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GROUP PROJECT BRIEF

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

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Los Padres National Forest

- Managed by the United States Forest Service (USFS)
- Covers 1.75 million acres
- Spans across 220 miles
- Split into 2 land divisions (North & South)
- 2 dominant landscapes: chaparral (~70%) and forested lands (~30%)
- Habitat types include: mixed evergreen forests, oak woodland, pinyon-juniper woodland, and conifer forest

Benthic Macroinvertebrates

- BMIs are sensitive to habitat characteristics such as sediment load, water temperature, carbon input, sunlight input, and flow velocity.[3]
- Invertebrates that dwell at the bottom of rivers, lakes, and streams (insects, crustaceans, snails)
- SoCal IBI based on BMI characteristics such as taxa type, pollution tolerance, and feeding habits and mechanisms
- Changing water body conditions due to land use and natural disturbance can alter the BMI community.

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 exceedingly important. In order to improve and maintain water quality, the USFS outlines several objectives, one of which is monitoring the impact of land uses on water condition.[1]

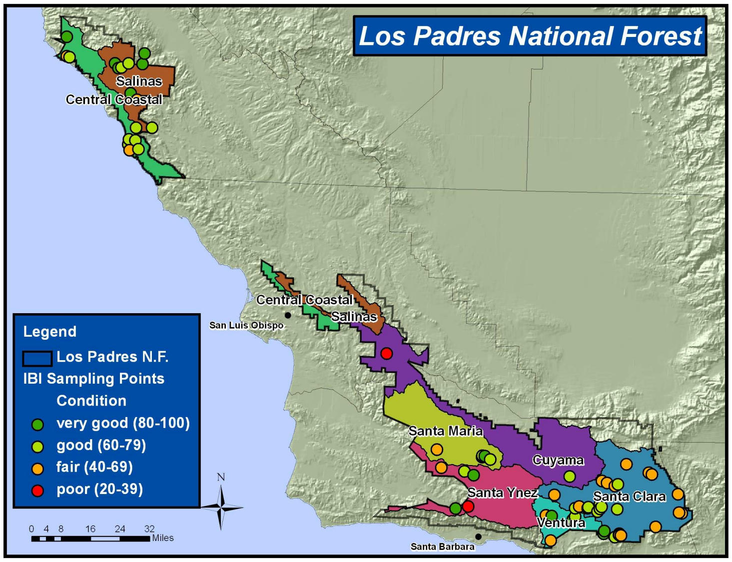

Figure 1. IBI sampling points and results in the Los Padres National Forest. Different color areas represent sub-basin delineations, used in the calculation of the IBI predictor model.

This project focuses on evaluating the impacts of four anthropogenic stressors along with the dominant local disturbance regime, fire, on streams and rivers on USFS lands. A well known bioassessment tool, the Index of Biotic Integrity*[1], was used to determine stream condition in the Los Padres National Forest (LPNF) in California. The results of the bioassessment were then compared to indices representing the intensity of use of stressors and burn events.*[2] 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 since they accumulate the effects of a wide range of biogeochemical factors. Benthic macroinvertebrate community compositions then shift 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 composition of its benthic macroinvertebrates.[2]

The IBI was originally based on 12 "metrics" with the goal of reflecting fish taxonomic compositions in Illinois and Indiana. 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. The SoCal IBI, which is used in this project, is based on 7 metrics which evaluate the benthic macroinvertebrate (BMI) community: 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 of up to 10, for a total score of up to 70. This score is then adjusted to a scale of 0 - 100 and associated with one of 5 condition categories, ranging from very poor to very good (Figure 1 legend).[4]

** represents a reference to side bars. For example, *[2] refers to information in the sidebar on page 2.*

Stressors

Stressor Indices

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 (Table 1).

Fire

Sediment pulses from post-fire erosion can provide revitalizing nutrients to streams but, at the same time, massive pulses of sediment and contaminants can surpass a stream's capacity to filter out the contaminants in the sediment.[5]

Grazing

Grazing in riparian zones can have potentially adverse affects on streamside vegetation composition, bank stability, and can introduce fecal coliform bacteria into streams.[6]

Mining

Mining can bring potentially harmful materials to the surface, which when mobilized by storm runoff increases sediment and chemical loading in streams.[7]

Recreation

Recreation activities can increase the ability of sediment along with trash, pathogens, and other pollution left behind by the public to be transported into rivers and streams.[8]

Roads

Impervious surfaces formed by hard packed and/or paved roads can increase the rate of runoff from rain and snowmelt events.[8] Road runoff can contain automobile contaminants along with potentially significant amounts of sediment depending on various physical characteristics of the road.[9]

Each of the 7 metrics and the final IBI score were calculated based on the SoCal IBI scoring criteria using datasets 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 disturbances in order to make a connection between stream condition based on the BMI communities and potentially detrimental forest activities.

Stressors

Numerous anthropogenic stressors and disturbance regimes exist within the LPNF. This study examines the effects of four anthropogenic stressors along with the dominant local disturbance regime, fire*2, which are of paramount concern to the Forest Service. Each of these stressors can affect streams in different ways and to varying extents*2. They do, however, share the same process of erosion as a mechanism for transporting harmful contaminants, sediment loads, etc. to enter streams.

Table 1. Real world values corresponding to representative index values of low, medium, and high stress.

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

Statistical Analysis and Results

An initial screening of the data by Chi-squared analysis, comparing categorical IBI rankings to low, medium, and high levels of stressors showed trends, but little significance in the relationship between stressors and IBI results. Low, medium, and high values were determined to have an index value of 15, 50, and 85, respectively. These values were chosen to demonstrate a representative spread of possible index scores. The relationships between seven site location-specific variables (sub-basin, forest district, latitude, ecosystem type, average annual precipitation, elevation, and slope) were analyzed to determine how much geographic location affects variation in IBI score . Results show that sub-basin (ANOVA, $p=0.0010$), forest district (t-test, $p=0.0054$), latitude (Linear regression, $R^2=0.0072$, $p=0.0072$), and ecosystem type (t-test, $p=0.0646$) each taken individually show a significant relationship with IBI score.

A multiple regression model with the four location variables as predictors of IBI showed that of all of the combination of variables, only sub-basin has a significant affect on stream health score ($p_{sub\text{-}basin}=0.0175$, $R^2=0.28$). This model, with four predictor variables (sub-basin, district, latitude, and ecosystem) explains 28% of the variation in IBI scores. A one-way analysis of variance model, comparing the mean IBI score between the seven sub-basins in the Los Padres National Forest, shows that sub-basin alone explains 26% of the variation in IBI scores ($df=6$, $F=4.23$, $p=0.0010$). Because of this, sub-basin was chosen as a covariate for analysis of stressor influence.

In order to explore how the stressors affected IBI score, a multiple regression model was designed 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. In this model, fire, grazing, mining, and roads have a significant effect on stream health, while recreation does not ($p_{sub\text{-}basin}<.0001$, $p_{fire}=0.0231$, $p_{grazing}=0.0073$, $p_{mining}=0.0365$, $p_{recreation}=0.8346$, $p_{roads}=0.0563$, $R^2=.48$, adjusted $R^2=.39$).

Building on the previous model, all stressors were examined individually along with all possible pairwise interactions. Stressor interactions were important to consider because multiple stressors were often present in the same areas (e.g. roads and recreation). The final model was selected using a "step-down*3" approach to eliminate non-significant interactions among stressors. This final model included all five individual stressors, the interaction between grazing and each of the other four stressors, and the interaction between recreation and fire ($p_{sub\text{-}basin}<.0001$, $p_{fire}=0.0274$, $p_{grazing}=0.0586$, $p_{mining}=0.0005$, $p_{recreation}=0.7850$, $p_{roads}=0.0337$, $p_{grazing*fire}=0.0044$, $p_{grazing*mining}=0.0517$, $p_{grazing*recreation}=0.0060$, $p_{grazing*roads}=0.0113$, $p_{recreation*fire}=0.0113$, $R^2=.58$, adjusted $R^2=.48$).

Watersheds

- A sub-basin is a delineation differentiating hydrogeologic characteristics.
- The LPNF includes 7 sub-basins: Central Coastal, Cuyama, Salinas, Santa Clara, Santa Maria, Santa Ynez, and Ventura.
- Sub-basins also serve as a regional grouping of the data, accounting for latitudinal and ecosystem gradients.

Statistical Analysis

- The “p-value” of a test is the probability that the result could have been obtained by random chance.
- A more relaxed alpha of .10 was chosen because of the noise in the data expected by a study of this scale.
- Chi-squared (X^2) analysis tests the relative frequency of two categorical variables in a data set.
- One-way analysis of variance (ANOVA) tests whether there is a difference in mean values between categorical groupings.
- A regression models the relationship between two or more variables.
- Adjusted R^2 of a model does not increase with the addition of new terms unless they explain more of the variation in the dependent variable, while R^2 always increases with the number of independent variables.
- A “step-down” approach to multiple regression model selection involves adding all possible variables into the model and removing those with the highest p-value one at a time.[10]
- Percent error = |Observed – Expected|/Expected

Because of the categorical sub-basin covariate, this method produced a single model with a different y-intercept for each sub-basin:

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**)

Discussion

On average the predicted IBI scores were within 16%[*3] of the observed IBI scores for the whole forest. For six of the seven sub-basins, the model proves to be a useful tool for management decisions, with an average percent error of less than 20%. The model has a poor ability to predict IBI scores in the Cuyama sub-basin, due to the presence of only two sampling points.

Scenarios were run using the multiple regression model with interactions to determine the effect of varied stressor levels on IBI score. Table 1 shows the real world value for each stressor corresponding to low, medium, and high index scores. Fire index was determined by the time since a fire and the area burned. As a result the real world value is a function of both variables and cannot be pinpointed.

Table 2. Test of multiple regression model accuracy.

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

IBI score changed as a result of varying stressor intensity (Figure 2). Grazing has the largest influence on IBI score. High levels of grazing have the potential to cause a three category change in IBI score (20 IBI points per category). The effect of grazing 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 rather than a beneficial effect on stream health.

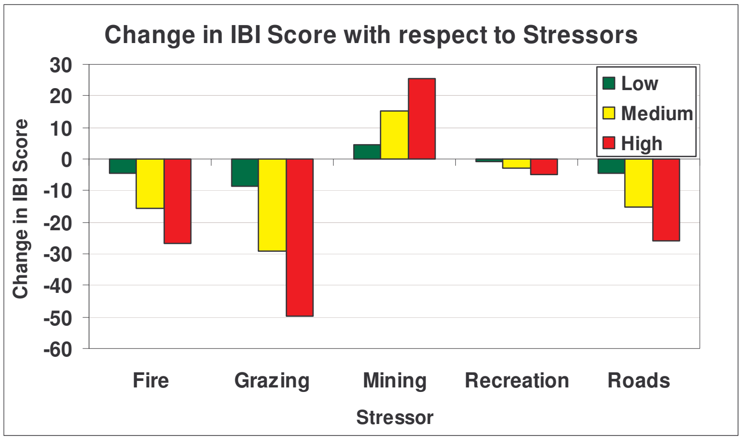

Figure 2. The changes in IBI score with respect to each individual stressor, while holding the other four constant. Low, medium, and high scores correspond to a stressor index value of 15, 50, and 85 respectively (see Table 2).

The results demonstrate that physical stressors have an impact on stream health and can have interactive effects. Based on our conclusions we recommend the following management strategies:

1. Because grazing has the greatest effect and 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.

Recommendations

- Conceptually, a watershed acts as a funnel by channeling sediment and pollutants from the land through the streams and releasing them through a terminal outlet.
- After analyzing the data provided by the FS, we have made recommendations to improve the quality of the data and decrease costs.
- Baseline samples should be taken before and after changes in land use in order to assess its impact on stream health.
- The initial equipment cost to analyze the recommended chemical parameters is approximately $3,000 per sampling team, however this is a one-time cost. It will cost approximately $20 per site to analyze the chemical data.
- We recommend the FS use volunteers to conduct benthic macroinvertebrate and chemical property sampling to reduce costs The California Department of Fish and Game (CDFG) and the Friends of the Santa Clara River (FSCR) have both had excellent success using trained volunteers to conduct sampling.

We have selected a minimum set of sub-watersheds to sample (Figure 3). These consist of the 18 sub-watersheds identified in red that contain a high occurrence of significant stressors, and 7 sub-watersheds identified in green that contain the least number of significant stressors present (Figure 3). 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.

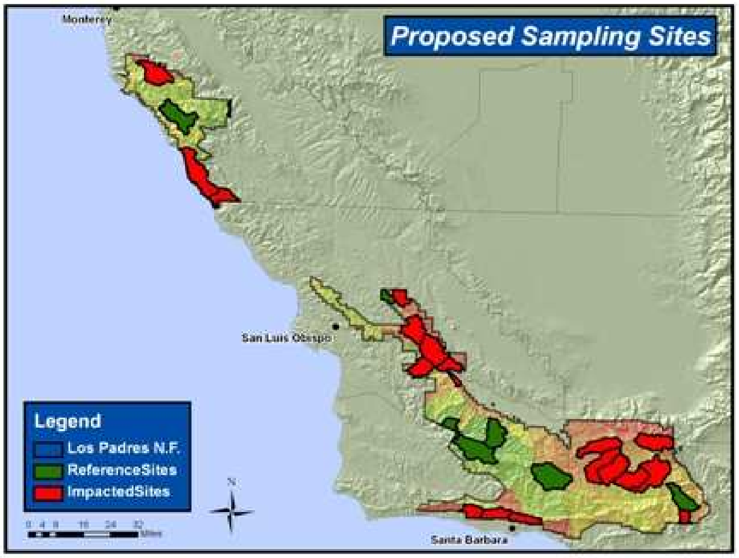

Figure 3. Proposed minimum sampling sites. Sub-watersheds listed in red have a high presence of significant stressors. Sub-watersheds shown in green have a low presence of significant stressors.

In conjunction with a rigorous physical assessment of the habitat, we also recommend the following physical and chemical properties be taken with every BMI sample: dissolved oxygen, pH, conductivity, turbidity, temperature, nitrogen, total suspended solids (TSS), and phosphorous. This additional set of 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 sampling protocol such as the California Stream Bioassessment Procedures (CSBP) to ensure comparable datasets. The CSBP was developed by the California Department of Fish and Game and is a cost effective and widely used sampling protocol.

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