Total insect abundance was highest during the spring at the pasture ditch, with species dominated by members of the order Hemiptera, primarily juvenile water boatmen (PWA et al. 1994, Figure IV-26). Beetles (Coleoptera) and mayfly larvae (Ephemeroptera) were also more abundant at this site during the spring sampling period (Figure F-2). Damsel fly and dragon fly (Odonata) larvae and fly (Diptera) larvae, however, became more abundant during the summer at the creek station.

Crustacean abundance in the pasture ditch was highest during the late winter, and steadily decreased toward summer (Figure F-3). This group was made up primarily of amphipods, copepods, daphnia, and ostracods. Copepods were the most abundant crustaceans throughout the year, with ostracods achieving comparable numbers only during the late winter (Figure F-3). Amphipods, were generally rare, with none present in the traps during the late winter.

Both the insect and the crustacean fauna were generally less abundant and diverse at the Redwood Creek site than at the pasture ditch or pond (Figures F-2 and F-3). This pattern was particularly evident during the late winter, when no insects or crustaceans were found in the Redwood Creek nocturnal traps. As at the pasture site, summer abundance was generally the same or lower than during the spring. Interestingly, the only insects found in substantially greater abundance in the creek were fly larvae, particularly mosquitoes and chironomids (Figures F-2 and F-3).

The results from the 1992–1993 seasonal aquatic insect survey indicate that expanding the extent and year round duration of ponded fresh water and associated aquatic vegetation will significantly increase the numbers, diversity, and persistence of insects, crustaceans, and amphibians found at the Big Lagoon project area (Table F-1). At least three factors likely contribute to the pattern of lower diversity and abundance in the creek compared to the pasture ponds. Winter flooding of Redwood Creek tends to flush out the insect and crustacean fauna along with much of the emergent aquatic vegetation with which these species associate. This pattern was most dramatic during the late winter and spring surveys in 1993, when insects, crustaceans, amphibians, and vegetation were still abundant in the pasture ditches, but greatly reduced at the Redwood Creek sites (Figures F-2 through F-4). Abundance of these species did not begin to increase in the creek until spring and summer, if at all.

A major factor limiting the abundance and duration of aquatic fauna and vegetation at the pasture sites is the combined action of seasonal drying and disturbance from grazing horses. As the ponds and areas of standing water associated with the drainage ditches begin to shrink with the onset of the summer dry period, the horses gain access to these habitats. This disturbance results in the trampling and destruction of emergent vegetation well before the natural drying cycle of the ditches, and was evident during the September 1992 survey. The combined desiccation and trampling apparently leads to the decline in pasture invertebrate communities at the beginning of summer in contrast to the persistence of many of these species in Redwood Creek during the same time period. Redwood Creek, unlike the horse pasture ditches, has a year round water source, and is not subject to horse grazing disturbance. Creation of a larger pond, with a more reliable water source will greatly reduce the effect of horse related disturbance.

The final factor influencing these patterns may be the relative absence of higher tropic levels in the ditches (i.e. larger predaceous fish) and therefore the greater numbers of predaceous insects (beetles, water boatmen, backswimmers, odonota larvae) and amphibian larvae in the pasture ponds and ditches compared to Redwood Creek. These differences likely contribute to the higher numbers of crustaceans and lower number of mosquitoes and other dipteran larvae in the ditches versus Redwood Creek. This later result will be of particular interest to those concerned that increasing ponded water at Big Lagoon will enhance mosquito production. This evidence suggests that the Redwood Creek backwaters, not the pasture ponds promote mosquito growth.

Tidal Lagoon

The tidal lagoon fauna was sampled to detect potentially important prey for creek fishes, and to determine if this brackish invertebrate community was well developed in the lower creek. Benthic invertebrates were sampled at three stations in the tidal lagoon (Figure D-2) using simple core samples pushed into the sandy substrate (Appendix D for sampling methods). Aquatic insect larvae (a fly larva) were the most abundant animals in the lagoon sediment (Figure F-5). Annelid worms, both oligochaetes and polychaetes (mostly nereids), were next in abundance. Preliminary qualitative surveys of the tidal lagoon the previous summer also revealed annelid worms and amphipod crustaceans, but not dense populations and only in quite limited habitat areas. The large number of oligochaetes at one station in March may have been a real seasonal pattern or a local patch sampled from a slightly deeper part of the lagoon bottom. The pericarid crustaceans, the amphipod Corophium and the cumacean Leucon, are common in estuarine systems at river mouths. Although they can be important food for young steelhead in other systems, their local population densities were low and the total area of tidal lagoon is too small for these groups to be major fish prey in Redwood Creek. Low standing biomass of crustaceans may be a function of predation.

Table F-1a. Insects observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
INSECTA				
Coleoptera				
Dytiscidae	X	X	X	X
Agabus				X
Dytiscus				X
Hydroporus				X
Rhantus				X
Elmidae		X		
Narpus		X	X	X
Optioservus		X	X	X
Ordobrevia			X	
Zaitzevia		X	X	
Gyrinidae	X			
Haliplidae	X			
Brychius		X		X
Hydraenidae				
Hydraena		X	X	
Hydrophilidae	X			
Enochrus				X
Tropisternus				X
Staphylinidae (Semi-aquatic)				

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Stenus				X
Collembola				
Poduridae	X			
Podura aquatica				X
Diptera				
Ceratopogonidae	X	X	X	X
Bezzia/Palpomyia				X
Chaeoboridae	X			
Chironomidae	X	X		
Chironominae				
Chironomini		X	X	X
Chironomus				X
Tanytarsini		X	X	X
Orthocladiinae		X	X	X
Tanypodinae		X	X	X
Dixidae	X			
Empididae				
Chelifera		X	X	
Trichoclinocera		X	X	
Pelecorynchidae				
Glutops			X	
Simuliidae		X		
Simulium		X	X	
Tipulidae		X		
Antocha		X		
Dicranota		X	X	
Hexatoma			X	
Limnophila		X	X	
Culicidae	X			
Culiseta				X
Cyclorraphous-Brachycera				X
Ephemeroptera				
Ameletidae				

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Ameletus			X	
Baetidae	X			X
Baetis		X	X	
Centroptilum				X
Diphetor		X	X	X
Ephemerellidae				
Ephemerella		X	X	
Heptageniidae				
Cinygmula			X	
Leucrocuta		X		
Rhithrogena		X	X	
Leptophlebiidae				
Paraleptophlebia		X	X	X
Hemiptera				
Belostomatidae	X			
Corixidae	X			X
Gerridae	X			
Nepidae	X			
Notonectidae	X			
Odonata	X			
Aeshnidae	X			
Coenagrionidae				
Enallagma				X
Ishnura				X
Plecoptera	X			
Capniidae		X	X	
Chloroperlidae		X		
Sweltsa		X	X	
Nemouridae				
Malenka		X	X	
Perlidae		X		
Calineuria		X	X	
Perlodidae				

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Isoperla		X		
Trichoptera				
Brachycentridae				
Amiocentrus				X
Glossosomatidae				
Agapetus		X		
Hydropsychidae				
Hydropsyche		X		
Hydroptilidae			X	
Lepidostomatidae				
Lepidostoma		X	X	
Leptoceridae	X			
Limnephilidae				
Eocosmoecus		X		
Rhyacophilidae				
Rhyacophila		X	X	
Sericostomatidae				
Gumaga			X	
Uenoidae				
Neophylax		X		
Chelicerata				

Table F-1b. Spiders observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	**1992/1993 (PWA et al. 1994)**	**1995 (Fong 2002a)**	**1997 (Fong 2002a)**	**2002 (Fong et al. 2003)**
ARACHNIDA				
Acarina			X	
Anisitsiellidae		X		
Aturidae			X	
Hygrobatidae				
Atractides		X	X	
Hygrobates				X
Lebertiidae				
Lebertia		X	X	
Torrenticollidae				
Torrenticola		X	X	
Pionidae				
Typhyinae				X
Piona				X
Oribatei		X		X
Terrestrial (?) Acarina				X
Crustacea				

Table F-1c. Branchiopods observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
BRANCHIOPODA				
Cladocera				
Daphniidae			X	
Simocephalus				X

Table F-1d. Copepods observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
COPEPODA				
Cyclopoida				
Cyclopidae		X	X	X
Acanthocyclops				X
Macrocyclops				X
Harpacticoida				X

Table F-1e. Malacostracans observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	**1992/1993 (PWA et al. 1994)**	**1995 (Fong 2002a)**	**1997 (Fong 2002a)**	**2002 (Fong et al. 2003)**
MALACOSTRACA				
Amphipoda				
Crangonyctidae				
Crangonyx				X
Hyalellidae				
Hyalella			X	X
Ostracoda				
Podocopa				X
Cyprididae		X		
Cyprinae				X
Cyclocyprididae				
Cypria				X

Table F-1f. Gastropods observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	**1992/1993 (PWA et al. 1994)**	**1995 (Fong 2002a)**	**1997 (Fong 2002a)**	**2002 (Fong et al. 2003)**
GASTROPODA				
Pulmonata				
Lymnaeidae				X
Fossaria			X	
Stagnicola				X
Physidae				
Physella			X	X

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Planorbidae				
Gyraulus			X	X

Table F-1g. Leeches observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
HIRUDINEA				
Rhyncobdellida				
Glossiphoniidae				
Helobdella stagnalis				X

Table F-1h. Oligochaetes observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
OLIGOCHAETA		X		
Haplotaxida				
Enchytraeidae			X	X
Naididae			X	X
Chaetogaster			X	X
Dero				X
Nais				X
Slavina				X

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Stylaria				X
Tubificidae			X	
Limnodrilus				X
Tubifex				X
Lumbriculida				
Lumbriculidae				X
Lumbricina		X	X	

Table F-1i. Hydrozoans observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
HYDROZOA				
Hydroida				
Hydridae				
Hydra				X

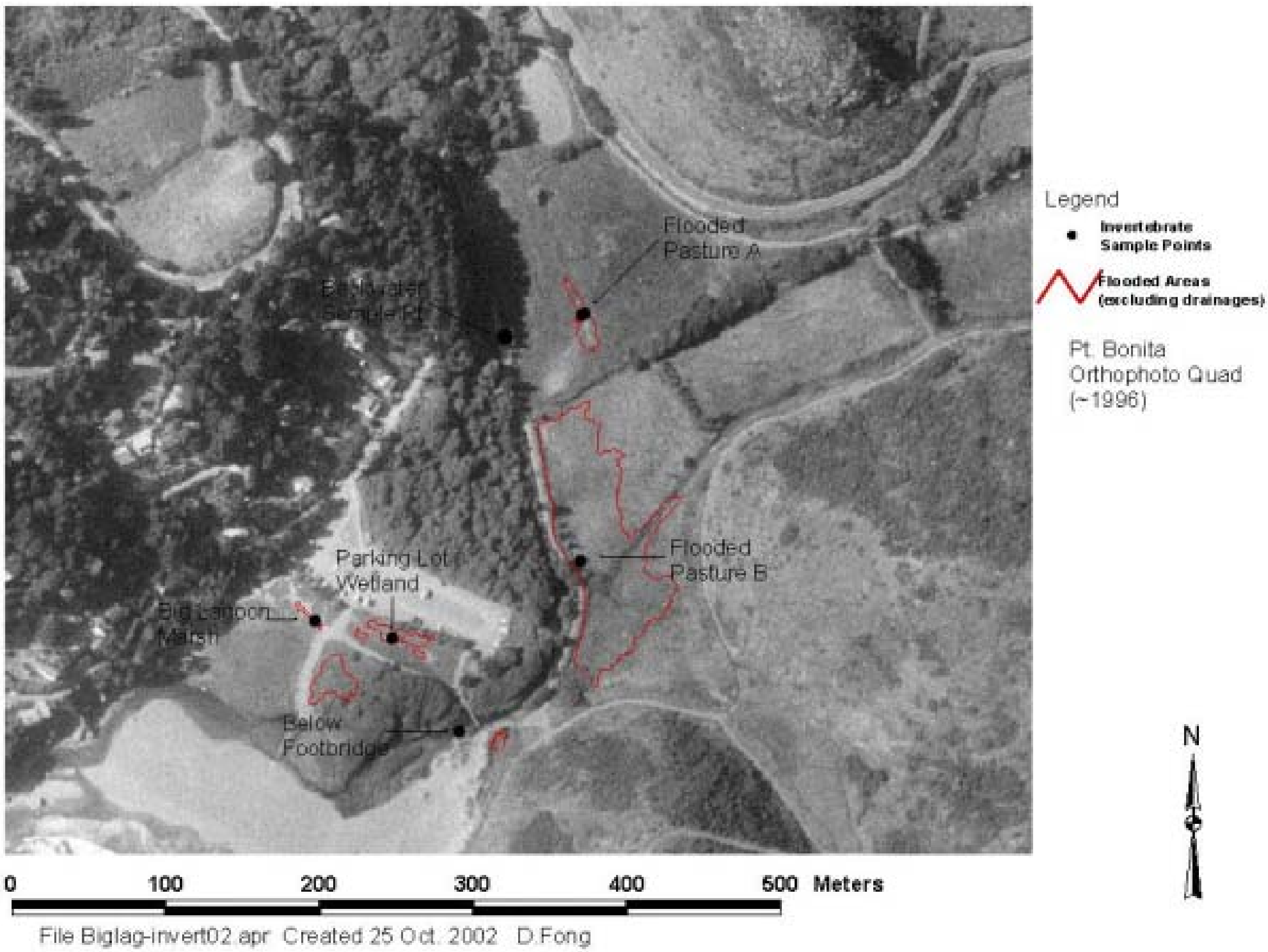
Table F-1j. Nematodes observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

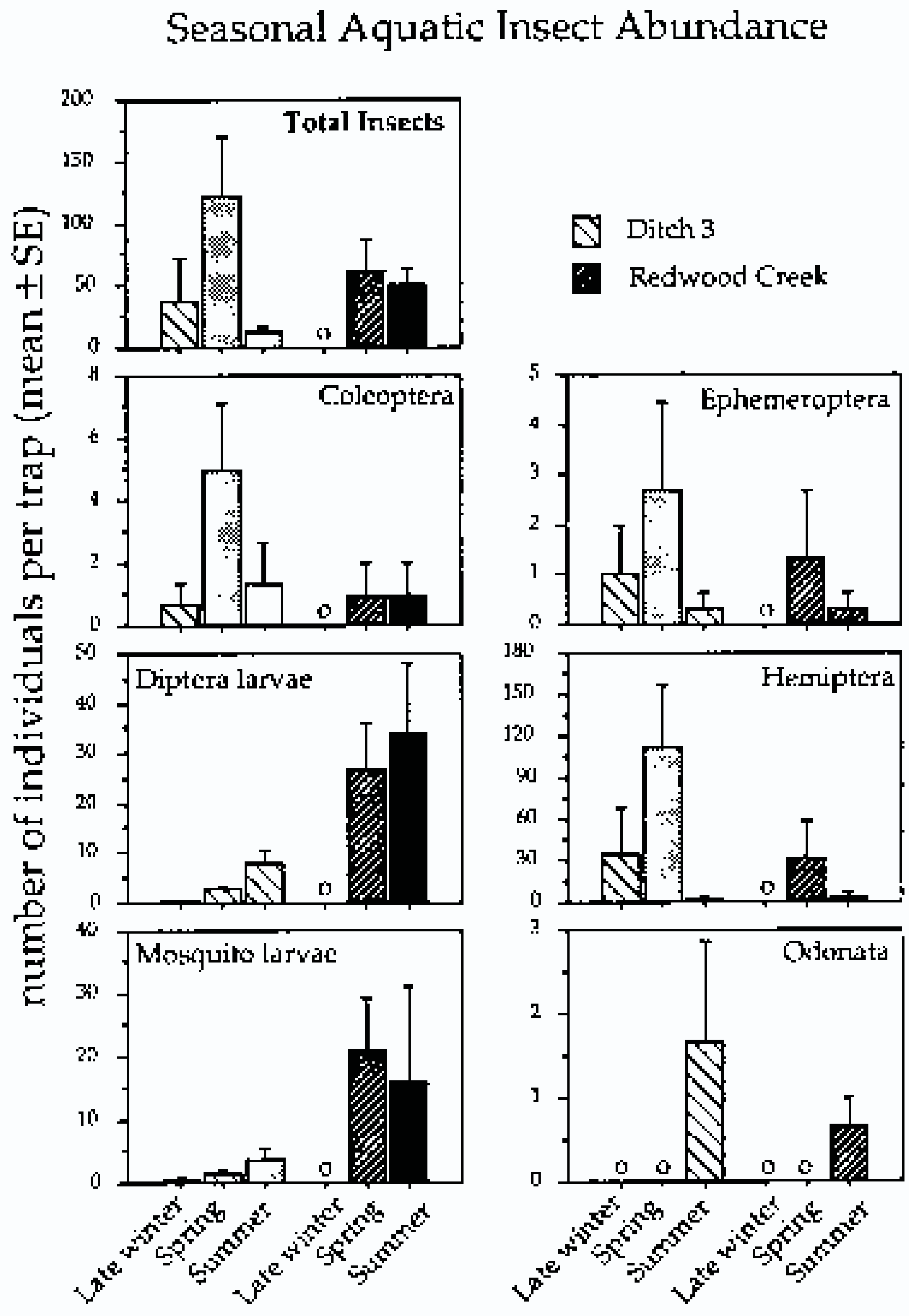
Genus	1992/1993 (PWA et al. 1994)	1995 (Fong 2002a)	1997 (Fong 2002a)	2002 (Fong et al. 2003)
Phylum NEMATODA				X
Mermithidae			X	

Table F-1k. Bivalves observed at Big Lagoon detected from surveys conducted in the Big Lagoon study area, 1992–2002. (Key: Bold caps = Class, Bold = Order, Regular = Family, Italics = Genus)

Genus	**1992/1993 (PWA et al. 1994)**	**1995 (Fong 2002a)**	**1997 (Fong 2002a)**	**2002 (Fong et al. 2003)**
Phylum BIVALVIA				
Pelecypoda				
Sphaeriidae				
Pisidium			X	

Figure F-1. Big Lagoon Invertebrate Sampling Locations, April 2002. From Fong et al. 2003.

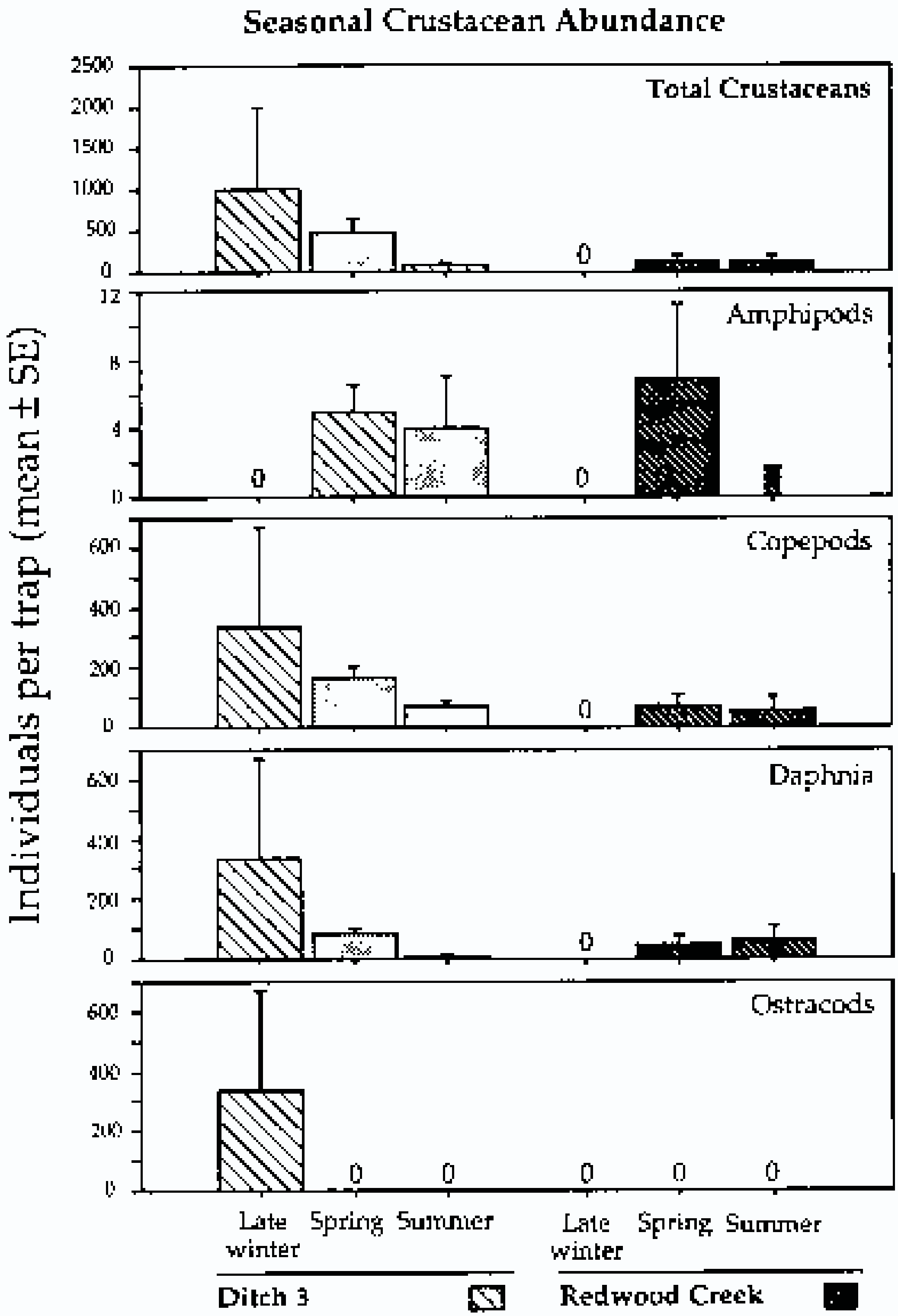




Seasonal abundance of major groups of aquatic insects found in night traps at the horse pasture pond (ditch 3) and Redwood Creek sampling sites (N = 3 per site). Zeros indicate no individuals captured. Note different scales.

Source: PWA et al. (1994)

Figure F-2

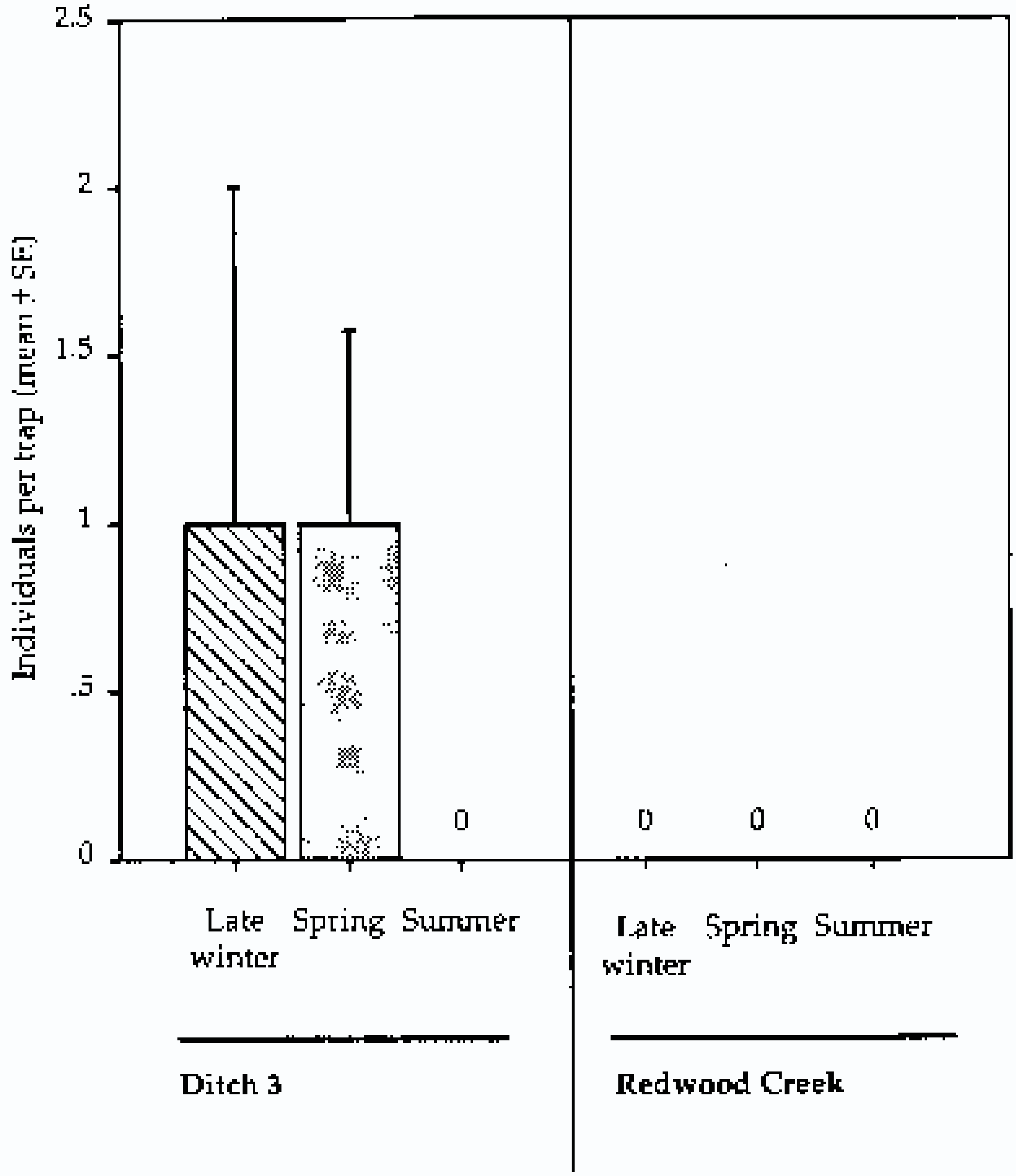


Changes in the seasonal abundance of major aquatic crustacean groups found in nocturnal traps at the horse pasture pond (ditch 3) and Redwood Creek sampling sites (N = 3 per site). Zeros indicate no individuals captured.

Source: PWA et al. (1994)

Figure F-3

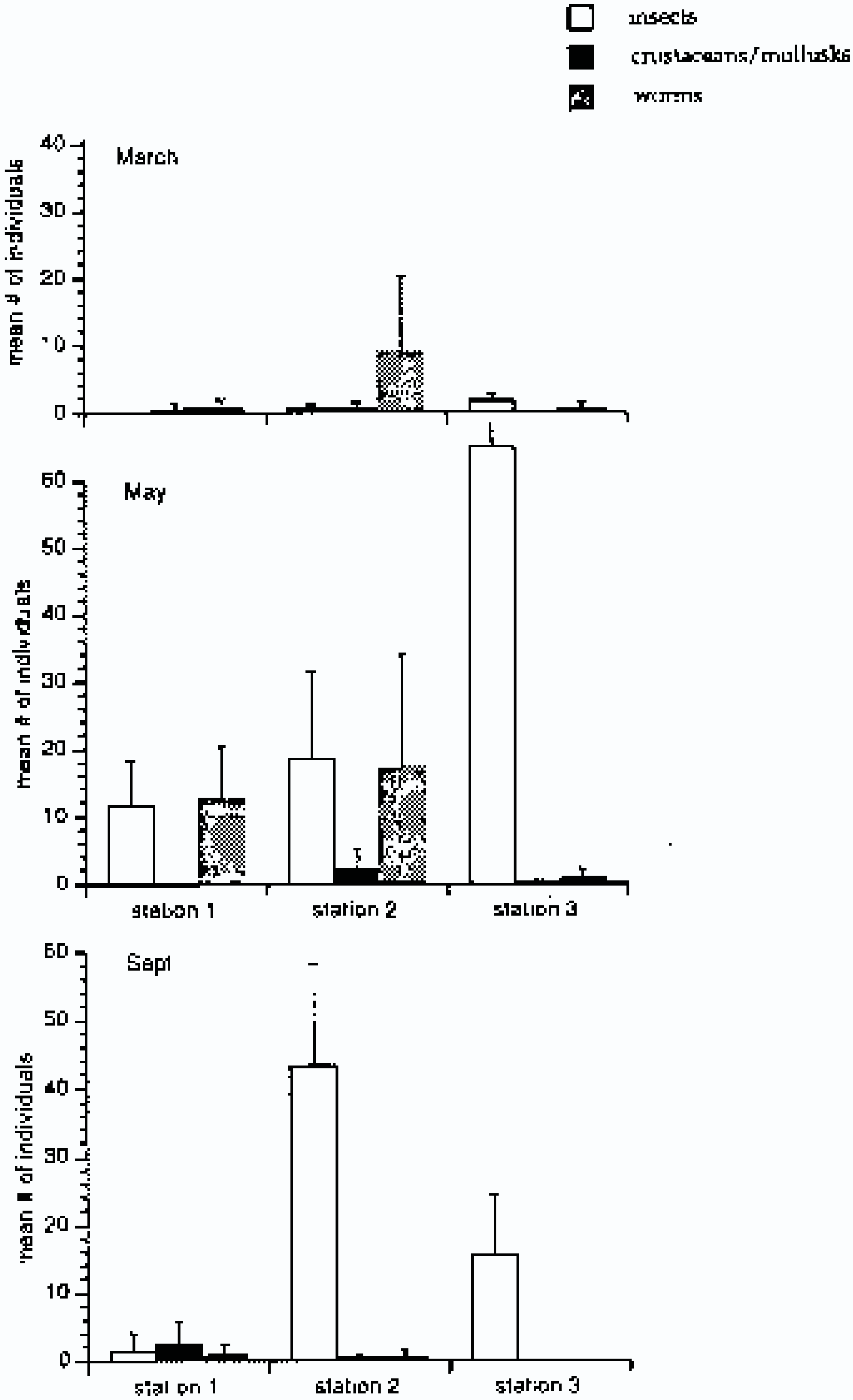
Seasonal Amphibian Larvae Abundance



Seasonal abundance of amphibian larvae found in nocturnal traps at the horse pasture pond (ditch 3) and Redwood Creek sampling sites (N = 3 per site). Zeros indicate no individuals captured.

Source: PWA et al. (1994)

Figure F-4



Benthic invertebrates and insect larvae abundances during 1993 seasons at Big Lagoon. Mean number of individuals of each group per core and standard deviation, n = 6. Station 1 was the most marine; station 3 the least saline.

Source: PWA et al. (1994)

Figure F-5

APPENDIX G

BIRD SURVEYS

APPENDIX G

Summary of Bird Surveys

This appendix summarizes the results of seasonal bird surveys at the Big Lagoon study area, conducted for 1.25 years (1992 – 1993) by PWA et al. (1994). A total of 11 surveys at 16 stations were conducted in all seasons. Survey stations were stratified by general habitat type. The objective was to measure seasonal use of a range of habitats that would potentially be affected by restoration activities. This appendix also includes several tables referenced in Section 4.3.2.3 of the main text.

PWA et al. (1994) surveys. Bird surveys were conducted at permanent stations in Big Lagoon to measure current seasonal use of a range of habitats potentially affected by future restoration efforts. Standardized counts were repeated in all seasons at 15 stations (see Appendix D for methods and station modifications during survey period; see Figure D-4 for station locations and Table D-1 for survey dates). Variation in both individual and species numbers between surveys is high and sample sizes are relatively low after one year of sampling a fauna which is known to vary greatly in space and time. In addition to comparisons of seasonal and habitat use, a species list was generated from survey data and incidental sightings; however, it was intentionally not made the primary focus of the field work. It should therefore be considered supplementary to more comprehensive lists compiled specifically for that purpose. All species names used in text and figures are accepted common names established by the American Ornithologists' Union (1983,1985).

Eleven standard bird surveys were conducted during the first annual survey period, 29 May 1992 – 9 August 1993. During this period, 1603 individuals comprising 67 bird species were recorded. An additional 33 species were incidentally observed outside station boundaries or on non-survey days (Table G-6) between 29 May 1992 and 31 October 1993. All 100 species were grouped according to known feeding associations with terrestrial or aquatic prey (Table G-6; National Geographic Society 1983, Shuford 1993, Small 1974). Most species observed at Big Lagoon (61 percent) were terrestrial associates, species which fed on terrestrial vertebrates, vegetation or associated insects or aerial insects. Of these terrestrial species, nearly all (93 percent) breed in Marin County (Shuford 1993) and most (77 percent) are year-round county residents. Brewer's blackbirds, red-winged blackbirds and pine siskins were the most abundant terrestrial species counted during surveys; all are year-round residents. Three species of swallows (tree, barn and rough-winged) comprised the most abundant summer resident species.

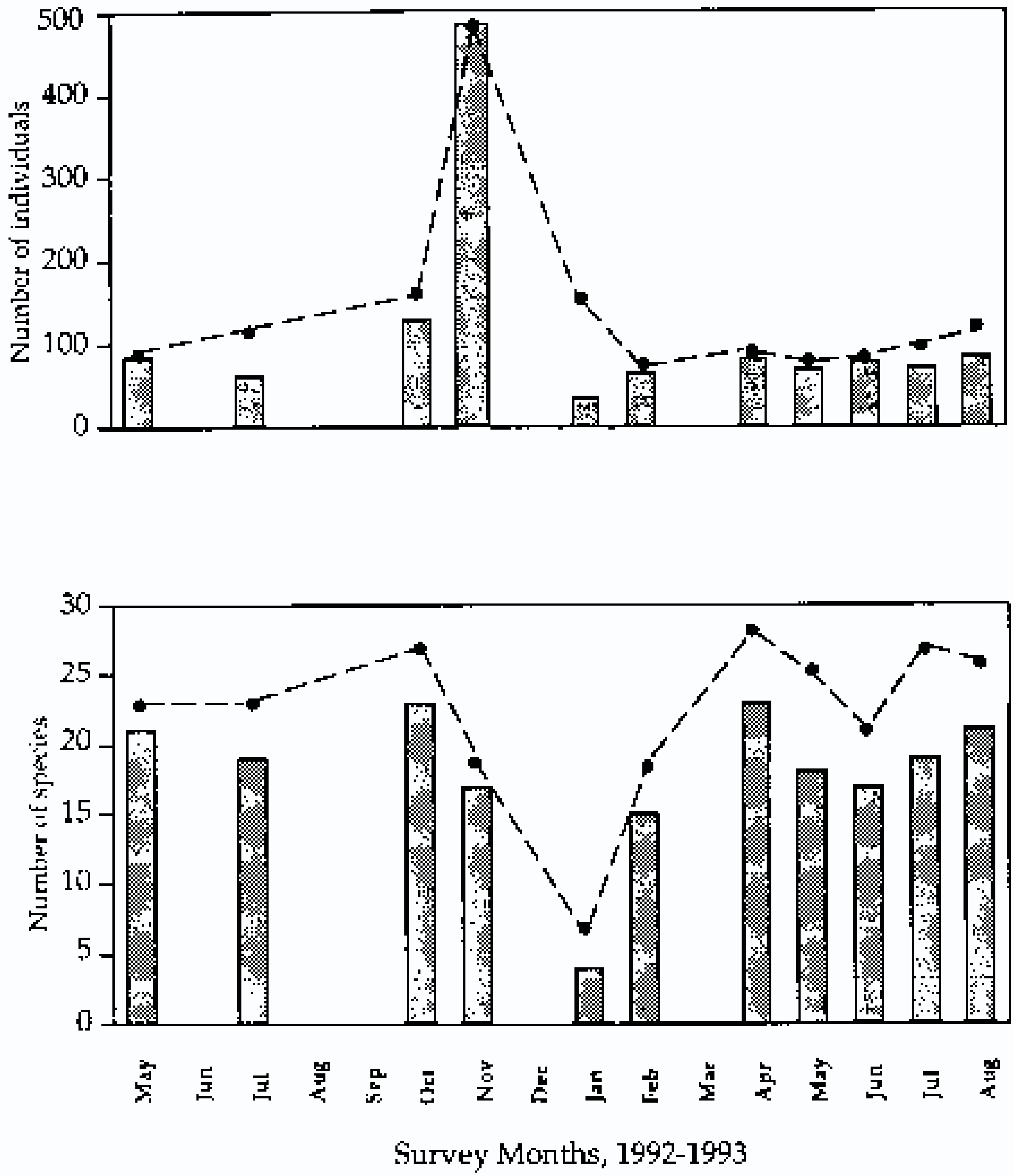
Wetland associates comprised the remaining 39 percent of species observed at Big Lagoon (Table G-6). About half of these wetland species (49 percent) occur in Marin County year-round (Shuford 1993); this includes the mallard, killdeer and great blue heron, which were the most abundant wetland individuals recorded. The remaining wetland species (51 percent) are winter resident/non-breeders (Shuford et al. 1989), overwhelmingly dominated by winter feeding flocks of American widgeons.

Total numbers of individuals and species observed at Big Lagoon stations varied greatly during the sampling period (Figure G-1). In particular, individual abundance was highest during late fall and winter. Note that the high November individual total is partly due to a single flock of 200 small unidentified passerines (probably finches) flying overhead, though omitting this sighting does not change the general trends shown in the Figure G-1. The January 1993 counts would have been much higher if weather permitted a complete survey of all stations. However, due to inclement weather, the survey included only the 3 pasture stations and an additional 1-time count of station 14 (see Appendix D for methods and station changes). At the time, station 13 was submerged by about 0.5 m water and over 100 waterfowl (primarily American widgeons) were feeding and resting along the edge of the temporary pond where station 14 was established.

The average numbers of birds observed during surveys of the three riparian stations bordering the footpath and the three pasture stations were grouped by season (i.e. spring/summer = March-June; fall = July-October; winter = November-February) to assess general trends in occurrence of migrants as well as summer and winter residents (Figure G-2). Wetland associate species, primarily waterfowl, were most common during winter in flooded pasture stations, comprising 34 percent of individuals and 46 percent of species observed. Wetland birds were less common in the riparian footpath stations than the pasture stations at all seasons (Figure G-2), and were represented primarily by herons and nesting mallards. In both station types, the fall season was generally low in total numbers and particularly wetland bird numbers, apparently reflecting a transition period between breeding activity and the appearance of winter residents. Figure G-2 presents numbers of individuals per survey, not per m^2; therefore any comparison of relative abundances between station types should take into account that the riparian footpath stations are less than 1/4 the size of pasture stations (Table G-7: $600 m^2$ vs. $2500\ m^2$).

Average numbers of birds at the two Redwood Creek stations and the two riparian vegetation stations were similarly grouped by season and proportion of wetland species (Figure G-3). Not surprisingly, wetland species occurred only in the creek stations. The total numbers of terrestrial individuals and species was noticeably higher in the vegetation stations than the creek stations, despite the smaller size of the former (Table G-7: $250\ m^2$ vs. $450\ m^2$ creek stations). Note that the riparian vegetation stations, in addition to being subjected to relatively low levels of human disturbance compared to the road-front creek stations, also encompassed a greater variety and density of vegetative cover. The riparian vegetation stations were consistently occupied by a variety of small resident passerines including chestnut-backed chickadees, pine siskins, song sparrows and house finches.

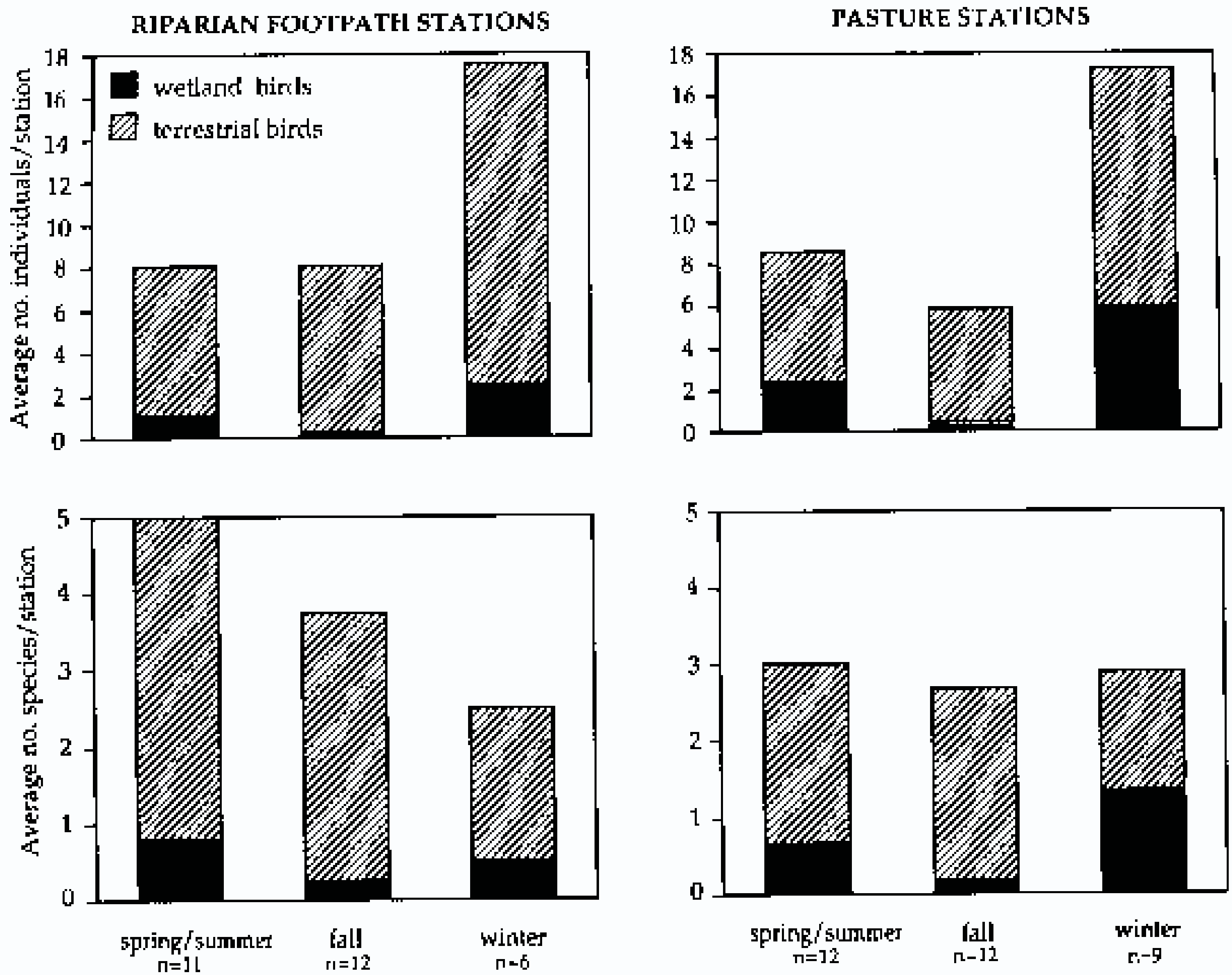
During the 1.25 year survey period, thirteen bird species were observed nesting or exhibiting breeding behavior at or near the Big Lagoon project area. This includes nine species and one subspecies within Big Lagoon and an additional three nesting species nearby. Two are particularly noteworthy: the peregrine falcon and salt marsh subspecies of the common yellowthroat. The peregrine falcon is state and federally endangered; a peregrine falcon pair nested successfully in 1992 at the "overlook" cliff site immediately north of Muir Beach (Onorato pers. comm., as cited in PWA et al. 1994); peregrine falcons have also successfully nested on cliffs just south of Muir Beach in previous years (GGNRA rangers, pers. comm., as cited in PWA et al. 1994). The salt marsh common yellowthroat is a federal candidate 2 and state species of special concern. A pair was observed in a coyote bush at the boundary of the Kikuyu meadow station (near the lowest section of Redwood Creek) on 9 August 93. They may have nested in or near Big Lagoon. All of the remaining nesting species observed in Big Lagoon chose nest sites in available vegetation near the creek, drainage channels or the remnant marsh in the southernmost pasture.



Total number of individuals and species of birds counted during 11 surveys at Big Lagoon, May 29, 1992 to August 9, 1993. Dotted line is summed for 12 stations. It includes sums from four additional stations surveyed less than 9 times, or only qualitatively

Figure G-1

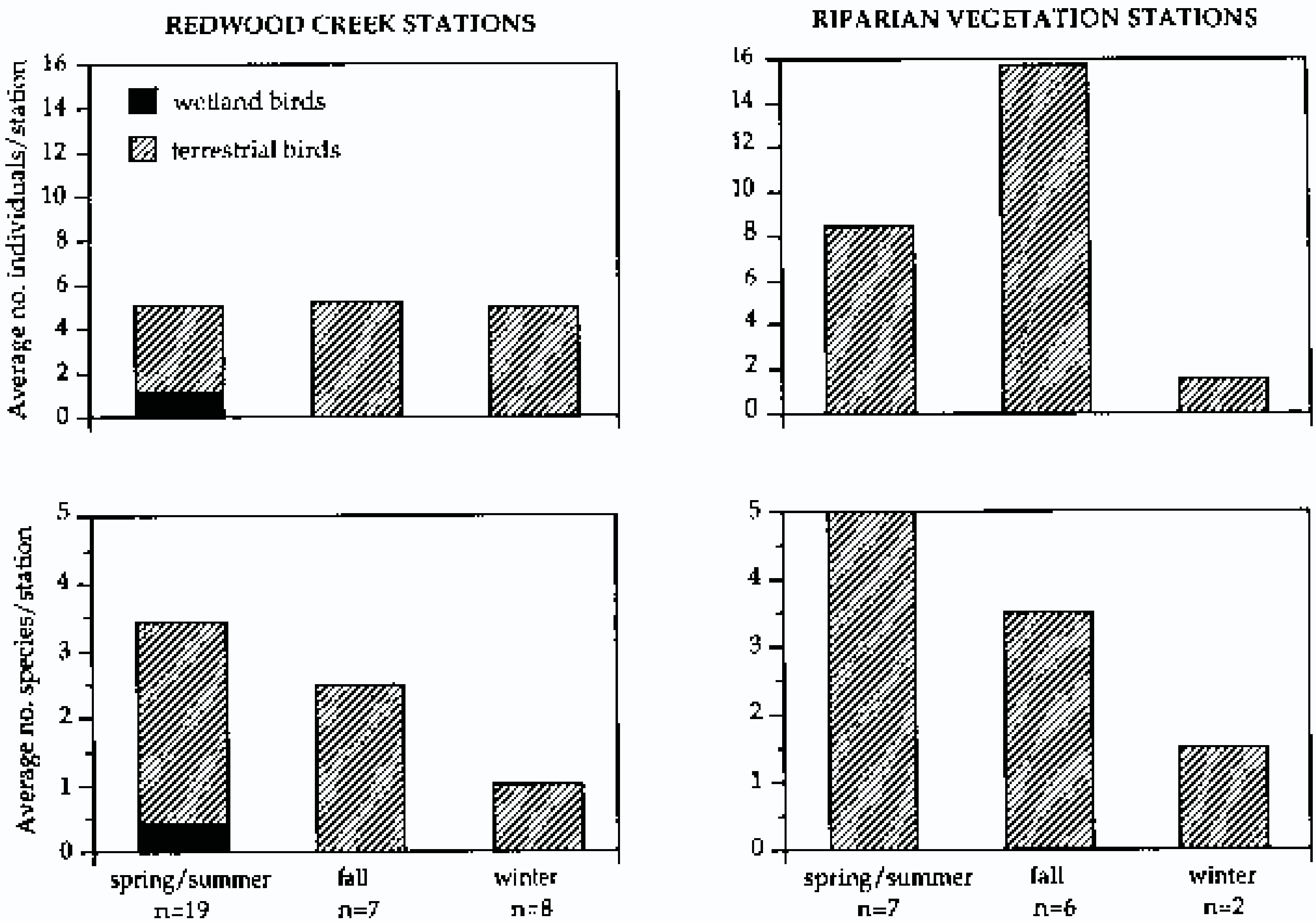
Source: PWA et al. (1994)



Average number of bird species and individuals at Riparian Footpath Stations and Pasture Stations during spring/summer, fall, and winter seasons. Bars represent sum of wetland species and terrestrial species; see Table X.

Source: PWA et al. (1994)

Figure G-2



Average number of bird species and individuals at Redwood Creek Stations and Riparian Vegetation Stations during spring/summer, fall, and winter seasons. Bars represent sum of wetland species and terrestrial species.

Source: PWA et al. (1994)

Figure G-3

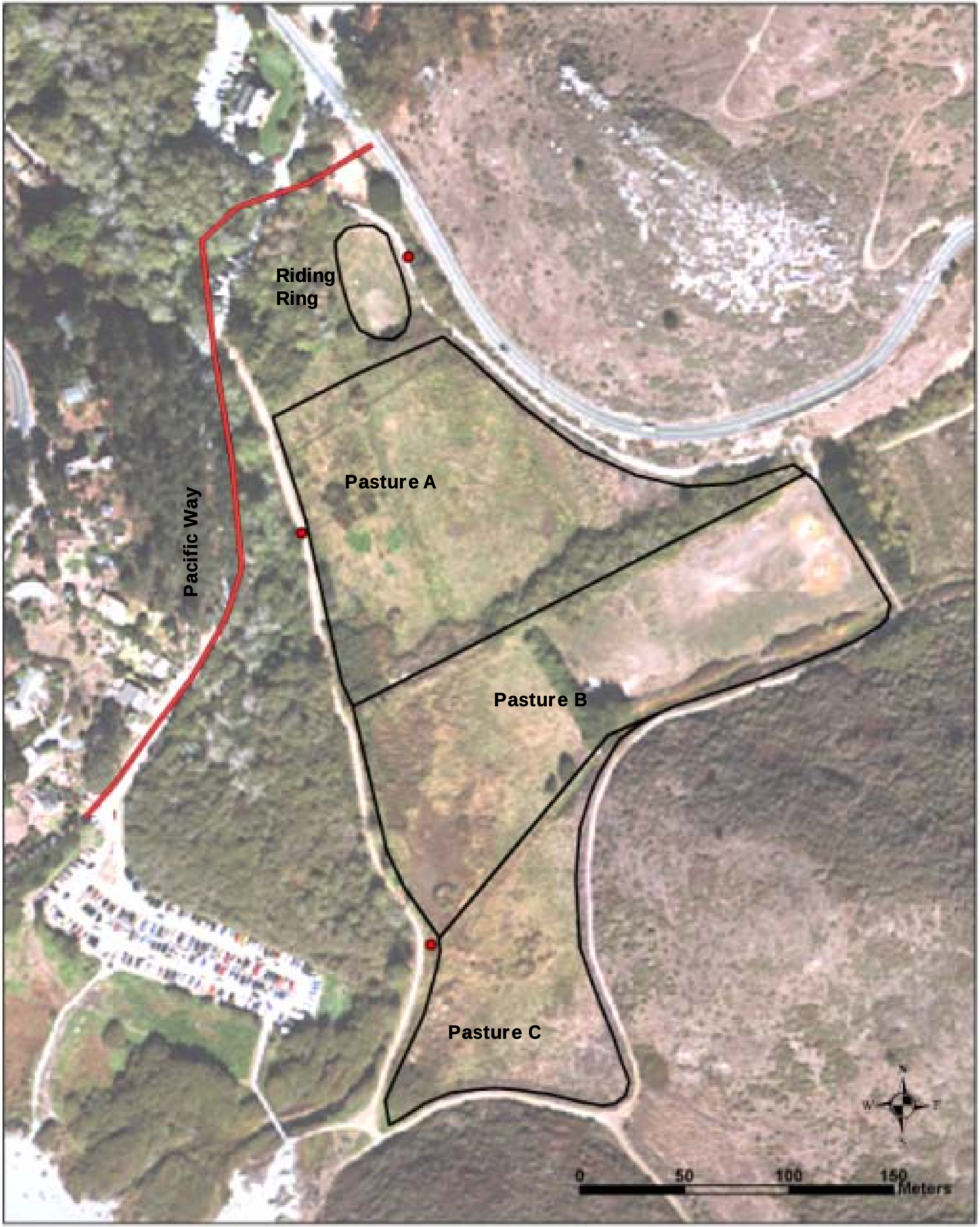


Figure G-4. Schematic of survey areas and locations of survey points (red dots) from Big Lagoon waterbird surveys, Dybala 2002.

Table G-1. Bird species documented in the Big Lagoon Wetland and Creek Restoration site

Bird Species	Scientific Name	Season[a]	Habitat[b]	Data Source
Red-throated Loon	*Gavia stellata*	W	C	2
Pacific Loon	*Gavia pacifica*	W	C	2
Common Loon	*Gavia immer*	W	C	2
Horned Grebe	*Podiceps auritus*	W	C	2,3
Eared Grebe	*Podiceps nigricollis*	W	C	2
Pied-billed Grebe	*Podilymbus podiceps*	W	F	2,4
Red-necked Grebe	*Podiceps grisegena*	W	C	5
Western Grebe	*Aechmophorus occidentalis*	W	C	2
Clark's Grebe	*Aechmophorus clarkii*	W	C	2
American White Pelican	*Pelacanus erythrorhynchos*	W	A	5
California Brown Pelican	*Pelacanus occidentalis californicus*	P	C, O	2,3
Magnificent Frigatebird	*Fregata magnificens*	S	A,B	5
Double-crested Cormorant	*Phalacrocorax auritus*	P	C, O, A	2,3
Pelagic Cormorant	*Phalacrocorax pelagicus*	P	C, O	2
Brant's Cormorant	*Phalacrocoraz penicillatus*	P	C, O	2
Great Blue Heron	*Ardea herodias*	P	F, H	2,3
Great Egret	*Casmerodius albus*	P	F, H	2,3,4
Snowy Egret	*Egretta thula*	W	F	2,3
Cattle Egret	*Bubulcus ibis*	W	H	2
Green Heron	*Butorides striatus*	S	F, R	2,3
Black-crowned Night Heron	*Nycticorax nycticorax*	W, P	R	2,3
Greater White-Fronted Goose	*Anser albifrons*	M	A	5
Canada Goose	*Branta canadensis*	W	F, H	2,3
Brant	*Branta bernicla*	W	F, C	3
Wood Duck	*Aix sponsa*	W, P	R	2
Mallard	*Anas platyrhynchos*	W	F, H	1,2,3,4
Gadwall	*Anas strepera*	W	F, H	2
Northern Pintail	*Anas acuta*	W	F, H	2
American Wigeon	*Anas americana*	W	F, H	2,3,4
Eurasian Wigeon	*Anas penelope*	W	H	2,3
Northern Shoveler	*Anas clypeata*	W	F, H	2
Cinnamon Teal	*Anas cyanoptera*	W	F, H	2,3
American Green-winged Teal	*Anas crecca*	W	F, H	2,3
Ring-necked Duck	*Aythya fuligula*	W	F, H	5
Greater Scaup	*Aythya marila*	W	C	2,4
Lesser Scaup	*Aythya affinis*	W	C	2
Surf Scoter	*Melanitta perspicillata*	W	C	2
Common Goldeneye	*Buchephala clangula*	W	C	2,3
Barrow's Goldeneye	*Bucephala islandica*	W	F	3
Bufflehead	*Bucephala albeola*	W	C, H	2,3,4
Common Merganser	*Mergus merganser*	R, F	M, P	3
Red-breasted Merganser	*Mergus serrator*	W	C	2,5

Bird Species	Scientific Name	Season[a]	Habitat[b]	Data Source
Ruddy Duck	*Oxyura jamaicensis*	W	C	5
Turkey Vulture	*Cathartes aura*	P	A	2,3
Golden Eagle	*Aquila chrysaetos*	M	A	5
Northern Harrier	*Circus cyaneus*	M, P	A	2,3
White-tailed Kite	*Elanus leucurus*	M, P	A	2,3
Sharp-shinned Hawk	*Accipiter striatus*	W, P	R, G	1,2
Cooper's Hawk	*Accipiter cooperii*	W, P	R, G	1,2,3
Broad-winged Hawk	*Buteo platypterus*	M	F	5
Red-shouldered Hawk	*Buteo lineatus*	P	R, G, H	1,2,3
Red-tailed Hawk	*Buteo jamaicensis*	P	A	1,2,3
Ferruginous Hawk	*Buteo regalis*	W	A	2
Osprey	*Pandion haliaetus*	S, P	A	2,3
Merlin	*Falco columbarius*	W	A, H	2
American Kestrel	*Falco sparverius*	W	A, H	2,3
American Peregrine Falcon	*Falco peregrinus anatum*	W, P	A	2,3
Ring-Necked Pheasant	*Phasianus colchicus*	P	H	5
California Quail	*Callipepla californica*	P	R, U, H	1,2,3
Common Moorhen	*Gallinula chloropus*	W	F	5
American Coot	*Fulica americana*	W	F, H	2,3,4
Virginia Rail	*Rallus limicola*	P	F	2,3
Sora	*Porzana carolina*	W	F	2
Black-bellied Plover	*Pluvialis squatarola*	W	B	2
Semipalmated Plover	*Charadrius semipalmatus*	W	B	2
Killdeer	*Charadrius vociferus*	W	U, F, H	1,2,3,4
American Avocet	*Recurvirostra americana*	M	F, H	5
Black Oystercatcher	*Haematopus bachmani*	P	O	2,3
Greater Yellowlegs	*Tringa melanoleuca*	W	F, H	2
Lesser Yellowlegs	*Tringa flavipes*	W	F	3
Willet	*Catoptrophorus semipalmatus*	W	B	2,3
Spotted Sandpiper	*Actitis macularia*	W	O	2,3
Whimbrel	*Numenius phaeopus*	W	B	2,3
Long-billed Curlew	*Numenius americanus*	W	B	2
Marbled Godwit	*Limosa fedoa*	W	B	2,3
Ruddy Turnstone	*Arenaria interpres*	W	O, B	2
Black Turnstone	*Arenaria melanocephala*	W	O	2
Wandering Tattler	*Heteroscelus incanus*	W	O	2,3
Surfbird	*Aphriza virgata*	W	O	2
Sanderling	*Calidris alba*	W	B	2
Dunlin	*Calidris alpina*	W	B	2
Western Sandpiper	*Calidris mauri*	W	B	2
Least Sandpiper	*Calidris minutilla*	W	H	2
Long-billed Dowitcher	*Limnodromus scolopaceus*	W	F, H	2
Wilson's Snipe	*Gallinago gallinago*	W	F	3
Red Phalarope	*Phalaropus fulicaria*	W	B	2
Red-necked Phalarope	*Phalaropus fulicaria*	W	B	2,3
Bonaparte's Gull	*Larus philadelphia*	M	C, H	2
Mew Gull	*Larus canus*	W	C, B	2,3
Ring-billed Gull	*Larus delararensis*	W	C, B	2,3
California Gull	*L. californicus*	W	C, B	2,3

Bird Species	Scientific Name	Season[a]	Habitat[b]	Data Source
Herring Gull	*Larus argentatus*	W	C, B	2,3
Thayer's Gull	*Larus thayeri*	W	C, B	2
Glaucous-winged Gull	*Larus glaucescens*	W	C, B	2
Western Gull	*Larus occidentalis*	P	C, O, B	2,3
Heermann's Gull	*Larus heermanni*	M	C, B	2
Caspian Tern	*Sterna caspia*	S	C, A	2
Elegant Tern	*Sterna elegans*	M	C, A	2
Forster's Tern	*Sterna forsteri*	M	C, A	2
Common Murre	*Uria aalge*	P	C	2
Pigeon Guillemot	*Cepphus columbia*	S	C	2
Marbled Murrelet	*Brachyramphus marmoratus*	W	C	5
Ancient Murrelet	*Synthliboramphus antiquus*	M	C	5
Mourning Dove	*Zenaida macroura*	P	A, R, G	1,2,3
Rock Dove	*Columbia livia*	P	A, H	2,3
Band-tailed Pigeon	*Columba fasciata*	P	A, G	1,2
Barn Owl	*Tyto alba*	M	R	2
Long-eared Owl	*Asio otus*	M	R	5
Great Horned Owl	*Bubo virginianus*	P	G	2,3
Vaux's Swift	*Chaetura vauxi*	M	F, H	5
White-throated Swift	*Aeronautes saxatalis*	S, P	A	2
Anna's Hummingbird	*Calypte anna*	P	R, U, G	1,2,3
Allen's Hummingbird	*Selasphorus sasin*	S, W	R, U, G	1,2
Rufous Hummingbird	*Selasphorus rufus*	M	R, U, G	1
Belted Kingfisher	*Ceryle alcyon*	W, P	F, C	1,2,3
Acorn Woodpecker	*Melanerpes formicivorus*	P	G	2
Red-breasted Sapsucker	*Sphyrapicus ruber*	W	R, G	2
Downy Woodpecker	*Picoides pubescens*	P	R	1, 2,3
Hairy Woodpecker	*Picoides villosus*	P	R, G	1,2,3
Nuttall's Woodpecker	*Picoides nuttallii*	M, P	R, G	2
Northern Flicker	*Colaptes auratus*	P	R, G	1,2,3
Pileated Woodpecker	*Dryocopus pileatus*	W	R, G	5
Olive-sided Flycatcher	*Contopus copperi*	S	R, G	1,2,3
Western Wood-pewee	*Contopus sordidulus*	S	R	1,2
Pacific Slope Flycatcher	*Empidonax difficilis*	S	R	1,2
Willow Flycatcher	*Empidonax traillii*	M	R	1,2
Least Flycatcher	*Empidonax minimus*	M	R	2
Gray Flycatcher	*Empidonax wrightii*	M	R	2
Black Phoebe	*Sayornis nigricans*	P	R, F, H	1,2,3
Say's Phoebe	*Sayornis saya*	W	H	2
Ash-throated Flycatcher	*Myiarchus cinerascens*	M	R	2
Tropical Kingbird	*Tyrannus melancholicus*	M	R, G	5
Western Kingbird	*Tyrannus verticalis*	M	H	2
Loggerhead Shrike	*Lanius ludovicianus*	W	H	2
Warbling Vireo	*Vireo gilvus*	S	R	1,2
Hutton's Vireo	*Vireo huttoni*	P	R, G	1,2
Cassin's Vireo	*Vireo cassinii*	M	R	2
Blue-Headed Vireo	*Vireo solitarius*	M	R	2
Steller's Jay	*Cyanocitta stelleri*	P	R, G	1,2,3
Western Scrub Jay	*Aphelocoma coerulescens*	P	R	1,2,3

Bird Species	Scientific Name	Season[a]	Habitat[b]	Data Source
Common Raven	*Corvus corax*	P	A, B	1,2
American Crow	*Corvus brachyrhynchos*	P	B, U, R, H	1,2,3
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	S	A, C	1,2,3
Violet-green Swallow	*Tachycineta thalassina*	S	R	1,2,3
Tree Swallow	*Tachycineta bicolor*	S	R	1,2,3
Cliff Swallow	*Hirundo pyrrhonota*	S	R, A	1,2,3
Barn Swallow	*Hirundo rustica*	S	R, A	1,2,3
Chestnut-backed Chickadee	*Parus rufescens*	P	R	1,2,3
Bushtit	*Psaltriparus minimus*	P	R	1,2,3
Red-breasted Nuthatch	*Sitta canadensis*	M	R, G	2
White-breasted Nuthatch	*Sitta carolinensis*	M	R, G	3
Pygmy Nuthatch	*Sitta pygmaea*	P	R, G	1,2,3
Brown Creeper	*Certhis americana*	W	R	2,3
Bewick's Wren	*Thryomanes bewickii*	P	R	1,2,3
House Wren	*Troglodytes aedon*	W	R, G	2,3
Winter Wren	*Troglodytes troglodytes*	W	R	2
Marsh Wren	*Cistothorus palustris*	P	F	1,2,3
Rock Wren	*Salpinctes obsoletus*	W	O	5
Wrentit	*Chamaea fasciata*	P	R, H	1,2
Golden-crowned Kinglet	*Regulus satrapa*	W	R, G	2
Ruby-crowned Kinglet	*Regulus calendula*	W	R	2,3
Blue-gray Gnatcatcher	*Polioptila caerulea*	M	H, U	5
Western Bluebird	*Sialia mexicana*	W	H	1,2
Varied Thrush	*Ixoreus naevius*	W	R	2
American Robin	*Turdus migratorius*	P	R, G	1,2,3
California Swainson's Thrush	*Catharus ustulatus oedicus*	S	R	1,2,3
Hermit Thrush	*Catharus guttatus*	W	R	2,3
Northern Mockingbird	*Mimus polyglottos*	W	G	2
European Starling	*Sturnus vulgaris*	P	U, R, H	1,2,3
American Pipit	*Anthus rubescens*	W	U, H	2
Cedar Waxwing	*Bombycilla cedrorum*	W	A, R	1,2,3
Northern Parula	*Parula americana*	M	R	5
Orange-crowned Warbler	*Vermivora celata*	S	R	1,2
Tennessee Warbler	*Vermivora peregrina*	M	R, G	5
Nashville Warbler	*Vermivora ruficapilla*	M	R	2
Yellow Warbler	*Dendroica petechia*	M, S	R	1,2,3
Chestnut-sided Warbler	*Dendroica pensylvanica*	M	R	5
Magnolia Warbler	*Dendroica magnolia*	M	R	5
Cape May Warbler	*Dendroica tigrina*	M	G	2
Blackburnian Warbler	*Dendroica fusca*	M	R	5
Yellow-rumped Warbler	*Dendroica coronata coronata* and *D. c. audubonii*	W	R, H, F, G	2,3
Black-throated Gray Warbler	*Dendroica nigrescens*	M	R	2,3
Townsend's Warbler	*Dendroica occidentalis*	M, W	R, G	2,3
Hermit Warbler	*Dendroica occidentalis*	M, W	R, G	2
Prairie Warbler	*Dendroica discolor*	M	H	5

Bird Species	Scientific Name	Season[a]	Habitat[b]	Data Source
Palm Warbler	*Dendroica palmarum*	M	R	2
Blackpoll Warbler	*Dendroica striata*	M	R, G	5
Black and White Warbler	*Mniotilta varia*	M	G	2
American Redstart	*Setophaga ruticilla*	M	R	2,3
Northern Waterthrush	*Seiurus noveboracensis*	M	R	5
MacGillivray's Warbler	*Oporonis tolmiei*	M	R	2
San Francisco Common Yellowthroat	*Geothlypis trichas sinuosa*	W, P	F	1,2,3
Wilson's Warbler	*Wilsonia pusilla*	S	R	1,2,3
Western Tanager	*Piranga ludoviciana*	M	R	2
Black-headed Grosbeak	*Pheucticus melanocephalus*	S	R, G	1,2,3
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	M	F, H	5
Spotted Towhee	*Pipilo californicus*	P	R	1,2,3
California Towhee	*Pipilo californicus*	P	G, R	1,2,3
Clay-colored Sparrow	*Spizella pallida*	M	F	5
Chipping Sparrow	*Spizella passerina*	M	U	2
Savannah Sparrow	*Passerculus sandwichensis*	W	U, H	2
Golden-crowned Sparrow	*Zonotrichia atricapilla*	W	U, R, H	2,3
White-throated Sparrow	*Zonotrichia albicollis*	W	H	2
White-crowned Sparrow	*Zonotrichia leucophrys*	W	U, R, H	1,2,3
Fox Sparrow	*Passerella iliaca*	W	R, G	2,3
Song Sparrow	*Melospiza melodia*	W	R, G	1,2,3
Lincoln's Sparrow	*Melospiza lincolni*	W	U	2
Swamp Sparrow	*Melospiza georgiana*	W	F, U	2
Dark-eyed Junco	*Junco hyemalis*	W	R	2
Western Meadowlark	*Sturnella neglecta*	W	H	2
Brown-headed Cowbird	*Malothrus ater*	S	R	1,2
Yellow-headed Blackbird	*Xanthophalus xanthophalus*	W	H	2
Tricolored Blackbird	*Agelaius tricolor*	W	F	3
Red-winged Blackbird	*Agelaius phoeniceus*	P	H, F	1,2,3
Brewer's Blackbird	*Euphagus cyanocephalus*	P	R, U	1,2,3
Bullock's Oriole	*Icterus bullockii*	M	R	2
Purple Finch	*Carpodacus purpureus*	P	R, G	1,2,3
House Finch	*Carpodacus mexicanus*	P	H, R, U	1,2,3
Red Crossbill	*Loxia curvirostra*	W	G	2
Pine Siskin	*Carduelis pinus*	P	R	2,3
Lesser Goldfinch	*Carduelis psaltria*	M	R, H	2,3
American Goldfinch	*Caruelis tristis*	S	R, H	1,2,3
House Sparrow	*Passer domesticus*	P	H	2

[a] Season that the species will mostly likely be detected at Muir Beach/Big Lagoon (as determined by Stallcup 1995) and secondarily (if applicable) its status in Marin County (based on Shuford 1993, PRBO unpubl. data). W = Winter: mostly winter also late fall and spring migrant, S = Summer: mostly summer also early fall and spring migrant, M = Migrant: passing migrant (many nest nearby), P = Permanent Resident: present all year.

[b] Habitat where the species will most likely be detected at Muir Beach /Big Lagoon (as determined by Stallcup 1995). A = Aerial: flying above, B = Beach, C = Cove: foraging cove to

200 meters off Muir Beach, O = Rocks: offshore rocks or headland cliffs. F = Freshwater marsh, H = Horse pasture and fences, R = Riparian: willow and alder forests, G = Gardens: town edge including pines, U = Upland: dry weedy areas.

Data Source: 1 = PRBO unpubl. data, 2 = Stallcup 1995, 3 = PWA 1994, 4 = Dybala 2002, and 5 = Dave MacKenzie in litt.

Table G-2. Total number of species detected from unlimited radius point counts at the Big Lagoon project area from 1998 to 2002. Species are listed from most common to least common based on 5-year average. Species names that are underlined are confirmed breeders at the Big Lagoon project area. Species with an asterisk* breed in Marin County. RHVJ (2000) focal species are in **bold**.

Species	1998	1999	2000	2001	2002	Average
Red-winged Blackbird	43	60	39	31	51	44.8
Song Sparrow	25	33	37	39	57	38.2
Swainson's Thrush	12	10	17	17	13	13.8
Cedar Waxwing	5	16	6	0	40	13.4
Wilson's Warbler	7	9	4	8	8	7.2
American Robin	6	11	5	7	5	6.8
Black-headed Grosbeak	5	9	6	4	7	6.2
Tree Swallow	11	3	4	6	4	5.6
Mourning Dove	3	8	2	2	10	5
Violet-green Swallow	13	8	0	1	3	5
American Crow*	2	2	5	9	6	4.8
Chestnut-backed Chickadee	5	3	5	4	6	4.6
European Starling	4	3	4	3	9	4.6
House Finch	0	6	0	0	16	4.4
American Goldfinch	1	1	5	5	9	4.2
Brown-headed Cowbird	2	1	5	7	4	3.8
Barn Swallow	4	6	2	3	2	3.4
California Towhee	5	1	3	3	5	3.4
Mallard	12	0	0	0	5	3.4
Brewer's Blackbird	3	2	0	0	11	3.2
Western Scrub-Jay	2	3	3	2	6	3.2
Wrentit*	1	4	4	2	5	3.2
Allen's Hummingbird	2	2	5	2	4	3
California Quail	5	5	2	0	3	3
Common Raven*	3	1	4	3	2	2.6
Downy Woodpecker	2	0	3	3	3	2.2
Nuttall's White-crowned Sparrow	1	5	1	2	2	2.2
Bushtit	2	4	4	0	0	2
Common Yellowthroat*	1	0	4	3	2	2
Purple Finch	4	0	0	3	2	1.8
Spotted Towhee	1	7	1	0	0	1.8
Steller's Jay	4	1	0	1	2	1.6
Western Wood-Pewee	1	1	4	2	0	1.6
Anna's Hummingbird	2	2	1	0	2	1.4
Cliff Swallow*	0	0	4	3	0	1.4

Species	1998	1999	2000	2001	2002	Average
Red-shafted Flicker	3	0	0	0	4	1.4
Hairy Woodpecker*	2	0	0	0	4	1.2
Marsh Wren	0	0	0	0	6	1.2
Olive-sided Flycatcher	1	1	1	0	1	0.8
Bewick's Wren	1	0	0	1	1	0.6
Orange-crowned Warbler	0	3	0	0	0	0.6
Northern Rough-winged Swallow	0	2	0	0	0	0.4
Warbling Vireo	0	2	0	0	0	0.4
Black Phoebe	0	1	0	0	0	0.2
Hutton's Vireo	0	0	0	1	0	0.2
Killdeer	0	0	0	1	0	0.2
Pacific-slope Flycatcher	1	0	0	0	0	0.2
Pygmy Nuthatch	0	0	0	0	1	0.2
Red-tailed Hawk	1	0	0	0	0	0.2
Western Bluebird*	0	0	0	0	1	0.2
Yellow Warbler*	0	1	0	0	0	0.2

Table G-3. Number of territories for RHJV (2000) focal species at the Big Lagoon project area as determined from territory mapping data in 1997, 1998, and 1999.

Species	1997	1998	1999
Black-headed Grosbeak	1	3	5-7
Common Yellowthroat	1	0	0
Song Sparrow	11	26-29	24-30
Swainson's Thrush	8	9-10	10-11
Warbling Vireo	1	0	1-2
Wilson's Warbler	8	11	11-12

Table G-4. Number of nests located for each species at the Big Lagoon project area in 1997, 1998, 1999 and proportion successful (fledged at least one young). RHVJ (2000) focal species are in **bold**. Species are listed in taxonomic order.

	1997		1998		1999	
Species	# Nests	Proportion Successful	# Nests	Proportion Successful	# Nests	Proportion Successful
Red-tailed Hawk	0	-	1	1	0	-
American Kestrel	1	0	0	-	0	-
Mourning Dove	0	-	0	-	1	1
Anna's Hummingbird	0	-	3	0.67	3	0.33
Allen's Hummingbird	0	-	5	0.20	4	1
Downy Woodpecker	0	-	1	1	1	1
Hairy Woodpecker	0	-	0	-	1	1
Red-shafted Flicker	0	-	2	0.50	0	-
Olive-sided Flycatcher	1	0	0	-	0	-
Black Phoebe	2	0.50	2	1	0	-
Tree Swallow	0	-	0	-	2	1
Chestnut-backed Chickadee	0	-	2	1	3	0.67
Bushtit	3	0	5	0.4	2	0.50
Pygmy Nuthatch	2	1	2	1	2	0.50
Swainson’s Thrush	7	0.14	3	0.67	5	0
American Robin	3	0.33	17	0.29	15	0.27
Wilson’s Warbler	4	0	5	0	3	0
California Towhee	1	1	3	0.33	1	0
Song Sparrow	2	0.50	5	0.60	10	0.40
Black-headed Grosbeak	1	1	1	0	5	0.40
House Finch	0	-	3	0	0	-
American Goldfinch	0	-	1	0	1	0
Brewer’s Blackbird	1	1	0	-	1	0
European Starling	0	-	0	-	1	1
House Finch	0	-	0	-	1	0

Table G-5. Number of adults, young, unknown age, and total mist-net captures at Banducci during the autumns of 2001 and 2002 (15 August to 31 October). Average of the annual totals is also presented. Species are listed from most common to least common based on 2-year average. RHVJ (2000) focal species are in **bold**.

	2001				2002				
Species	Adults	Young	Unk.	Total	Adults	Young .	Unk.	Total	Average
Song Sparrow	13	30	1	44	3	17	0	20	32
Hermit Thrush	2	35	0	38	13	12	0	25	31.5
Warbling Vireo	2	45	0	47	0	14	0	14	30.5
Pacific-slope Flycatcher	0	24	0	24	0	20	0	20	22
Swainson's Thrush	8	11	0	19	4	14	0	18	18.5
Wilson's Warbler	9	3	0	12	3	10	0	13	12.5
American Goldfinch	6	7	0	13	2	2	0	4	8.5
Fox Sparrow	1	5	0	6	4	7	0	11	8.5
Lincoln's Sparrow	0	8	0	8	0	5	0	5	6.5
Golden-crowned Sparrow	0	3	0	3	2	6	0	8	5.5
Yellow Warbler	0	2	0	2	2	7	0	9	5.5
Spotted Towhee	4	3	0	7	1	2	0	3	5
Willow Flycatcher	1	4	0	5	1	0	0	1	3
Wrentit	0	0	0	0	0	6	0	6	3
Chestnut-backed Chickadee	0	1	1	2	2	1	0	3	2.5
Ruby-crowned Kinglet	1	3	0	4	1	0	0	1	2.5
Common Yellowthroat	1	2	0	3	0	1	0	1	2
Purple Finch	1	0	0	1	1	2	0	3	2
Winter Wren	0	2	0	2	0	2	0	2	2
Rufous Hummingbird	1	3	0	4	0	0	0	0	2
Bushtit	0	0	0	0	0	0	3	3	1.5
Hutton's Vireo	0	1	0	1	2	0	0	2	1.5
MacGillivray's Warbler	0	1	0	1	0	2	0	2	1.5
Orange-crowned Warbler	0	2	0	2	1	0	0	1	1.5
Puget Sound White-crowned Sparrow	0	2	0	2	0	1	0	1	1.5
American Robin	0	1	0	1	0	1	0	1	1
Bewick's Wren	1	0	0	1	0	1	0	1	1
Downy Woodpecker	0	1	0	1	0	1	0	1	1
Lesser Goldfinch	0	1	1	2	0	0	0	0	1
Western Scrub-Jay	0	0	0	0	1	1	0	2	1

Species	2001 Adults	2001 Young	2001 Unk.	2001 Total	2002 Adults	2002 Young .	2002 Unk.	2002 Total	Average
Western Wood-Peewee	1	1	0	2	0	0	0	0	1
Black Phoebe	1	0	0	1	0	0	0	0	0.5
Brown Creeper	0	1	0	1	0	0	0	0	0.5
Connecticut Warbler	0	0	0	0	0	1	0	1	0.5
Chestnut-sided Warbler	0	0	0	0	0	1	0	1	0.5
Golden-crowned Kinglet	0	0	0	0	0	1	0	1	0.5
Least Flycatcher	0	0	0	0	1	0	0	1	0.5
Nutall's White-crowned Sparrow	0	0	0	0	1	0	0	1	0.5
Sharp-shinned Hawk	0	0	0	0	0	1	0	1	0.5
Steller's Jay	0	1	0	1	0	0	0	0	0.5
Allen’s Hummingbird	0	0	0	0	0	1	0	1	0.5

Table G-6. Total number of waterbird individuals detected from surveys at Big Lagoon during the winter 2000–2001 (Dybala 2002). Site map showing survey locations provided in Appendix G.

Species	Pasture A		Pasture B		Riding Ring	
	2001	2002	2001	2002	2001	2002
Bufflehead (*Bucephala albeola*)	--	--	--	1	1	2
Killdeer (*Charadrius vociferous)*	--	--	1	--	--	3
Mallard (*Anas platyrhynchos*)	20	19	2	7	4	2

Bird species recorded at Big Lagoon on 1992-1993 surveys and as incidental sitings.

Table G-7

Numbered species were recorded during 10-min. station counts, arranged here in decreasing order of total abundance.

= total n all sightings
* observed at qualitatively surveyed beach station
• observed outside bird station boundaries or on non-survey day

Terrestrial Associates

Feeding on terrestrial vegetation/associated insects

Brewer's Blackbird	188	Audubon's Warbler	7	Black-throated Gray Warbler	•
Red-winged Blackbird	110	Swainson's Thrush	6	Brown Creeper	•
Pine Siskin	89	American Crow	5	California Quail	•
Song Sparrow	52	Hermit Thrush	5	Cedar Waxwing	•
House Finch	48	Northern Flicker	4	Downy Woodpecker	•
Chestnut-backed Chickadee	35	Black-headed Grosbeak	3	Olive-sided Flycatcher	•
Rock Dove	25	Purple Finch	3	Steller's Jay	•
American Goldfinch	21	Fox Sparrow	2	Townsend's Warbler	•
White-crowned Sparrow	21	Marsh Wren	2	Tri-colored Blackbird	•
Anna's Hummingbird	18	American Redstart	1	White-breasted Nuthatch	•
Wilson's Warbler	17	Hairy Woodpecker	1	Yellow Warbler	•
Golden-crowned Sparrow	17	House Wren	1	Bushtit	•
Mourning Dove	15	Lesser Goldfinch	1		
Scrub Jay	15	Pygmy Nuthatch	1		
European Starling	12	Rufous-sided Towhee	1		
American Robin	11	Bewick's Wren	1		
California Towhee	10				
Ruby-crowned Kinglet	10				

Aerial Insect Feeders

Tree Swallow	39
Barn Swallow	38
Northern Rough-winged Swallow	37
Black Phoebe	10
Cliff Swallow	10
Violet-green Swallow	10

Raptors

Turkey Vulture	4	American Kestrel	•
Red-tailed Hawk	1	Black-shouldered Kite	•
		Cooper's Hawk	•
		Great-horned Owl	•
		Northern Harrier	•
		Peregrine Falcon	•
		Red-shouldered Hawk	•

Wetland Associates

Benthic invertebrate feeders

Killdeer	21	Black Oystercatcher	•
Western Gull	7	Marbled Godwit	*
Herring Gull	3	Ring-billed Gull	*
Lesser Yellowlegs	1	Whimbrel	•
Spotted Sandpiper	1	Willet	•
Mew Gull	•	Brown Pelican	•
Wandering Tattler	•	California Gull	•
		Common Snipe	•

Piscivores

Great Blue Heron	8	Double-crested Cormorant	1
Snowy Egret	7	Horned Grebe	1
Black-crowned Night Heron	4	Green-backed Heron	•
Belted Kingfisher	2	Osprey	•
Great Egret	2		

Feeding on aquatic vegetation/associated invertebrates

Mallard	119	American Coot	•
American Wigeon	105	Cinnamon Teal	•
Common Yellowthroat	3	Brant	•
American Green-winged Teal	1	Canada Goose	•
Barrow's Goldeneye	1	Common Merganser	•
Common Goldeneye	1	Eurasian Wigeon	•
Red-necked Phalarope	1	Virginia Rail	•
		Bufflehead	•

Source: PWA et al. (1994)

Number of bird species and individuals recorded at 15 stations in Big Lagoon, 1992-1993.

Table G-8

No.	STATIONS Locations	Approx. Size (m2)	TOTAL OBSERVED (total all surveys) species	indiv.	# SURVEYS	AVERAGE #/SURVEY species mean	species sd	individuals mean	individuals sd	AVERAGE #/m2 (x.001) species rank	species mean	species sd	individuals rank	individuals mean	individuals sd
1	Lagoon	7000	26	97	10	2.6	3.20	9.7	7.45	10	1.3	1.60	10	4.9	3.73
2	Riparian Footpath	600	24	159	10	2.4	2.66	15.9	22.9	4	4.0	4.43	4	26.5	38.17
3	above bridge	600	15	45	9	1.7	1.39	5.0	2.5	8	2.8	2.32	9	8.3	4.17
4	above bridge	600	20	88	10	2.0	2.49	8.8	6.86	7	3.3	4.14	6	14.7	11.43
6	Redwood Creek	450	16	54	10	1.6	1.26	5.4	4.45	6	3.6	2.81	7	12.0	9.89
7		450	15	44	9	1.7	1.80	4.9	4.73	5	3.7	4.01	8	10.9	10.51
5	Riparian Vegetation	250	18	119	10	1.8	1.52	11.9	15.28	3	7.2	6.10	2	47.6	61.11
9		250	12	37	5	2.4	1.22	7.4	4.28	2	9.6	4.90	3	29.6	17.11
8	Pasture	2500	20	130	11	1.8	0.83	11.8	10.34	12	0.7	0.33	11	4.7	4.14
12		2500	17	83	12	1.4	1.45	6.9	5.01	13	0.6	0.58	13	2.8	2.00
13		2500	14	115	13	1.1	1.37	8.8	17.80	14	0.4	0.55	12	3.5	7.12
10	Dense willows	150	15	73	10	1.5	1.62	7.3	16.48	1	10.0	10.80	1	48.7	109.86
11	Kikuyu meadow	1600	13	277	9	1.4	1.59	30.8	75.23	11	0.9	0.99	5	19.2	47.02
20	Beach (qualitative)	n/a	10	142	10	1	1.5	14.2	16.78						
30	Chaparral	500	4	5	4	1.0	0.82	1.3	0.96	9	2.0	1.63	14	2.5	1.91

Source: PWA et al. (1994)

APPENDIX H
TERRESTRIAL MAMMALS

Table H-1

Terrestrial mammals occurring historically or currently within the Big Lagoon wetland and riparian areas and adjacent habitats. I = introduced from North America; A = alien, introduced from outside North America; P = potentially present; E = extirpated; CSC = California species of special concern; 2 = Federal candidate for listing. (From Takekawa et al. 2003)

Common name	Scientific name	Note
MARSUPIALS		
Oppossums (Didelphidae)		
Oppossum	*Didelphis marsupialis*	I
INSECTIVORES		
Shrews (Soricidae)		
Ornate Shrew	*Sorex ornatus*	
Pacific Shrew	*Sorex pacificus*	
Trowbridge Shrew	*Sorex trowbridgei*	
Vagrant Shrew	*Sorex vagrans*	
Moles (Talpidae)		
Shrew Mole	*Neurotrichus gibbsii*	
California Mole	*Scapanus latimanus*	
BATS		
Evening bats (Vespertilionidae)		
Pallid Bat	*Antrozous pallidus*	CSC
Big Brown Bat	*Eptesicus fuscus*	
Red Bat	*Lasiurus borealis*	
Hoary Bat	*Lasiurus cinereus*	
Pacific Western Big-eared Bat	*Plecotus townsendiii townsendi i*	2
Western Pipestrelle	*Pipistrellus hesperus*	
California Myotis	*Myotis californica*	
Long-eared Myotis	*Myotis evotis*	
Little Brown Myotis	*Myotis lucifugus*	
Fringed Myotis	*Myotis thysanodes*	
Long-legged Myotis	*Myotis volans*	
Yuma Myotis	*Myotis yumanensis*	
Silver-haired Bat	*Lasionycteris noctivagans*	
Free-tailed Bats (Molossidae)		
Brazilian Free-tailed Bat	*Tadarida brasiliensis*	
Greater Western Mastiff Bat	*Eumops perotis californicus*	2
CARNIVORES		
Ursidae		
California Grizzly	*Ursus arctos*	E
Weasels (Mustelidae)		
Long-tailed Weasel	*Mustela frenata*	
Short-tailed Weasel	*Mustela erminea*	
Mink	*Mustela vison*	

Source: PWA et al. (1994)

Striped Skunk	*Mephitis mephitis*	
Spotted Skunk	*Spilogale putorius*	
Badger	*Taxidea taxus*	CSC
River Otter	*Lutra canadensis*	
Racoons (Procyonidae)		
Ringtail	*Bassariscus astutus*	
Raccoon	*Procyon lotor*	
Dogs (Canidae)		
Coyote	*Canis latrans*	
Gray Fox	*Urocyon cinereoargenteus*	
Red Fox	*Vulpes fulva*	P,A
Cats (Felidae)		
Mountain Lion	*Felis concolor*	
Bobcat	*Lynx rufus*	
RODENTS		
Mountain beavers (Aplodontiidae)		
Point Reyes Mountain Beaver	*Aplodontia rufa phaea*	2
Squirrels (Sciuridae)		
Yellow-cheeked chipmunk	*Tamias ochrogenys*	
Sonoma chipmunk	*Tamias sonomae*	
Douglas' Squirrel	*Tamiasciurus douglasii*	
California Ground Squirrel	*Spermophilus beecheyi*	
Western Gray Squirrel	*Sciurus griseus*	I,P
Gray Squirrel	*Sciurus carolinensis*	
Fox Squirrel	*Sciurus niger*	I,P
Pocket gophers (Geomyidae)		
Pocket Gopher	*Thomomys bottae*	
Pocket mice (Heteromyidae)		
California Kangaroo Rat	*Dipodomys californicus*	P
Native rats and mice (Cricetidae)		
Deer Mouse	*Peromyscus maniculata*	
Piñon Mouse	*Peromyscus truei*	
Western Harvest Mouse	*Reithrodontomys megalotis*	
Dusky-footed Wood Rat	*Neotoma fuscipes*	
California Vole	*Microtus californicus*	
Red Tree Vole	*Arborimus longicaudus*	CSC
Western Red-backed Vole	*Clethrionomys californicus*	
Muskrat	*Ondatra zibethica*	I
Old world rats and mice (Muridae)		
House Mouse	*Mus musculus*	A
Norway Rat	*Rattus norvegicus*	A
Black Rat	*Rattus rattus*	A
Jumping mice (Zapodidae)		
Point Reyes Jumping Mouse	*Zapus trinotatus orarius*	2 ,CSC

APPENDIX I
FISH SURVEYS

APPENDIX I

Summary of Fish Surveys

This section summarizes available data collected since 1992 to document fish distribution and abundance in Redwood Creek and its estuary. Fish surveys were conducted in 1992 and 1993 for the Preliminary Environmental Assessment (PWA et al., 1994). Subsequent investigations have included a report on the use of lower Redwood Creek and Big Lagoon by juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) (Fong, 1996), annual distribution and abundance surveys for juvenile coho salmon and steelhead (Smith, 1994b, 1995, 1996, 1997, 1998, 2000, 2001), salmonid outmigrant trapping in 1996 (Fong, 1997a), anadromous salmonid spawner and carcass surveys, conducted by NPS each winter from 1994 to the present (Fong, 1997c), and a study of the use of the Big Lagoon estuary (and other central California estuaries) by rearing coho salmon and steelhead (Laidig, 2003).

In addition to the limited aquatic habitat data collected as part of several of the above fish investigations, a comprehensive stream habitat inventory was conducted in 1995 by GGNRA staff (Fong, 2002). This inventory includes data on channel morphology, substrate, water temperature, habitat types, LWD, residual pool volume, streamside cover, riparian canopy density, and benthic macroinvertebrates for approximately five miles of Redwood Creek, from Big Lagoon upstream to Bridge 4 in Muir Woods National Monument. In a separate study, woody debris abundance and distribution in Redwood Creek from 1994–1996 were reported by Vore (1996) for reaches in and immediately downstream of Muir Woods.

Results of fish surveys are summarized below by three general reaches of Redwood Creek: the intermittently tidal lagoon, the backwater channel adjacent to the levee (near the parking lot) and just upstream of the footbridge. In addition to the species documented during these surveys, NPS has observed Sacramento blackfish (*Orthodon microlepidotus*) and yellowfin gobies (*Acanthogobius flavimanus*) at the site, and Fellers and Guscio (2003) observed Sacramento pikeminnow (*Ptchocheilus grandis*) in Green Gulch Creek.

INTERMITTENTLY TIDAL LAGOON

The intermittently tidal lagoon at Big Lagoon was sampled in 1992 and 1993 by seining (PWA et al., 1994). Water quality data were also collected in the lagoon in 1992 and 1993; the results are discussed in the Water Quality section (including timing of the opening/closing of the mouth of the lagoon). The lagoon was sampled again in February 1995 by electrofishing and in March and October 1995 using a combination of beach seine and snorkel techniques to document use by juvenile salmonids and other fish (Fong, 1996). In 2001 and 2002 the Big Lagoon estuary, including the tidal lagoon, was snorkeled repeatedly between March and December to document use by rearing salmonids over the course of each year (Laidig, 2003). The estuary between the ocean and the footbridge at Muir Beach was surveyed 34 times in 2001 and 27 times in 2002, and salinity and water temperature data were collected throughout the survey periods.

1992 and 1993 surveys. In 1992 the size and depth of the lagoon varied substantially with sand bar formation and streamflow. The sand bar was closed by 23 June and the deepest part of the lagoon was probably about 1.25 m (PWA et al., 1994). However, streamflows declined over the summer, and by 19 September there was no inflow and maximum lagoon depth had dropped to only 0.65 m. On 23 June, with a recently closed sand bar and good streamflow, the lagoon was mostly freshwater (0.6 ppt salinity), except for a thin layer of more brackish water on the bottom (PWA et al., 1994). In August and September the shallow, wind mixed lagoon was brackish and unstratified. The sand bar was by breached by a late September storm, but reformed; in November the lagoon was again deeper, very salty and stratified (PWA et al., 1994).

In 1993 the lagoon was open, shallow and stratified on 4 June (PWA et al., 1994). Runoff from a heavy storm on that day lowered the partial sand bar. On 9 June and 24 June the lagoon was shallow and draining at the time of sampling; during that part of the tidal cycle the lagoon was freshwater. On 19 August the sand bar was in place, and the lagoon was relatively deep (1.2 m) and stratified (PWA et al., 1994). By September low streamflows had reduced the lagoon to a shallow (0.65 m), unstratified, freshwater pool. Inflows in excess of 0.5 cfs are probably needed to keep the summer lagoon over 1.2 m deep and to back water into the adjoining salt marsh (PWA et al., 1994).

Because of wind mixing, dissolved oxygen levels in the lagoon were generally good in 1992 and 1993 (PWA et al., 1994). However, when detrital kelp was present (November 14, 1992) and during prolonged calm, overcast periods (September 10, 1993) dissolved oxygen levels were lower. However, because the lagoon was shallow and unshaded, afternoon water temperatures were often quite high (PWA et al., 1994). On 23 June 1992 early evening water temperatures throughout the water column reached 23.5 ^{o}C (75 ^{o}F). When the lagoon was stratified for salinity, the highest water temperatures were within the salt water lens near the bottom (August 19, 1993) (PWA et al., 1994).

Threespine stickleback (*Gasterosteus aculeatus*) were always abundant in the lagoon (PWA et al., 1994). In 1992 juvenile steelhead were common in the lagoon in August (PWA et al., 1994), despite the high afternoon water temperatures. Coho require cooler water, and none were collected in 1992. In 1993 both coho and steelhead were present on 4 June, but the storm on that day apparently flushed them from the shallow lagoon; none were seen in the lagoon during the remainder of the summer. In 1992 juvenile striped bass (*Morone saxatilis*) (to 7 inches long) were abundant in the lagoon. Other fishes collected in the lagoon in 1992 and 1993 were Pacific staghorn sculpin (*Leptocottus armatus*), starry flounder (*Platichthys stellatus*), and yellowfin goby (*Acanthogobius flavimanus*) (PWA et al., 1994).

No tidewater gobies (*Eucyclogobius newberryi*) were collected in either 1992 or 1993. Tidewater gobies tolerate a wide range of salinity, dissolved oxygen and temperature conditions and lagoon sizes, but require lagoons with some refuge from the high currents of winter floods. Big Lagoon presently has no backwater channels or salt marsh potholes to serve as winter refuges for gobies.

1995 Surveys. The mouth of the lagoon was reportedly open to the ocean during snorkel surveys on March 1 and March 30, 1995, and the mouth had closed by the time sampling occurred on October 31, 1995 (Fong, 1996). No water quality data were reported for the 1995 lagoon surveys.

Two steelhead smolts (147 and 178 mm) were observed during the February electrofishing survey in the lagoon, but no coho salmon were reported. Juvenile coho salmon were observed during both March snorkel surveys, with maximum coho density (0.05 fish/m^2) reported on March 30 (Fong, 1996). All coho salmon observed in the March surveys were < 35 cm in length. Juvenile steelhead were not observed on March 1 but were present in low numbers on March 30. The October 31 survey documented low numbers of juvenile steelhead in the lagoon but no coho salmon. Fong (1996b) theorized that juvenile coho salmon found in the lagoon in spring 1995 may have been displaced from more favorable upstream rearing habitat by competition or high flows. It was also noted that juvenile coho salmon likely do not rear in the lagoon during summer due to poor water quality (PWA et al. 1994), predation, or other factors.

All steelhead observed in the lagoon were found in water approximately 1 m deep, in association with rubble substrate (Fong, 1996). The majority (74 percent) of juvenile coho salmon observed in the late March surveys of the lagoon and upstream areas were associated with emergent or overhanging vegetation. Woody debris, including rootwads, (12 percent) and cobble substrates (7 percent) were the next most frequently used cover types, although it is unclear which of these features, if any, were present in the lagoon. Large amounts of filamentous green algae and decaying algae were noted on the bottom of the lagoon during the October snorkel survey (Fong 1996).

In addition to coho salmon and steelhead, Fong (1996b) also observed or collected topsmelt (*Atherinops affinis*), Pacific staghorn sculpin (*Leptocottus armatus*), striped bass, and threespine stickleback in the lagoon.

2001 and 2002 Surveys. Salinity and water temperature data were collected in the lower portion of the Big Lagoon project area during snorkel surveys in 2001 and 2002 (Laidig, 2003). Salinity in 2001 was low until late-May and fluctuated until early July in response to periodic salt water intrusion. Water in the estuary was largely fresh from early July through the end of 2001. In 2002 the estuary was freshwater until late April, after which the salinity fluctuated through November. Estuarine water temperatures in 2001 ranged from a low of 11°C in March to a high of 29.2°C in late August. In 2002, water temperatures followed a similar pattern, with a low of 12°C recorded in March and November and a high of 22°C in August.

In 2001, young-of-the-year (YOY) steelhead were first observed on June 12, and were present only in low numbers during the year (n=7) (Laidig, 2003). Abundance of smolts and age 1+ steelhead in 2001 was highest when they were first seen on March 26, with smolt abundance declining through April and May and the last smolt observed on June 23. Abundance of 1+ steelhead was lowest in early May, with a brief increase in mid-June followed by a decline to zero by mid-July. In 2001, YOY coho were only observed in the upstream end of the lagoon, immediately downstream of the Muir Beach footbridge (see the following subsection, *Redwood Creek, Pools Near Parking Lot*). Coho smolts in 2001 were first observed on April 22, and abundance peaked in early May. Coho smolts remained in the estuary for a total of 31 days, and none were observed during or following the May 27 survey.

In 2002, YOY steelhead were observed from late April to mid-August, with the peak abundance reported in mid-June (Laidig, 2003). Steelhead smolts and 1+ fish first appeared in the estuary in late March and early April, with peak smolt abundance in early May. Steelhead smolts were not observed after mid-June. Abundance of 1+ steelhead in 2002 peaked at nine fish in mid-June and declined to zero by mid-August. YOY coho were very abundant in 2002, with 150 fish observed during sampling in late May and numbers increasing to 900 fish by late April (Laidig, 2003). YOY coho were observed in the estuary until early September, 2002. Coho smolts in 2002 were first observed in late March, with numbers peaking at 60 fish in late April and dropping to nearly zero until they were last observed in early August.

In 2001, threespine stickleback and sculpin were also observed in the Big Lagoon project area (Laidig, 2003). Stickleback and sculpin were observed again in 2002, as well as striped bass, which were not seen in 2001. Striped bass, ranging in length from 100–150 mm, were present from April–June, and were believed to be feeding on YOY coho, steelhead, and possibly stickleback.

REDWOOD CREEK BACKWATER CHANNEL (NEAR PARKING LOT)

Immediately upstream of the intermittently tidal lagoon, a depositional delta, gabion bank protection, channel realignment and levee construction combine to produce a long, deep mid-channel pool and a backwater channel behind the creek levee (PWA et al., 1994). This portion of Big Lagoon was surveyed in 1992 and 1993 (PWA et al. 1994) and again in 1994 (Smith 1994b) and 1995 (Fong, 1996). Aquatic habitat data were also collected in this reach in 1995 (Fong, 1996; Fong, 2002). In 2001 and 2002, this area of the estuary was snorkeled to document its use as rearing habitat by juvenile coho salmon and steelhead (Laidig, 2003).

1992 and 1993 Surveys. Depth of the mid-channel pool during the 1992–1993 surveys was up to 1.2 m and depth of the backwater channel was up to 1.6 m. Neither habitat was well shaded, resulting in growth of abundant algae and rooted and floating aquatic plants. In addition, since the backwater channel is not scoured by winter flows, organic detritus up to 0.2 m thick accumulates on the bottom. Detrital algae, cattails and riparian leaves also accumulate in summer in the mid-channel pool.

The highest water temperatures in 1992 and 1993 briefly exceeded 20^{o}C near the surface in late afternoon, but cooled off substantially (15–18^{o}C) over night and during overcast periods. However, because of algal growth and detrital decomposition, the pools experienced low summer dissolved oxygen levels in morning and during cloudy periods (PWA et al., 1994). During 19 September 1992 sampling, the dissolved oxygen levels ranged between 2.0 and 4.3 mg/l in the morning (PWA et al., 1994), and because of overcast, they increased little from photosynthesis during the day. Juvenile steelhead were observed in the morning gulping at the surface to force more highly oxygenated boundary water over their gills. At the time, there was no surface inflow from Redwood Creek to the pools. Even in 1993, when surface inflows were present, morning dissolved oxygen levels were mostly below 6.0 mg/l during August and September sampling (PWA et al., 1994). Near the foot bridge at the tail of the large mid-channel pool, dissolved oxygen levels near the bottom were often very low, even in the afternoon. Bottom disturbance by swimming dogs was usually responsible; most unleashed dogs crossing the bridge jumped in the water for a swim, and on one afternoon four dogs were counted splashing in the water within 15 minutes.

In 1992 and 1993 both coho and steelhead were abundant in the pools in early summer (PWA et al., 1994). Not only were numerous fish caught by relatively inefficient deepwater electroshocking, but schools of coho and steelhead were regularly seen. In 1992, however, both species disappeared over the summer, presumably due to poor dissolved oxygen levels. In 1993 coho and steelhead also declined substantially over the summer, but some fish were still present in September (PWA et al., 1994). PWA (1994) reported that the primary value of the pools for coho and steelhead was probably as feeding and resting areas in winter and spring for outmigrating smolts.

Threespine stickleback and prickly sculpin (*Cottus asper*) were common in the pools throughout the year. In both 1992 and 1993 yellowfin goby were also commonly collected. All gobies exceeded 80 mm standard length (adult size), so it is not known whether a reproducing population is established in the lagoon. In 1992 juvenile Sacramento blackfish (*Orthodon microlepidotus*) were present in the pools and in 1993 two Sacramento perch (*Archoplites interruptus*) were collected. Both species are present in a pond in Green Gulch, and occasional individuals probably enter the creek with pond overflow.

1994 and 1995 Surveys. Sampling in July 1994 documented use of the pools by steelhead, but no coho salmon were present in this area (Smith, 1994b). A total of one YOY steelhead and three older juvenile steelhead (age 1+ or 2+) were found in the pools in July 1994. Whereas juvenile steelhead at all sites sampled were found to be considerably more abundant in 1994 than in 1992 or 1993, abundance of juvenile coho salmon in 1994 was lower and their distribution was more restricted throughout Redwood Creek and Big Lagoon than in the two previous years (Smith, 1994b). Other species documented in July 1994 in the pools near the parking lot were threespine stickleback and prickly sculpin.

In 1995 the pools were sampled by seining and snorkeling (Fong, 1996). The maximum depth of the pools during October 1995 sampling ranged from 0.25–0.9 m, with dense overhanging vegetation and abundant woody debris. Most coho were found during April and May surveys, with 250 and 152 juvenile coho observed, respectively. Although this area appeared to be suitable habitat for summer rearing by coho salmon, coho apparently did not rear in the pools through the summer. Only one juvenile coho salmon was found during the October sampling. Abundance of juvenile steelhead was generally very low, peaking during the May sample period. Age 1+ steelhead were present in the pools in low numbers, and most were found near the channel bottom, in dense cover. Most steelhead observed in this area and upstream reaches were associated with emergent and overhanging vegetation, woody debris, and cobble substrates (>64 mm). It is likely that the number of steelhead was underestimated during the snorkel surveys due to their behavior and poor visibility (Fong, 1996).

Other fish species observed in the pools during the 1995 surveys were prickly sculpin, coastrange sculpin (*Cottus aleuticus*), and threeespine stickleback (Fong, 1996).

2001 and 2002 Surveys. In 2001, a total of five YOY coho were observed in this part of the estuary, all of which were located in the upstream end of the lagoon, immediately downstream of the Muir Beach footbridge. YOY coho were first observed on April 28 and none were found after mid-July. Coho smolts in 2001 were also observed in the pools near the parking lot. As noted above for the intermittently tidal lagoon, coho smolts were first observed on April 22, and abundance peaked in early May. Coho smolts remained in the estuary for a total of 31 days, and none were observed during or following the May 27 survey. Steelhead YOY and smolts were also present in 2001 in this portion of the estuary (Laidig, 2003). Details are described above in the *Intermittently Tidal Lagoon* section).

Distribution of rearing coho salmon and steelhead in the estuary in 2002 was not reported by Laidig (2003). Nevertheless, YOY coho salmon were reported to be "very abundant" in the estuary in 2002, and it can be assumed that YOY coho were present in the pools near the parking lot.

Laidig (2003) noted the presence of threespine stickleback and unidentified sculpin species in the estuary in both 2001 and 2002, and striped bass were observed in 2002. The exact location of these species was not reported, so their presence in the pools is speculative. Water quality data reported by Laidig (2003) for the estuary as a whole are summarized above (see the *Intermittently Tidal Lagoon* section).

REDWOOD CREEK - UPSTREAM OF FOOTBRIDGE

Systematic sampling of Redwood Creek upstream of the Muir Beach footbridge began in 1992 in association with the Big Lagoon restoration planning effort (PWA et al., 1994) and, with the exception of 1999, has taken place annually since then. Backpack electrofishing has been used each year to document fish distribution and abundance. Results are currently available through 2001 (Smith 1994b, 1995, 1996, 1997, 1998, 2000, 2001). In addition to these annual surveys, outmigrant trapping was used in 1996 to document outmigrating anadromous salmonids (Fong, 1997a), and coho salmon spawner and carcass surveys conducted each winter from 1994 to the present(Fong, 1997c).

Studies characterizing the aquatic and riparian habitat in portions of Redwood Creek upstream of the footbridge have also been conducted since 1994. These include a survey to document woody debris recruitment in and downstream of Muir Woods National Monument from 1994–1996 (Vore, 1996), and a 1995 stream habitat and benthic macroinvertebrate inventory (Fong, 2002). Daily water temperature at the Muir Beach footbridge (mid-February–mid-July) and daily Redwood Creek discharge (March–June) were also collected as part of the 1996 GGNRA salmonid outmigrant trapping program (Fong, 1997a). The 1996-1997 spawner and carcass survey included information on habitat type distribution and substrate composition for Redwood Creek (Fong, 1997c). Water temperature and water clarity were also apparently recorded during the spawner and carcass surveys but were not included in the report. The annual fall surveys to document distribution and abundance of juvenile coho salmon and steelhead in Redwood Creek have included limited information on dissolved oxygen and estimates of stream discharge (Smith 1995, 1996, 1997, 1998, 2000, 2001).

1992 and 1993 surveys. In 1992 and 1993 four stream sites, from the Muir Beach footbridge upstream to Muir Woods National Monument, were sampled by backpack electroshocker (PWA et al., 1994). In 1992 coho outnumbered steelhead in summer sampling at all four sites. In 1993 coho densities were similar to those of 1992, but steelhead densities substantially increased (PWA et al., 1994).

At the Pacific Way bridge, streamflows declined to only about 0.01 cfs in late summer 1992. Salmonid densities declined by almost 40 percent between July and November (PWA et al., 1994), apparently due to the loss of shallow run and riffle habitat for rearing. In 1993 collected coho were less abundant than in 1992, reducing total coho and steelhead density compared to 1992 (PWA et al., 1994). Part of the observed difference was due to inability in 1993 to sample a pool that in 1992 had both high fish densities and a high proportion of coho. Threespine stickleback and some prickly sculpin and coastrange sculpin were also collected at the site. Although the site has primarily fine gravel and sand substrate, some suitable steelhead and coho spawning sites are present.

Downstream of the agricultural and domestic diversions, Redwood Creek was reduced to isolated pools in 1992, although flows upstream of the diversion remained above 0.2–0.25 cfs. Dissolved oxygen levels were as low as 2.5 mg/l in some of the isolated pools, and coho density dropped by two thirds between September and November sampling (PWA et al., 1994). Total fish density at the end of the summer was probably less than 20 percent of that of the site upstream of the diversion, and less than 16 percent of the next site downstream, where summer flows dropped to only 0.01 cfs (PWA et al., 1994). In 1993 streamflows were maintained at the site and total coho and steelhead density was 9 times that of 1992 (PWA et al., 1994). In 1993 most of the fish present were steelhead. Threespine stickleback and some prickly sculpin and riffle sculpin were also collected. Substrate at the site includes more sand and finer gravel than upstream, but suitable coho and steelhead spawning sites are present. Pool development is also less than at upstream sites, possibly partly due to bank modifications.

Upstream of the third bridge on Redwood Creek, within Tamalpais State Park, fish densities were substantially less than at Muir Woods in both 1992 and 1993 (PWA et al., 1994), despite good pool and cover development and substrate conditions. The site is very heavily shaded (99 percent canopy), and fish production may be limited by food availability. Threespine stickleback, prickly sculpin and riffle sculpin were also collected.

At Muir Woods, coho salmon were very abundant (84 to 91 fish per 100 feet) in both 1992 and 1993, and in 1992 coho outnumbered steelhead by over 3 to 1 (PWA et al., 1994). The high fish abundance and dominance by coho reflect good pool and cover development and excellent substrate conditions. Riffle sculpin were also abundant at the site, and some prickly sculpin were also present.

1994–1998, 2000, and 2001 Surveys. Annual fall electrofishing surveys have been conducted by Dr. Jerry Smith of San Jose State University to document the distribution and abundance of coho salmon and steelhead in Redwood Creek (Table I.1). Results of these surveys have documented the regular presence of both coho salmon and steelhead at sites from the Pacific Way bridge upstream to Muir Woods, although not all sites were sampled in all years. Annual variability in the relative abundance of these salmonids has been attributed to differences in habitat conditions and life history traits (Smith, 2001).

Table I.1 Habitats sampled and estimated mean number of coho and steelhead per 100 feet in Redwood Creek in 1994–1998, 2000, and 2001

Sample Date	Number of Sites	Habitat Types Sampled				Total Length Sampled (feet)	Fish/100 feet		
							Coho[a]	Steelhead	
		Pool	Glide	Run	Riffle			0+	1+, 2+
Jul 1994	7	58	25	12	6	1,287	2	69	14
Oct 1994	5	83	10	4	3	1,018	2	34	6
Aug 1995	4	41	30	19	10	796	42	97	4
Nov 1996	3	51	31	11	7	604	39	33	11
Sep–Oct 1997	5	72	18	9	1	984	23	15	5
Oct 1998	5	58	25	15	1	1,174	32	47	4
Oct 2000	6	71	27	3	0	1,077	1.1	39	15
Oct 2001	5	78	15	0	7	956	27	6	6

[a]All coho salmon are assumed to be young-of-the-year (YOY)

Source: Smith, 2001

Sampling has shown high juvenile coho salmon recruitment in 1992/1995/1998, as well as 1993/1996. Because female coho salmon in this part of their range generally spawn as 3-year olds (Shapovalov and Taft, 1954), these year classes represent subsequent years in the 3-year cycle. Other year classes since 1992 (i.e., 1994/1997/2000) have been comparatively weak. Coho abundance was extremely low in 1994 and 2000, and about 50 percent lower in 1997 (Table 4.2-9). Similar patterns have also been documented for coho salmon in Santa Cruz County and San Mateo County streams (Smith, 2001).

Steelhead, due to their ability to return to the ocean after spawning and their tendency to spawn at a variety of ages, have not shown pronounced annual variability in abundance in Redwood Creek. Abundance of YOY steelhead, however, was particularly low in 1997 and 2001, and particularly high in

1995 (Table 4.2-9). Smith (1997, 2001) attributes low YOY steelhead abundance to loss of suitable rearing habitat and reduced food availability resulting from low summer and fall stream flows, especially at the most downstream sites. The impacts of low summer and fall flows on steelhead and coho salmon may also be exacerbated by groundwater pumping from the wells that supply the town of Muir Beach and impoundments at Green Gulch Farms, especially in years with low rainfall.

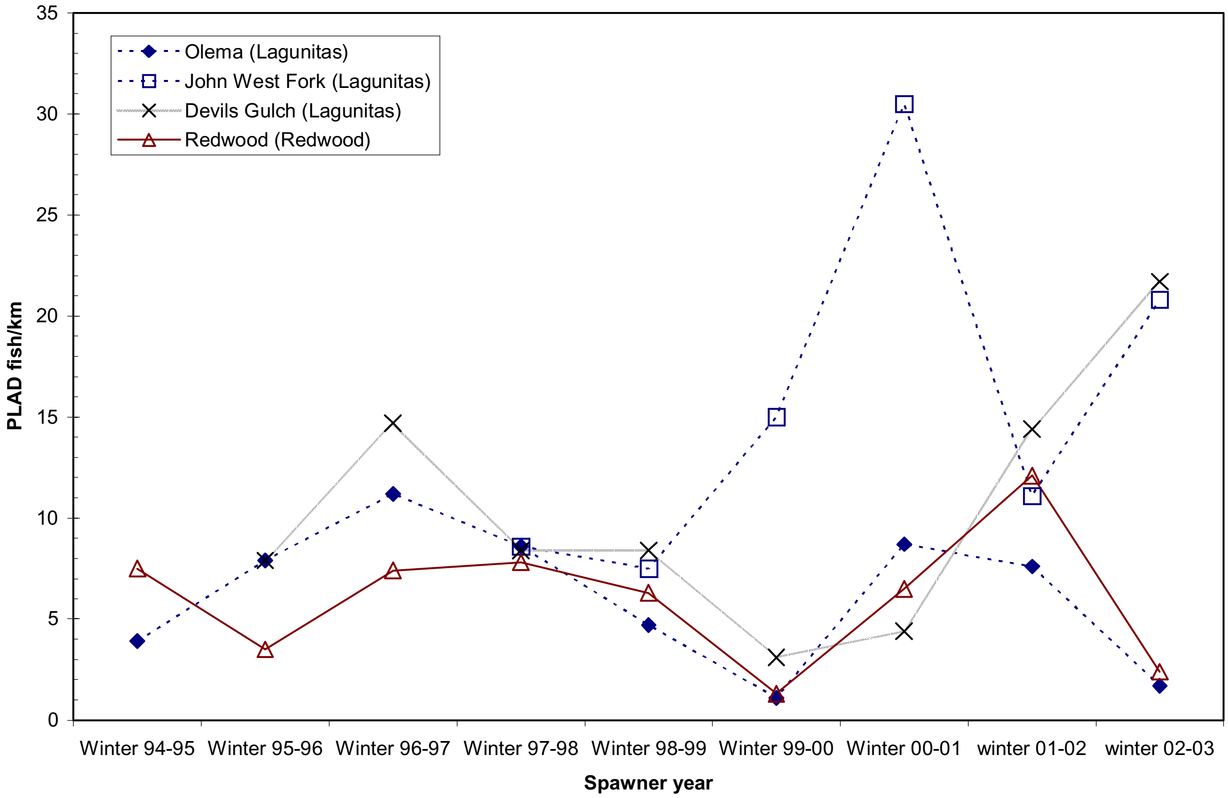
Survey data have indicated that coho salmon and steelhead year class success in Redwood Creek may be highly dependent on habitat and flow conditions (e.g., Smith 1997, 2001). By dewatering shallow habitats and reducing pool volume, low flows can reduce food availability by lowering benthic macroinvertebrate production and can limit the amount of suitable rearing habitat. Low flows may also result in poor water quality due to increased temperatures and reduced dissolved oxygen levels. Conversely, high winter flows can damage redds, reconfigure the stream channel, and displace rearing salmonids from preferred rearing habitat. The availability (i.e., distribution and abundance) of valuable instream cover, especially woody debris in upper stream reaches, is largely responsive to high flows. Vore (1996) found that woody debris in Redwood Creek appeared to be recruited to upstream reaches during the winter of 1994-95 and redistributed downstream in 1996 in response to storm events.

Outmigrant trapping during spring of 1996 documented at least five fish species at the trap location in lower Redwood Creek. In addition to coho salmon (YOY, juveniles, and smolts) and steelhead (YOY, juveniles, smolts, and adults), threespine stickleback, prickly sculpin, and other unidentified sculpins were captured in the trap (Fong, 1997a). The majority of fish captured were YOY coho salmon and steelhead, which together accounted for 87 percent of all fish trapped. Fry of both species appeared to emigrate downstream in response to high flows, with the peak capture of YOY fish occurring in mid- to late March when average flows were highest. In contrast, outmigration peaks for coho salmon and steelhead smolts did not appear to correspond with peak flow events (Fong, 1997a). Peak capture of emigrating smolts occurred from late April through mid-May, at which time flows were relatively low. Coho salmon production for the Redwood Creek watershed was estimated at 60.5 fish/km. This falls within the lower end of the range reported for Waddell Creek in Santa Cruz County (34–1,120 coho/km) by Shapovalov and Taft (1954). Steelhead production was estimated at 1.3 fish/km. These estimates, however, could not be confirmed because trap efficiency was not assessed and the duration of the trapping period may not have captured the entire outmigration period.

The spawner and carcass surveys conducted each winter since 1994 have documented spawning by coho salmon and steelhead in the Redwood Creek watershed. Counts are conducted once every two weeks during the winter months, following the sampling protocol developed the the Redwood Creek watershed in Humboldt County (Redwood National Park) by Dave Anderson and others (Haux and Anderson, 1992 as cited in Fong, 1997c). Figure I-1 summarizes the coho salmon data collected to date. Counts are represented as the sum of peak live and accumulated dead per kilometer surveyed. Since this is the peak number of coho (dead and alive) during a single count, the index represents the minimum number of spawners observed during each survey period. Total distance surveyed varies somewhat each year because in some years the NPS did not survey Kent Canyon.

CDFG also conducted counts in 1969, 1977, and 1985. These counts included smaller portions of Redwood Creek and did not use the same methods as those used by NPS 1994-current.

Figure I-1: Peak live and accumulated dead coho salmon per mean survey distance for select streams in the Lagunitas Creek and Redwood Creek watersheds, Marin Co.



APPENDIX J
SPECIAL STATUS SPECIES

Table J-1. Special-status species recognized by CNPS that may have historically occurred at Big Lagoon. Code is the status recognized by CNPS: larger numbers indicate greater problem concerning a) rarity, b) endangerment, c) distribution.

Scientific Name	Common Name	Code	Habitat
Alopecurus aequalis var. *sonomensis*	Sonoma alopecurus	3-3-3	marsh
Elymus californicus	California bottlebrush grass	1-1-3	forest
Calamagrostis crassiglumis	Thurber's reed grass	3-3-1	marsh
Campanula californica	Swamp harebell	2-2-3	marsh
Cordylanthus maritimus var. palustris	Point Reyes bird's beak	2-2-2	salt marsh
Erysimum franciscanum	San Francisco wallflower	1-2-3	dunes
Layia carnosa	Beach layia	3-3-3	dunes
Lupinus tidestromii var. layneae	Point Reyes lupine	3-3-3	Dunes
Pleuropogon refractus	Nodding semaphore grass	1-2-1	forest
Polygonum marinense	Marin knotweed	3-3-3	salt marsh

Modified from PWA et al. 1994

Table J-2. Special Status Bird Species at Big Lagoon

Taxon	Season[a]	Habitat[b]	T&E[c]	Fully Protected[d]	CA BSSC[e]	USFWS 2002[f]	WatchList 2002[g]	Natural Heritage[h]	IUCN 2000[i]
Common Loon (*Gavia immer*)	W	C	-	-	EX	-	-	1	-
California Brown Pelican (*Pelacanus occidentalis californicus*)	P	C, O	SE, FE	X	-	-	-	1/2	-
Double-crested Cormorant* (*Phalacrocorax auritus*)	P	C, O, A	-	-	-	-	-	3	-
Black-crowned Night Heron* (*Nycticorax nycticorax*)	W, P	R	-	-	-	-	-	3	-
Wood Duck* (*Aix sponsa*)	W, P	R	-	-	-	-	-	2	-
Osprey* (*Pandion haliaetus*)	S, P	A	-	-	-	-	-	3	-
White-tailed Kite* (*Elanus leucurus*)	M, P	A	-	X	-	-	-	3	-
Northern Harrier* (*Circus cyaneus*)	M, P	A	-	-	2	-	-	3	-
Sharp-shinned Hawk* (*Accipiter striatus*)	W, P	R, G	-	-	-	-	-	3	-
Cooper's Hawk* (*A. cooperii*)	W, P	R, G	-	-	-	-	-	3	-
Ferruginous Hawk (*Buteo regalis*)	W	A	-	-	-	-	Y	-	LR
Merlin (*Falco columbarius*)	W	A, H	-	-	-	-	-	3	-
American Peregrine Falcon (*Falco peregrinus anatum*)	W, P	A	SE	X	-	X	-	2B, ?N	-
Black Oystercatcher (*Haematopus bachmani*)	P	O	-	-	-	X	Y	-	-
Whimbrel (*Numenius phaeopus*)	W	B	-	-	-	X	Y	-	-
Long-billed Curlew (*Numenius americanus*)	W	B	-	-	-	X	R	2	LR
Marbled Godwit (*Limosa fedoa*)	W	B	-	-	-	X	Y	-	-
Black Turnstone (*Arenaria melanocephala*)	W	O	-	-	-	X	Y	-	-
Surfbird (*Aphriza virgata*)	W	O	-	-	-	-	Y	-	-
Heermann's Gull (*Larus heermanni*)	M	C, B	-	-	-	-	R	-	LR
California Gull (*L.*	W	C, B	-	-	-	-	-	2	-

Table J-2. Special Status Bird Species at Big Lagoon

Taxon	Season[a]	Habitat[b]	T&E[c]	Fully Protected[d]	CA BSSC[e]	USFWS 2002[f]	WatchList 2002[g]	Natural Heritage[h]	IUCN 2000[i]
californicus)									
Elegant Tern (*Sterna elegans*)	M	C, A	-	-	3	X	R	1	LR
Band-tailed Pigeon* (*Columba fasciata*)	P	A, G	-	-	-	-	Y	-	-
White-throated Swift* (*Aeronautes saxatalis*)	S, P	A	-	-	-	-	Y	-	-
Rufous Hummingbird (*Selasphorus rufus*)	M	R, U, G	-	-	-	-	Y	1/2	-
Allen's Hummingbird (*S. sasin*)	S, W	R, U, G	-	-	-	-	Y	-	-
Belted Kingfisher* (*Ceryle alcyon*)	W, P	F, C	-	-	-	-	-	3	-
Nuttall's Woodpecker* (*Picoides nuttallii*)	M, P	R, G	-	-	-	-	R	-	-
Olive-sided Flycatcher (*Contopus copperi*)	S	R, G	-	-	2	-	Y	-	-
Willow Flycatcher (*Empidonax traillii*)	M	R	SE	-	-	-	Y	1/2	-
California Swainson's Thrush (*Catharus ustulatus oedicus*)	S	R	-	-	3		-	-	-
Wrentit* (*Chamaea fasciata*)	P	R, H	-	-	-		Y	-	-
American Pipit (*Anthus rubescens*)	W	U, H	-	-	-		-	2	-
Yellow Warbler* (*Dendroica petechia*)	M, S	R	-	-	2		-	-	-
Hermit Warbler* (*Dendroica occidentalis*)	M, W	R, G	-	-	-		Y	3?	-
San Francisco Common Yellowthroat* (*Geothlypis trichas sinuosa*)	W, P	F	-	-	1	X	-	2	-

Table J-2. Special Status Bird Species at Big Lagoon

Notes:

Species with that are underlined are confirmed breeders within the Big Lagoon project area. Species with an asterisk* breed in Marin County.

[a] Season that the species will mostly likely be detected at the Big Lagoon project area (as determined by Stallcup 1995) and secondarily (if applicable) its status in Marin County (based on Shuford 1993, PRBO unpubl. data). W = Winter: mostly winter also late fall and spring migrant, S = Summer: mostly summer also early fall and spring migrant, M = Migrant: passing migrant (many nest nearby), P = Permanent Resident: present all year.

[b] Habitat where the species will most likely be detected at Muir Beach /Big Lagoon (as determined by Stallcup 1995). A = Aerial: flying above, B = Beach, C = Cove: foraging cove to 200 meters off Muir Beach, O = Rocks: offshore rocks or headland cliffs. F = Freshwater marsh, H = Horse pasture and fences, R = Riparian: willow and alder forests, G = Gardens: town edge including pines, U = Upland: dry weedy areas.

[c] Species listed as threatened or endangered by state or federal law. SE = state endangered and, FE = federally endangered. The federal government no longer maintains a list of Category 1 and Category 2 candidates for consideration for possible addition to the List of Endangered and Threatened Wildlife (USFWS 1996). Taxa are now considered "candidates" only if a proposed listing is likely (equivalent to former Candidate 1 status). Taxa formerly listed as Category 2 candidates (of conservation concern but information not available to support listing) with occurrences in Big Lagoon are Ferruginous Hawk, Elegant Tern, Long-billed Curlew, San Francisco Common Yellowthroat.

[d] X = species listed by California state law as "fully protected."

[e] Species, subspecies, and distinct populations on the draft 2003 list of Bird Species of Special Concern in California (Shuford and Gardali in review). Numbered designations indicate priority levels within the list (1, 2, or 3; highest to lowest). FNS = listed as federally, but not state, threatened or endangered; EX = taxon extirpated from the state totally or in its primary seasonal or breeding role but never listed as state threatened or endangered.

[f] X = species on the USFWS list of "Birds of Conservation Concern 2002" that have been considered of concern in Bird Conservation Region 32 (Coastal California—U.S. portion only).

[g] The Audubon WatchList priority categories are: RED (R) = species identified by BirdLife International as Threatened or Near-threatened at the global level and all species identified by Partners In Flight as Extremely High Priority at the national level, YELLOW (Y) = the remaining species identified by Partners In Flight at the national level as of Moderately High Priority or Moderate Priority.

[h] Natural Heritage status rankings at the S (subnational) level for California (NatureServe 2001; see for expanded definitions). 1 = critically imperiled, 2 = imperiled, 3 = vulnerable to extirpation or extinction, ? = inexact or uncertain rank (reported only for taxa considered of concern by other lists in this table), N = rank refers to non-breeding population, B = rank refers to breeding population. Ranks separated by a slash (e.g., 2/3) indicate uncertainty as to the exact status of the taxon. Ranks for populations that are "apparently secure" and "demonstrably widespread, abundant, and secure" are not reported here.

[i] California species with IUCN global conservation status ranks (listed here in descending order of conservation concern): CR = critically endangered, EN = endangered (no California species assigned to this category), VU = vulnerable, and LR = lower risk (Hilton-Taylor 2000). All California species given "lower risk" status were placed in the sub-category of "near threatened" (close to qualifying for "vulnerable").

APPENDIX K
LIST OF PREVIOUS STUDIES

Appendix K

Prior Studies

Geomorphology:

Pacific Watershed Associates, Ltd. 2002. S.B. 271 Watershed Assesment and Erosion Prevention Planning Project for the Redwood Creek Watershed, Marin County, California. Prepared for Muir Beach Community Services District and CA DFG.

Stillwater Sciences. 2003. Sediment Budget for Redwood Creek Watershed, Marin County, California. Prepared for Golden Gate National Parks Association.

Hydrology/Water Rights:

Bennet, A. 1999. Redwood Creek longitudinal profile. Prepared for the National Park Service, Golden Gate National Recreation Area.

Johns, Alice. 1993. Redwood Creek Water Rights Assessment. Technical Report NPS/NRWRD/NRTR-93/16. National Park Service Water Rousers Division, Denver, CO.

Klein, R., G. Smillie, and J. Vick. 2002. Potential Interim Actions to Reduce Flooding adjacent to Lower Redwood Creek, Marin County, California. Prepared for the Golden Gate National Recreation Area, San Francisco, CA.

Leonardson, R. February 2003. Redwood Creek Topographic Data 2000-2002. Division of Natural Resources and Sciences Golden Gate National Recreation Area, San Francisco, CA.

Martin, L. 2000. Hydrogeology of the Muir Beach Community Services District Well Site Frank Valley, Redwood Creek, California, Golden Gate National Recreation Area. National Park Services Water Resources Division Technical Report NPS/NRWRD/NRTR-2000/265, Ft. Collins, CO.

National Park Service. July 2002. Lower Redwood Creek Interim Flood Reduction Measures and Floodplain/Channel Restoration. Draft Environmental Assessment. Golden Gate National Recreation Area. San Francisco, CA.

Paulson, H., B. Petersen, and S. Thurman. 2000. Redwood Creek Longitudinal Profile, Muir Woods Concrete Bridge to Bridge 4 in Muir Woods Monument, November 8 to December 12, 2000. National Park Service, Golden Gate National Recreation Area.

Philip Williams & Associates, Ltd., (PWA). January 1995. Analysis of Land Use Impacts on Water Quality and Quantity in Redwood Creek. Prepared for The National Park Service, Golden Gate National Recreation Area.

Water Quality:

Beutel, M., Beutel Environmental. June 1998. Golden Gate National Recreation Area Stormwater Monitoring Program 1997/1998. Final Report. Submitted to National Park Service Division of Resource Management and Planning Golden Gate National Recreation Area, San Francisco, CA.

Leach, P.S., M. Podlech, and R.J. Brown. 1997. Rodeo Valley/Tennessee Valley/Redwood Creek Water Quality Monitoring Report. October 1996-March 1997. Institute of Chemical Biology, University of San Francisco, San Francisco, CA. Prepared for the National Park Service, Golden Gate National Recreation Area.

Madej, M. 1989. Analysis of USGS Water Quality Data Marin Headlands GGNRA 1986-1988. Redwood National Park, Arcata, CA. Prepared for National Park Service, Golden Gate National Recreation Area.

Project Designs:

Philip Williams & Associates, Ltd. (PWA), Moss Landing Marine Laboratory, Jerry Smith, John Northmore Roberts and Associates, and Nancy Hornor. 1994. Preliminary Environmental Assessment of Wetland Restoration Alternatives for Big Lagoon at Muir Beach, Marin County. Prepared for California Department of Transportation, District IV.

Vegetation:

National Park Service. Various Dates. Compilation of Vegetation in Big Lagoon Project Area. Golden Gate. National Recreation Area. San Francisco, CA.

Wildlife:

Ely, E. 1993. Sensitive Species Herpetological Survey, Golden Gate National Recreation Area 1993. Prepared for the Golden Gate National Parks Association, San Francisco, CA.

Fong, D. 1997b. 1996 California Freshwater Shrimp (Syncaris pacifica) Surveys within Point Reyes National Seashore and Golden Gate National Recreation Area. Prepared for the National Park Service, Golden Gate National Recreation Area. Division of Natural Resource Management. San Francisco, CA.

Fong, D. April 2000. Winter 1998-2000 Frog Breeding Survey, Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area, Division of Resource Management.

Fong, D. December 2002. Western Pond Turtle (Clemmys marmorate) Inventory, Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area, Division of Resource Management.

Manning, D., R.W. Smith, B.J. Ketcham, and K.N. Kundargi. March 1999. Annual coho salmon spawner survey report: 1997-1998. Coho and steelhead restoration project. Unpublished document. 44 pp+appendices.

National Park Service. no date (digital file). Coho salmon and steelhead trout restoration project (CSRP) Powerpoint ™ posters. 2 pp. [215k]

Osbourn, M. 2001. Winter 2000-2001 Waterbird Survey, Golden Gate National Recreation Area. Prepared for the National Park Service, Golden Gate National Recreation Area. Division of Natural Resource Management. San Francisco, CA.

Rauber, A. 2000. Age and Growth of Coho Salmon and Steelhead Trout in Marin and San Mateo Counties. National Park Service, San Francisco, CA.

Fong, D. April 1999. 1997 California Freshwater Shrimp (Syncaris pacifica) Surveys Within Point Reyes National Seashore and Golden Gate National Recreation Area. Prepared for the Golden Gate National Recreation Area Division of Resource Management and Planning.

Fong, Darren. 1996a. Introduced aquatic animals in Golden Gate National Recreation Area (with emphasis on fish and crayfish), Natural resources aquatic ecology report Golden Gate National Recreation Area: Annual report 1994-1996.

Fong, D. 2002. Summer 1995 stream habitat and benthic macroinvertebrate inventory, Redwood Creek, Marin County, California. Prepared for the National Park Service, Golden Gate National Recreation Area. Division of Natural Resource Management and Science. San Francisco, CA. 70 pp. [2.1Mb]

Fong, D. 1997a. 1996 Outmigrant trapping program Redwood Creek, Marin County. National Park Service, San Francisco, CA.

Fong, D. February 1996b. Usage of Lower Redwood Creek and Big Lagoon by Juvenile Coho Salmon and Steelhead. Ecology Program 1995 Annual Report. National Park Service, Golden Gate National Recreation Area.

Fong, D. 1996c. 1994-1995 Redwood Creek spawner and carcass survey. Aquatic Ecology Program 1995 Annual Report. National Park Service, Golden Gate National Recreation Area.

Fong, Darren. 1997c. 1996-1997 Redwood Creek spawner and carcass survey. Golden Gate National Recreation Area, San Francisco, CA.

Gardali, T., C. Shoulders, D. Hatch, A.L. Holmes, S.E. Scoggin, and G.R. Geupel. 2001. Songbird monitoring in the Golden Gate National Recreation Area: A Multifaceted Tool for Guiding the Restoration of Redwood Creek. Park Science Volume 21, Number 1.

Hafernik, J. E. and D.L. Mead. 1992. Golden Gate National Recreation Area Rare Insect Inventory Project. Prepared for the Golden Gate National Parks Association and Division of Planning, Golden Gate National Recreation Area. San Francisco, CA.

May, Kenneth. 1954. A biological survey of Redwood Creek, Muir Woods National Monument, Mill Valley, California. September 30, 1954.

Scoggin, Sandra E. et. al. March 2000. PRBO. Assessment of Songbird Response to Cape-ivy Removal in the Redwood Creek Watershed: A progress report to the Golden Gate National Recreation Area.

Smith, J. 1995. Distribution and Abundance of Coho and Steelhead in Redwood Creek in August 1995. Dept. of Biol. Sciences, San Jose State University, CA.

Smith, J.J. 1994a. The effect of drought and pumping on steelhead and coho in Redwood Creek from July to October 1994. Prepared for the National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 6 pp.

Smith, J.J. 1994b. Abundance of coho and steelhead in Redwood Creek in 1994. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 10 pp.

Smith, J.J. 1994c. Effects of streamflow reductions on fish habitat quality in Redwood Creek and lagoon. Prepared for the National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 4 pp.

Smith, J.J. 1996. Distribution and abundance of coho and steelhead in Redwood Creek in November 1996. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Smith, J.J. 1997. Distribution and abundance of coho and steelhead in Redwood Creek in Fall 1997. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Smith, J.J. 1998. Distribution and abundance of coho and steelhead in Redwood Creek in Fall 1998. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 12 pp.

Smith, J.J. 2000. Distribution and abundance of juvenile coho and steelhead in Redwood Creek in Fall 2000. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 8 pp.

Smith, J.J. 2001. Distribution and abundance of juvenile coho and steelhead in Redwood Creek in Fall 2001. Prepared for National Park Service, Golden Gate National Recreation Area. San Francisco, CA. 9 pp.

Takekawa, J.Y., M.A. Bias, I. Woo, S.A. Demers, and E.E. Boydston. 2003. A Small Mammal Survey at Big Lagoon. Draft Feb. 6, 2003.