2006

Shade and salinity in a coastal lagoon : what bugs the bugs?

Matthew Gregory Johnston
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Johnston, Matthew Gregory, "Shade and salinity in a coastal lagoon : what bugs the bugs?" (2006).
Master's Theses. 2890.
DOI: <https://doi.org/10.31979/etd.zdfm-2r44>
https://scholarworks.sjsu.edu/etd_theses/2890

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

SHADE AND SALINITY IN A COASTAL LAGOON:
WHAT BUGS THE BUGS?

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Matthew Gregory Johnston

May 2006

UMI Number: 1436916

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI[®]

UMI Microform 1436916

Copyright 2006 by ProQuest Information and Learning Company.

All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

© 2006

Matthew Gregory Johnston

ALL RIGHTS RESERVED

APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

Dr. Rachel O'Malley, Associate Professor

Dr. Lynne Trulio, Associate Professor

Donna Meyers, National Marine Fisheries Service

APPROVED FOR THE UNIVERSITY

ABSTRACT

SHADE AND SALINITY IN A COASTAL LAGOON: WHAT BUGS THE BUGS?

By Matthew Johnston

During the summer of 2000, macroinvertebrate samples were collected during the initial phase of the upgrade of the levees along the San Lorenzo River, in Santa Cruz, California, to determine the effects of adding shade to a coastal lagoon system. Samples were obtained from three microhabitats influenced by tides in the lagoon: 100% fresh water, partial inundation by salt water, and constantly inundated with salt water. Overall, there was more diversity of species in freshwater reaches than in saline, and more individuals in shaded areas than in areas exposed to full sun. This data suggests that (1) due to salinity, an EPT (*Ephemeroptera*, *Plecoptera*, *Tricoptera*) index is not appropriate for determining water quality in a coastal lagoon; (2) adding shade to a coastal lagoon may increase the abundance and diversity of macroinvertebrates that are an essential food source for salmonids.

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Related Research	3
The Effects of Riparian Canopy on Macroinvertebrates	4
Other Environmental Variables that Affect Macroinvertebrate Distribution	8
Restoration	10
METHODS	13
Study Site	13
Stream Morphology, Habitat, and Water Quality	20
Study Design	21
Data Collection	24
Data Analysis	26
RESULTS	27
Abundance Distribution	27
Mayfly	30
Caddisfly	31
Stonefly	32
Other Species	32
DISCUSSION	34
Lagoon Process	34

Findings	35
CONCLUSIONS	38
RECOMMENDATIONS	39
BIBLIOGAPHY	40

LIST OF FIGURES

Figure 1. San Lorenzo River Watershed	13
Figure 2. Conceptual Design of the San Lorenzo Levee Project	19
Figure 3. San Lorenzo River Study Area	23
Figure 4. Hester-Dendy Sampler	24
Figure 5. Sun versus Shade	27
Figure 6. Individuals by Reach	28
Figure 7. Diversity of Species: Sun versus Shade	29
Figure 8. Diversity of Species by Reach	29
Figure 9. Mayfly Distribution by Reach	30
Figure 10. Mayfly Distribution: Sun versus Shade	30
Figure 11. Mayfly Distribution in Freshwater	30
Figure 12. Caddisfly Distribution: Sun versus Shade	31
Figure 13. Caddisfly Distribution by Reach	31
Figure 14. Other Species: Sun versus Shade	32
Figure 15. Other Species by Reach	33

INTRODUCTION

The conceptual framework for this study of the effects of adding shade on the macroinvertebrate community in a channelized coastal lagoon includes the following facts: (1) that the collection of baseline biotic data is an essential and key element in evaluating the success of a restoration project (Bash and Ryan, 2002), (2) that success in planning a restoration effort requires a thorough understanding of ecosystemic parameters and dynamics (Bash and Ryan, 2002; Karr and Chu, 1998), and (3) that coastal lagoons are the primary rearing habitat for young salmonids before they go to sea (Pollard, 1994).

California rivers have been increasingly degraded over the past two centuries as a result of mining, timber harvests, construction of dams and water diversions, and more recently, as a result of intensive residential development throughout watersheds and on the river banks themselves (Brown and Krygier, 1970) (Burns, 1972) (Kondolff 1994, 1995). For coastal communities situated near rivers, the construction of levees has led to the development of historic flood planes and severe impacts on the coastal lagoon environment (Griggs and Paris, 1982) (Kondolff 1994, 1995). This landuse history has had profound effects on riparian ecosystems such as siltation of spawning gravels, increased temperatures, urban runoff that contains heavy metals and petrochemicals (May, et al., 1997) (Wang et al., 2001), and led to the demise of many riparian species, such as steelhead, coho, and tidewater gobies (Smith 1987, 1990). The Endangered Species Acts, both federal and Californian, mandate efforts by federal and state agencies to protect and restore threatened species. Steelhead (*Oncorhynchus mykiss*) and Coho salmon (*Oncorhynchus kisutch*) restoration efforts have included regulation of fisheries,

introduction of new stock, and significant investments in habitat restoration. Research has shown that coastal lagoons are valuable habitat for salmonids (Smith 1987, 1990). Many of these coastal lagoons have been degraded, but habitat restoration in these areas may conflict with levee building and other government efforts to protect public and private property from flooding.

Such is the case in Santa Cruz, California, where flood control concerns prompted the construction of levees and the channelization of the coastal lagoon on the San Lorenzo River. Irregular sand bar breaching, high water temperatures, and a dearth of vegetation resulted in a severely degraded lagoon ecosystem, limit the potential biological productivity of the lagoon (Smith 1987, 1990). Recognizing these problems, the City of Santa Cruz, California Department of Fish and Game (CDFG), and the Army Corps of Engineers (ACOE), in consultation with the Nation Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS), have supported research and management to improve riverine habitat and restore the salmonid fisheries (Swanson Hydrology et al., 2002). Together, these agencies have constructed the recent multimillion-dollar engineering project to modify the flood levee system and reintroduce vegetation within the levees. However, the lack of adequate biotic baseline data may inhibit efforts to monitor and assess the efficacy of restoration actions (Bash, 2002).

The City of Santa Cruz allows willow growth to establish annually along the banks of the San Lorenzo within the levees but the willows are culled back mid-summer each year just as water levels drop and temperatures climb. The City thins the willows to reduce drag on floodwater flows, thereby improving flood capacity. Recently the City

has allowed some of the emergent willow to mature and establish a row of trees that would provide some year-round shade farther into the channel that the annual sprouts can affect. The final stage of the levee upgrade involved building a wall at a bend in the river where flood forces had eroded the banks and some of the roadway above. The stretch of riverbank downstream from the wall to the ocean has no vegetative cover . The wall project included the planting of several hundred willow stakes to provide natural protection at the toe of the wall, and shade cover for the scour pool that forms there. This was completed in 2005. The levee raising also included planting alder and sycamore trees atop the levee that, when mature, will provide morning and evening shade to the lower reaches of the river.

This thesis explores the proposition that adding shade to the open reaches of the channelized river would improve habitat values across a range of reaches influenced by varied exposures of salt water, as reflected in the presence of key invertebrate species that serve as an indicator of the relative health of the ecosystem. The data provided here will assist planners in implementing effective measures to assist salmon survival and will be useful as baseline information for assessing the progress of the restoration aspect of the San Lorenzo River restoration project.

Related Research

Karr and Chu (1999), among others, show that macroinvertebrates can be used to determine the health of a stream and to monitor changes in habitat over time. By identifying the presence and relative abundance of groups of macroinvertebrate species

that are known to be more or less tolerant to water quality degradation, a researcher can determine the relative health of that stream. One of the most often used and studied indexes is the *Ephemeroptera*, *Plecoptera*, *Tricoptera* Index of Biotic Integrity, or EPT IBI (Plafkin et al., 1989, Hannaford and Resh, 1995). These three species are common throughout the United States and the world, and are easily sampled. Macroinvertebrate monitoring was the first type of monitoring widely used in the United States by volunteers to assess stream health (Ely, 2005). Macroinvertebrate monitoring has an advantage over chemical or physical monitoring in that the abundance and diversity of macroinvertebrates can show how well a stream can support living species both at the moment sampled and historically (Li et al., 2001; Barbour et al., 1992). Chemical monitoring only produces a snapshot image of the stream that could change day to day, and physical measurements indicate only what type of habitat is available, not whether it is utilized (Hannaford and Resh, 1995). Ideally all three parameters will be tested, but often financial considerations limit the amount of monitoring feasible.

The Effects of Riparian Canopy on Macroinvertebrates

Riparian canopy has been shown to have a wide range of effects on stream ecosystems (c.f., Towns, 1981; LeBlanc et al., 1997). Sunlight promotes algal growth, which is a source of primary productivity for the aquatic community (Sabater et al., 1998). Sunlight also raises water temperature (Dong et al., 1998), increasing invertebrate metabolism rates and food demand (Sabater et al., 1998).

For example, Towns (1981) conducted research in New Zealand examining the effects of artificial shading on periphyton and invertebrates and found that reducing the degree of sunlight accessible to the periphyton decreased the algal mass and affected the distribution of several invertebrate species. In this case, the link between periphyton and invertebrates is quite complex, with some species using it as a food source, others as cover, and often responding differently, either increasing or decreasing in abundance.

More recently, Kelly et al. (2003) looked at the effects of solar ultraviolet radiation (UVR), both mid-ultraviolet (UVB; 280–320 nm) and near ultraviolet (UVA; 320–400 nm), on benthic algal and invertebrate communities. Their study compared three reaches of a British Columbia coastal stream that differed in the degree of shading by riparian canopy (a full canopy, a partial canopy, and no canopy) and found that sites with less canopy shading had greater algal accrual, decreased biomass of total invertebrates, mayflies, and stoneflies, and reduced invertebrate community diversity compared to the heavily shaded reach of the stream. UVR produced responses in specific species that varied across sites and increased with increasing UVR as summer progressed. The results indicate that riparian shading may moderate UVR effects on benthic communities, mainly through impacts on invertebrates with indirect effects on algae. By reducing UVR exposure of streambeds, riparian canopies may be important for ameliorating UVR effects on shallow lotic systems, especially during late-summer, low-flow periods when dissolved organic carbon (DOC) concentrations are reduced. DOC in marine and freshwater ecosystems is one of the Earth's largest actively cycled reservoirs of organic matter; it is a source of energy and nutrients to the microbial food chain; by

attenuating UVR, it protects aquatic organisms from the harmful effects of this radiation, it restricts the depth of the euphotic zone, it stabilizes the depth of the thermocline, and it depresses primary productivity in lakes (Bushaw et al., 1996).

Hawkins, et al. (1982) looked at invertebrate guilds in six Oregon streams with varying degrees of canopy and substrates, and concluded that canopy type is more important than substrate character in influencing total abundance and guild character. The researchers suggest that the canopy affects the type and productivity of the periphyton, which in turn determines which invertebrate guilds are predominant in a given location, i.e.; scrapers and smaller taxa do better in areas with more shade and less algal growth, whereas the larger shredder/piercers thrive on more abundant stands of algae and macrophytes. Predators were determined to be positively correlated with larger prey, and therefore were predominantly found in open areas.

Another study that looked at the effects of canopy cover on stream macroinvertebrates focused on the ability of grazing snails (*Elimia clavaeformis*) to function at varying levels of sunlight (Hill et al., 1995). Through the use of plexiglass chutes placed in stream currents beneath natural streamside vegetation and in areas where the vegetation had been cleared away, researchers were able to vary the snail populations and lighting to measure the amount of periphyton that grew on ceramic tiles placed in the sample areas. Under normal snail populations, high sunlight produced more periphyton. However, consumption also increased to maintain the same level of standing biomass in both the sunny and shaded reaches, resulting in snails that grew larger and faster in the high sun areas.

Behmer and Hawkins (1986) conducted a study on the Blacksmith Fork River, Utah, which looked at the effects of overhead canopy on macroinvertebrate production. They found that seasonal production for most taxa at the open sites was twice that of the shaded sites, reflecting a difference in productivity of algae between sites, rather than a difference in invertebrate growth rates. They also found significant difference in biomass between sites for midges (*Chironomidae*) and four species of mayfly (*Ephemeroptera*), with a greater, but non-significant abundance of most other macroinvertebrates at the open sites. These differences were attributed to either higher food quality or a phototactic attraction to sunlit areas. The preponderance of midges in the shaded reaches was attributed to competition with the thickly matted algae on rock surfaces in the open areas that can smother the larvae.

Feminella et al. (1989) found a direct correlation between an increase in canopy cover and a decrease in periphyton on ceramic tiles elevated above the stream bottom. This study compared the elevated tiles to control tiles placed on the stream bottom, which were accessible to crawling invertebrate grazers (cased caddisfly larvae and snails). As periphyton increased from 15% to 98%, the periphyton on the elevated tiles decreased. The controls were not affected by the increasing canopy, suggesting that the grazers present could maintain low periphyton standing biomass across the range of canopy cover.

The studies above detail various cause and effect relationships between canopy and various aquatic communities. They show that the relationship between canopy and

ecosystem functions can be complex and can have a cascade effect on other aspects of the aquatic ecosystem.

Other Environmental Variables that Affect Macroinvertebrate Distribution

Canopy is but one of many factors that affect the aquatic ecosystem. Researchers have studied the effects of substrate, water chemistry, refuge availability, stream flow and seasonal changes on the macroinvertebrate community.

Rabeni and Minshall (1977) looked at the relationship between macroinvertebrates and current velocity, size of substrate, and detritus. They found that the particle size of the substrate affected the type of detritus material collected and available to the insects, with preference being shown for 2.5 - 3.5 cm sizes over all others.

Their findings are consistent with other studies that found a greater abundance and species diversity in faster currents and on preferable substrates, and that food sources are important in determining community structure (Wood and Armitage, 1997). Richards et al. (1993) looked at the physical and chemical factors influencing the structure of stream macroinvertebrate communities within a large agricultural catchment. They found significant correlations between substrate quality, from silt to cobble, and total numbers of *Ephemeropteran*, *Plecopteran*, and *Trichopteran* species. Borchardt (1993) studied the effects of flow and refugia on drift loss of benthic macroinvertebrates in an artificial stream. Her results highlighted the importance of in-stream structure to mitigate for drift loss due to high sheer stresses and unstable substrate. Scarsbrook and Townsend (1993) took Borchardt's (1993) study out of the lab and into the field, where they confirmed her

findings that streams with a high disturbance frequency and low refuge availability are characterized by a low invertebrate species diversity. Hilderbrand et al. (1996) found that placing large woody debris in stream channels changed the pool/run/riffle ratio, and while it did not affect the total benthic macroinvertebrate population, it increased numbers of *Ephemeroptera* and decreased numbers of *Plecoptera*, *Coleoptera*, *Trichoptera*, and *Oligochaeta*.

Tate and Heiny (1995) assessed the environmental factors that affect the benthic invertebrate communities of the South Platte River Basin at various scales, and found that those factors are scale dependent. They found greater species richness and more insect families in the mountain streams than in the plains streams. Detrended correspondence analysis indicated significant relationships between more diverse insect communities and lower water temperature, specific conductance, and nutrient concentrations.

A few researchers have analyzed the impact of a salinity gradient in a coastal river or estuary. Williams & Williams (1998) studied the insect community structure in an estuarine environment in North Wales. They sampled five locations along the salt water gradient of the Afon Aber Estuary, and found that the densities of most of the insect taxa decreased downstream of the sample site just above the extent of salt water intrusion, and that the distribution of most taxa was seasonal, moving downstream toward the mouth in higher flows and contracting upstream as flows dropped off in June and July. This shift was contrary to the authors' expectations, as the highest tides (and greatest salt water inundation) peaked in October and November with the higher flows, and were least intrusive in June and July. The authors noted that salinity tolerance increased as

temperature dropped, which may explain the winter distribution shift. They postulated that there may also be some correlation between the contraction into the more freshwater reaches and the emergence of the adult insects in summer as well, but this was not studied. Although salinity reduced macroinvertebrate diversity and abundance, significant numbers of freshwater insects were encountered even at locations that were inundated twice daily by the saltwater wedge.

Rundle et al. (1998) also looked at the macroinvertebrate community in the freshwater-estuarine transition zone. They found a distinct community just before the recognized transition from fresh and brackish water (salinity < 0.2 practical salinity units (PSU)). This transition community was made up of both freshwater and estuarine taxa, and remained significantly distinct from all other sample sites throughout the seasonal changes. The effects of varying salinity levels can be looked at in this study by sampling above, within, and below the saltwater influenced areas.

Research has shown that aquatic ecosystems react to a wide variety of environmental factors that can be studied in isolation. However, care must be taken in interpreting results of these studies to consider the wide range of pressures on any given system.

Restoration

Considering the status of salmonids in the San Lorenzo River system, any restoration or habitat improvement project can help slow the decline or improve the fisheries in this region. But monitoring the effectiveness of restoration projects can be

difficult to assess. A project must begin with specific goals, such as improving water quality, and must include the means to measure the success of attaining that goal, as through the changes recorded in regular monitoring of indicator species (Karr and Chu, 1998). Paramount to determining success is the establishment of baseline data with which to compare to post-project data (Karr and Chu, 1998). In 1995, the United States Army Corps of Engineers (COE) commissioned a research project to evaluate non-Corps restoration projects in North America (Shreffler et al., 1995). The authors studied 91 river, marsh, wetland and estuarian restoration projects throughout North America through telephone interviews and questionnaires. Of the 91 contacts, 39 responded with some information on project descriptions, goals, major engineering features, monitoring techniques, costs, and project performances. The project performance in many cases had no criteria established by which to measure success. Most projects made no reference to any baseline data in their monitoring plans, and ten of the 39 had no monitoring plan after completion. The approach taken in the San Lorenzo Restoration project was consistent with the projects reviewed by Shreffler et al. (1995), in that it lacked baseline data with which to measure the relative success of the restorative efforts. This thesis will provide a data set from which success criteria may be measured.

The research discussed above indicates that shade can have a variety of effects on the make-up of the aquatic invertebrate community. This study investigated specifically whether adding shade over lagoon areas with three different water saline conditions had an impact on the total abundance of macroinvertebrates and of the three main indicator species, *Ephemeroptera*, *Plecoptera*, and *Trichoptera*, and how these species were

affected by the saline gradient present in the San Lorenzo river lagoon. The innovative techniques employed in the levee project by the City of Santa Cruz and the Army Corps of Engineers, such as the lack of a root barrier within the levee and allowing for in-channel vegetation, provide an opportunity to study the effects on habitat and water quality of the peripheral shade incorporated into the project, and can provide further knowledge of methods to improve channelized lagoon systems for fish habitat. If these techniques are successful, an argument can be made for incorporating them into future Corps projects.

The hypothesis for this study is that adding shade to the open reaches of the channelized river will improve the habitat across a range of salt water-influenced reaches, as reflected in the presence of key invertebrate indicator species.

METHODS

Study Site

The San Lorenzo River watershed drains a 138 square mile area of coastal mountains located along the Central Coast of California (Figure 1). The river meets the

Figure 1. This map of the San Lorenzo River watershed was created from IKONOS satellite imagery by National Oceanic Atmospheric Administration (NOAA) Coastal Services Center for inclusion in the Salmonid Recovery Planning Information Resource for San Mateo and Santa Cruz Counties project, 2004.

Pacific Ocean at the north end of Monterey Bay in the City of Santa Cruz, approximately 112 kilometers south of San Francisco. The watershed is currently home to some 41,000 people, with 17,174 developed parcels (not including areas within the City of Santa Cruz). Approximately 3,150 of the developed parcels are located within the City of Scotts Valley. The large remainder of the watershed is unincorporated and includes the communities of Felton, Mt. Hermon, Ben Lomond, Brookdale, Boulder Creek, Lompico, and Zayante. All residents of the watershed derive their water supply from surface and groundwater in the watershed. The San Lorenzo River and its tributaries directly provide 60% of the water supply for the 90,000 customers served by the City of Santa Cruz (San Lorenzo River Watershed Management Plan Update, December, 2001).

The San Lorenzo River historically supported the largest salmon and steelhead fishery south of San Francisco Bay and the fourth largest steelhead fishery in the state (Boughton, 2003). For example, in 1965 the run of steelhead number approximately 20,000. Recent data from the California Department of Fish and Game estimate current levels at 15% of those 30 years ago, and coho are extirpated from this system (Boughton, 2003). Coho salmon and steelhead are now listed as threatened or endangered species. Historically, the watershed has been used for timber harvesting, and limestone quarrying, and both of these uses continue at a diminished level today. Agriculture in the watershed includes several small Christmas tree farms, orchards, nurseries, and vineyards. The tourist industry has been and continues to be important, with three state parks, scattered summer homes, and riverside motels. Summer homes were the dominant residential use in the watershed until the 1950s. After that time, summer homes were converted to year-

round use and the watershed experienced a high rate of residential development, peaking at some 3,300 new units built in the 1970s. With the exception of the City of Scotts Valley, and some small sewerred communities, some 13,000 properties are served by individual onsite sewage disposal systems. The rapid rate of development fueled by the conversion of second homes to year round use lead to extensive degradation of the river from failing septic systems, urban runoff, excessive erosion and sedimentation, and reduced stream flow from water extraction. Since the 1970s, considerable efforts have been undertaken to address these issues through the development and implementation of numerous resource management plans including the San Lorenzo River Watershed Management Plan (1979), Santa Cruz County Growth Management Plan (1980), North County Water Supply Master Plan (1984), San Lorenzo Wastewater Management Plan (1995), San Lorenzo Nitrate Management Plan (1995), and the Evaluation of Water Resources Monitoring and Management (1998). While many of these efforts made substantial progress toward addressing the problems of supply and water quality, the San Lorenzo River continues to be listed on California's 2002 Section 303(d) List of Water Quality Limited Segments due to sediment, nutrients, and pathogens. Steelhead levels continue to be depressed below historic levels, Coho salmon runs are nonexistent, and the majority of water customers served by the watershed do not have adequate, dependable long-term supplies. (San Lorenzo River Watershed Management Plan Update, December 2001)

Habitat degradation and declining fish runs have also been affected by engineering efforts to reduce the risk of flooding as the river enters the city of Santa

Cruz. Heavy rains in the winters of 1955 and 1959 caused severe flooding through the City of Santa Cruz. The Army Corps of Engineers worked with the City to construct a pair of levees 3-kilometers long through the downtown area. The design, as built, underestimated the volume of sediment that the river transported and that drops out once the river slows into the lagoon (Griggs and Paris, 1982). It also failed to predict the increase in development in the upper watershed, and the resulting increase in sediment load (Griggs and Paris, 1982). In order to maintain the designed capacity, the city was required to excavate hundreds of thousands of cubic yards of sediment each summer to gain flood capacity, although reaching design capacity was beyond the physical and fiscal means of the city (Griggs and Paris, 1982).

Storms in 1982 almost topped the levees and damaged one of the five vehicle bridges that cross the river in town, and the city once again enlisted the aid of the Army Corps of Engineers, this time to raise the existing levees (Swanson, 2002). Between the Corps and the City, plans for raising the levees and a conceptual design for habitat enhancement were developed: the 1987 San Lorenzo Design Concept Plan and the 1989 San Lorenzo River Enhancement Plan. The levee improvement project was stalled when the 1989 Loma Prieta Earthquake destroyed most of downtown Santa Cruz, and the plans were put on hold until the city could financially recover. The project was reinitiated in 1998 and work commenced on a three-phase project that broke ground in 1999 and was completed in 2005.

The levees stretch from the river mouth to the Highway 1 Bridge on the north side of town. Between the train trestle bridge that carries the tracks over the beach sand and

the highway bridge there are four local traffic bridges, in order from the coast; Riverside, Broadway / Laurel Street, Soquel, and Water Street bridges. Typically, a sandbar forms at the mouth of the San Lorenzo River sometime between July and September. When the sand bar at the mouth is not present, the saltwater wedge comes in with the highest tides as far inland as the Water Street Bridge. The San Lorenzo River sandbar is breached several times each summer either by surfers who want to surf the waves that form as the lagoon washes out, by tourists playing in the sand, or by unknown people who breach the lagoon in the dark of night.

When the sandbar forms and open exchange between the river and the ocean is blocked, the saltwater forms a lens on the floor of the lagoon (Griggs and Paris, 1982, Smith, 1987). As the lagoon fills the temperature of the water rises, with the colder inflow of fresh-water separating the warm saltwater lens from the warm fresh-water. If the sandbar remains in place, the building hydrostatic pressure forces the saltwater through the sandbar and can in some cases convert the lagoon to freshwater (Griggs and Paris, 1982, Smith, 1987).

When the sandbar is breached, the tides push the saltwater lens upstream until the sandbar closes again, once again leaving a saltwater lens. Because there is little to no mixing between the layers, the saltwater lens is subject to dramatic swings in dissolved oxygen (DO) as aquatic plants produce in the day and consume at night, and over time the DO can be totally depleted through the process of decomposition (Smith, 1990). Once the DO is gone, anoxic decomposition continues, producing hydrogen sulfide and ammonia gasses (Smith, 1990). When the lagoon is eventually opened, these toxic gasses

can mix into the entire water column and if concentrated enough, can kill off organisms throughout the entire lagoon (Smith, 1990).

As a result of the city involvement, levees were installed with restoration features never before included in an Army Corps flood control project. For example, in-stream vegetation was allowed to remain between the levees in some reaches, willow stakes were planted to prevent erosion at the toe of a constructed floodwall in a sharp bend in the river, and tall shade trees were planted along the top outer edge of the levees to eventually provide some morning and evening shade and wildlife habitat (Figure 2).

Figure 2. Conceptual Design of the San Lorenzo River Levee Project.
From the San Lorenzo Urban River Restoration Plan Task Force (SLURRP) website.

Stream Morphology, Habitat, and Water Quality

As the San Lorenzo River passes through the levee system in Santa Cruz, seasonal emergent growth, reeds, and sandy beaches characterize the reaches. The upper reaches of the San Lorenzo River, though heavily populated and impacted by excessive sediment and nutrient levels, retain a dense riparian canopy of redwood, willow, cottonwood, sycamore, alder, and other native and non-native vegetation throughout most of the entire watershed, down to the crossing of Highway 1 (Swanson, 2002). The final 3 kilometers of the river, as it runs between the levees through downtown Santa Cruz, is maintained by the City of Santa Cruz annually by cutting back the seasonal willow brush to decrease the roughness of the flood control channel. The in-stream sandbars are broken up either by tractor or drafting horse to allow the sand to mobilize in larger storm events. An occasional young alder or cottonwood rises above the wall of willow through the fresh-water and intertidal reaches, and into the coastal reach. The exception to this is in the downtown area where a 500-meter section in the center of town is benched to provide additional flood protection, and willow and alder have been allowed to mature along one side of the river. Sand bars are seasonally colonized by salt-tolerant grasses, and in the less saline reaches some aquatic plants grow along the stream edges (Swanson, 2002).

The substrate in the channelized reach is primarily sand and gravel, with a few patches and scatterings of cobble, and primarily sand and silt in the coastal reach. Water temperature varies through the summer. Highs reach into the 20's Celsius, but as the sandbar forms and closes the lagoon from the ocean, the water stratifies, with a saltwater

layer that retains heat on the bottom, and the colder incoming freshwater flowing in on top of the saltwater. As the freshwater warms, it rises and is displaced by the incoming colder water. The water retains a high nutrient load throughout the year, particularly in the rainy season when the ground is saturated and septic systems in the upper watershed leach into the river.

Study Design

Data collection for this research occurred from June through September of 2000. Using the bridges to define three separate reaches, sampling took place in the freshwater reach above the Water Street Bridge (2.3 kilometers from the mouth) where there is no saltwater influence, the intertidal reach between the Water Street and Soquel Street Bridges (1.7 kilometers from the mouth) with intermittent salt water influence, and the coastal reach between the Broadway/Laurel Street Bridge (1.25 kilometers from the mouth) and Soquel Street Bridge which is predominantly influenced by saltwater (Figure 3).

In June of 2000, after the seasonal rains, nine paired sample sites - three paired sites in each of the three reaches for a total of 18 samplers - were randomly selected. The three reaches are distinct from each other in the degree of tidal influence when the sand bar at the river mouth is open. The first reach is just above the uppermost extent of the saltwater lens at the highest tide and was considered completely freshwater. The second reach is occasionally affected by the waxing tide, and the coastal reach typically is inundated with a saltwater lens at all but lower tides (Smith, 1999).

All sample locations were set in a fully exposed (no canopy) area of the randomly selected transect, at a depth of approximately 0.5 to 1.0 meters at a tide of 1.6 feet and the river mouth open to the ocean.

Figure 3: San Lorenzo River Study Area

Three sample reaches on the San Lorenzo River are shown in this historic photo was taken by Ed Weber in 1967. The saline reach between the Soquel Bridge and the Broadway / Laurel Street Bridge, just above the bend in the river, the intertidal reach between the Water Street Bridge and the Soquel Bridge (this includes the smaller pedestrian bridge seen in the center of the photo), and the freshwater reach above the Water Street Bridge.

Data Collection

Hester-Dendy samplers, a series of identical, 3-inch, pressed-wood washers, separated by 1-inch washers, threaded onto an 8-inch eye-bolt, were anchored into small concrete blocks that were completely buried in the streambed. Each sampler carried 14 large washers, separated by 1, 2, 3, or 4 small washers, allowing each sampler to present an identical surface area to be colonized (Figure 4). The concrete blocks were cured in

Figure 4. Hester-Dendy Sampler

the bottom of a 5-gallon bucket and were between 2 and 3 inches thick, with a 1-inch long hex-bolt set into the center. The smooth, round, flat blocks were set flush with the substrate at each location, placing the sampler surfaces between 2 and 6 inches off the riverbed.

The river flows north to south through the entire test area. Pairs of samplers were set into the substrate about 3.0 meters apart, and one of the two samplers was randomly staggered 1.0 meters to the north.

The samplers were installed in the river in mid-June of 2000 in locations that were exposed to sun throughout the day. Samplers were collected and all invertebrates were removed and preserved following the guidelines set up in the EPA's Rapid Bioassessment Protocols (Plafkin et al., 1989). The initial colonization period was three weeks. Each sample was labeled and preserved in the field in a 70% ethyl alcohol solution. This collection was to establish a baseline population, to be compared with the treatment of added shade.

The samplers were replaced the following day, and a 1.5-meter square shade cloth cover set 0.5 meters above the water surface was installed on a rebar frame over the sampler staggered towards the north. The northern sampler was chosen to avoid the shadow of the shade cloth passing over the open sunlit sampler as the sun swings through the sky. The 1.6 meter rebar stakes were hammered into the stream bottom around each sampler, with the sampler itself set to catch as much of the shadow as possible. After six weeks, the samplers were removed; the macro-invertebrates collected and preserved as before, and the samplers were once again set in the river in the same locations. The final sampling period was three weeks. Three weeks was chosen for the final period as it was later in the season, and water temperatures were warmer, leading to higher metabolisms and quicker growth rates of the invertebrates. This allowed the entire process to be completed before the onset of the rainy season.

Data Analysis

Differences in the total abundance of invertebrate individuals, species richness, and the distribution of mayfly larvae (*Ephemeroptera*), caddisfly larvae (*tricoptera*), stonefly larvae (*plecoptera*), and all other species encountered were explored. Samples were identified to order, and averaged for each individual sampler in the analysis. The data produced by this study was analyzed using analysis of variance (ANOVA) with two primary categorical variables; sun vs. shade (two levels), and location in the lagoon (three variables; coastal, intertidal, and freshwater), using the program SYSTAT.

When the samplers were first set in the three reaches, the river mouth was open. The saltwater lens dropped to the river mouth at the lowest tides, and reached upstream to just below the fresh-water reach at the highest tides. Total immersion time in salt water in the coastal reach is estimated at 70-90%, 30-60% in the intertidal reach, and none at all in the freshwater reach. Once the river mouth closed, sometime in late July, the coastal reach sites were immersed 100% of the time in salt water and the intertidal reach varied in the 30-60% range as the lens seeped through the sandbar. During the course of this study the sandbar was breached several times, alternating between flowing and tidally influenced, and a more static, stratified lagoon. The effects of the breaching should not have an effect on the outcomes of the paired samplers, as the pairs were equally affected by any impacts.

RESULTS

Abundance Distribution

The effects of adding shade were most detectable in the coastal reach, where shaded sites collected approximately twice as many individuals than the exposed sites (Figure 5), although high variability and low replication weakened the statistical significance.

Figure 5. There was a strong trend ($P = .058$) toward more individuals in the shaded areas.

When the samples were analyzed by reach, the abundance of individual species was heavily weighted towards the coastal reach and intertidal reaches over the freshwater reach (Figure 6). Analysis of the species richness in sun versus shade found there was a tendency toward more species in the sun ($P = 0.11$, Figure 7), but there were significantly

more species in the freshwater region ($P < 0.00$) than the intertidal and coastal zones (Figure 8).

Figure 6. There were significantly more individual species ($P = .026$) in the coastal and intertidal reaches than in the freshwater reaches.

Figure 7. This study found a weak trend ($P = 0.113$) toward more species in the sun, with a mean of 3.8 species versus a mean of 3.4 species in the shade.

Figure 8. The freshwater region had significantly higher ($P < 0.000$) diversity than the intertidal and coastal reaches.

Mayfly

Mayflies were found only in the freshwater sites ($P < 0.000$, Figure 9), with a weak trend (0.11) toward more individuals in the shade. When taken together the trend strengthened ($P = 0.08$, Figure 10). When the natural log was taken, the P values for the trends were similar at 0.10 in the shade and 0.07 with all variables considered (Figure 11).

Figures 9 and 10. There are significantly more mayfly larvae in the freshwater reach than the reaches influenced by salt water. There is a weak trend toward more mayfly larvae in the shaded sample sites.

Figures 11. Few mayfly larvae were encountered in the saltwater influenced reaches. In the freshwater reach there is a strong trend toward more mayfly larvae in the shaded sites ($P = 0.07$).

Caddisfly

Significantly more Caddisfly larvae were found in freshwater ($P=0.02$), but were not significantly higher in the shade than in sun, due to high variability among sites.

Figure 12. Caddisfly larvae in shade were not significantly higher than in sun owing to high variability among sites.

Figure 13. More caddisfly larvae were found in the saltwater influenced reaches.

Stonefly

Stoneflies were discovered on a single sampler. As a result there were no significant distributions found.

Other Species

After separating out the three indicator species, all other insects found were grouped into a single category and analyzed for any significant differences either by reach or by solar exposure. As in the analysis of all individuals (Figure 5), the other species as a group were found in significantly greater numbers in the shade than in the sun (Figure 14).

Figure 14. Other species were counted as a whole and were found in significantly more numbers ($P = 0.02$) in the shade.

When analyzed by reach, other species as a group were found in significantly greater numbers in the areas affected by salt water (Figure 15), primarily due to the overwhelming presence of two saltwater-tolerant species of arthropods.

Figure 15. There was a strong trend away from the freshwater ($P = 0.07$). This trend was heavily weighted by two saltwater tolerant species that dominated the lower two reaches.

DISCUSSION

Lagoon Process

Lagoon function is controlled by a variety of factors including the amount of sediment transported along the coast, the size of the lagoon, the activity of the ocean related to climatic events, the amount of stream flow at various times of the year, and anthropogenic effects (Griggs and Paris, 1982, Smith, 1987, 1990). The San Lorenzo River lagoon has been shut off from its historic expanse and confined to the flood control channel. At the same time, the amount of summer water flow has dropped considerably.

The saltwater lens that enveloped at the sites in the coastal region and passed back and forth over the sites in the intertidal region had the most pronounced and significant effect on macroinvertebrate distributions. There relatively few types of aquatic species, flora or fauna, which have adapted to and can thrive in an environment that changes from fresh to saline regularly (Smith, 1999). Analyses of samples collected further upstream showed that the diversity of species increased with freshwater and lower water temperatures, changing in taxa from the two species of crustacean that dominated the coastal zone to a makeup more typical of a slightly impaired freshwater stream, with a combination of sensitive species (caddisfly, stonefly, mayfly) and more tolerant species (midges, worms) in the freshwater zone. Rundel, et al (1998) and Williams and Williams (1998) both found distinctions in the macroinvertebrate communities between the fresh and saline zones, with the actual zone moving up and down stream with the seasons. This is consistent with the findings of this study, in as much as the distinct zones were known. To accurately gage the movement of the saline/freshwater boundary, real-time

monitors would need to be installed with the samplers and data collection of physical parameters would need to be recorded throughout the colonization period.

Findings

This study found that macroinvertebrates prefer to colonize wooden structures in a sandy coastal lagoon that are shaded rather than fully exposed; that diversity of species, both sensitive and tolerant, is greater in freshwater than in brackish; and macroinvertebrates, overall, are more abundant in the saline reaches of the lagoon than in the freshwater. The results of this study are supported by the findings of Rundle et al., (1998) where increased salinity resulted in a low species diversity, and Williams and Williams (1998) who found that diversity dropped off as salinity influence increased. However, Williams and Williams also found that abundance decreased with increased salinity, which was contrary to the findings of this study. This may be due to seasonal factors, in that the Williams and Williams study sampled through the winter months and there was no sandbar and lagoon formation. These findings are relevant to fishery production. As water temperature increases, the metabolism of fish rearing in the lagoon rises, driving up their demand for food. This study indicates that by providing shade in the saline reaches of the San Lorenzo lagoon, we may be able to produce more food for fish.

Adding shade in the fresh-water reach produced less than significant results, but showed a trend toward a greater diversity of species found in the sites without shade. This trend is not supported by Kelly, et al (2003), who found that less canopy and more

solar exposure increased algal mass and decreased diversity. Algae was present on the samplers but was never seen to mat the sampler surface. This may be supported by Feminella, et al (1989), who determined that algae could be kept at a constant level by grazers. It also may be due to the interruption in growth that resulted from removing and replacing the samplers.

Different species of macroinvertebrates perform different functions in a system, often related to their food source; some insects eat leaf litter, some control algae and moss, some are predatory. A greater diversity of species allows for all the necessary functions of a healthy ecological system to take place. As a food source for fish, diversity allows for the overall macroinvertebrate community to persevere when individual species experience population crashes.

Where the differences in the coastal reach were probably temperature driven, in the fresh-water reach, sunlight and the resulting growth of algae on the samplers may have been the main factor in recruiting a greater variety of species. In the coastal reach, colonization of a sampler was limited to two species, and the space available was a factor. *Corophium* was the dominant specie, as well as some type of pill bug that was not identified. These invertebrates were much larger in size than the species found in the freshwater reach, and more plentiful. *Corophium* is a vital food source for the growing salmonids in the lagoon (Smith, 1999). The greater size and numbers of the two salt-tolerant species in some cases completely filled the space between washers on the samplers. The fresh-water reach did not have such constraints, as the abundance and relative size of the species present was an order of magnitude less than in the coastal

reach. The growth of water plants across the surface of the water in the vicinity of the samplers in the fresh-water reach may also have been a confounding factor by casting some morning and evening shade on the sunlit samples.

The intent of this study was to determine the relative importance of shade on the macroinvertebrate communities in the lower San Lorenzo River. The study found a strong preference or trend towards the overall number of macroinvertebrates in the shaded areas in the saline reaches but less so in the freshwater reaches. The positive attributes provided by the addition of shade, including lower water temperature, increased numbers and types of insects, cover from predation, will benefit fish populations and success of future generations (Leland and Fend, 1998).

CONCLUSIONS

The results of this study highlight the potential to increase potential food supply for salmonids in summer lagoon rearing habitat through the installation of shade structures with some woody debris that macroinvertebrates can colonize. The Hester-Dendy samplers in this study were often placed in sandy substrate in the lower reaches, where stable in-stream structure was limited.

The data collected for this study also provide biotic baseline information for monitoring change and tracking the success of the San Lorenzo River restoration project. In particular, this study produced basic information on the presence and absence of a limited number of key indicator species. As the restoration project adds shade species, sampling for macroinvertebrates can show increased presence of the sensitive species. Stoneflies in this case were very rare. Future sampling that found an abundance of stoneflies may indicate improved habitat.

It is important to note that the collection method for this study can be costly, labor intensive, and time consuming. There may be less expensive and more standardized collection methods to determine the presence of macroinvertebrate indicator species, such as those developed by volunteer monitoring programs. However, to best use the data collected for this study, macroinvertebrate monitoring techniques should be comparable to the methods used here.

RECOMMENDATIONS

Based on the results of this study, in-stream shade, such as floating islands or more mature streamside vegetation, will increase the abundance of macroinvertebrates. Studies on the effects of seasonally adding woody debris to provide for colonization and refuge would be an important next step in understanding and improving habitat in a coastal lagoon. Further study on the chemical processes that take place are currently underway by the City of Santa Cruz, and any future study in the lagoon should incorporate those findings.

BIBLIOGRAPHY

- Barbour M.T., Plafkin J.L., Bradley B.P., Graves C.G., Wisseman R.W. (1992) Evaluation of EPA's rapid bioassessment benthic metrics: metric redundancy and variability among reference stream sites. *Environmental Toxicology and Chemistry*, **11**, 437-449.
- Bash, Jeffrey S., Ryan, Clare M. (June 2002) Stream Restoration and Enhancement Projects: Is Anyone Monitoring? *Environmental Management*, **6(5)**, 877 – 885.
- Behmer D.J., Hawkins C.P. (1986) Effects of overhead canopy on macroinvertebrate production in a Utah stream. *Freshwater Biology*, **16**, 287-300.
- Borchardt Dietrich (1993) Effects of flow and refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. *Freshwater Biology*, **29**, 221-227.
- Boughton, David (2003) Updated status of federally listed ESUs of west coast salmon and steelhead. *National Marine Fisheries Service*, publication 684.
- Brown, G.W.; Krygier, J.T. 1970. Effects of clear cutting on stream temperatures. *Water Resources Research* **6**: 1133-1139.
- Brown S.C., Smith Kevin, Batzer Darold (1997) Macroinvertebrate responses to wetland restoration in northern New York. *Entomological Society of America*, **26**, 1016-1023.
- Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. *Transactions of the American Fisheries Society* **101**, 1-17.
- Bushaw, K. L., R. G. Zepp, M. A. Tarr, D. Schulz-Janders, R. A. Bourbonniere, R. E. Hodson, W. L. Miller, D. A. Bronk and M. A. Moran. (1996) Photochemical release of biologically available nitrogen from aquatic dissolved organic matter. *Nature*, **381**, 404-407.
- Ely, Eleanor (2005) Volunteer Macroinvertebrate Monitoring. *Volunteer Monitor*, **17 #2**, 1-24.
- Feminella J.W., Power M.E. Resh V.H. (1989) Periphyton responses to invertebrate grazing and riparian canopy in three northern California coastal streams. *Freshwater Biology*, **22**, 445-457.

Goodwin C.N., Hawkins C.P., Kershner J.L. (1997) Riparian restoration in the Western United States: overview and perspective. *Restoration Ecology*, **5**, 4-14.

Griggs, Gary B. and Paris, Lance (September 1982) Flood control failure: San Lorenzo River, California, *Environmental Management*, **6(5)**, 407 – 419.

Hawkins C.P., Murphy M.L., Anderson N.H. (1982) Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology*, **63**, 1840-1856.

Hilderbrand R.H., Lemly A.D., Dolloff C.A. Harpster K.L. (1997) Effects of large woody debris placement on stream channels and benthic macroinvertebrates. *Canadian Journal of Fisheries and Aquatic Science*, **54**, 931-939.

Hill W.R., Ryon M.G., Schilling E.M. (1995) Light limitation in a stream ecosystem: responses by primary producers and consumers. *Ecology*, **76**, 1297-1309.

Karr J.R. (1991) Biological Integrity: A long-neglected aspect of water resource management. *Ecological Applications*, **1**, 66-84.

Karr, J.R. and E.W. Chu. 1998. *Restoring Life in Running Waters: Better Biological Monitoring*. Island Press, Washington, DC.

Kelly, David J., Bothwell, Max L., Schindler, David W. (2003) Effects of solar ultraviolet radiation on stream benthic communities: an intersite comparison. *Ecology*, **84**, 2724-2740.

Kondolf, G. M. 1994. Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning* **28**:225-243.

Kondolf, G. M. 1995. Managing bedload sediments in regulated rivers: Examples from California, USA. *Geophysical Monograph* **89**:165-176.

Leland H.V., Fend S.V. (1998) Benthic invertebrate distributions in the San Joaquin River, California, in relation to physical and chemical factors. *Canadian Journal of Fisheries and Aquatic Science*, **55**, 1051-1067.

Li, Judith, Herlihy, Alan, Gerth, William, Kaufmann, Philip, Gregory, Stanley, Urquhart, Scott, Larsen, David P. (2001) Variability in stream macroinvertebrates at multiple spatial scales. *Freshwater Biology* **46**:1 87-97.

Mackay R.L. (1992) Colonization by lotic macroinvertebrates: a review of processes and patterns. *Canadian Journal of Fisheries and Aquatic Science*, **49**, 617-628.

May, Christopher W., Horner, Richard R., Karr, James R., Mar, Brian W., Welch, Eugene B. (1997) Effects Of Urbanization On Small Streams in the Puget Sound Ecoregion *Watershed Protection Techniques*, **2(4)**, 483-494.

Hannaford M.J. & Resh V.H. (1995) Variability in macroinvertebrate rapid-bioassessment surveys and habitat assessments in a northern California stream. *Journal of the North American Benthological Society*, **14**, 430-439.

Mitsch W.J. and Wilson R.F. (1996) Improving the success of wetland creation and restoration with know-how, time, and self-design. *Ecological Applications*, **6**, 77-83.

Modde Timothy, Drewes, Henry G. (1990) Comparison of biotic index values for invertebrate collections from natural and artificial substrates. *Freshwater Biology*, **23**, 171-180.

Nichelson T.E., Solazzi S.L., Johnson S.S., Rodgers J.D. (1992) Effectiveness of selected stream improvement techniques to create suitable Summer and Winter rearing habitat for juvenile coho salmon in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Science*, **49**, 790-794.

Osborn L.L., Bayley P.B., Higler L.W.G., Statzner B., Triska F., Iversen T.M. (1993) Restoration of lowland streams: an introduction. *Freshwater Biology*, **29**, 187-194.

Palmer M.A., Arensburger Peter, Martin A.P., Denman D.W. (1996) Disturbance and patch-specific responses: the interactive effect on woody debris and floods on lotic invertebrates. *Oecologia*, **105**, 247-257.

Plafkin J.L., Barbour M.T., Porter K.D., Gross S.K., Hughes R.M. (1989) Rapid bioassessment protocols for use in streams and rivers. *Benthic Macroinvertebrates and Fish*. EPA/444/4-89/001. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, DC.

Pollard, D. A. (Sep., 1994) A Comparison of Fish Assemblages and Fisheries in Intermittently Open and Permanently Open Coastal Lagoons on the South Coast of New South Wales, South-Eastern Australia. *Estuaries*, **Vol. 17, No. 3**, pp. 631-646.

Rabeni C.F., Minshall G.W. (1977) Factors affecting micro-distribution of stream benthic insects. *Oikos*, **29**, 33-43.

Rabeni C.F., Sowa S.P. (1996) Integrating biological realism into habitat restoration and conservation strategies for small streams. *Canadian Journal of Fisheries and Aquatic Science*, **53**, 252-259.

Richards Carl, Host G.E. (1993) Identification of predominant environmental factors structuring stream macroinvertebrate communities in a large agricultural catchment. *Freshwater Biology*, **29**, 285-294.

Rundle, S.D., Attrill, M.J., Arshad, A. (1998) Seasonality in macroinvertebrate community composition across a neglected ecological boundary, the freshwater-estuarine transition zone, *Aquatic Ecology*, **32**: 3, 211-216.

Scarsbrook M.R., Townsend C.R. (1993) Stream community structure in relation to spatial temporal variation: a habitat template study of two contrasting New Zealand streams. *Freshwater Biology*, **29**, 395-410.

Shields F.D.Jr., Cooper C.M., Knight S.S. (1995) Experiment in Stream Restoration, *Journal of Hydraulic Engineering*, **121**, 494-502.

Shreffler D.K., Thom R.M., Scott M.J., Wellman K.F., Walters M.A., Curran Mark (1995) National review of non-corps environmental restoration projects. Institute for Water Resources report 95-R-12, for the Army Corps of Engineers.

Smith, J. J. (1987) Aquatic habitat and fish utilization of Pescadero, San Gregorio, Wadell and Pomponio Creek estuary/lagoon systems. San Jose State University and the California Department of Parks and Recreation. Report prepared under Interagency Agreement 4-823-6004. 35 pp.

Smith, J.J. (1999) Personal communication in Aquatic Ecology Course at San Jose State University.

Smith, J. J. 1990. The effects of sandbar formation and inflows on aquatic habitat and fish utilizations in Pescadero, San Gregorio, Waddell, and Pomponio creeks estuary/lagoon systems, 1985-1989. Report prepared under Interagency Agreement 84-04-324.

Stark J.D. (1998) QMCI: a biotic index for freshwater macroinvertebrate coded-abundance data. *New Zealand Journal of Marine and Freshwater Research*, **32**, 55-66.

Swanson Hydrology and Geomorphology, Native Vegetation Network, and Hagar Environmental Science. (2002) "Lower San Lorenzo River and Lagoon Management Plan." Prepared for City of Santa Cruz Redevelopment Agency, San Lorenzo Urban River Task Force, City of Santa Cruz, State Coastal Conservancy.

Tate C.M., Helny J.S. (1995) Coordination of benthic invertebrate communities in the South Platte River Basin in relation to environmental factors. *Freshwater Biology*, **33**, 439-454.

Wang, Lizhu, Lyons, John, Kanehl, Paul, Bannerman, Roger (March 2001) Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales, *Environmental Management*, **28(2)**, 255 – 266.

Williams D.D., Williams N.W. (1998) Aquatic insects in an estuarine environment: Densities, distribution and salinity tolerance. *Freshwater Biology*, **39**, 411-421.

Wissmar R.C., Beschta R.L. (1998) Restoration and Management of riparian ecosystems: a catchment perspective. *Freshwater Biology*, **40**, 571-585.

Wood P.J., Armitage P.D. (1997) Biological effects of fine sediment on the lotic environment. *Environmental Management*, **21**, 203-217.