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ASSESSMENT OF STRESSOR IMPACT ON STREAMS IN THE LOS PADRES NATIONAL FOREST USING BENTHIC MACROINVERTEBRATE INDICES

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Donald Bren School of Environmental Science & Management

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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ABSTRACT

The goal of this project is to identify land uses and disturbances in the Los Padres National Forest (LPNF) in California that are chronically stressing the forest's streams and degrading physical, chemical, and biological condition. To do this, stream condition was first evaluated at sites throughout the forest using a widely known bioassessment tool, the Index of Biotic Integrity (IBI) (Karr and Chu 2000). This project used a version of the IBI designed by Ode and Rehn (2005) that was specifically calibrated for Southern California streams. We then quantified the intensity of four anthropogenic stressors (roads, grazing, recreation, and mining) and the dominant local disturbance regime, fire, in order to compare stressor intensity to IBI score and evaluate whether stressors have an impact on stream condition. We constructed a multiple regression model that accounted for each of the 5 stressors and their pairwise interactions, as well as location specific variables that may affect IBI scores. We used this model to predict the impact that different stressor intensity levels (low, medium, high) would have on IBI scores.

We found that grazing, roads, and fire had the greatest impacts on IBI scores and stream health. Using our model, we suggested thresholds at which these significant stressors should be managed to prevent stream deterioration. We also made recommendations to improve the quality of datasets by using common sampling protocols such as the California Stream Bioassessment Procedures, measuring physical and chemical parameters, and sampling repeatedly over time. We also suggested using volunteers to collect samples and data to reduce costs and increase efficiency. Following these suggestions will help the USFS meet their goal to improve stream and watershed condition in the LPNF.

EXECUTIVE SUMMARY

Introduction

The improvement of watersheds is a top priority for the United States Forest Service (USFS). Because so many people rely on National Forest System watersheds for recreation, industry, and drinking water, maintaining high water quality in these areas is essential. In order to improve and maintain water quality, the USFS has outlined several objectives, of which monitoring the impact of land uses on water condition is one of the most important.

This project evaluates the impacts of four anthropogenic stressors along with fire, the dominant local disturbance regime, on streams and rivers on USFS lands. A well known bioassessment tool, the Index of Biotic Integrity, was used to determine stream condition in the Los Padres National Forest (LPNF) in California. The results of this bioassessment were then compared to indices representing the intensity of use of stressors and burn events. Correlations derived from this comparison allowed us to identify which, and the extent to which, stressors can affect IBI scores. Recommendations were then created with the goal of improving bioassessment monitoring and the quality and availability of data.

Index of Biotic Integrity

The Index of Biotic Integrity (IBI), first developed by Dr. James Karr in 1981, is a bioassessment tool that uses living organisms to evaluate the condition of various water bodies (i.e. lakes, rivers, streams). The IBI accounts for the fact that the organisms in a water body reflect changing environmental conditions because they accumulate the effects of a wide range of biogeochemical factors. The community composition of organisms then shifts to those which can tolerate new conditions. Therefore, we can gain a large amount of insight into the overall quality of a stream or river based on the community composition of organisms.

The IBI was originally based on 12 “metrics” with the goal of reflecting fish taxonomic compositions in Illinois and Indiana (Karr and Chu 2000). Since its inception, the IBI has been calibrated for numerous regions around the world. Ode and Rehn recently developed an IBI adjusted for Southern California (SoCal) Coastal Streams (2005). The SoCal IBI, which was used in this project, is based on 7 metrics which evaluate the benthic macroinvertebrate (BMI) community. BMIs are inverts (such as insects, crustaceans, and snails) that inhabit the bottom of rivers, lakes, and streams, and are sensitive to habitat characteristics such as sediment load, water temperature, carbon input, sunlight input, and current velocity (Karr and Dudley 1981, Reice and Wohlenberg 1993). The metrics used in the SoCal IBI are: *Coleoptera* taxa, EPT taxa, Predator taxa, percent collector individuals, percent intolerant individuals, percent noninsect taxa, and percent tolerant taxa. Each metric can receive a score from 0 to 10 (10 being best), for a total score of up to 70. This score is then adjusted to a scale of 0 - 100 and designated as one of 5 condition categories, ranging from very poor to very good.

In this project, each of the 7 metrics and the final IBI score were calculated using the SoCal IBI scoring criteria from datasets originally from the California Department of Fish and Game (DFG) and the USFS. These scores were then compared to the intensity of surrounding land uses and fire disturbances to examine links between stream condition based on the BMI communities and potentially detrimental forest activities.

Stressors

Numerous anthropogenic stressors and disturbance regimes, such as fire, exist within the LPNF. This study examines the effects of four anthropogenic stressors along with fire, the dominant local disturbance regime, both of which are of paramount concern to the USFS. Each of these stressors can affect streams in a myriad of different ways and to varying extents. However, they do share the same following erosion process as a mechanism for transporting harmful contaminants, sediment loads, etc. into streams:

- Fire: Sediment pulses from post-fire erosion can provide revitalizing nutrients to streams but, at the same time, massive pulses of sediment can inundate streams with mud and contaminants.
- Grazing: Grazing in riparian zones can have potentially adverse affects on streamside vegetation composition, bank stability, and can introduce fecal coliform bacteria and nitrogen from urea into streams.
- Mining: Mining can bring potentially harmful materials to the surface, which when mobilized by storm runoff increases sediment and chemical loading in streams.

- Recreation: Recreation activities can facilitate movement of sediment and trash, pathogens, and other pollution left behind by the public into rivers and streams.
- Roads: Impervious surfaces formed by hard packed and/or paved roads can increase the rate of runoff from rain and snowmelt events. Depending on various physical characteristics of the road, road runoff can contain automobile contaminants along with potentially significant amounts of sediment.

In the absence of specific intensity and type of use data we created an intensity index to represent each stressor based on its occurrence per area. Each index ranged from 0-100, where 100 represented the highest stressor intensity in the forest, and 0 represented the lowest stressor intensity.

Statistical Analysis and Results

A multiple regression model was designed to explore how the physical stressors affected IBI score. The model was constructed with IBI score as the dependent variable, the five stressors (fire, grazing, mining, recreation, and roads) as independent variables, and sub-basins as the covariate. A sub-basin is a delineation differentiating hydrogeologic characteristics and serves as a regional grouping of the data, accounting for latitudinal and ecosystem gradients. Sub-basin was used as a covariate because it explained the most significant amount of variation in IBI score. In this model, fire, grazing, mining, and roads have a significant effect on IBI score and hence stream health, while recreation does not.

Building on this single model, we examined the individual effects of stressors and all possible pairwise interactions. Stressor interactions were important to consider because multiple stressors were often present in the same areas (i.e. roads and recreation). The final regression model was selected using a "step-down" approach that involves adding all possible variables into the model and then removing the least significant variables one at a time, in order to eliminate non-significant interactions among stressors. The final regression model included all five individual stressors, the interaction between grazing and each of the other four stressors, and the interaction between recreation and fire.

Discussion

On average for the whole forest, the predicted IBI scores generated from the model were 84% accurate. For six of the seven sub-basins examined in this project, the model proves to be a useful tool for management decisions, with an average percent error of less than 20%. Scenarios were run using the multiple regression model with interactions to determine the effect of varied stressor levels on IBI score. Grazing has the largest influence on IBI score, and is amplified by its high level of interaction with each of the other stressors. The model shows that the presence of mining increases IBI score. This result, however, is most likely an indicator of the lack of other stressors in mining areas and remediation efforts rather than a beneficial effect of mining on stream health.

These results demonstrate that physical stressors can have an impact on stream health and often have interactive effects. Based on our results we recommend the following management strategies using a low, medium, and high stressor level delineation:

1. Because grazing has the greatest effect on IBI scores and has strong interactions with each of the other stressors it should be stringently managed. We recommend grazing allotments be limited to 15% of a sub-watershed region to limit its impact on stream health.
2. Roads have a significant impact on stream health and as a result we recommend no further road development beyond 78 roads per 1000 hectares of forest.
3. Current management practices for controlling mining and recreation are sufficient for controlling the impacts of stream health.
4. The Forest Service aggressively manages wildfires. We emphasize the importance of continuing these efforts for the protection of stream health.

Monitoring Recommendations

Based on our analysis we recommend that monitoring sites target specific watersheds rather than the entire forest because stressor impacts are limited by watershed boundaries but not necessarily by forest administration boundaries. It is also important to sample the same sites repeatedly because this will allow for a mechanistic understanding of trends associated with stressor changes over time. We recommend that each monitoring site be sampled at least once a year, preferably twice per year (spring and fall), and always at the same time of the year.

We have selected a minimum set of sub-watersheds to sample. These consist of the 18 sub-watersheds that contain a high occurrence of significant stressors, and 7 sub-watersheds that contain the least number of significant stressors present. At a minimum we recommend that the terminal outlet of each sub-watershed be sampled. As resources allow, sampling additional sites throughout the sub-watershed would provide more complete information about stressor impacts in the area and should be ranked by the number of significant multiple stressors in a locality.

In conjunction with a rigorous physical assessment of the habitat, we also recommend the following chemical properties be measured with every BMI sample: dissolved oxygen, pH, conductivity, turbidity, temperature, total suspended solids (TSS), nitrogen, and phosphorous. This additional data will increase the robustness of analysis, as they provide the mechanistic explanation for stressor impacts.

Additionally, when collecting BMI samples, we recommend the use of a consistent, cost effective, and widely used sampling protocol such as the California Stream Bioassessment Procedures (CSBP) to ensure comparable datasets between agencies. We also recommend that the USFS use volunteers to conduct benthic macroinvertebrate and physical and chemical property sampling to reduce labor costs.

COMMONLY USED ACRONYMS

ABL	Aquatic Bioassessment Laboratory (at the California Department of Fish and Game)
ANOVA	Analysis of Variance
BMI	Benthic Macroinvertebrate
BMP	Best Management Practices
Bug Lab	Utah State University National Aquatic Monitoring Center
CDFG	California Department of Fish and Game
CSBP	California Stream Bioassessment Protocol
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EMAP	Environmental Monitoring and Assessment Program
EPT	Ephemeroptera, Plecoptera, and Trichoptera taxa richness
FSCR	Friends of the Santa Clara River
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
LPNF	Los Padres National Forest
NEPA	National Environmental Policy Act
SoCal IBI	Southern California Index of Biotic Integrity (developed by Ode & Rehn 2005)
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
WQCBs	Water Quality Control Boards

INTRODUCTION

Background

The United States Forest Service (USFS) follows the dual credo of "caring for the land and serving the people" (USDA Forest Service 2004a). The Forest Service must therefore balance the often conflicting duties of ecological stewardship of the land with that of providing services for the general public. Successful management strategies must account for these dual goals and integrate them into a cohesive plan that meets the obligation to provide these services while protecting ecosystems. One of the primary goals of the USFS in upcoming years is to improve watershed condition (USDA Forest Service 2004b). Over 3,000 cities and towns rely on a water supply from USFS lands, and many streams in these areas do not meet State water quality standards. Furthermore, many of these watersheds are at risk from intensive land use and, in the west, disastrous wildfires. The USFS aims to assess the conditions of these watersheds and to monitor the impacts of the activities occurring on USFS lands in order to improve overall watershed health (USDA Forest Service 2004b).

The Los Padres National Forest (LPNF), managed by the USFS, is the focus of this biotic assessment and management plan, which evaluates the impact of surrounding land uses and disturbances, such as grazing, recreation, mining, roads, and fires on the condition of streams in the forest. The LPNF covers 1.75 million acres spread across 220 miles, and is sub-divided into 2 major land divisions. The Northern part of the forest extends into Monterey and San Luis Obispo Counties (36°21' N by -121°51'W), while the Southern part of the forest covers San Luis Obispo, Santa Barbara, Ventura, and Kern Counties (34°6' N by -119°36' W) (USDA Forest Service 2005). As with other USFS lands, the LPNF provides substantial water resources to Californians, and management of the forest includes protecting and enhancing watersheds (USDA Forest Service 2004b).

The LPNF is home to over 450 species of plants and animals, 26 of which are threatened or endangered, and 91 of which are considered sensitive (USDA Forest Service 2005). The LPNF is an increasingly important refuge for the protection of plants and wildlife living within because of forest conversion for land development outside the forest boundaries (USDA Forest Service 2005).

The climatic conditions of the LPNF range from semi-desert, in the eastern portion of the southern section of the forest, to Mediterranean along the more coastal reaches of the forest's extent. The terrestrial habitats within the forest are classified into two vegetation types: chaparral (68%) and forested lands (30%). The forested lands in the LPNF include mixed evergreen forests, oak woodland, pinyon-juniper woodland, and conifer forest. (USDA Forest Service 2005).

Objectives

The goal of this project is to identify land uses and disturbances in the LPNF that stress the forest's streams and rivers and degrade stream condition. To achieve this goal, we evaluated stream condition at sites throughout the forest using a quantitative bioassessment tool, the Index of Biotic Integrity (Karr and Chu 2000, Ode and Rehn 2005). We then compared the stream condition to the intensity of surrounding land uses and disturbances which included roads, fire, grazing, recreation, and mining. Based on the results of these comparisons, we identified the land uses most detrimental to the forest's streams and rivers. Stressors were evaluated both individually and collectively, and ranked in terms of overall effect on stream health and hence the needs of management. Finally we offer recommendations to improve and streamline current monitoring techniques based on the quantitative assessment of IBI and stressor interactions.

INDEX OF BIOTIC INTEGRITY

Aquatic bioassessment is a tool used to evaluate the condition of various water bodies, such as streams, rivers, and lakes by surveying resident biota, such as fish or macroinvertebrates (US Environmental Protection Agency 2006a). One such bioassessment tool is the Index of Biotic Integrity (IBI), developed by James Karr in 1981. The IBI assesses the living organisms in these water bodies to determine whether they retain their characteristic biological components, such as species composition and population density, and ecosystem processes, such as biogeochemical cycles (Karr and Chu 2000). Karr (2000) states that "Living communities reflect watershed conditions better than any chemical or physical measure because they respond to the entire range of biogeochemical factors in the environment." Further, he states, "Actions that protect the biota tell us directly if we are protecting the water cycle" (Karr and Chu 2000). By protecting the biological integrity of water bodies, we will subsequently protect the quality of water for human uses as well.

In order to construct a successful IBI model, reliable and relevant attributes that provide information about human activities' effects on biological processes must be measured (Karr and Chu 2000). These attributes or "metrics" are selected because they show a predictable organismal response to changes in the environment due to human influence (Karr and Chu 2000). The ability to measure biological response of organisms to human influences and determine which of these responses can be consistently predicted, indicates which metrics will best detect impairment in a given water body.

The IBI was originally developed for streams in Illinois and Indiana, and examined fish communities to assess stream health (Karr 1981). Various metrics that reflect fish species composition and abundance, among others, are calculated and summed for a single, final IBI score. This numeric score indicates the condition of the water body in question. This tool has since become very popular for evaluating water body condition and many different versions of the IBI have been developed for regions around the world (Simon and Lyons 1995). Current versions of the IBI differ from the original in the type of organisms evaluated and in the number, identity, and scoring of metrics (Simon and Lyons 1995).

Southern California IBI model

The model used in this project is the Southern California Index of Biotic Integrity (SoCal IBI) developed by Peter Ode and Andrew Rehn (Ode and Rehn 2005). The use of IBIs is problematic in California because of its arid climate, the ephemeral nature of its streams, and its rapidly growing population and subsequently an increased human impact and disturbance. It is, therefore, imperative that a unique IBI model be used to evaluate this geographic area (Ode and Rehn 2005). The SoCal IBI model was developed specifically for the region ranging from Monterey County in the north to the Mexican border in the South, and inland to the eastern edge of the Southern Coast Ranges. This area covers two ecoregions, the Southern California Mountains and the Chaparral/Oak Woodlands, and shares a common geology and hydrology (Figure 1) (Ode and Rehn 2005). Because of the ephemeral nature of many of the streams in this region, the SoCal

IBI model uses benthic macroinvertebrates (BMIs), as opposed to fish, to evaluate stream condition in Southern California. BMIs are advantageous for use in bioassessment because they are "ubiquitous" in that they are affected by environmental disturbances in various aquatic habitats (Rosenberg and Resh 1993). There are also a large number of species of BMIs, which provides a wide range of responses to environmental changes, and their sedentary nature allows for important spatial analyses of the effects of pollution and disturbance (Rosenberg and Resh 1993). Temporal analyses of disturbance effects can also be made because BMIs have long life cycles and continually indicate the condition of the waters in which they live (Rosenberg and Resh 1993).

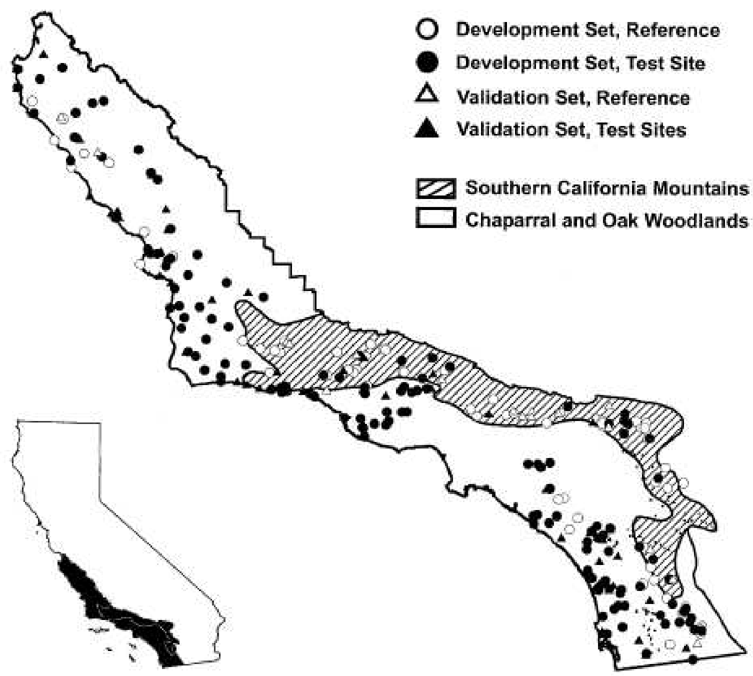

Figure 1. Ecoregions where the SoCal IBI model applies and region wide Ode and Rehn test and reference sites (Ode and Rehn 2005)

Ode and Rehn evaluated 61 metrics for possible use in the model (2005). Seven metrics were found to be minimally correlated with one another, covered a wide enough range to be used in scoring, and were responsive to disturbance variables at both watershed and reach scales. These metrics included: *Coleoptera* taxa, EPT (*Ephemeroptera*, *Plecoptera*, *Trichoptera*) taxa, predator taxa, percent collector individuals, percent intolerant individuals, percent noninsect taxa, and percent tolerant taxa. Because IBI scores using these metrics differed significantly between ecoregion type, the metrics affecting the scores, namely EPT taxa, percent collector individuals, and percent intolerant individuals, are given two scoring criteria based on ecosystem type (6=chaparral and oak woodlands, 8=Southern California mountains) to adjust for this difference. After the adjustment, there was no significant difference found in IBI scores between the two ecosystem types (Ode and Rehn 2005). Each of the seven metrics is given a ranking score from 0 to 10 based on that metric's observed value, and ranking scores are then summed for a total score of up to 70 (Table 1). This total ranking score is then adjusted to a 100 point scale. This 100 point scale is divided into five stream conditions ranging from very poor to very good, to give a general description of stream health (Table 2).

Table 1. Scoring Criteria for SoCal IBI (Ode and Rehn 2005)

Metric score	Coleoptera taxa (all sites)	EPT taxa		Predator taxa (all sites)	% Collector individuals		% Intolerant individuals		% Noninsect taxa (all sites)	% Tolerant taxa (all sites)
		6	8		6	8	6	8		
10	>5	>17	>18	>12	0–59	0–39	25–100	42–100	0–8	0–4
9		16–17	17–18	12	60–63	40–46	23–24	37–41	9–12	5–8
8	5	15	16	11	64–67	47–52	21–22	32–36	13–17	9–12
7	4	13–14	14–15	10	68–71	53–58	19–20	27–31	18–21	13–16
6		11–12	13	9	72–75	59–64	16–18	23–26	22–25	17–19
5	3	9–10	11–12	8	76–80	65–70	13–15	19–22	26–29	20–22
4	2	7–8	10	7	81–84	71–76	10–12	14–18	30–34	23–25
3		5–6	8–9	6	85–88	77–82	7–9	10–13	35–38	26–29
2	1	4	7	5	89–92	83–88	4–6	6–9	39–42	30–33
1		2–3	5–6	4	93–96	89–94	1–3	2–5	43–46	34–37
0	0	0–1	0–4	0–3	97–100	95–100	0	0–1	47–100	38–100

Note: Three metrics have separate scoring ranges for the two Omernik Level III ecoregions in southern coastal California region (6 = chaparral and oak woodlands, 8 = Southern California mountains).

Table 2. Relation between quantitative IBI score and qualitative assessment of stream condition

IBI Score	Stream Condition	
0-19	Very Poor	
20-39	Poor	
40-59	Fair	
60-79	Good	
80-100	Very Good	

Benthic Macroinvertebrate (BMI) Characteristics

Many of the biotic metrics used in the SoCal IBI are based on specific characteristics of the benthic macroinvertebrate (BMI) community. Benthic macroinvertebrates are invertebrate organisms such as insects, crustaceans, and snails that inhabit the bottom substrates (organic/inorganic sediments, debris, and algae) of rivers, lakes, and streams. The BMI characteristics used for the SoCal IBI metrics include taxa type, tolerance to pollution, and particular feeding habits. The tolerance values assigned to each taxon are based on the Hilsenhoff Biotic Index (Aquatic Bioassessment Laboratory 2003). The metric was originally used to measure the tolerance of communities to organic pollution in Wisconsin, USA, but is now widely used as a general measure of pollution tolerance (Aquatic Bioassessment Laboratory 2003). This index is based on a tolerance scale from 0 to 10, with 0 being highly intolerant and 10 being highly tolerant to pollution. Functional Feeding Groups are classifications based on BMI primary feeding habits and food acquisition mechanisms (Merritt and Cummins 1996). Since many organisms have variable feeding modes and mechanisms, many taxa are assigned both a primary and secondary functional feeding group. The functional feeding groups recognized by the California Department of Fish and Game (CDFG) include: predator, parasite, collector-gatherer, collector-filterer, macrophyte herbivore, piercer herbivore, scraper, shredder, omnivore, and xylophage (Aquatic Bioassessment Laboratory 2003). Of these feeding groups, the five dominant groups are predators, collector-gatherers, collector filterers (aka filter feeders), scrapers, and shredders. Predators feed on other invertebrates. Collector-gatherers collect algae, detritus, and bacteria from sediments, while collector-filterers filter similar materials directly from flowing water. Scrapers rely on detritus and algae that they “scrape” from the surface of rocks and twigs, and shredders feed on woody debris in the water such as twigs and leaves (Merritt and Cummins 1996).

BMIs are also sensitive to habitat characteristics such as substrate type (i.e. cobbles, gravels, sands, and silts), water temperature, and riparian conditions that can control debris input, sunlight intensity, and flow velocity (Karr and Dudley 1981, Reice and Wohlenberg 1993). The BMI community is further affected by nutrient concentrations in a stream (Merritt and Cummins 1996, Reice and Wohlenberg 1993).

Biotic Metrics

Biotic metrics respond to changes in the physical and chemical conditions in the stream, such that when streams are impaired, each metric responds by either increasing or decreasing (Table 3).

Table 3. Description of SoCal IBI metrics and the responses to impairment (Ode and Rehn 2005)

Metric	Description	Response to Impairment
Coleoptera taxa	Number of taxa in the order Coleoptera (beetle)	Decrease
EPT taxa	Number of taxa in the orders *Ephemeroptera* (mayfly), *Plecoptera* (stonefly), and *Tricoptera* (caddisfly)	Decrease
Predator taxa	Number of taxa that prey on other invertebrates	Decrease
Percent collector individuals	Percent of BMIs that collect or gather material	Increase
Percent noninsect taxa	Percent of BMIs that are not in class Insecta	Increase
Percent intolerant individuals	Percent of BMIs that are highly intolerant to water and/or habitat quality impairment as indicated by tolerance values less than 4	Decrease
Percent tolerant taxa	Percent of BMIs that are highly tolerant to water and/or habitat quality impairment as indicated by tolerance values greater than 7	Increase

Coleoptera taxa (beetles) tend to decrease in the presence of impairment. Coleoptera have complex life cycles, often living as both larval and adult forms in water, and are therefore susceptible to fine sediments and decreases in habitat quality over the majority of their life cycle (Brown 1973, Ode and Rehn 2005). *Ephemeroptera*, *Plecoptera*, and *Tricoptera* taxa (mayflies, stoneflies, caddisflies) also decrease with impairment. These taxa have low tolerance to pollution, low dissolved oxygen levels, and changes in sediment loading, and show a corresponding decrease in abundance with poor stream conditions (Lenat 1988, Resh and Jackson 1993). Predator taxa generally decrease as the diversity of their prey items decrease in response to impairment (Resh and Jackson 1993). The percent collector individuals typically increase, likely because nutrient and organic loading increases their food sources (Klemm 2003). The percent noninsect taxa also increase with impairment because they tend to be less specialized than insects, having fewer habitat requirements (Gullan and Cranston 2000). The percent intolerant individuals decrease as they are less tolerant of chemical and physical impairment, while percent tolerant taxa increase with impairment as they can better withstand these same impacts (Aquatic Bioassessment Laboratory 2003).

Data

Description

The data used for this project originated from two separate sources. The first dataset was supplied by the USFS and the second dataset was supplied directly by Ode and Rehn (2005) (Figure 2). The USFS data were collected by USFS crews in the northern and southern divisions of the Los Padres National Forest (LPNF) during 1999 and 2000 using the sampling protocol developed by Charles Hawkins of Utah State University (Hawkins et al. 2000). Forty sites located in the LPNF were used from this dataset in our analysis. BMI samples were taken from rivers, streams, and tributaries and were designated as test or reference based on the presumed condition of the stream. The reference sites were assumed to be the least impaired and least impacted by human uses, such as recreation, grazing, or roads. Test sites were similar to reference sites in habitat characteristics along the same stream, but located in disturbed areas or areas of suspected human impact. Reference sites were often located upstream of particular impacts or disturbances of interest to the USFS including: campgrounds/recreation, bridges/roads, cattle grazing, fire, landslides, oil and gas operations, and pick and shovel mining. Test sites were typically located downstream of reference sites. These paired sites were sampled with the intention of comparing “pristine” sites to “impacted” sites to determine the effects of physical stressors on stream condition (Chan et al 2005). Several sites within the dataset, however, were not paired and were comprised of only one sample point. Of the 40 total sites, 24 were paired and 16 were unpaired. Unfortunately, little consistency was apparent in BMI sampling protocol or data analysis. Sample dates in 1999 ranged from May to December, but most sampling occurring during the summer (June-September). The 2 sample dates in 2000 both occurred in January (Chan et al 2005).

BMIs were collected in subsamples in contiguous riffles using a 0.5 mm mesh, 0.1 m^2 Surber sampler to a depth of 10 cm. BMIs were collected within the frame of the Surber sampler that was placed underwater along the stream bed. All of the rocks, plants, leaves, and debris within the frame were rinsed in front of the net, which was placed downstream of the collection area. Any BMIs from within the frame were, then, collected in the net for later identification. The individual subsamples at each site were analyzed separately, with most sites having six to eight subsamples. However, some subsamples were pooled or omitted from analysis. These inconsistencies resulted in some sample sites being represented by only 3, 4, or 5 subsamples. The collected BMI samples were identified to the lowest taxonomic level possible, usually species, genus, or family, by the Utah State University National Aquatic Monitoring Center (Bug Lab) (Chan et al 2005). The Bug Lab compiled this data to produce a taxonomic list and abundance of each taxon for each subsample collected. This particular dataset was then used to assess stream health in the LPNF for this current project.

The second dataset used in this project was generated from the original survey used by Ode and Rehn to develop the SoCal IBI (Figure 2) (Ode and Rehn 2005). The dataset used for their study was collected from 275 sites using three different surveying protocols (Ode and Rehn 2005). The California Stream Bioassessment Protocol (CSBP) was used by regional Water Quality Control Boards (WQCBs), the USFS collected data based on the protocol developed by Charles Hawkins, and the US Environmental Protection Agency (EPA) used the Environmental Monitoring and Assessment Program (EMAP) to collect their samples. Of the 275 sites sampled in the Ode and Rehn study, 41 fell within the LPNF and thus were used in this current project. The majority of these 41 samples were taken during the "Spring" season, however several others were taken during August, September, and Fall from 2000-2003. In this dataset there were no subsamples collected; hence there was only 1 value generated for each metric per site.

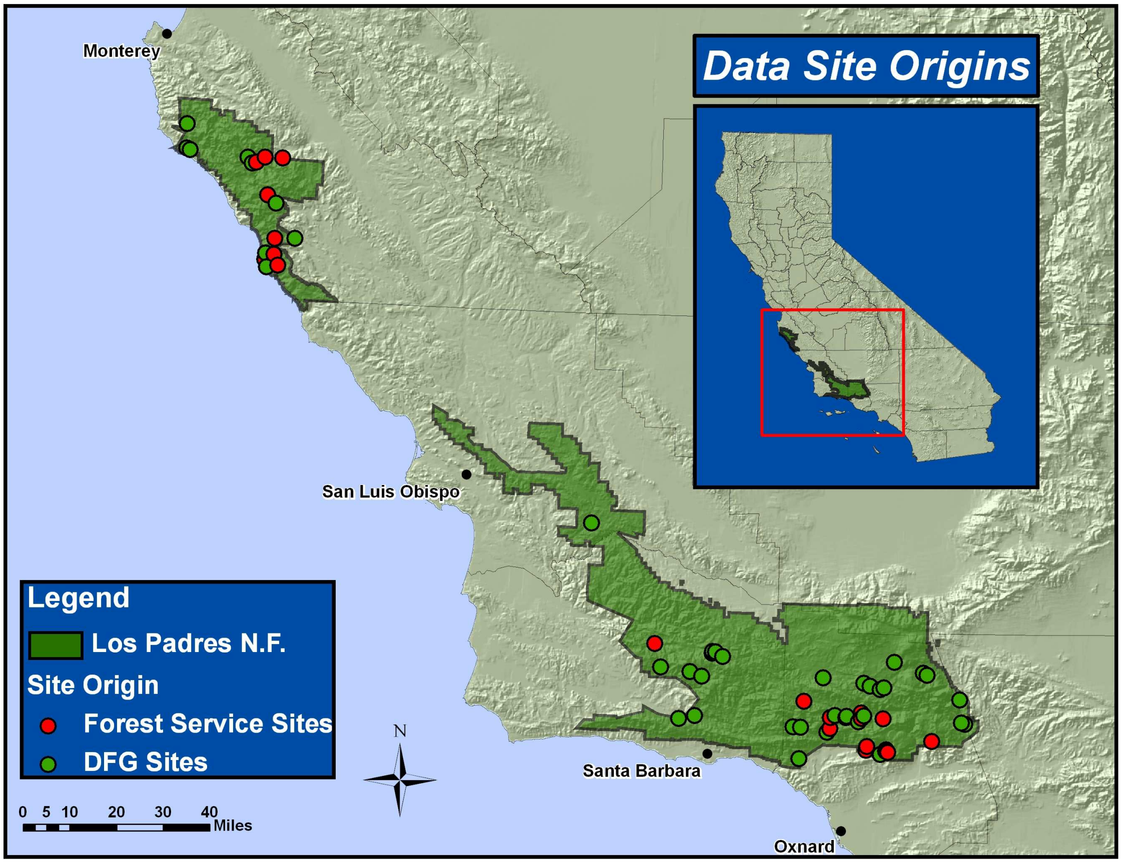

Figure 2. Location of BMI sampling sites from Ode and Rehn, California Department of Fish and Game (CDFG), and from USFS

Scoring

The Bug Lab BMI data which was collected from the USFS sampling sessions had to be processed from the raw counts to ranking scores for each of the seven metrics. For each subsample in a site, values for each metric were calculated and then averaged, resulting in 1 value for each metric for each site. Using the Ode and Rehn (2005) scoring criteria, these values were then converted to a metric "score" ranging from 0-10. The 7 metric scores were then summed for a total of up to 70 points. These scores were finally converted to a 100 point scale and scores were ranked from very poor to very good, with 0 being very poor and 100 being very good (Figure 3). The dataset received from Ode and Rehn had been previously processed and the values for each metric were already calculated using exactly the same protocols. After confirming these calculations, metric values were adjusted and scored as above, resulting in IBI scores of up to 100.

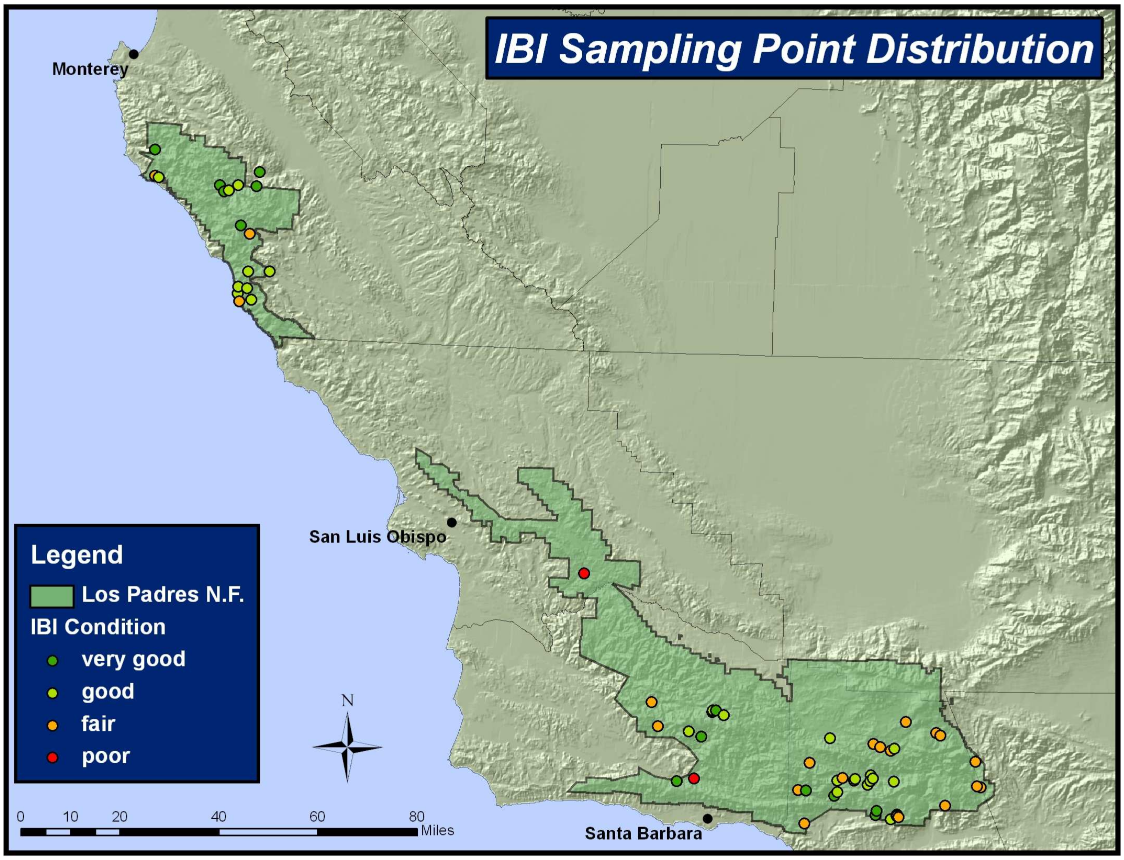

Figure 3. IBI sampling point distribution showing IBI condition (ranging from very good to poor)

STRESSORS

Per the Forest Service request, this study examined the effects of four anthropogenic stressors, mining, grazing, recreation, and roads, and the dominant local disturbance regime, fire, on the overall health of LPNF streams. The spatial distributions of the individual stressors as well as the spatial relationships between the BMI sampling points and stressors were examined to determine if BMI ranking scores were related to stressor type and intensity.

Data indicating stressor occurrence were provided by the USFS. The raw data for each stressor were provided as shapefiles in a spatial geodatabase, which comprised information on the location of a particular stressor. Select files also housed information describing additional attributes such as relevant dates (e.g. year of burn), aerial extent of stressors, if relevant, and status of use (e.g. active vs. inactive allotments). For example, the fire geodatabase not only had information about the location of fires throughout the forest, but also included burn perimeters, areas, and year of burn for each fire. Unfortunately, none of the geodatabases possessed information on stressor intensity. In the absence of this vital piece of information, we created proxy intensity indices based on the occurrence of a given stressor per area of sub-watershed.

We chose to examine each stressor by sub-watershed boundaries due to their status as the smallest USGS watershed delineation available within the forest. The US EPA defines a watershed as "the area of land that catches rain and snow and drains or seeps into a marsh, stream, river, lake or groundwater" (US Environmental Protection Agency 2006b). With this definition in mind, a watershed can be viewed conceptually as a funnel, with mountain ridges acting as the rim, which channels all storm water and sediment flow between ridgelines into streams and through an outlet at the terminal end of the watershed or funnel. Using the smallest available delineation allowed the quantification of stressors to represent the extent of stressor effects at an ecologically meaningful scale. Errors in the extent of the effects of any one stressor were diminished by making use of the smallest watershed delineation available. If a larger hydrologic unit delineation, such as a sub-basin, were used stressor effects would be assumed to carry over ridgelines, which is physically unrealistic (Figure 4). Thus, when stressor indices were compiled for each sub-watershed the effects of stressors occurring in a particular sub-watershed are largely limited to physically realistic bounds imposed by the watershed's topography.

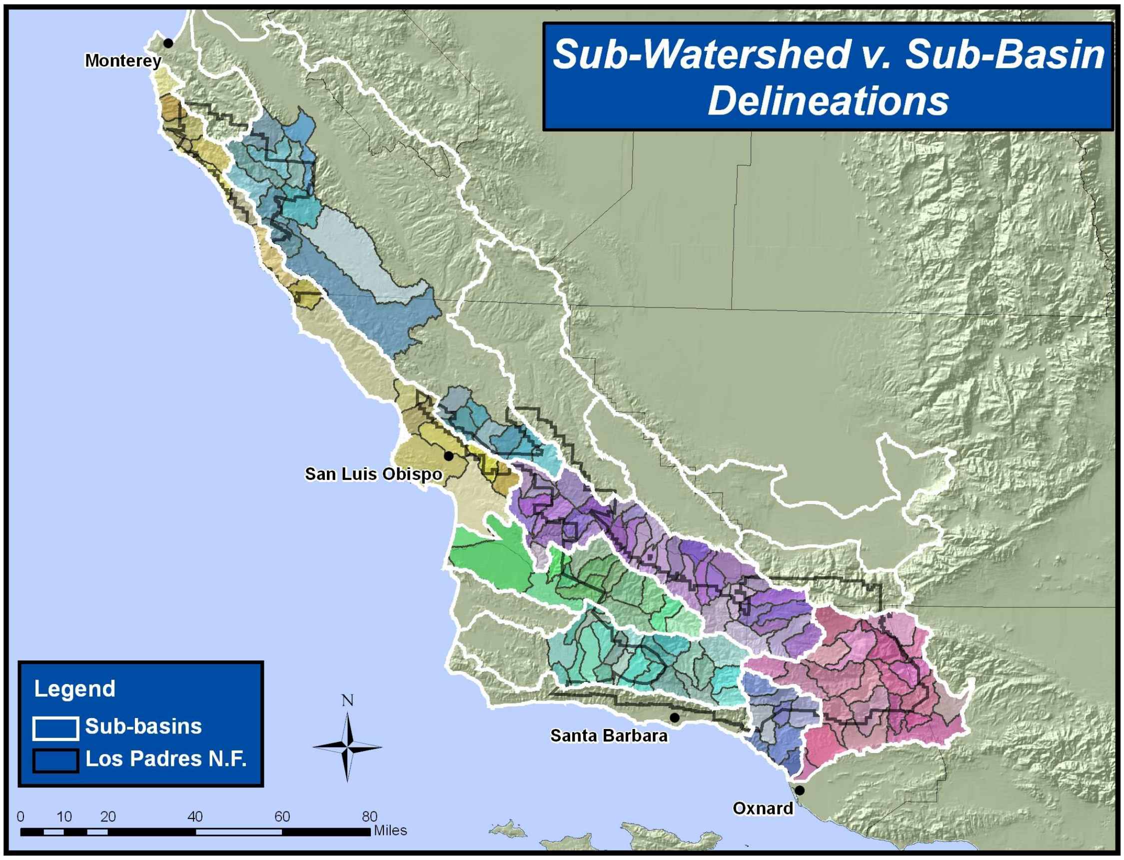

Figure 4. A comparison of the aerial extents of sub-watersheds (smaller, colored delineations) versus sub-basins. Note numerous sub-watersheds are encompassed in one sub-basin.

After the raw indices were calculated at the sub-watershed level they were normalized using a maximum value transformation (Malczewski 1999). Normalizing the data ensured all indices would have values ranging from 0 to 100. This transformation was used because it preserves the integrity of the magnitude of the range of values in the raw indices while creating a platform for easy comparison between stressors. After the indices were normalized the geographic coverage of each index was limited to the extent of the forest boundary. These forest wide indices were then compiled into a database along with various physical landscape features and the IBI scores associated with each IBI sampling point.

Fire

Impacts of Fire

The effects of fire on stream ecosystems can be highly variable (Spittler 1995). Post-fire erosion episodes can provide nutrients to aquatic and terrestrial systems. However, massive sediment pulses can inundate streams with mud and debris (USGS 1998). These massive post fire sediment pulses are created by the combination of decreased vegetative cover, hydrophobic soils, and the steep slopes of the transverse ranges (Spittler 1995). Inundation of streams with sediment can seriously affect BMI assemblages, and subsequent IBI scores, due to their sensitivity to alterations in habitat, availability of food sources, and the chemical composition of the stream (DeBarry 2004).

The extent of post-fire erosion is typically a function of the intensity of the burn in conjunction with physical landscape parameters such as slope, erosive capacity of soils, and land cover (Spittler 1995). Chaparral floral communities depend on the presence of fire to return nutrients to the soil from biomass stored in plants (Rundell and Parsons 1980) and for the heat from fires to germinate seeds stored in the soil seed bank (Borchert and Odion 1995). Low intensity burns typically create higher species diversity and a fine grained matrix of mixed age vegetation (Keeley and Fotheringham 2001). These low intensity fires usually only burn off the foliage of woody chaparral plants, leaving the defoliated skeleton intact (Mount 1995). Preservation of the structural integrity of the vegetative community is important when considering the potential effects of fire on streams because the ability of the landscape to absorb some of the sedimentation pulse also remains after low intensity burns. Root systems enhance the structural integrity of slopes while rodent, worm, insect and root activity disrupt water repellent hydrophobic soils, which create avenues for percolation (Spittler 1995). In addition, the burned skeletons of chaparral flora protect soil from raindrop impacts which can act to mobilize soil (Mount 1995). High intensity burns, on the other hand, can convert all vegetative cover to ash, which diminishes or completely eliminates the ability of the landscape to inhibit rain drop impacts and overland flow (Mount 1995).

Data Compilation

The fire data used for this analysis originate from a GIS polygon shapefile provided by the USFS. The corresponding database provides information on 143 fire events that occurred in the forest between 1985 and 2003. Included in this database were the aerial sizes of all fires and the corresponding years when each burn event occurred. Unfortunately, this data lack information on burn intensity. While the importance of measuring burn intensity is not a new technique (Moreno and Oechel 1991), it has not been regularly recorded by the USFS until recently.

In the absence of burn intensity information, fire data were compiled based on the year a burn occurred and the area the fire burned. Using Environmental Systems Research Institute's (ESRI) ArcMap9.1, the year of fire occurrence was transformed to reflect the actual year since a burn occurred. Spittler (1995) observed chaparral ecosystems recover from wildfire approximately 15 years after they occur (Spittler 1995). Accounting for this information, we included fires in our analysis which occurred 15 years prior to our first IBI sampling date in 1999. Thus the oldest fire used in this study occurred in 1984 and the most recent fire occurred in 2003. This margin between the oldest and most recent fire resulted in the 'year since burn' index having a range of values between 0 and 19 years. This index was then normalized using the maximum value transformation (Malczewski 1999). Once normalized, the values in the "year since burn" index ranged from 0 to 100. Thus, the older a fire event, the lower its "year since burn" index value and conversely the more recent a fire event, the higher its "year since burn" index value.

After the "year since burn" index was created, the fire area data was normalized by a maximum value transformation, producing a range from 0 to 100, where a value of 100 was positively correlated with the largest fire. To analyze the interactive effect of burn year and burn size we multiplied the normalized indices together and, once again, normalized the product, utilizing a maximum value transformation, to derive scores ranging from 0 to100. In this case, the values were grouped by the fires' perimeters, and not by sub-basin. To allocate the overall fire impact values for each sub-basin a zonal statistics calculation was run which calculated and then assigned the mean standardized fire impact score to each sub-basin.

Distribution

The product of the combination of 'year since burn' and 'fire area' indices indicates that sub-watersheds in the central section of the forest located in San Luis Obispo County (35.13° N by -120.18° W) has been most impacted by fire events in the past 20 years. The southeast portion of the forest near the Los Angeles County border (34.48° N by -118.88° W) also shows some heavy burn events (Figure 5). The majority of the LPNF has not been impacted by high intensity burns, but rather a mosaic of low intensity burns. This burn pattern can be attributed to fire suppression measures, such as prescribed burning (Keeley and Fotheringham 2001).

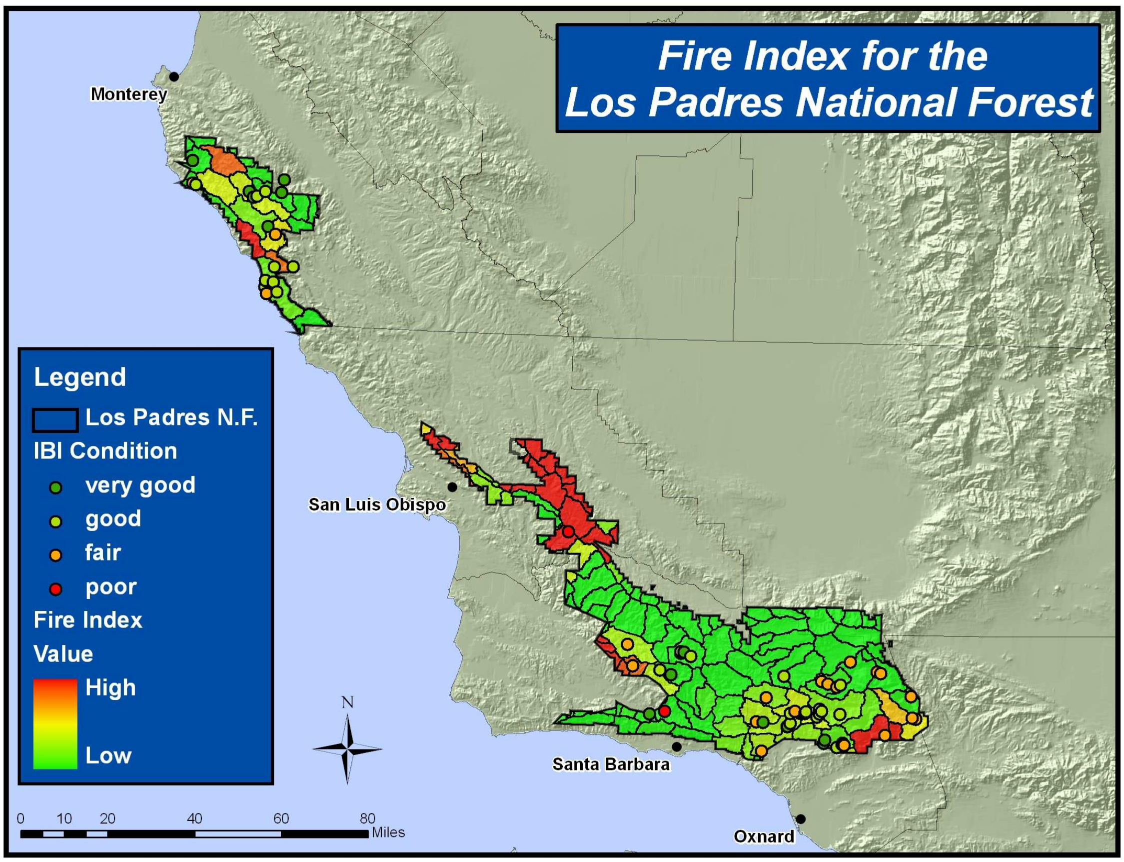

Figure 5. Fire index for Los Padres National Forest, showing high intensity burns in red and low intensity burns in green. Points indicate sample sites and IBI condition.

Grazing

Impacts of Grazing

The majority of the active grazing allotments in the LPNF are specified for cattle. Cattle grazing can be extremely damaging to stream health, depending on how it is managed (Platts 1981). The effects of cattle grazing on streams depend on numerous factors including periodicity of grazing, proximity to streams, and number of cattle per allotment (Platts 1981). Grazing in riparian zones can affect stream communities via nutrient loading, degradation of stream banks, changes to streamside vegetation, and alterations of substrate size (Scrimgeour and Kendall 2003).

Cattle consumption of streamside vegetation can result in the decreased ability of riparian vegetation to absorb runoff (Platts 1981). Loss of vegetative cover from cattle grazing may increase sedimentation to streams via increased erosion. Cattle grazing may also decrease streamside vegetative cover which can alter stream microclimates because of losses in shade providing cover, which in turn can affect invertebrates sensitive to stream temperature (Platts 1981). Further, the amount of detritus, an important source of sustenance for many invertebrates, is also diminished when overgrazing in riparian zones occurs (Platts 1981).

The physical presence of cattle may also have numerous negative impacts on stream ecosystems (Scrimgeour and Kendall 2003). When cattle are allowed to be present in streams and on stream banks, their immense weight causes the trampling of banks which can facilitate channel erosion. Bank stability deteriorates further when streamside vegetation is reduced via intense grazing (Platts 1981). Marcuson (1977) found that ungrazed portions of creeks in Montana had 2.5 times less channel erosion than adjacent sections of stream that were grazed. When stream banks are eroded into streams, turbidity increases (Mount 1995) and potentially harmful chemicals and pathogens that were once sequestered in the soil can be released into the streams (Schlesinger 1997). In addition, fecal coliform can be loaded into streams if cattle defecate in close proximity to or in streams (Platts 1981).

Data Compilation

The USFS provided data on the location of 189 active grazing allotments ranging from approximately 5 hectares to 27,050 hectares in aerial size. This information was used to identify sub-watersheds with the potential to experience detrimental affects from grazing. The USFS data we used indicated the presence of active allotments but did not specify how each allotment was measured. This dataset therefore does not indicate whether or not cattle are permitted in or near streams. Thus, for all active allotments we assumed cattle were unrestricted within the active allotments.

The grazing data was compiled based on the area of active grazing allotments present per area of sub-watershed. The percentage of watershed grazed by cattle was then normalized using the maximum value transformation to obtain a grazing index with values ranging between 0 and 100.

Distribution

Figure 6 shows a distinct clumping of active grazing allotments. Active grazing allotments were concentrated in the San Luis Obispo County (35°13'N by -120°19'W) portion of the main section of the forest and the southern most portion of the Monterey section (35°9'N by -121°41'W). Hence, these areas have the highest potential for grazing related impacts on streams.

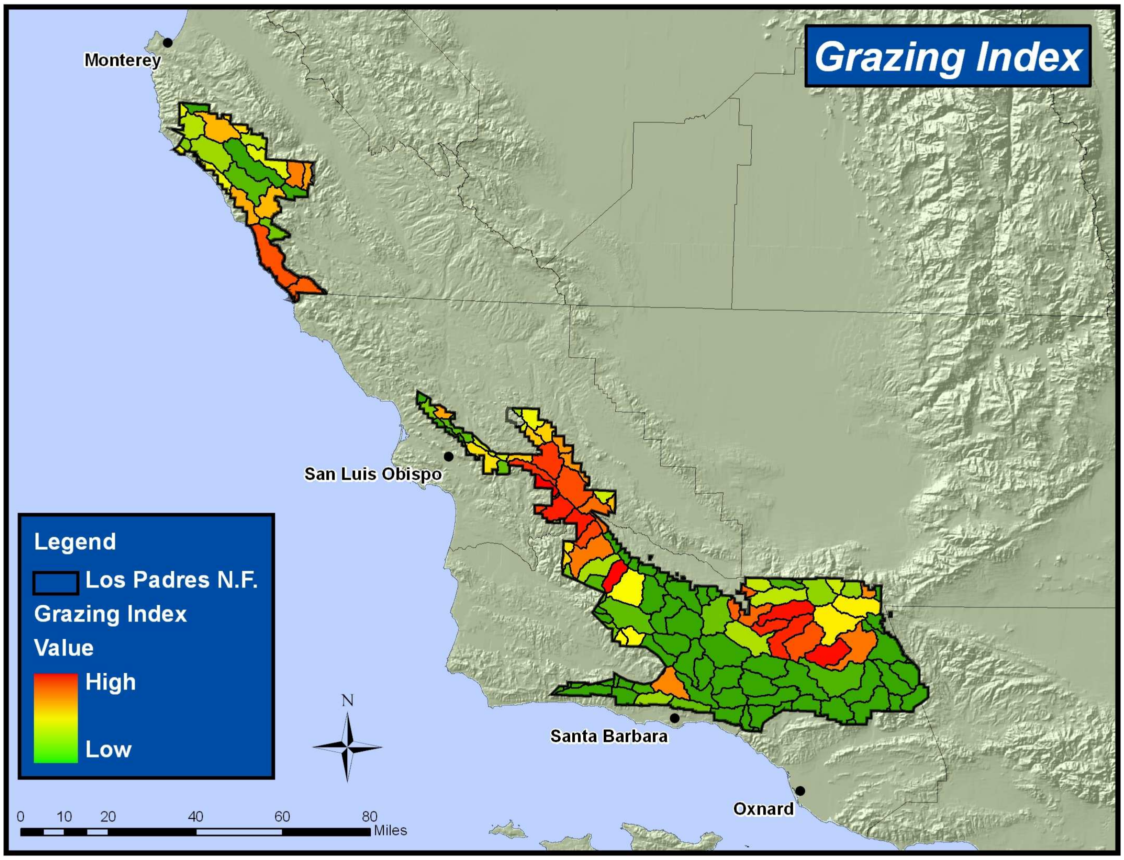

Figure 6. Grazing index with high intensity grazing in red and low intensity grazing in green.

Mining

Impacts of Mining

Excavation of minerals from the earth disturbs the soil and potentially harmful elements and compounds, which were once sequestered in the soil column, can be brought to the earth's surface (Mount 1995). The interaction of these elements and compounds, along with benign substances combined with water provided by rain events can lead to numerous chemical reactions which can produce toxic materials (Mount 1995). Runoff caused by rain events can then transport these toxic tailings over the terrestrial landscape into rivers. Abandoned mines can thus pose serious threats to stream health if the shafts overflow with water and leach contaminants into the surrounding landscapes or directly into streams (Mount 1995).

Active mines can also contribute massive quantities of sediment to streams (Wagner and LaPerriere 1985). At present there are very few active mining operations being conducted within the boundaries of the forest (K. Cooper, personal correspondence, 2006). Therefore, the biggest concern regarding the effects of mining on stream health is related to the relic tailings.

Data Compilation

The mining data supplied by the Forest Service shows 880 sites within or near the LPNF. The database for mining did not provide information regarding the intensity of use of any mines, so a proxy intensity index was constructed based on the number of mining sites per area of each sub-watershed. The resulting index was normalized to obtain values ranging from 0 to 100.

Distribution

Mining sites were concentrated in the southern district of the LPNF (34°69'N by -118°9' W) (Figure 7). The majority of mines were located in the Branch Canyon, Santa Paula, and Lower Sespe Creek sub-watersheds and the Piru Creek area. Only one mining site occurs in the northern district of the forest (Figure 7).

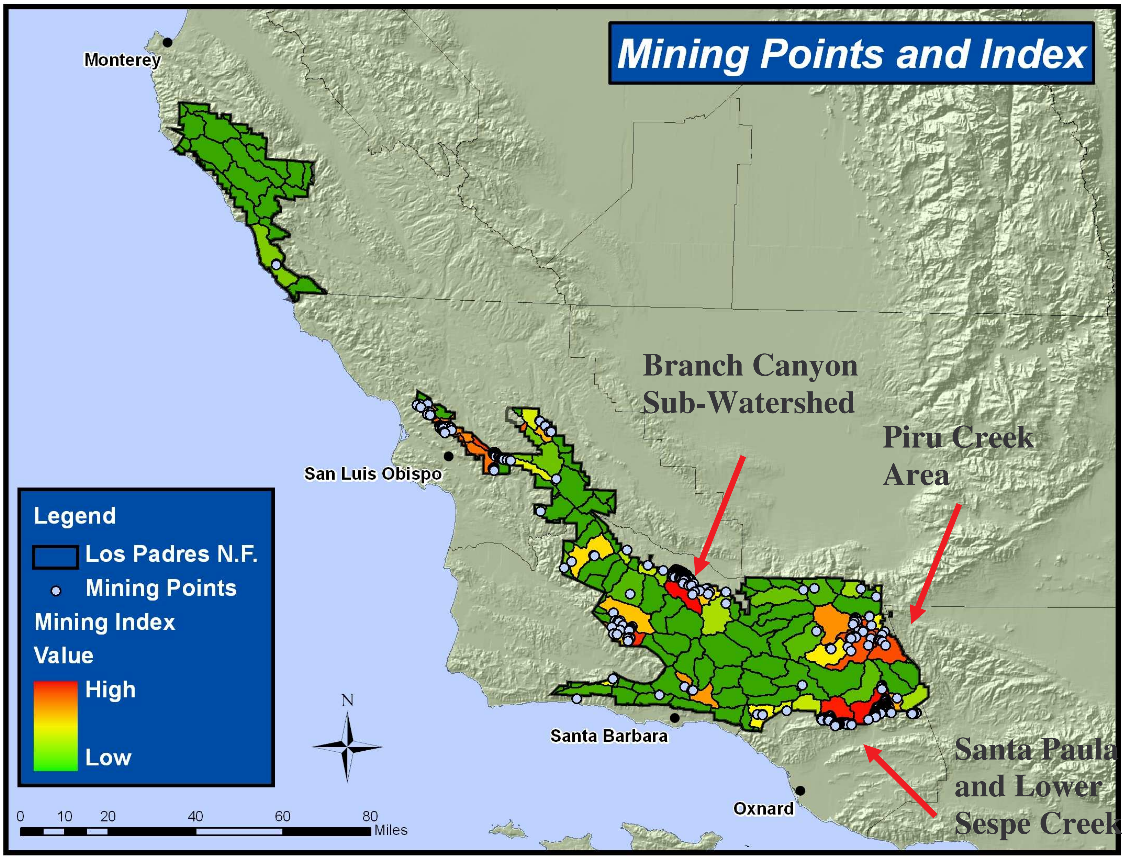

Figure 7. Locations of mining sites, with high concentrations of mines in red and low concentrations of mines in green

Recreation

Impacts of Recreation

The USFS manages recreation opportunities for the public by providing campsites and hiking trails to enhance access to the forest (USDA Forest Service 2004). The demand for recreational use of the LPNF is especially high because of its close proximity to two of California's largest urban centers, Los Angeles and San Francisco. Human recreational use of trails (i.e., hiking, riding horses, mountain biking) and campsites can result in increased exposure of bare soil, likely due to trampling of vegetation, which can lead to increased erosion transport to streams (Thurston and Reader 2001). In addition to soil sediment, rain events can transport trash, pathogens, and other pollution from recreation sites into rivers and streams.

Data Compilation

579 recreation points within the LPNF were digitized into cartographic feature files from USGS topographic quadrangle maps. These points represent eight different recreation types, including: cabins, camping, USFS facilities, horse trails, observation sites, picnic areas, trailheads, and 22 undesignated sites, which could include camp sites, trailheads, cabins, or other USFS structures (Table 4). Variability in the intensity of these land uses may impart different stresses on the landscape. Since the actual frequency and intensity of use of these recreation types was not available for every recreation point we created a proxy index to quantify recreation impacts. This index, with values ranging from 0 (as the lowest value) to 100 (as the highest value), was derived based on the number of recreation points per sub-watershed area.

Table 4. Recreation types and abundances throughout Los Padres National Forest

Recreation Types	
Cabin	1
Camping	386
FS Facility	19
Horse Trails	2
Observation Sites	4
Picnic Areas	46
Trailheads	99
Undesignated	22

Distribution

Recreation sites are concentrated the northern district (36°12’N by -121°47’W) and the southernmost portion of the southern district of the forest (34°55’N by -119°20’W). Although these portions of the forest have the highest concentration of recreation sites, recreation is ubiquitous throughout the LPNF (Figure 8).

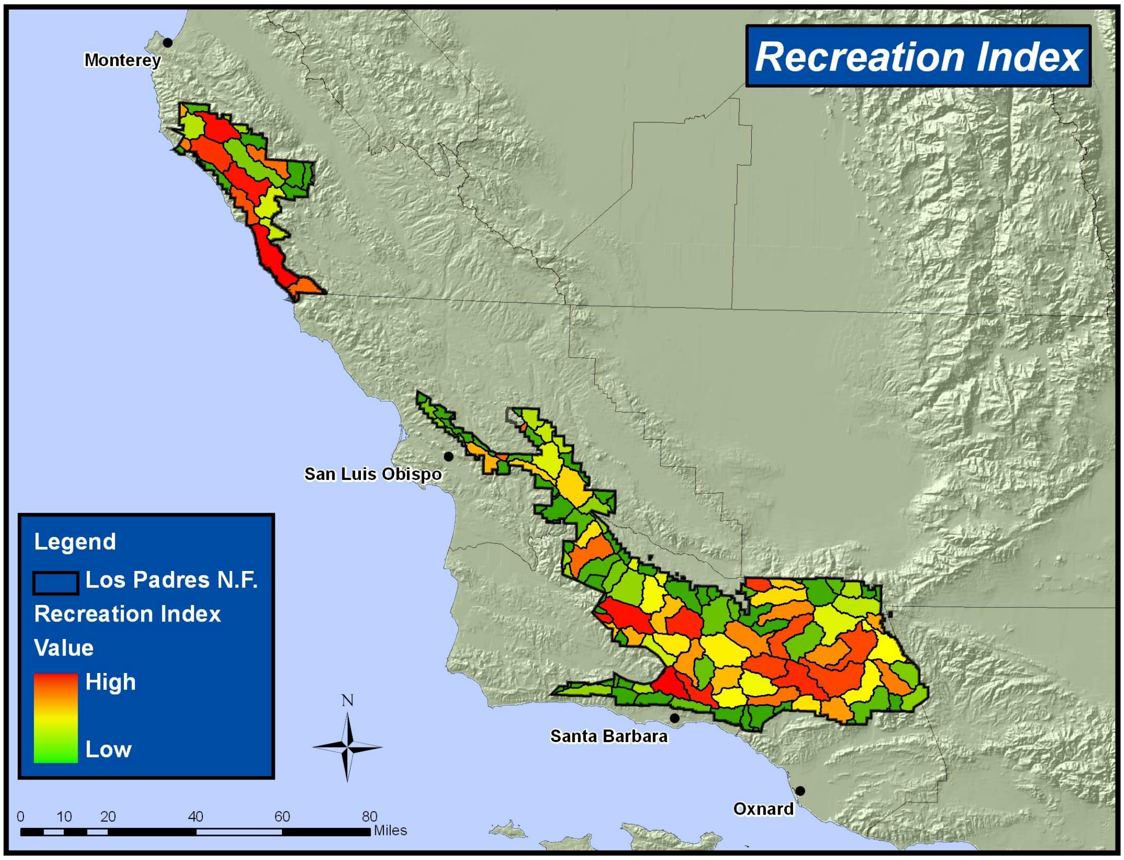

Figure 8. Recreation index in the Los Padres National Forest, with high concentrations of recreation activities in red and low concentrations of recreation activities in green

Roads

Impacts of Roads

The USFS maintains a network of paved and unpaved roads throughout the forest to provide access to recreation sites, remote locations, and private in-holdings. Unpaved roads are a bare dirt surface with no vegetative anchor. As vehicles pass over dirt roads the soil is compacted which reduces its permeability and infiltration capacity (Mount 1995). Paved roads also create sediment, and create an impermeable surface that holds heavy metals, oil, tire particles, petrol, and other automotive pollutants (Angold 1997) until rainfall or overland flow (i.e. runoff) mobilize them to streams. While rain can dislodge soil particles, consequently making them available for transport to streams during rain events, runoff, or overland flow, is the most significant means of transportation of sediment and pollutants from roads to streams (Mount 1995).

The characterization of roads used in this analysis is very thorough, ranging from highways to OHV trails. Unfortunately, the designations for these various road types are not present in the road geodatabase. Assigning a cost value based on the type of road would be useful, because the size and frequency of use will greatly influence the amount of soil sediment mobilized and washed into the rivers and streams. Due to this data limitation, all roads were treated as if they were the same road type. A record of trip frequency per road would have also been useful. These data were not present, so a road index was constructed as a proxy to quantify the predicted effects of roads on streams.

Data Compilation

The road index was compiled using the number of road segments present per sub-watershed area. Once the initial index was compiled it was normalized using the maximum value transformation to ensure road index values existed with a range of 0 to 100. The road index reflects the hypothesis that the denser the roads network in a sub-watershed, the higher the potential detrimental impacts to streams and rivers.

Distribution

The densest road networks tend to exist along the southern and western fringes of the forest in both the northern (35°89’N by -121°46’W) and southern (34°55’N by -119°78’W) districts of the LPNF (Figure 9).

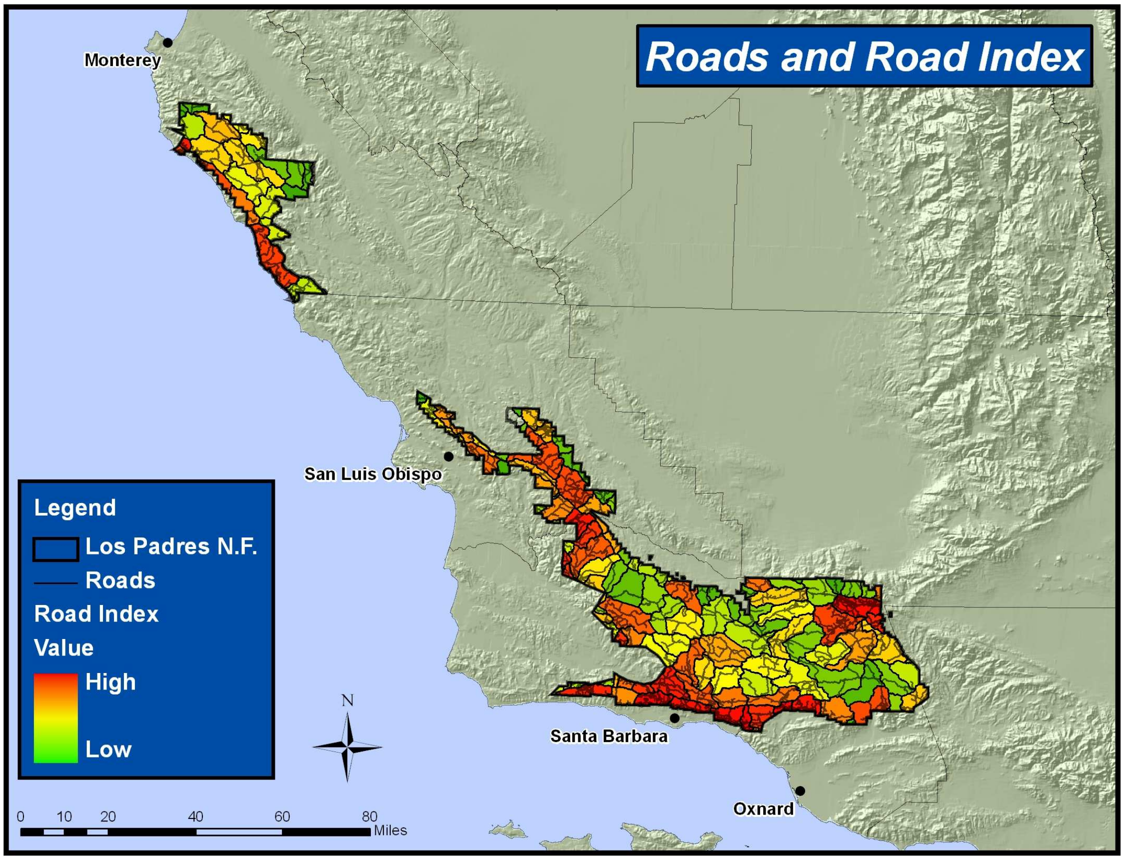

Figure 9. Roads and road index in the Los Padres National Forest, with high road density in red and low road density in green.

STATISTICAL ANALYSES

Chi-Squared Analysis (X^2)

Pearson's chi-squared tests were used to initially screen the data, with IBI condition categories as a function of each individual stressor's ranking category. A chi-squared test evaluates the relative frequency of occurrence between two categorical variables (Zar 1999). Five individual chi-squared tests were performed, testing each of the five stressors (grazing, fire, mining, roads, recreation) against IBI categories. A significant chi-square score indicates that the relative frequencies between categories are higher or lower than expected by random distribution (Zar 1999). Based on chi-squared analysis, only two data points fell in the "poor" IBI category. Because of the law of statistical power, these points were not included in the analysis.

Location Variables

Since the LPNF spans a vast area of forest from Monterey to Los Angeles County, there is a high degree of geologic, meteorological, and ecological variability (USDA Forest Service 2005). These location specific variables have the potential to affect IBI score. In order to decipher the impacts of possible effects of location variables on IBI scores, seven location-specific variables were explored, including sub-basin, forest district, latitude, ecosystem, precipitation, elevation, and slope. The values for each of these seven variables were determined at each of the 81 sample sites, using GIS data as described in the following pages.

Sub-basin

A sub-basin is a discrete hydrologic unit and watershed designation. This delineation serves as a robust regional grouping, as hydrologic units differentiate between regions of different hydrologic characteristics (Steeves and Nebert 1994). Seven sub-basins are located in the LPNF (Figure 10). The data were collected by the Geographic Information Retrieval and Analysis System, and digitized by the United States Geological Survey (USGS) Office of Water and Data Coordination in 1994.

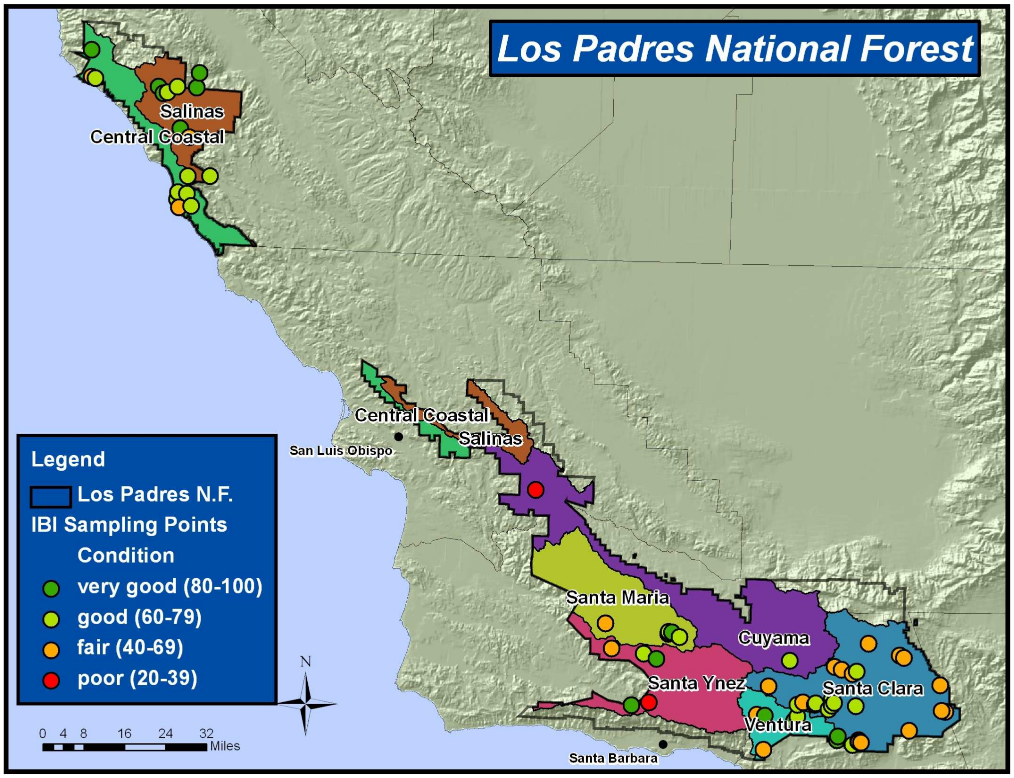

Figure 10. IBI sampling points and ranks in the Los Padres National Forest, where different color areas represent sub-basin delineations

The "sub-basin" delineation was chosen for this analysis because the next coarser scale, "basin," only divided the data into two basins, whiles the next finer scale, "watershed," divided the data too sparsely, often leaving only one test site per watershed. The sub-basin delineation is the best grouping of this data set to both explain hydrologic variability and retain statistical power for stressor-IBI analysis (Table 5).

Table 5. The number of IBI sample sites located within each sub-basin.

Sub-basin	IBI sites
Central Coastal	13
Cuyama	2
Salinas	14
Santa Clara	31
Santa Maria	7
Santa Ynez	5
Ventura	9

A one-way analysis of variance (ANOVA) was used to, compare mean IBI scores between the seven sub-basins of the LPNF (Figure 14). A Tukey-HSD test was then run as a post hoc pairwise comparison of the means to further explain the differences between sub-basins.

Northern vs. Southern Districts

The LPNF consists of two discontinuous districts of forest (Figure 11). The northern district lies in Monterey county and the very northern edge of San Luis Obispo County, while the southern districts fall mostly in southern San Luis Obispo county, Santa Barbara, and Ventura counties, as well as the south western corner of Kern County and the north western corner of Los Angeles County. It is possible that the locations of these two disjoint sections of forest may have an influence on IBI score. A two-way t-test was performed to test the difference in mean IBI scores between the two districts (Figure 15).

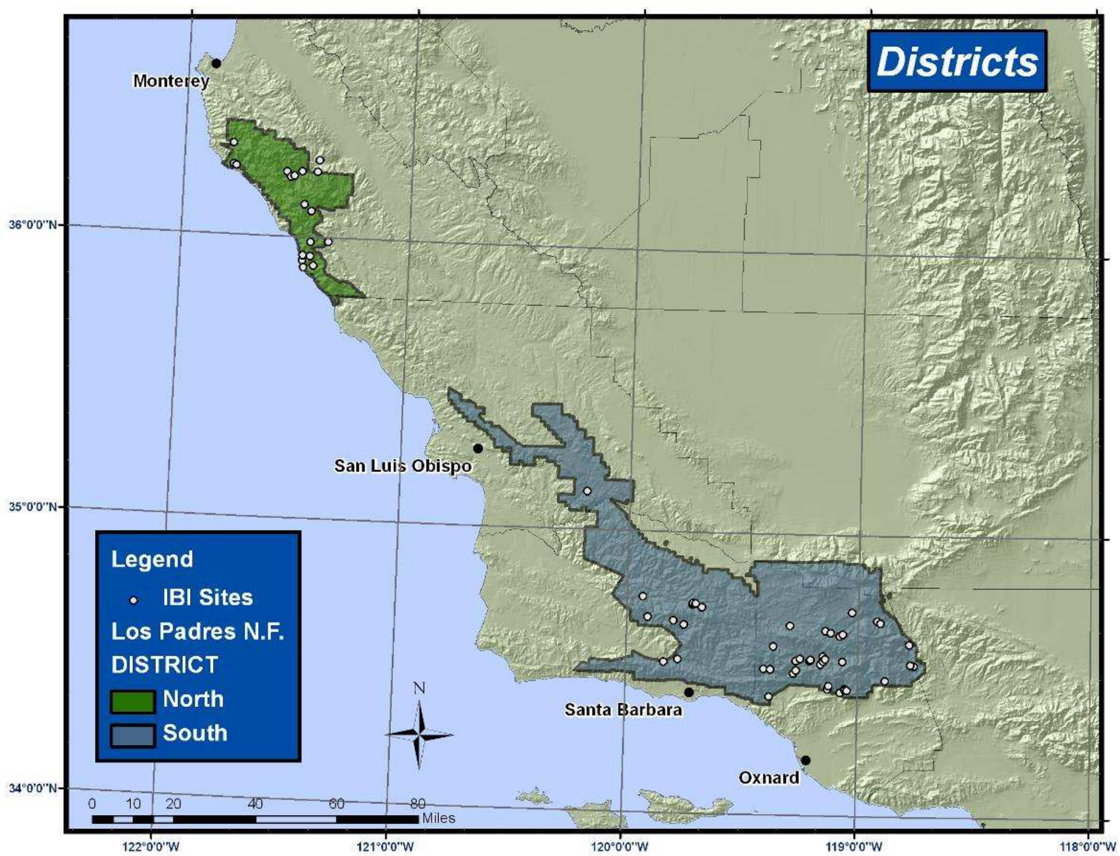

Figure 11. Northern and southern districts of the Los Padres National Forest

Latitude

Latitude and longitudinal coordinates were taken with a handheld GPS tool at the time of sample collection (J. Uyehara, personal correspondence, 2005). The data points range from 34.4° to 36.3°N. In order to test if a latitudinal gradient is reflected in IBI score, IBI was linearly regressed on latitude (Figure 16).

Ecosystem type

Eighty-one IBI data points lie in one of two ecosystem types, as determined by Level 3 Omernik categorizations (Omernik 1987). Fifty-one sites are classified as Southern California mountain habitat, and 30 sites as chaparral and oak woodland habitat (Figure 12). Southern California mountain habitat is dominated by conifers, while oak woodland and chaparral habitats are dominated by oak and woodland herbaceous vegetation (J. Uyehara, personal correspondence, 2005). It is possible that these different vegetation types may result in different levels of nutrient loading and may affect substrate composition in the streams, which may both influence IBI scores. A two-way t-test was performed to test the difference in mean IBI scores between the two ecosystem types (Figure 17).

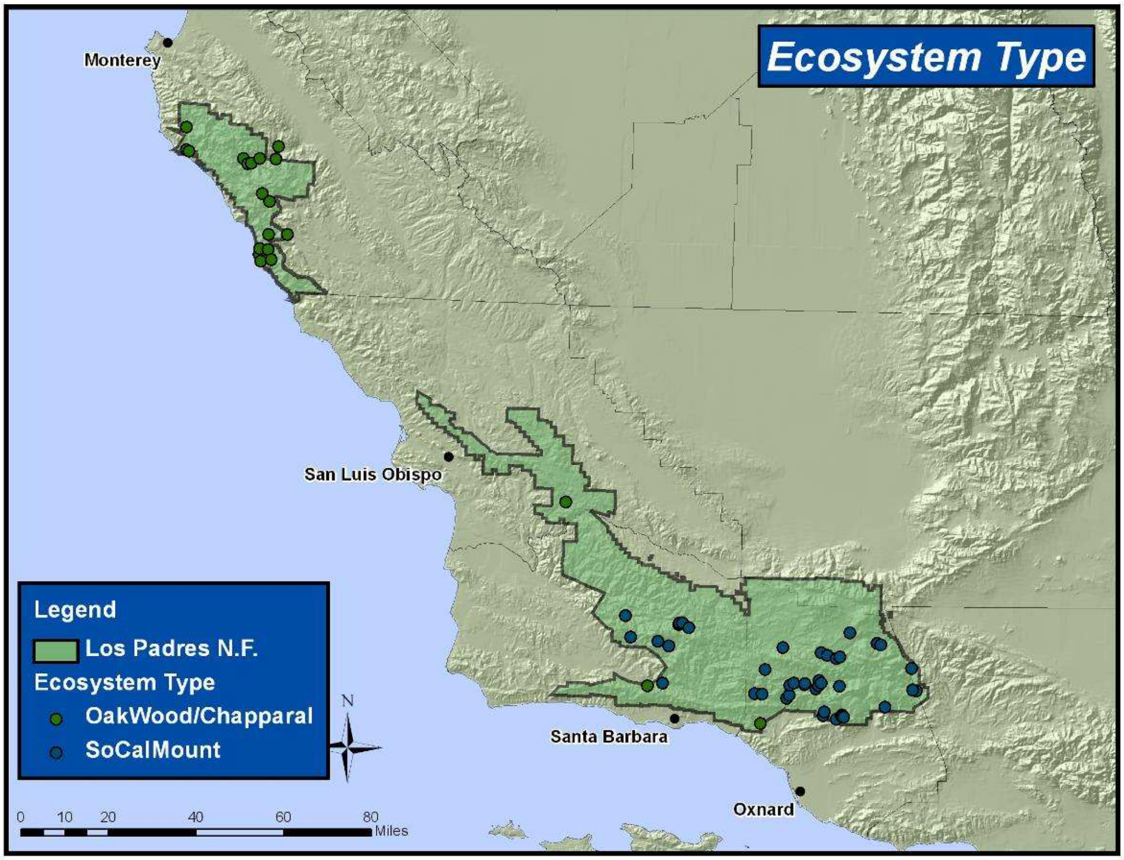

Figure 12. Ecosystem type classification for the IBI test sites, with Oak Woodlands and Chaparral in Green and Southern California Mountain in blue.

Precipitation

The level of precipitation varies between 9 inches per year in the arid Badlands area to up to 65 inches per year in the wet Monterey district (Figure 13). The mean annual precipitation values for the LPNF were obtained from the California Spatial Information Library. These data consist of the long-term mean annual precipitation data compiled from USGS, California Department of Water Resources, and California Division of Mines map and information sources. It is plausible that variations in precipitation could affect stream flow and nutrient loading, which may result in variations in IBI scores. IBI scores were linearly regressed on the mean annual precipitation values to determine if the precipitation gradient is reflected in IBI score (The California Spatial Information Library 2005b).

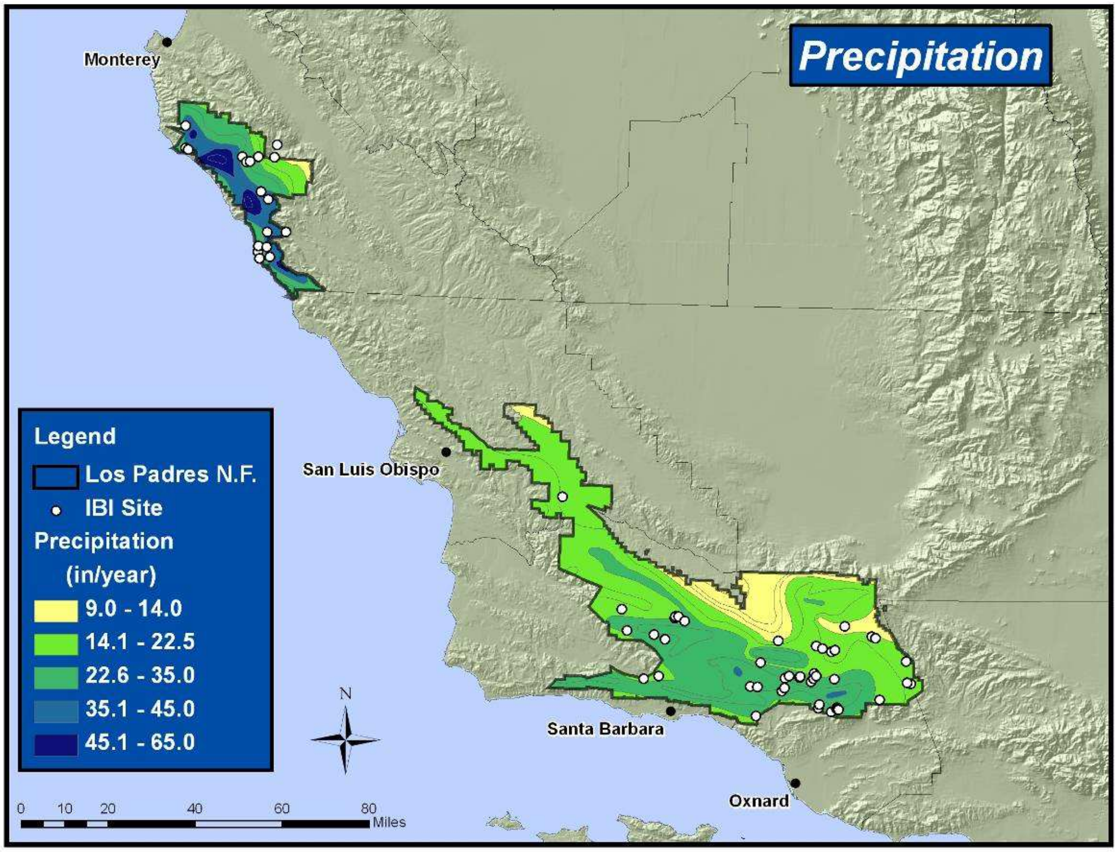

Figure 13. Mean annual precipitation rates within the Los Padres National Forest

Elevation

The LPNF ranges in elevation from sea level to over 8,000 feet. Site elevations were determined from a 30 m digital elevation model (DEM) developed by the USGS. Temperature, vegetation, and precipitation tend to vary with elevation. These physical factors influence BMI composition and, as a result, overall IBI score. To determine if an elevation gradient tracks IBI score, IBI scores were linearly regressed on site elevation (The California Spatial Information Library 2005a).

Slope

Percent slope was determined from the 30 m DEM using the spatial analyst slope function with a z value of 1 in ESRI ArcMap 9.1. Slope plays a large role in determining a stream's flow rate which in turn could influence the structure of the BMI community. To determine if slope gradient reflects IBI score, IBI scores were linearly regressed on a site's percent slope.

All statistical analyses were performed using the statistics package, JMP 5.1.2 for Windows XP Professional.

RESULTS

Significance levels in all statistical tests were evaluated at an alpha level of 0.10. The standard of $\alpha = .05$ was not used to compensate for the natural noise in the data sets.

Chi-Squared Analysis (X^2)

Chi-squared analysis was performed on three categorical rankings of IBI score (very good, good and fair) and the low, medium and high rankings of each stressor (where stressor rankings correspond to one third of each stressor's index) (

Table 6). Recreation has a significantly different relative frequency with respect to IBI scores than can be expected at random (p=0.0003). Grazing showed a trend in the same manner (p=0.1086), while the other three stressors were not significantly different with respect to IBI scores expected at random (

Table 6). The lack of significant effects suggests that the stressors have no effect on IBI scores, or that there might be other factors influencing IBI scores.

Table 6. Chi-squared analysis of IBI score as a function of each individual stressor

Stressor	df	X^2	prob.
Fire	4	1.128	0.8898
Grazing	4	7.571	0.1086
Mining	2	1.270	0.5300
Recreation	2	16.013	**0.0003**
Roads	4	2.987	0.5600

Location Variables

IBI scores showed significant variation with respect to four of the seven location variables examined (Table 7). Linear regression analysis showed that IBI score did not differ with respect to precipitation gradient, elevation gradient, or gradient in slope, but was significantly effected by sub-basin (p=0.001), forest districts (p=0.0054), latitude (p=0.0072), and ecosystem type (p=0.0646) (Table 7).

Table 7. Location variables tested for their influence on IBI score

Variable	Model R^2	P-value
Sub-basin	0.26	**0.001**
Districts	0.09	**0.0054**
Latitude	0.09	**0.0072**
Ecosystems	0.04	**0.0646**
Precipitation	0.01	0.1746
Elevation	0.01	0.2098
Slope	0.00	0.3704

Sub-basin

A one-way Analysis of variance (ANOVA) showed that the mean IBI score significantly differs between sub-basin (p=0.0010) (Figure 14). Salinas is significantly different from Cuyama and Santa Clara, and Cuyama is different from Salinas and Ventura (Figure 14).

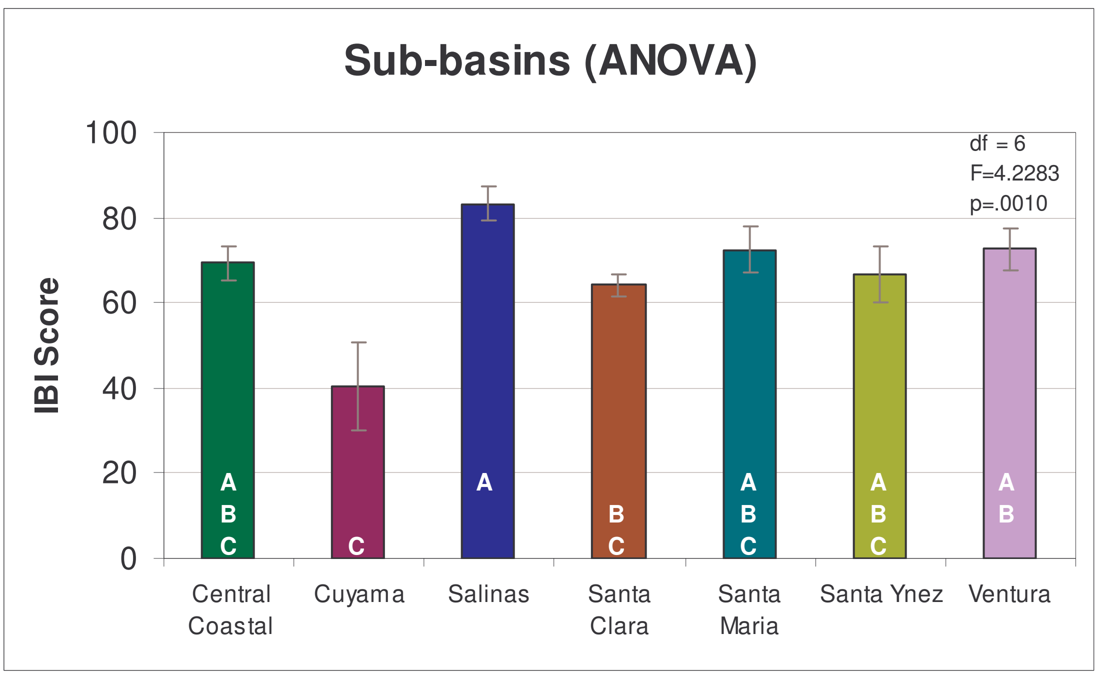

Figure 14. One-way analysis of variance of mean IBI score compared between sub-basins. The error bars represent one standard error of the mean. The white letters for each bar represent the Tukey-HSD post hoc pairwise mean comparison results such that the mean for sub-basins with the same letter are considered statistically indistinguishable from each other.

Northern vs. Southern Districts

A two-way t-test comparing the mean IBI scores between northern and southern districts show that scores in the northern district are significantly higher than those in the southern region (df=79, t=2.86, p=.0054) (Figure 15).

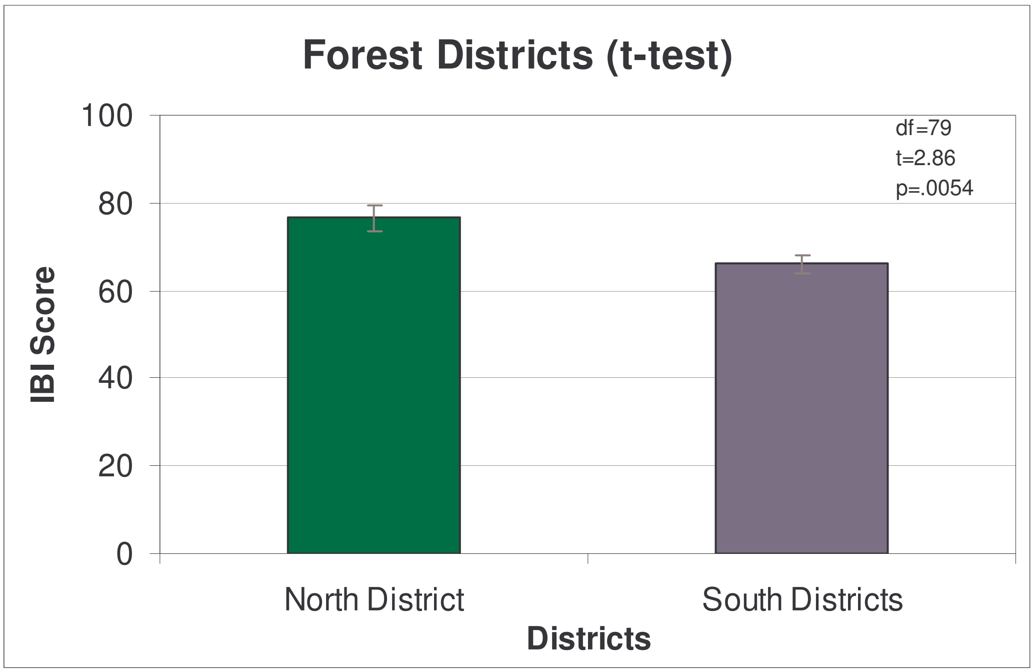

Figure 15. Two-way t-test of mean IBI score compared between northern and southern districts of the Los Padres National Forest. The error bars represent one standard error of the mean.

Latitude

Linear regression analysis shows that IBI scores increase with latitude (R^2=.09, p=.0072) (Figure 16).

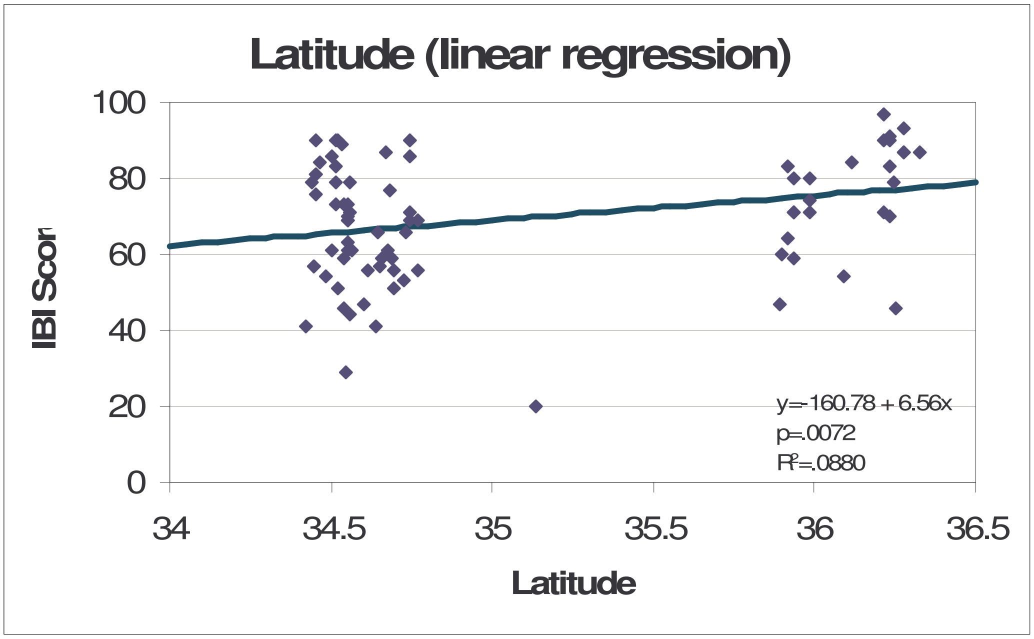

Figure 16. IBI score linearly regressed on latitude.

Ecosystem type

A two-way t-test comparing the mean IBI scores between oak woodland and chaparral habitat and Southern California mountain habitat show that scores in the woodland and chaparral habitat are significantly higher than those in the mountain habitat (df=79, t=1.87, p=.0646) (Figure 17).

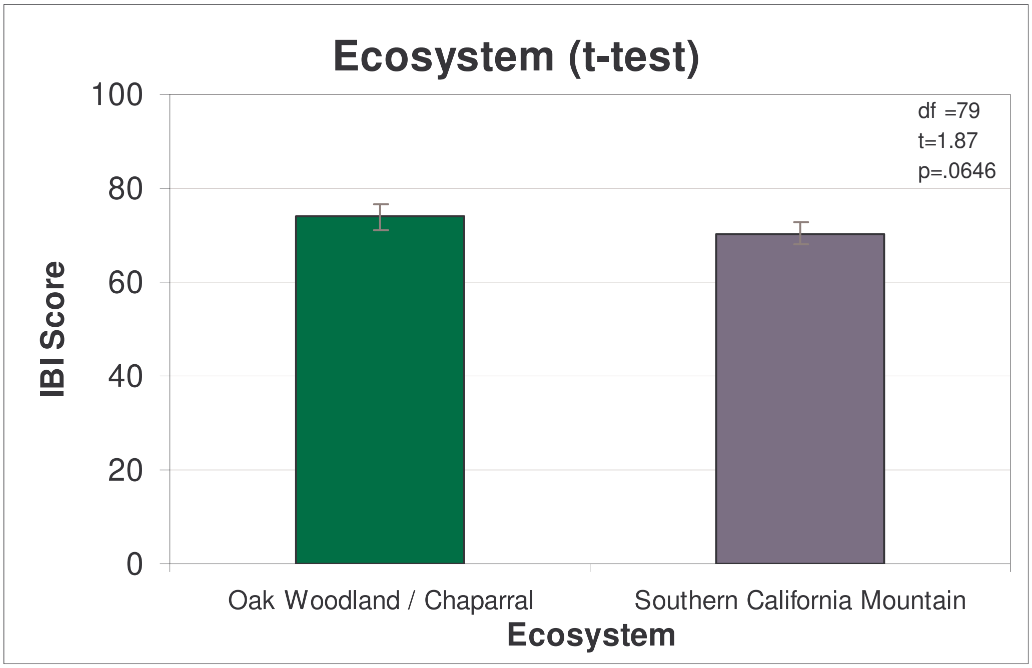

Figure 17. Two-way t-test of mean IBI score compared between oak woodland and chaparral habitats with Southern California mountain habitats. The error bars represent one standard error of the mean.

Precipitation, Elevation, Slope

Linear regression analysis showed that IBI score did not differ with respect to precipitation gradient (R^2=.01, p=.1746), elevation gradient (R^2=.01, p=.2098), or gradient in slope (R^2=-.002, p=.3704).

Determining location covariate

The four location variables which had a significant effect on IBI score (sub-basin, ecosystem type, latitude, and districts) were then analyzed in a linear multiple regression model.

When combined in the model, sub-basins are the only factor which significantly affects IBI scores. The multiple regression model explains 28% of the variation in IBI scores, while sub-basin alone explains 26% (Table 8, Table 9). Of the seven location variables explored (sub-basin, forest district, ecosystem type, latitude, precipitation, slope and elevation) sub-basin explains the greatest variance in IBI scores and was used as a covariate in the statistical analysis of physical stressors.

Table 8. Multiple regression model with IBI as a function of four location variables

Independent Variable	Coefficient	$df_{variable}$	$F_{variable}$	$p_{variable}$
Intercept	543.66			
$\text{Sub-basin}_{\text{Central Coastal}}$	15.99	6	2.96	**0.0175**
$\text{Sub-basin}_{\text{Cuyama}}$	-0.08			
$\text{Sub-basin}_{\text{Salinas}}$	-18.38			
$\text{Sub-basin}_{\text{Santa Clara}}$	16.37			
$\text{Sub-basin}_{\text{Santa Maria}}$	-5.99			
$\text{Sub-basin}_{\text{Santa Ynez}}$	4.83			
$\text{District}_{\text{North}}$	0.00	1	.	
Latitude	-13.43	1	0.61	0.4385
$\text{Ecosystem}_{\text{Oak woodland/Chaparral}}$	-6.62	1	1.82	0.1813
R^2 = 0.28				

Table 9. ANOVA regression of IBI score as a function of sub-basin

Independent Variable	Coefficient	p
Intercept	66.99	<.0001
$\text{Sub-basin}_{\text{Central Coastal}}$	2.32	0.5707
$\text{Sub-basin}_{\text{Cuyama}}$	-26.49	**0.0042**
$\text{Sub-basin}_{\text{Salinas}}$	16.22	**0.0001**
$\text{Sub-basin}_{\text{Santa Clara}}$	-2.77	0.3793
$\text{Sub-basin}_{\text{Santa Maria}}$	5.44	0.2944
$\text{Sub-basin}_{\text{Santa Ynez}}$	-0.39	0.9475
R^2 = 0.26 df=6 F=4.23 p=.0010		

MODEL

Model Building

In order to explore how the physical stressors affect IBI score, a multiple regression model was constructed with IBI score as the dependent variable, the five stressors, (fire, grazing, mining, recreation, and roads) as the independent variables, and sub-basins as the covariate (Table 10). Because the physical stressors are not mutually exclusive in a location, the multiplicative interactions between these stressors were also explored (Table 11).

A stepwise multiple regression model was constructed using all possible pairwise stressor interaction terms. The final model was then selected using a "step-down" approach where all independent variables were entered into the model and the variables with the highest, most non-significant p-values were removed one at a time. The five individual physical stressor variables and covariate sub-basin were always included in the model.

A forward-selection procedure, where variables are entered into the model one at a time based on the lowest p-value was also considered. However, in this situation, this method lacks statistical robustness because it may fail to identify significant variables when interactions between variables are present, and may not produce the strongest model. This is especially when dealing with a categorical, or "dummy" variable such as sub-basins (Zar 1999).

Model Results

This final model explains 48% of the variation in IBI scores (Table 11), which is substantially more variation than the linear regression model that only explains 39% (Table 10). Our model results show that fire, grazing, mining, and roads have a significant effect on IBI scores, while recreation does not (Table 11). The effects of physical stressors on IBI scores, however, may be interactive. The results show that the magnitude of the effect on IBI by grazing is dependent on fire, mining, recreation, and roads, whereas the magnitude of the effect on IBI by recreation is dependent on fire (Table 11).

Table 10. Multiple regression model with IBI score as a function of sub-basin and stressors

Variable	Coefficient	p
Intercept	89.07	<.0001
Sub-basin$_{Central\ Coastal}$	8.07	**0.0927**
Sub-basin$_{Cuyama}$	-12.12	0.1819
Sub-basin$_{Salinas}$	8.19	**0.0574**
Sub-basin$_{Santa\ Clara}$	-10.95	**0.0029**
Sub-basin$_{Santa\ Maria}$	4.16	0.3924
Sub-basin$_{Santa\ Ynez}$	-1.13	0.8357
Sub-basin		**<.0001**
Fire	-0.18	**0.0231**
Grazing	-0.17	**0.0073**
Mining	0.17	**0.0365**
Recreation	0.02	0.8346
Roads	-0.25	**0.0563**
R^2 = .48 adjusted R^2 = .39		

Table 11. Multiple regression model with IBI score as a function of sub-basin, stressors, and stressor interactions

Variable	Coefficient	p
Intercept	88.70	<.0001
Sub-basin$_{Central\ Coastal}$	-1.45	0.7891
Sub-basin$_{Cuyama}$	-23.48	**0.0518**
Sub-basin$_{Salinas}$	12.18	**0.0078**
Sub-basin$_{Santa\ Clara}$	-16.23	**<.0001**
Sub-basin$_{Santa\ Maria}$	15.28	**0.0126**
Sub-basin$_{Santa\ Ynez}$	11.80	**0.0760**
Sub-basin		**<.0001**
Fire	-0.31	**0.0274**
Grazing	-0.58	**0.0586**
Mining	0.30	**0.0005**
Recreation	-0.06	0.7850
Roads	-0.31	**0.0337**
Grazing*Fire	-0.01	**0.0044**
Grazing*Mining	-0.02	**0.0517**
Grazing*Recreation	-0.03	**0.0060**
Grazing*Roads	0.03	**0.0113**
Recreation*Fire	0.02	**0.0113**
R^2 = .58 adjusted R^2 = .48		

Model Accuracy

To test the accuracy of the multiple regression model the error was calculated, comparing the actual IBI scores to those predicted by the model (Table 12).

$$\text{Error} = \frac{|\text{Observed} - \text{Expected}|}{\text{Observed}}$$

On average, model predictions are 83.66% accurate. Excluding the Cuyama sub-basin, which only contains two IBI sampling points, the model accuracy is 85.22% accurate.

Table 12. Average error of the final multiple regression model

Sub-basin	Number of Observations	Avg. Percent Error	Standard Deviation
Central Coastal	13	15.50	13.47
Cuyama	2	77.98	99.33
Salinas	14	13.07	13.13
Santa Clara	31	13.48	15.31
Santa Maria	7	13.93	8.74
Santa Ynez	5	17.32	20.36
Ventura	9	20.13	17.12
All Sub-basins	81	16.34	20.60
All Sub-basins, excluding Cuyama	79	14.78	14.46

DISCUSSION

The final model is represented by the following equation:

IBI = Sub-basin intercept – 0.58**Grazing** – 0.06**Recreation** + 0.30**Mining** – 0.31**Roads** – 0.31**Fire** + 0.02**Recreation** (**Fire**) – 0.02**Grazing** (**Mining**) – 0.01**Grazing** (**Fire**) + 0.03**Grazing** (**Roads**) – 0.03**Grazing** (**Recreation**)

At an 85% level of accuracy this model can serve as an insightful management tool for the USFS (Table 12). The model has the ability to accurately predict the effects of defined physical stressors (grazing, recreation, mining, roads, fire) on IBI scores.

To make the discrete results of this model more user friendly for USFS managers, a system of management thresholds was derived. The model will produce a predicted IBI score based on the "intensity of use" indices for each of the physical stressors. Because this numerical value may be difficult to translate into a useful management plan a 100 point stressor scale was divided into three “use/intensity” levels: low (0-33.33), medium (33.34-66.66), and high (66.67-100) (Figure 18). The midpoint values for each category (15, 50, and 85) were then used as an indicator of the potential effect of each physical stressor on IBI score if all other stressors are held constant. The values of 15, 50, and 85, representing the midpoints of each management category, are associated with “real world” quantitative values for stressors (Table 13). Results indicated that high use categories tend to cause large fluctuations in predicted IBI scores (Figure 18).

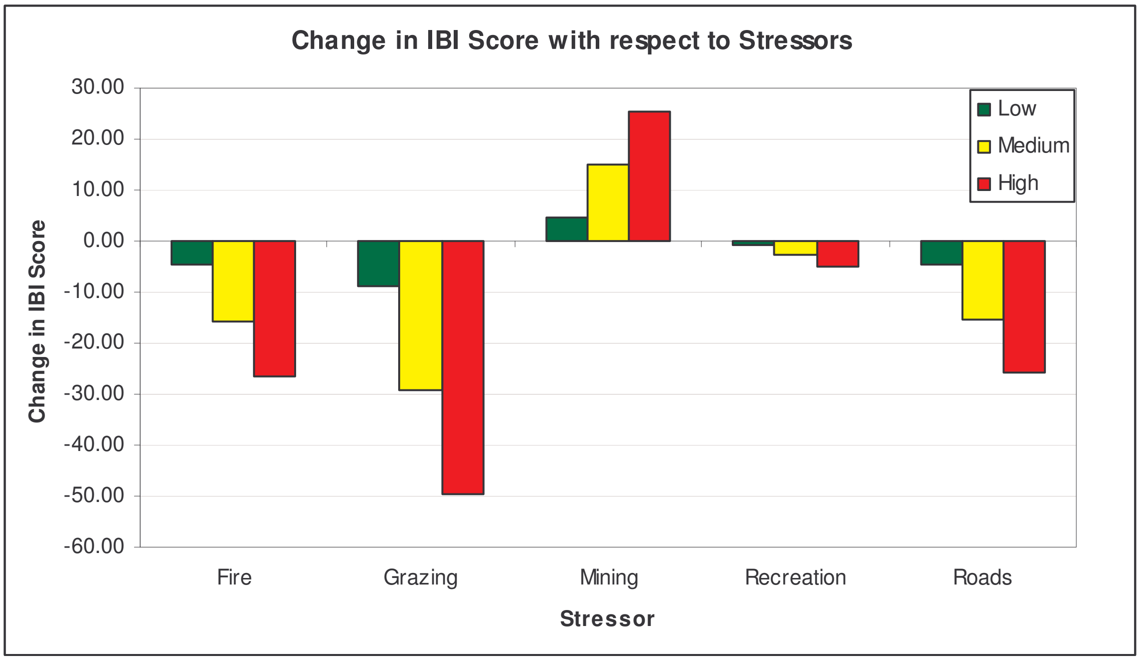

Figure 18. Change in predicted IBI score with respect to each stressor

Table 13. Quantitative values for each stressor for the low, medium, and high stressor levels

Stressor	Low	Medium	High
Fire	15 Index value	50 Index value	85 Index value
Grazing	allotments in 15% of sub-watershed	allotments in 50% of sub-watershed	allotments in 85% of sub-watershed
Mining	1.19 sites/ 1000 hectares	3.97 sites/ 1000 hectares	6.74 sites/ 1000 hectares
Recreation	0.34 sites/ 1000 hectares	1.12 sites/ 1000 hectares	1.90 sites/ 1000 hectares
Roads	23.51 roads/ 1000 hectares	78.37 roads/ 1000 hectares	133.22 roads/ 1000 hectares

Fire

Low index values for fire have the ability to decrease predicted IBI scores by 5 points (Figure 18). This rather minor decline in IBI score induced by fire is likely due to the relatively fire adapted vegetation serving as land cover in the LPNF watersheds

(Chandler et al. 1983). Low intensity fires, which are assumed to be represented by low fire index values, play an essential role in nutrient cycling in chaparral ecosystems (DeBano and Conrad 1978) and are not generally associated with complete destruction of the land cover (Borchert and Odion 1995). When the skeletons of woody plants are left behind they can inhibit overland flow of rain runoff and provide conduits into the soil which can aid in the absorption of runoff (Mount 1995). Therefore, when the structural integrity of a watershed's vegetative cover is spared by lower intensity fires, streams within those watersheds will not be as susceptible to erosion as watersheds that have experienced high intensity fires that destroy the vegetative structure of the (Mount 1995).

High-intensity fires can have detrimental effects on IBI scores. The predictive model shows a 25 point decrease in predicted IBI scores due to the presence of "high" fire levels (Figure 18). This means a relatively large, new burn can cause IBI scores to drop a complete ranking category (i.e. from good to fair). This dramatic drop in IBI score is likely due to sediment loading into streams from a landscape devoid of vegetative anchors and skeletons (Mount 1995).

Fire suppression techniques have limited ability to prevent large scale fire disturbances (Moritz 2003). Max Moritz (1997) suggests that climatic conditions were the main driver of extreme fire events in the LPNF rather than the age of vegetation or any other biophysical or environmental factors. While decreasing the amount of biomass in the forest under story may decrease the intensity of a fire by limiting fuels (Minnich 1995), large scale fires will occur regardless of the presence of suppression and will occur on the order of every 40 to 70 years in the LPNF (Moritz 1997). The incidence of large fires is therefore largely out of the USFS's control. USFS fire suppression measures have, however, decreased the amount of low intensity fires throughout LPNF.

The USFS should continue to implement best management practices (BMPs) to prevent small fires from progressing to large, devastating wildfires, which in turn can have a large effect on overall stream health.

Grazing

Grazing had the largest impact on IBI scores (Figure 18). The effects of all other stressors were dependent on the pressures of grazing. High levels of grazing have the potential to reduce predicted IBI scores by 50 points. This decline in ranking score would be large enough to reduce IBI condition from "very good" to "poor". Unlike large wildfire incidence, the USFS can control grazing within forest boundaries. Grazing impacts on streams occur in two main ways: (1) erosion and increased runoff due to removal of vegetation and compaction of soils and (2) deterioration of riparian corridors and aquatic habitats (Mount 1995).

Removal of vegetation throughout watersheds increases runoff due to a decrease in interception and evapotranspiration. When removal of vegetation is coupled with compaction of soils from large ungulates, the potential for runoff significantly increases (Mount 1995).

Cattle also trample stream banks and increase nutrients loaded into streams via urination and defecation, and decrease streamside vegetation. When cattle consume streamside vegetation they cause alterations in the amount of detritus entering streams, thus altering nutrient flows. Decreases in riparian vegetation can also exacerbate runoff and erosion to streams (Mount 1995) and cause changes in microclimate temperatures due to a lack of cover (Platts 1981; Scrimgeour and Kenall 2003). All of these effects can seriously affect benthic macroinvertebrate assemblages (Hauer and Lamberti 1996).

Impacts to stream health from grazing can be reduced if cattle are not permitted in stream or on stream banks. Because the effects of numerous stressors are dependent on the effects of grazing, ensuring that cattle are kept out of streams will decrease the effect of grazing independently as well as its interaction with other stressors. If it is not possible to keep cattle out of direct contact with streams and their banks, impacts to streams could be reduced by limiting grazing allotments to the low intensity stressor category (15% of any sub-basin). As shown in Figure 18, keeping grazing intensity low could result in a 10 point reduction in IBI score, which is not enough to drastically change IBI condition.

Limiting grazing operations to 15% of a sub-basin, however, would decrease the amount of land available for grazing, and may thus decrease funding to the USFS provided by allotment permitting. It might also be extremely difficult to monitor allotments to ensure cattle are kept clear of streams, and restricting cattle from streams may prevent them from reaching their source of water. The best course of action for the

USFS depends on their desired targets for stream health standards and depends on their budget and resource constraints.

Mining

The positive effects of mining on predicted IBI score may seem counterintuitive (Figure 18). It seems unreasonable to think the presence of mining could be associated with an increase in overall stream health. The current state and recent history of mining in the LPNF provides a rational for these surprising results.

In the past, numerous mining operations were active throughout the LPNF. These operations consisted of excavating metals such as mercury, gold, and copper, and drilling for oil. With the exception of oil drilling, the majority of the mines in the LPNF have not been active since the 1940s, and many of the inactive mining sites have had extensive restoration (K. Cooper, personal correspondence, 2006). These restoration efforts seem to be successful, based on the increased IBI scores near mining sites. If the USFS can continue to restore inactive sites with similar results, current mining operations should not be a serious concern for stream health. However, more detailed data that clearly shows which mines are active, the type of mining present, and the size of the mine would be necessary to more accurately determine the effects of mines within the LPNF.

Recreation

Overall stream health does not seem to be greatly affected by recreational activities in the LPNF. However, recreational activities such as the operation of campgrounds can still have local effects on stream health due to trampling of stream banks and loading of trash into streams (Cole 2000). More detailed data for recreational areas, such as the discrimination between the locations of campgrounds versus hiking trails, may provide more insight on the local effects of recreation on IBI scores.

Roads

The presence of roads in the LPNF was found to have a significant, negative effect on IBI scores. Holding all other stressors constant, areas with high road density (133 roads per 1000 ha) are associated with a 25 point drop in IBI score (Figure 18, Table 13). A drop in score of this magnitude will reduce a ranking score one complete IBI category (i.e. good down to fair, or fair down to poor). In some circumstances, a drop of 25 IBI points could be enough to reduce IBI condition two complete categories. Intermediate levels of road density (78 roads per 1000 ha) still provide the possibility for a 15 point drop (Figure 18, Table 13) which could be associated with a one category drop in IBI condition.

Roads can act as conduits for runoff due to the absence of vegetation and compacted soils or impermeable surfaces. These factors allow water to flow, unrestricted, down slope into streams. Eliminating the use of roads during heavy rains or snow melts, for example, would decrease the loosening of soil and loading of pollutants from automobiles which can then be transported to streams at a faster rate.

While the presence of roads do not decrease IBI condition as severely as grazing or fire, but it should still be a major concern for the USFS in their efforts to monitor stream health. Reducing the stresses from roads within the forest is arguably the easiest to manage of all the physical stressors considered because many of the roads in the LPNF have locking gates which can be closed to restrict use during times of high erosion potential (i.e. winter/fall). The USFS can also restrict the construction of new roads and restore areas where roads are no longer in use.

If the USFS can restrict the density of roads in use to the “low” stressor level (23 roads per 1000 ha), the effects of roads should be limited on stream health (Table 13). At this level, IBI score has the potential to drop only 5 points, which will not significantly alter IBI condition (Figure 18).

Since road density can have a serious impact on IBI scores and can yet be easily managed should encourage the USFS to aggressively manage road use, especially during peak seasons associated with significant runoff potential.

Summary

Overall, the management of the physical stressors discussed in this study is highly dependent on the USFS budget and priorities. Personal correspondence with USFS employees has shown that stream health is a priority for the LPNF. However, there is no budget to implement a monitoring or action plan capable of providing necessary management.

Our analysis has shown that the physical stressors of grazing, fire, and roads can have the greatest significant impact on IBI score, and thus overall stream health. The USFS can actively manage the effects of grazing by restricting grazing activities or allotments in a watershed, and roads by decommissioning, restricting use, and managing the building of new roads. The incidence of large wildfires, on the other hand, is largely out of their control (Moritz 2002).

Currently, the USFS is undergoing a National Environmental Policy Act (NEPA) study on all grazing allotments in the forest. This study could provide more detailed information regarding grazing operations, such as grazing rotation patterns and number of cattle per allotment. This information could then be parameterized into our model to provide an even more accurate portrayal of the effects of grazing on IBI score. Additionally this information may provide insight into the construction of a feasible management plan.

All physical stressor data could be improved by gathering data regarding the intensity of use or burn. Stressors quantification was based on the occurrence of a given stressor per unit area, with the exception of fire which incorporated year since burn. If a measure of intensity is implemented into stressor quantification criteria, this model could better predict the effects of physical stressors on stream health in the LPNF. For example, the number of road trips per some standard time interval, coupled with the type of road substrate would allow the USFS to pinpoint which roads should be closed.

Management of these stressors that impact IBI scores the most will help the USFS improve stream condition in the LPNF and meet their goals to improve watershed condition (USDA Forest Service 2004). Figure 19 shows the IBI condition of sub-watersheds in the LPNF. Green watersheds indicate "low", or minimal, stressor impacts, while sub-watersheds colored red have "high" impacts from stressors. Prioritizing these sub-watersheds based on impact due to stressors can be a useful tool to target remediation and management efforts. A major component to ensure the health of streams, in any condition, is to implement a monitoring plan to track changes in land use, disturbance, and IBI scores. Based on our results, we made recommendations for the management of stressors and the monitoring of streams.

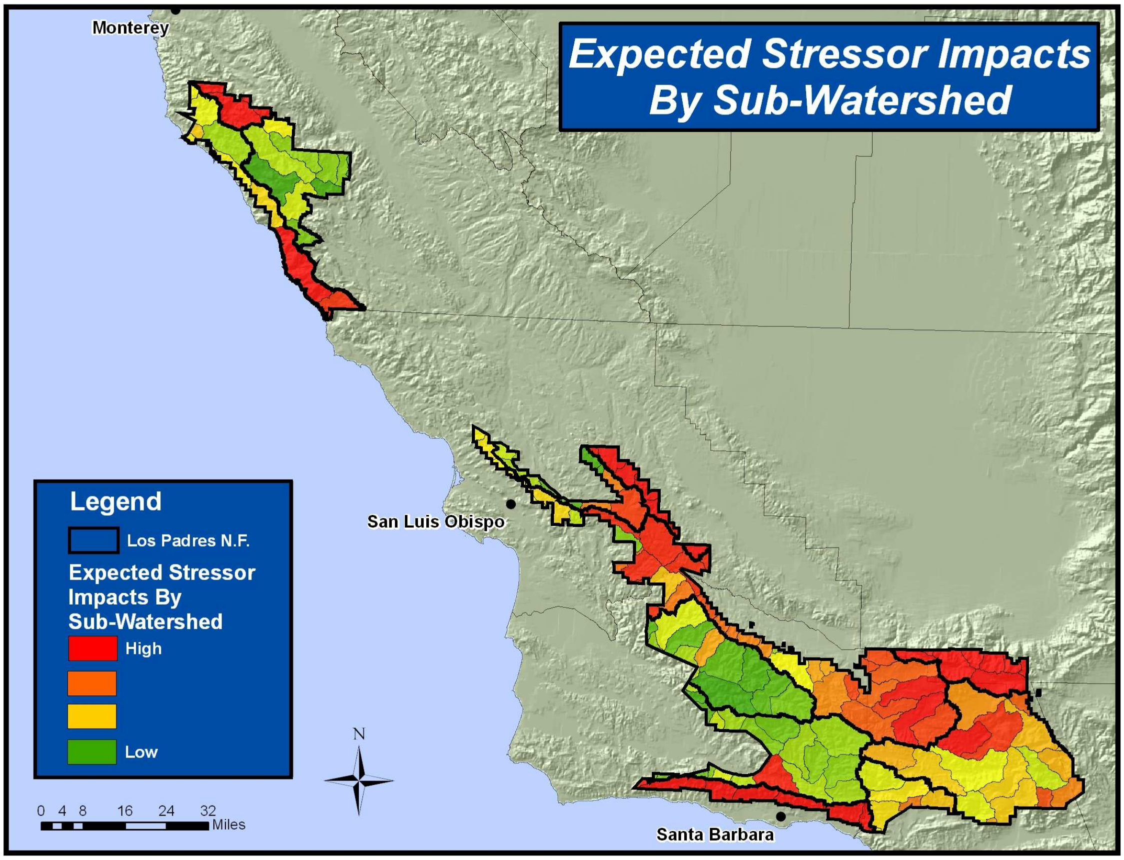

Figure 19. Expected stressor impacts by sub-watershed. The thick black lines represent sub-basin boundaries. Sub-watersheds in red are heavily impacted, while green sub-watersheds are associated with low impacts.

MANAGEMENT RECOMMENDATIONS

The results of our analysis demonstrate that physical stressors can have impacts on stream health. Based on our predictive model, we were able to make several management recommendations to the USFS to maintain stream health. The goal of these recommendations is to keep the IBI score at or above the "good" condition level (IBI score at or higher than 60) (Table 2). In the LPNF, all of the sub-basins with the exception of Cuyama fall within the "very good" or "good" categories, so we would like to maintain this level of health (Figure 18). Our management recommendations to the USFS are the following:

- Because grazing has the largest individual effect on IBI score, and significantly interacts with each of the other four stressors, it should receive careful consideration, and be limited to low intensity stressor levels (15% of a sub-watershed region)

(Figure 18, Table 13). This will prevent IBI condition from drastically decreasing (i.e. more than 10 IBI points).

- To help guide the construction or decommissioning of future roads, we recommend that road density should not exceed medium intensity stressor levels (78 roads/1000 hectares) (Figure 18, Table 13). At this stressor level, IBI condition will not decrease more than one category.
- Our model did not show a significant effect on IBI score from recreation, which indicates that the current management practices are sufficient to preserve stream health (Figure 18, Table 13). We recommend that these management practices be continued.
- Mining operations appear to increase IBI score (Figure 18, Table 13). This may be due to the decommissioning and restoration of the majority of mines in the LPNF. We suggest that the USFS continue these restoration efforts.
- High intensity fires cause negative impacts, while low intensity fires can be essential to stream health. We therefore recommend that the USFS continue to manage the incidence of high intensity fires.

The predictive model can be used by the USFS to set their own stream health level goals and adjust their management practices accordingly.

SAMPLING RECOMMENDATIONS

The various data sets used in our analysis to evaluate stream health suffered from two basic problems: the lack of associated physical/chemical data and lack of comparable data due to differences in sampling techniques. We suggest the following recommendations to improve the quality and quantity of the data available for stressor analysis and management decisions:

BMI Sampling Protocols

To date, California is one of the few remaining states that does not have a standardized protocol for the use of bioassessment methods (California State Water Resources Control Board 2003). To improve comparability of datasets, it would be extremely useful to conduct bioassessments throughout California based on a single methodology. This would result in the ability to compare data sets from various governmental and private entities.

Currently, the USFS samples benthic invertebrates based on methods designed by Charles Hawkins of Utah State University (Hawkins et al. 2000, J. Uyehara, personal correspondence, 2005). The USFS has chosen these methods so that they may assist in the development of a RIVPACS based monitoring plan for the Southern California National Forests. From our experience working with available data, we have concluded that an IBI based approach is a sound choice for monitoring the health of California streams.

One of the more widely used benthic invertebrate sampling protocols is the California Stream Bioassessment Procedures (CSBP) developed by the CDFG. This protocol was designed to investigate pollution events, bioassessment studies, and stressor identification. Due to its wide spread use in California and its compatibility with the IBI model, we recommend the USFS implement this protocol. We also recommend that the USFS make their data sets publicly available on their web site to assist in an exchange of data and information between various governmental and private entities.

Physical and Chemical Parameters

Benthic aquatic invertebrates integrate the effects of different pollutant stressors such as excessive sediment loading, toxic chemicals, increased temperature, and excess nutrients, and therefore provide insight into the aggregated impact of stressors on stream health. To assist in identifying the mechanisms responsible for the specific impacts of stressors, physical and chemical parameters must also be sampled when collecting invertebrates. The following are recommended physical and chemical parameters to gather in addition to those listed in the CSBP:

Dissolved Oxygen	Water Temperature
Conductivity	Nitrogen Concentrations
pH	Phosphorous Concentrations
Turbidity	Habitat Assessments
Total Suspended Solids	

Dissolved Oxygen

Dissolved oxygen (DO) is a key component to assessing the health of a water body. For a stream to support a diverse community of aquatic life, the dissolved oxygen concentration should be close to saturation (14 mg/L). When DO concentrations drop below 7 mg/L, the aquatic ecosystems becomes impaired; when the DO drops below 2mg/L most life requiring oxygen dies (Kentucky Water Watch 2006). Decreases in DO can occur through the oxidation of decaying organic matter, bacterial oxidation of ammonia to nitrate, and plant and algal respiration (Wissmar 2003).

When measuring and evaluating DO measurements, it is important to consider the diel flux of DO in a stream. Changes in water temperature will affect DO level; warmer water holds less DO than colder water. Additionally, primary production in a stream will act as both a source and a sink for DO. During daylight hours, photosynthesis will release oxygen into the water. As night falls and photosynthesis subsides, algal and plant respiration will consume oxygen and DO levels will drop (Barnes 1991). In a healthy stream the ratio of oxygen production to oxygen consumption is positive, but in a eutrophied stream or otherwise compromised habitat, DO levels can easily drop below 4 mg/L at night. A habitat with a negative oxygen production to oxygen consumption ratio will not support a diverse healthy ecosystem (Trout Unlimited 2006).

Because DO plays a critical role in supporting aquatic life, monitoring of DO can be very insightful when assessing the health of a stream and can be useful evidence for identification of a stressor’s effect in the watershed. It is for these reasons that DO measurements should be included in stream sampling protocols.

Conductivity

Electrical conductivity is a measurement of water’s ability to conduct electricity. It is affected by the amount, type and charge of dissolved solids in the water. Measurement of a streams electrical conductivity can be used to evaluate the general quality of water and to track changes in quality. Conductivity will change in response to inputs of sediments and pollutants. The conductivity of most healthy waters will range from 10 to 1000 $\mu S\ cm^{-1}$ (Access Washington 2006). For polluted waters or waters receiving a high input of sediments the electrical conductivity can exceed 1000 μS cm^{-1} (California State Water Resources Control Board 2003).

pH

pH is a measure of the molar concentration of hydrogen ions present in the water. The pH of unpolluted surface waters will typically range from 6 to 9 (Kentucky Water Watch 2006). Stream pH will be controlled by dissolved chemical compounds and biogeochemical processes. Natural processes such as photosynthesis and respiration of algae as well as the presence of pollutants such as ammonia, will affect the pH of a stream. pH is also important for its synergistic effects because changing the pH of a stream can increase the amount of dissolved toxic metals. It is therefore important to monitor the pH to assess the health of a stream.

Turbidity and Total Suspended Solids

Turbidity is a measure of suspended particles in the water. It can be due to suspended sediments, phytoplankton, or other particulate organic and inorganic matter. High turbidity, especially due to sediments, can modify light penetration and smother benthic habitats. As suspended particles of silt, clay and other organic materials settle, they will fill in intercises between benthic substrata. These intercises are used by aquatic organisms as habitat and thus reduction leads to a decline in available space for macroinvertebrates (Karr and Chu 2000). Additionally, fine particulate materials can suffocate fish eggs, damage sensitive gill structures, and interfere with benthic invertebrates who feed from the water column (Trout Unlimited 2006). High turbidity can be caused by a variety of stressors such as eutrophication, excessive grazing, forest fires, and logging (DeBarry 2004). It is for these particular reasons that turbidity should be included as a critical component of the monitoring program.

Temperature

Stream temperature is greatly affected by the air temperature above the stream, and by relative humidity, percent shade, stream flow, and stream width (Land & Water Australia 2006). Changes in temperature in turn affect DO concentrations, pH, and the metabolisms of aquatic organisms. Most aquatic species, such as steelhead and BMIs, are sensitive to changes in water temperature and have a distinct temperature range in which they can survive (DeBarry 2004). Therefore, changes in temperature could result in changes in the benthic community.

Nitrogen

Nitrogen concentrations can be an important indicator of stream health. High levels of nitrogen can induce eutrophication in a stream which can lead to an over-production of organic matter (Vitousek et al.1997). Decomposition of this organic mater can quickly consume available oxygen which can leave the river without sufficient oxygen to support life (Access Washington 2006, Trout Unlimited 2006). Additionally, excessive levels of nitrogen are often associated with the use of fertilizers and the presence of livestock. Nitrogen concentrations can be a good indicator of livestock's effects in the watershed (Belsky et al. 1999). Nitrogen should be measured in three general forms, ammonium, nitrate, and total dissolved nitrogen.

Phosphorous

The majority of phosphorous in aquatic ecosystems is derived from the dissolution of minerals in soil and organic matter such as leaf litter. Phosphorous can often be a limiting nutrient in plant and algae growth but too much phosphorous can lead to excessive plant growth and algal blooms (Kentucky Water Watch 2006). As the plants and algae die, decomposition of these materials can rob the water of oxygen, killing aquatic organisms.

Habitat Assessments

A habitat assessment can play a critical role in identifying stressors and evaluating management actions. The health of a stream will be dictated by the quality of the surrounding physical habitat (Southwood 1977). Three important elements to asses are the vegetation, sediment type, and sun exposure. The riparian vegetation assists in soil conservation, stream bank stability, and water quality. Sediment type is also important as it creates banks and habitat for biota, however, excessive amounts of fine sediments can suffocate stream ecosystems. The size, type and consistency of the source sediments, as well as flow velocity, will dictate how sediment is transported in the stream (Dietrich and Dunne 1993). The amount of sun exposure a stream experiences will dictate water temperature through direct radiation and plays a key role in algal growth. Due to the important role the habitat quality can play in stream health, we recommend the USFS follow the CSBP for assessment of vegetation type, sediment type, and sun exposure

Stream condition, and thus BMI communities will respond to changes in these physical and chemical parameters (Karr and Chu 2000). Detecting these changes will require repeated measurements for comparative analysis. An aquatic ecosystems' response time to changes in the environment can vary greatly depending on the biological level of organization (Capuzzo 1981). In addition there will be both acute and chronic exposure to stressors. Organisms can take hours to months to respond, communities can take days to years, populations can take months to decades and communities/ecosystems dynamics can take years to decades (Capuzzo 1981). Because of these time lags in biotic response, repeated measurements of these parameters, collected in a comparable method are critical to identification of physical stressors.

Sampling Sites

In addition to these physical and chemical parameters, we also recommend the following approaches to choosing sampling site locations:

Point Source Pollution

When there is an identifiable single source of pollution from a stressor, such as acid mine drainage or a waste water disposal pipe, we recommend sampling upstream and downstream of the stresses. It would also be useful to have multiple sites upstream and downstream from the source area to estimate the extent of stressor effects in the stream and watershed. All previously mentioned physical and chemical parameters, including benthic invertebrate samples following the CDFG protocols should be taken at each sampling site.

Non-point Source Pollution

If the source of the environmental stress is not identifiable, the entire watershed should be strategically sampled. The method of least cost is to sample one location at the terminal end of the watershed. This site will be influenced by all management activities occurring within the watershed (T. Robinson, personal correspondence, 2006). Analysis of this site may indicate the overall health of the watershed. If the site is impacted, analyzing the physical and chemical properties of the stream along, habitat typing, and determining IBI scores will provide information on which impairments may be contributing to the decline in stream health. Additionally, sites should be sampled over time to identify temporal and seasonal trends and look for patterns in the BMI response to the stressors. With the knowledge gained from evaluating the terminal end of the watershed, more sites can be placed further up in the watershed at appropriate strategic locations. However, sampling the terminal end of a watershed may result in a diluted composite sample of the health of the watershed, and signals present in the upper watershed may not reach the terminal end, but can still create a significant impact on stream health (T. Robinson, personal correspondence, 2006).

A more robust sampling approach for measuring non-point source pollution is to place many sampling points through out the watershed (T. Robinson, personal correspondence, 2006). Initially, sampling points could be placed below main tributaries and at the terminal end of the watershed. These points would be able to measure the input from each tributary. Additionally, sampling locations can be compared to estimate how much impact each section of the watershed is contributing to its related sampling point. For example if a sampling point has very high NO_3 concentrations while another sampling point has only minimal NO_3 concentrations, it can be assumed that the area of the watershed that drains into the stream between the sampling points contributes the NO_3 (T. Robinson, personal correspondence, 2006).

If the USFS believes a stressor within the LPNF is having impacts on streams, a reach that has the greatest exposure to the suspected stressor should be sampled. For example, if the USFS suspects cattle grazing is a stressor in the watershed, then they should place a sampling location just downstream of the grazing allotment. If time and resources allow, they should also sample the watershed upstream of the grazing allotment. This sampling design allows for a comparison of the physical, chemical, and biological composition of the water between the two sites and can assist in identifying the impacts associated with cattle grazing.

Baseline Samples

A baseline of sample sites should be established to get an overall estimate of stream condition within the LPNF. Considering the concept of a watershed, we concluded that stressor impacts on particular streams are limited by watershed boundaries. Thus, we recommend that monitoring sites should target watersheds, whose boundaries create a unit within which water movement is confined, rather than target political forest boundaries. To improve future datasets and analysis, we have selected a minimum number of watersheds that should be sampled by the USFS. This sample set consists of 18 watersheds that our model has predicted to have high stressor impacts, and 7 watersheds that our model has predicted to have low stressor impacts (Figure 20). The seven low impact sites will be used as reference sites. We recommend, at a minimum, sampling the terminal end of each of these watersheds. Terminal end sampling will produce a composite sample of the entire drainage area upstream of the sampling point. As resources increase or as impairment is detected, more sampling points can be placed further upstream in the watershed.

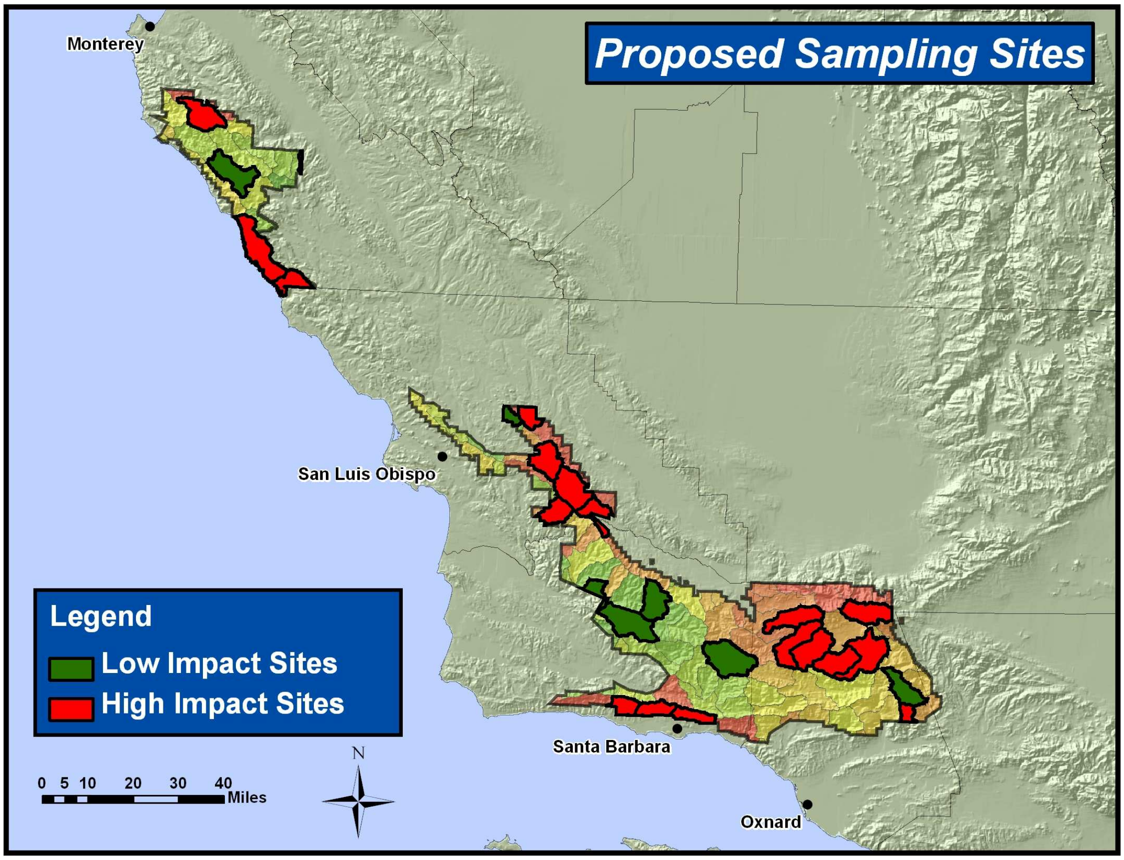

Figure 20. The minimum number of recommended watersheds (25) to sample for future analyses of stressors are highlighted. Our model predicts that watersheds in red will have significant impacts from stressors, whereas watersheds in green will have low impacts and can be used as reference sites.

It will also be important to sample before any land use changes within a watershed in order to achieve a baseline for future comparisons. This type of dataset can provide critical insight into the mechanisms driving decreases in IBI scores.

Consistent and repeated sampling of sites over the years will allow the USFS to monitor trends in the stream composition, to quantify environmental impacts of the stressors, to assess stream and watershed response to management, and to track the cumulative effects of stressors in the watershed. At a minimum, we recommend sampling the high priority watersheds at least twice a year, at the same times each year (Figure 20). This sampling approach will create a dataset that can be used to understand temporal variations, and both naturally and anthropogenically induced changes.

Volunteers

Collection of BMI samples and water quality samples can be time consuming and expensive. Currently, the USFS uses volunteers in many of their projects (K. Cooper, personal correspondence, 2006). It would be also be beneficial for the USFS to use volunteers in their stream sampling program. Volunteers will decrease the cost of labor and can increase the number of data points collected allowing for more robust analysis of stressors. For a volunteer stream monitoring program to be successful, the methods of sample collection must be simple, straight forward and easily repeatable. The Friends of the Santa Clara River (FSCR) and the CDFG have both been successful in their use of volunteers to gain valuable stream assessment data (CDFG 2003).

Based on methods developed by the FSCR and the CDFG (2003), volunteers should be broken into teams. The teams should then receive some basic training in general hydrology, ecology, safety, quality assurance and quality control measures, sampling procedures, field analytical techniques and data recording. This training can be conducted by USFS employees who are knowledgeable in these areas. A small amount of training will help to ensure quality data. Each team will then be lead by a USFS team captain. It will be the captains' responsibility to assure quality control by overseeing their teams, monitoring their sampling techniques, and ensuring samples are gathered in the proper fashion. As the teams become more successful using these techniques, the captains will be able to give the teams increased freedom to sample with less supervision. The use of a captain results in only one USFS employee being utilized to gather data as opposed to a team of USFS employees. This will reduce the labor costs associated with sampling, decrease the amount of time USFS personnel need to spend collecting samples, and increase sampling volume while decreasing costs.

These recommendations will all help the USFS to improve the quality of bioassessment datasets and the comparability and efficiency of sampling procedures. These improvements will allow for improved analysis of stressor impacts on BMI communities and, in turn, stream condition throughout the LPNF.

CONCLUSION

In summary, this project has shown that physical stressors in the Los Padres National Forest, such as fire, grazing, mining, recreation, and roads, can have impacts on stream health. Using the Southern California Index of Biotic Integrity to evaluate stream condition, and by constructing a statistical model to predict the effects of stressors of interest on IBI scores, we were able to identify the stressors most in need of management, which include grazing, fire, and roads. We then made recommendations to improve management by suggesting limits to stressor intensity. To ensure high quality, comparable datasets, we also recommended using common sampling protocols, measuring chemical and physical parameters, and sampling over time. Using volunteers would also ensure that future sampling is more efficient and cost effective. Considering these recommendations will aid the United States Forest Service in meeting their goals to improve stream and watershed condition in the Los Padres National Forest.

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