# Evaluating Stream and Watershed Conditions in Northern California

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***Abstract***

*A map based approach for watershed assessment was developed to estimated potential salmonid habitat within two watersheds in Northern California. Current stream condition was assessed using stream gradient and streamside vegetation. For the entire study area roughly 40% of the 900 miles of stream lengths analyzed were classified as low gradient response reaches. Within the riparian zone of response stream reaches 23% of the area contained mature forests exceeding 24" dbh, while less than 10% of the area contained late seral stage vegetation exceeding 36" dbh. Overall, the riparian forests were shown to be dominated by younger seral stage trees. Several indices were developed to represent the contribution of of roads and timber harvesting to sediment delivery in streams. A classification of stream types combined with information on potential recruitment of LWD, hillslope stability, and road related sediment provides a basis for a watershed assessment. This baseline data was used to develop a prioritization model to identify the restoration potential for each sub-basin. This model uses spatially explicit information from a Geographic Information System (GIS) to identify basins that are in need of short term sediment risk reduction, longer term forest stand improvements and existing habitat protection.*

## INTRODUCTION

Techniques that describe habitat conditions at scales that exceed individual stream reaches, and encompass entire watersheds can improve the assessment of forest practices and restoration activities on salmon habitat. A holistic view will provide a better understanding of how the conditions along an individual stream reach reflect more complex interactions between hillslope processes and the riparian zone. Using a map based approach, a watershed assessment technique provides a logical framework to address linkages between hillslope processes and stream channel response. Aggregating measures of stream channel condition from individual stream reaches to sub-basins provides a consistent framework to conduct a watershed assessment. The baseline data resulting from the assessment can be used to evaluate cumulative land use practices and can assist in developing restoration strategies.

In the coastal watersheds in Northern California historic and present land use practices combined with natural erosion processes impact salmon habitat through alteration of existing fluvial processes. Stream channels have been affected by historic logging practices (Napolitano, 1998) and more recent channel clearance projects that have left streams deficient in large woody debris (LWD). LWD helps shape channel morphology through formation of pools and sorting of gravel (Fetherston, 1995). The distribution of LWD can in turn alter sediment transport which has been shown to be highly variable in both space and time (Benda, 1997). The variability in sediment transport decreases from smaller, low order stream tributaries to larger streams and main channels (Benda, 1997, Lewis, 1998). In addition, past forest practices have resulted in riparian vegetation dominated by younger forests with many young small trees and fewer large trees that would provide potential LWD recruitment.

The alteration of stream habitat through land management practices is one of many factors that has been associated with the severe declines in Coho salmon over the last several decades (Brown, 1994). The habitat requirements for Coho are dependent on life history traits. Coho salmon spawn in coastal streams and spend one to two years in stream before migrating to the ocean. Adult Coho spawn on gravel beds in shallow water, while juvenile Coho utilize deep pools with logs and ample shade. The combination of natural disturbance (i.e. mass wasting, floods and drought) with the legacy of land management practices has reduced the amount of available habitat. The relationship between the loss of salmonid habitat and salmonid population numbers is further confounded by cyclic fluctuations in marine environment conditions (Hare 1999).

Stream channel morphology has been shown to dramatically influence salmon habitat and can provide a coarse level indicator of potential habitat. A classification of stream reaches by gradient can be used as a coarse indicator of potential salmon habitat. Previous efforts have been made to describe stream channels based on physical characteristics (Rosgen, 1994). Using topographic data classification of stream channels into source, transport, and response reaches has proven to be an effective assessment technique (Lunetta, et. al. 1997, Montgomery, 1993, Bisson and Montgomery, 1996). Combining this geomorphic approach to channel typing with information on potential LWD recruitment, hillslope stability and timber harvesting provides the basis for a watershed assessment methods.

This study takes a map-based approach to watershed assessment with the overall goal of identifying potential salmon habitat at different spatial scales. Maps from GIS are used to estimate hillslope and stream conditions and to evaluate the current status of forest resources. This provides both a quantitative and a spatial descriptive view of watershed conditions that can play a vital role in evaluating the success of current land management strategies.

***Objectives***

This study was designed to identify both existing in stream habitat conditions and potential sedimentation risks. The method presented here represents a coarse level watershed assessment that describes hillslope and stream conditions that affect salmonid habitat. The study considers conditions that provide habitat (stream gradient and riparian vegetation) and factors that affect stream condition (hillslope condition, road hazards). The more specific project objectives include:

- Develop a method that describes hillslope and stream conditions that influence salmon habitat in northern California coastal watersheds.
- Develop a criteria for screening watersheds based on landscape characteristics.
- Assess potential large woody debris (LWD) recruitment from streamside vegetation.
- Assess potential risks for sedimentation from road hazards and timber harvesting

***Physical Setting***

The study area for this project covers the Noyo and Big River watersheds in Mendocino County. The Noyo has a drainage area of 166 $mi^2$, while the Big River has a drainage area of 200 $mi^2$. These basins are on the west slope of the Coast Range. Elevations range from sea level along the coast to over 3000 ft. The climate has a distinct wet season with 80% of the rain falling from November through April. The region periodically encounters heavy storms with high water and sediment flows that shape the channel morphology. This was well demonstrated when one of the most severe storms in the area occurred in December of 1964, causing a record high stream discharge for the Noyo River of over 20,000 cfs. Hillslope erosion associated with the severe storms increased sediment deposition and caused the channel bed to aggrade by 2 meters over six years. Scouring during lower flow levels, from 1970 to 1975, removed much of the deposited sediment as shown by the pre and post flood cross sections (Figure 1).

Approximately 75% of the two basins are under private land ownership. The watersheds are predominately covered by forests with different land use. Two timber companies, Georgia Pacific Corporation, and Mendocino Redwood Company own the majority of the private timberland. The remaining area is covered by the Jackson Demonstration State Forest (20%), state parks (2%), residential and urban areas (1%).

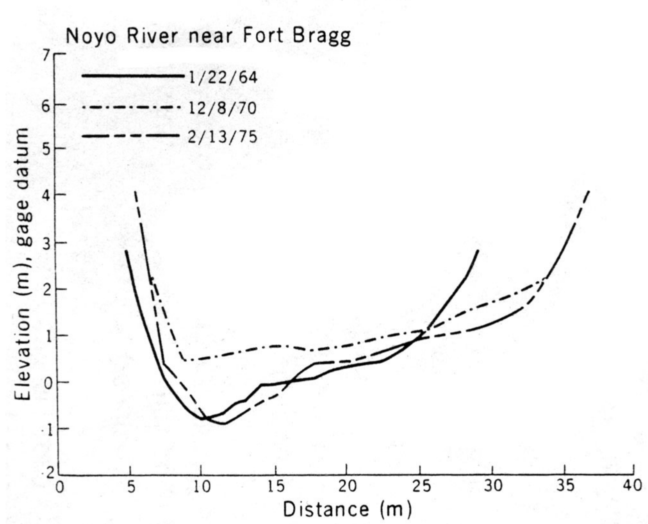


Figure 1: the major storm events in 1964 resulted in initial aggradation of the channel bed followed by degrading and a widening of the channel (modified from Lisle, 1982)

## WATERSHED ASSESSMENT METHODOLOGY

The evaluation of potential salmon habitat was conducted at multiple scales: stream reaches, sub-basins, and watersheds. Sub-basins are defined using the Calwater database and represent drainage basins 600 to 11,000 acres in size. This approach allows a detailed description of conditions within a specific sub-basin, and provides a framework for comparison among basins. The assessment of stream and hillslope condition was based on the following geographic data:

*Data Sources*

- 1:24,000 digital elevation model (DEM)
- 1:24,000 USGS streams
- 1:24,000 USGS roads
- Timberland Task Force (TTF) vegetation data

***Stream Gradient Method***

For this study potential salmon habitat was defined largely by stream gradient. To estimate stream gradient a stream network of sufficient scale was needed. Lunetta et al. (1997), demonstrated that streams depicted at 1:100k under-represent low gradient response reaches. For this study a combination of USGS 1:24k and DEM generated streams were used. To provide an accurate estimate of stream gradient the registration between streams and elevation data is an important issue.  A preliminary analysis indicated that mis-registration between USGS blue line and DEM data produced erroneous results in approximately 10% of the stream segments sampled.  To avoid this source of error a digital stream layer was derived from the DEM.  There are a several approaches available for constructing streams from DEM data.  Tarboton (1997), proposed a method for identifying stream channels from an infinite number of flow directions, where in previous studies (Jenson, 1988) only eight cardinal directions were considered.   When comparing the resulting network with streams found on a 1:24k map, the synthetic stream network showed difficulties in resolving flow in the unconfined reaches found in the coastal plain.  To improve the results, existing 1:24k stream data was superimposed on the DEM to guide flow in unconfined stream reaches (Univ. of Texas, 1998).

Using a modified version of Tarboton's D∞  a synthetic stream layer was created for both the Noyo and Big River basins.   Stream gradient was then calculated at 100-meter intervals for all streams in the study area.  The stream segments were then grouped into four classes that represent the source, transport, and response reaches shown in **Table 1**. This process identifies potential salmon and steelhead habitat as corresponding to low gradient (e.g. response) stream reaches.  This method provides a comprehensive evaluation of streams at a 100-meter sampling interval.  To provide a comparison between planning watersheds (i.e. sub-basins), the miles of streams associated with each stream gradient class was summarized at the planning watershed level using the CALWATER database.

Table 1. Stream Gradient Classes (Percent)

| | |
|---|---|
| Class 1 (response) | 0.0 – 4.0 |
| Class 2 (transport) | 4.1 – 8.0 |
| Class 3 (transport) | 8.1 – 12.0 |
| Class 4 (source) | > 12.0 |

***<u>Assessment of current  forest condition</u>***

An assessment of vegetation in the riparian belt provides a proxy for canopy cover, large woody debris recruitment and overall riparian habitat characteristics.  Recent work has demonstrated that LWD influences channel morphology through creating pools that are critical for salmon habitat and through its affects on sediment transport **(figure 2)**.  A working definition defines LWD as pieces greater than 1 meter in length and 10 cm in diameter (Fetherston, 1995).

Functionally, large woody debris ranges from clusters of smaller branches and logs, large tree segments, to whole trees. The amount and distribution of LWD has been shown to vary with channel size (Fetherston, 1995, Bilby and Ward, 1991) In addition to the varying spatial distribution, the residence time of LWD varies significantly for hardwood versus conifer (Hyatt, 1998). To account for these differences a distinction was made between hardwood and conifer seral stages. Furthermore, a general assumption is made that late seral stage forests will produce larger pieces of wood that will be more secure in the channel and more resistant to high flows, resulting in higher residence times.

Figure 2. Past land use practices have left many of the streams deficient in large woody debris. As a result the morphology of the stream channel has been altered, leaving straighter stream reaches. Along this section of Parlin creek wood has been placed in the channel to improve stream habitat.

Using the same sampling interval used to estimate stream gradient the vegetation composition was assessed at 100-meter intervals along all stream reaches within the study area. This analysis was based on a 60-meter stream buffer. The width of the buffer was considered larger than the area that directly contributes to LWD, but less than the area that may influence ecological processes (Brosofske, 1997). The vegetation data used in the assessment was based on CDF Timberland Task Force (TTF) and CDF Hardwoods, representing the forest condition from the early 1990s. The TTF data was used to represent conifer seral stages, while the hardwood seral stages were derived from the CDF hardwoods database. Forest seral stage classes were defined using a modified WHR size class definition (Table 2). A program was written to record for each 100-meter stream segment the acreage of vegetation for each seral stage class that fell within the 60-m buffer. This technique provides a quantitative measure of the vegetation that provides canopy cover and potential LWD recruitment. The forest condition for the upland portion of the basin (i.e. the area outside the riparian buffer) was also evaluated. This provides a comprehensive view of the total amount of late seral stage vegetation within a planning watershed, and allows for a comparison between riparian vegetation and upland vegetation.

Table 2. Forest vegetation classes.

| | |
|---|---|
| Early seral | < 11” dbh |
| Mid seral | 11” – 24” dbh |
| Mid-late seral | 24” – 36” dbh |
| Late seral | > 36” dbh |

***<u>Potential sediment delivery from road and timber harvests</u>.***

Mass wasting is a predominate form of erosion in steep terrain delivering sediment to streams (Beshetta, 1996, Benda and Dunne, 1997). Prior to current forest regulations, land management activities have been shown to alter hillslope erosion processes and increased sediment delivery to streams (Rice, 1998, Caffereta, 1998). With this in mind, the most significant human-induced risks to stream habitat in these watersheds are considered to come from increased sediment from roads and timber harvesting. Road construction to support timber harvesting is prevalent throughout the study area. Roads can provide a direct source of fine sediment when located near streams. When traversing steep hillslopes they can contribute to hillslope instability. The location of existing roads was derived from 1:24k topographic maps and supplemented with information from THPs. Timber harvesting on steep slopes can increase the susceptibility of hillslope failure, and has the potential to contribute coarse sediment to streams through increased landsliding (Sidle, 1992). The contribution of roads and related timber harvesting to increased sediment delivery was assessed using the following factors:

1. Roads near streams
2. Roads crossing streams
3. Roads crossing unstable slopes
4. Timber harvests on unstable slopes

The first two factors represent potential contribution of fine sediment to the stream channel, while the later are most likely to contribute coarse sediment. The percentage of roads crossing unstable slopes was estimated using a hillslope stability model. The output of the model is a probability map that identifies location of potentially unstable slopes. The length of roads crossing slopes with a high probability of failure was calculated and summarized for each

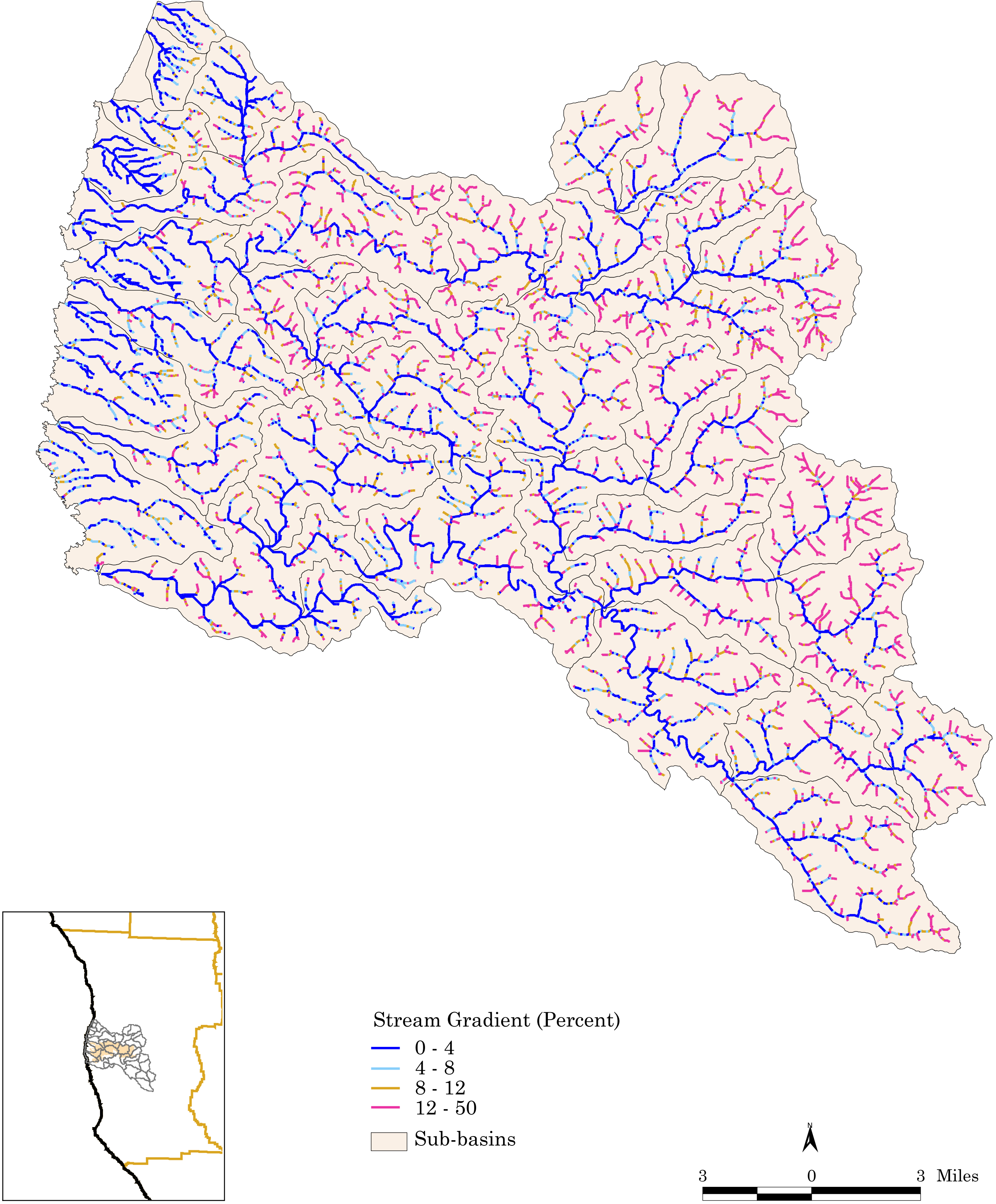


Figure 3:
Noyo and Big River Stream Gradient

planning watershed. These values were compared with the amount of timber harvesting on potentially unstable slopes for each sub-basin.

**RESULTS**

This section describes the results obtained from the stream gradient analysis, vegetation assessment, and the hazards from roads and timber harvesting. Summary reports describing the basin characteristics were created for each sub-basin.

The stream gradient analysis conducted resulted in a description of stream conditions for planning watersheds in the Noyo and Big River basins. The results can be view at several different scales. At its finest resolution the model predicts potential salmon habitat along 100-meter intervals within each sub-basin (**figure 3**). The steeper gradients are associated with the confined channels in the higher order (i.e. class 3 and 4) streams. Low gradient response reaches that are bordered by mid-late or late seral forests represent the best potential habitat. Miles of stream in each gradient class then summarized for each sub-basin and for the entire watershed. The results shown for the Noyo and Big River basins represent the total miles of streams that are potentially available to provide habitat for fish (**Table 3**).

Table 3. Miles of stream by stream gradient classes.

| | Gradient Class 1<br>0 – 4 % | Gradient Class 2<br>4 – 8% | Gradient Class 3<br>8 – 12% | Gradient Class 4<br>> 12% |
|---|---|---|---|---|
| Noyo | 192 mi. | 73 mi. | 115 mi. | 47 mi. |
| Big River | 214 mi. | 66 mi. | 123 mi. | 69 mi. |

The riparian vegetation was analyzed in a similar way. The amount of early, mid, mid-late and late seral stage vegetation was estimated for each 100-meter stream interval. The data was then aggregated to allow a comparison between sub-basins. **Figure 4** shows for each planning watershed the percentage of the area in the riparian zone and in the upland area that contains mid-late or late seral stage vegetation. While 50% of the sub-basins have at least 20% of their streams bordered by mid-late or late forests; nearly 80% of the sub-basins have less that 10% of their streams bordered by late seral forests. Of the total miles of streams in low gradient reaches, only 6% of the area in the riparian zone contained late seral late seral vegetation, while 23% has large trees that exceed 24” dbh.

*Comparison of riparian with upland vegetation*

Across all sub-basins a strong correlation exists between upland vegetation and riparian vegetation ($r^2$ = .84) in mid-late and late seral stages (**figure 4**). Due to restrictions on forest practices near streams the amount of mid-late and late seral stage vegetation was thought to be higher in the riparian zone. To test this hypothesis a comparison of riparian and upland vegetation was done. Using a paired T-test the probability of a T-value greater than the one observed (4.39) is 1% when Ho is true. This result suggests that riparian vegetation contained slightly higher amounts of mid-late and late seral stage vegetation. In general, most sub-basins are dominated by mid seral stage (**Table 4**) forests. The results further suggest that the sub-basins that are predominately covered by the Jackson Demonstration State Forest are serving as a reserve for mid-late and late seral vegetation. Of the sub-basins that are predominately on private timberlands all have less than 30% riparian vegetation that is at or beyond mid-late seral stage, and none have more than 15% in late seral stage.

Table 4. Percentage of riparian vegetation in seral stage classes. An assessment of vegetation in the riparian zone indicates that riparian forests are dominated by mid-seral vegetation.

| | Early Seral (< 11" dbh) | Mid Seral (11 – 24" dbh) | Mid-late Seral (24 – 36" dbh) | Late Seral (>= 36" dbh) |
|---|---|---|---|---|
| Noyo | 7% | 69% | 18% | 6% |
| Big River | 4% | 74% | 17% | 6% |

*Evaluation of roads and unstable lands*

The link between hillslope instability and downstream channel condition is well recognized (Lewis, 1998; Pitlick, 1995; Sidle, 1992). Pervious studies on north coastal watersheds have attributed significant portions of the sediment budget to location of roads (i.e. proximity to streams) and stream crossing (Best, 1995). An analysis of roads and timber harvesting on unstable slopes provided a coarse index of potential risk of a sub-basin to contribute sediment to the stream channel. Road condition was assessed to determine which sub-basins have the potential to contribute sediment to streams through both the density of the road network and the position of the roads within a sub-basin. An analysis of the density of roads on unstable slopes indicated that roughly a third of the sub-basins had 10% or more of the roads on unstable slopes. This provides a coarse indicator of the sediment delivery potential for a sub-basin.

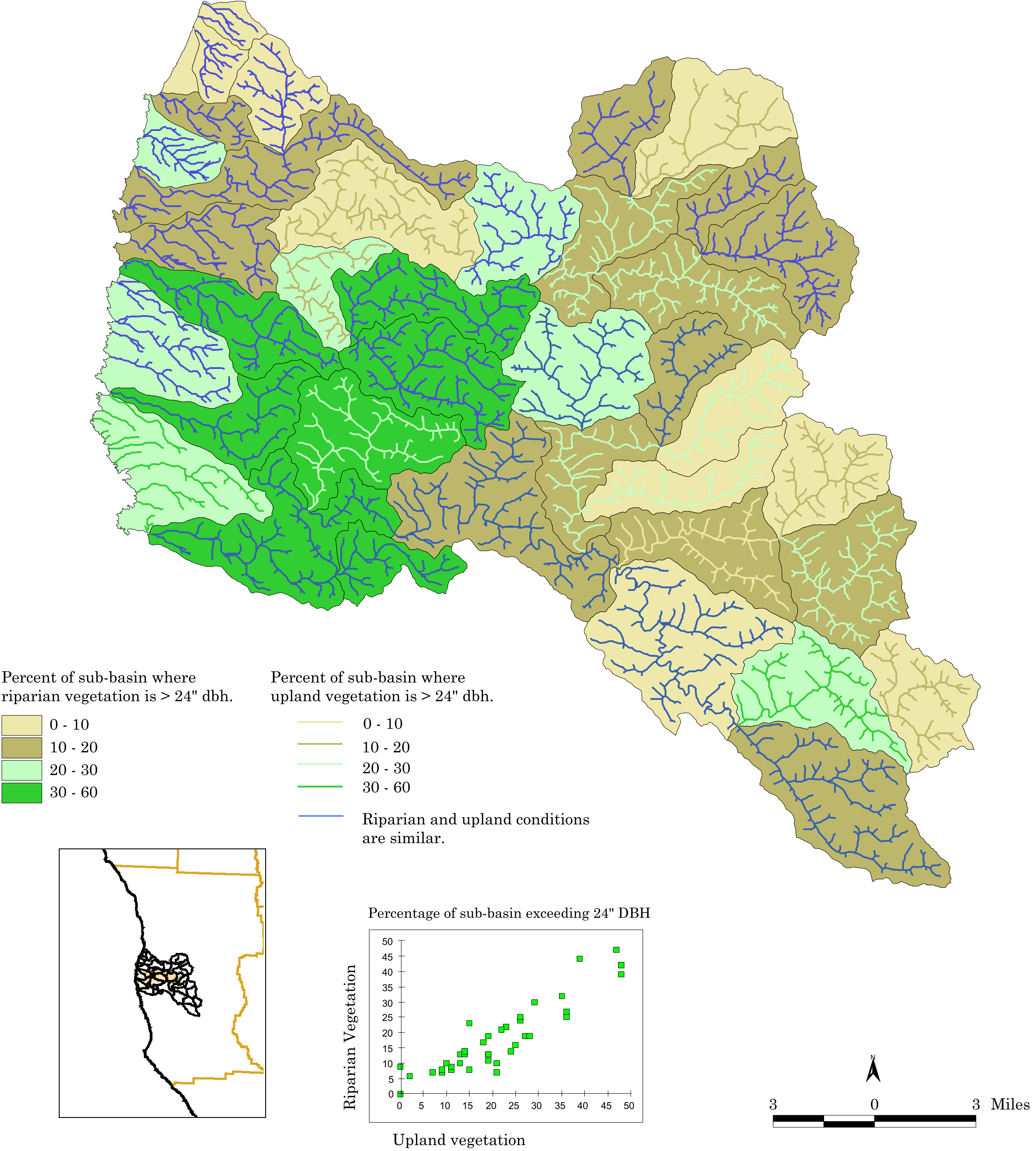


Figure 4:
Noyo and Big River Watersheds:
Comparison of riparian and upland vegetation

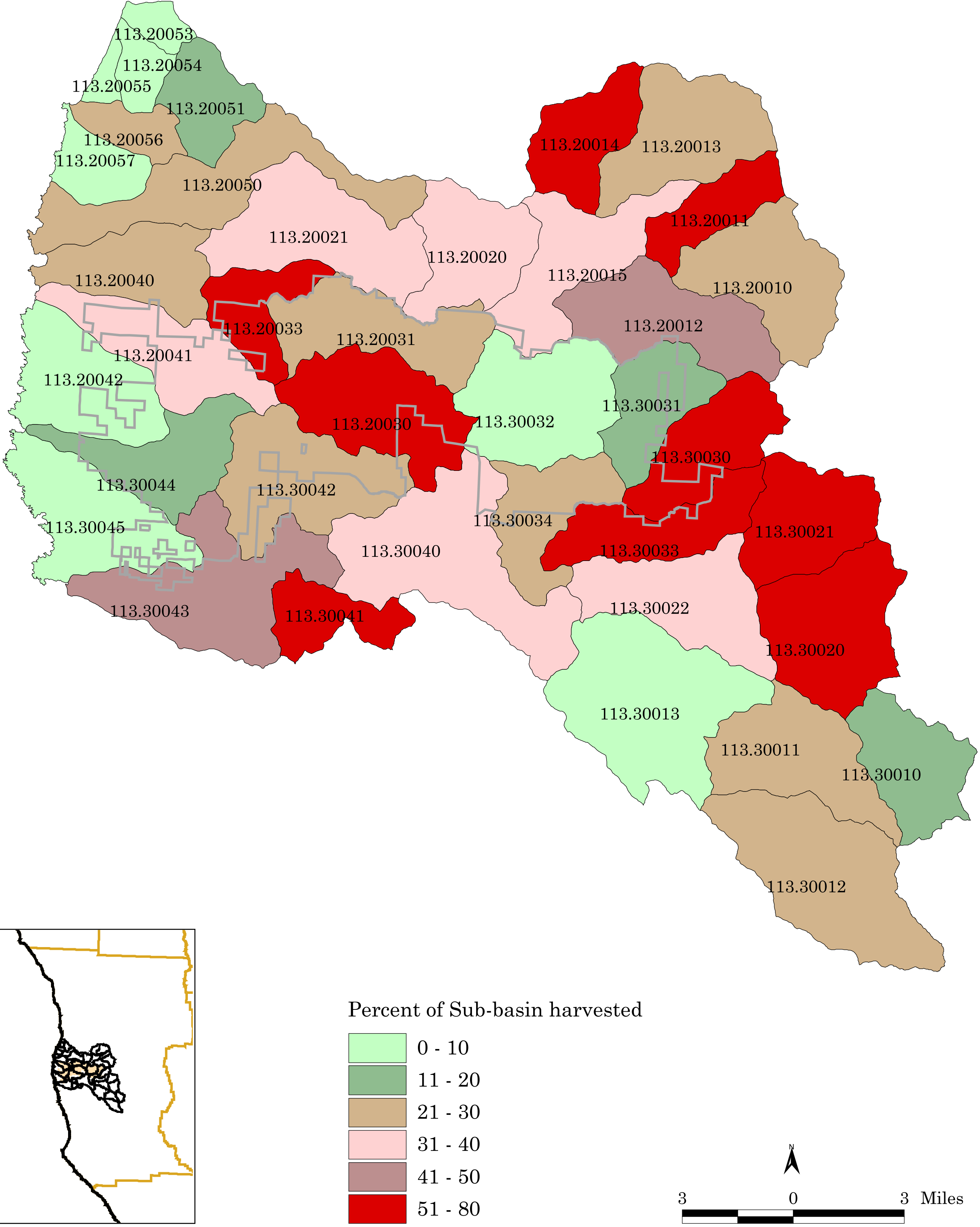


Figure 5:
Noyo and Big River Timber Harvesting: 1989 - 1988

The amount and location of timber harvests over a 10-year period (1988 – 1998) was also evaluated for each sub-basin. Both the Noyo and the Big River showed a comparable level of harvesting that resulted in 30% of the two watersheds being harvested within 10 years, and 15% of the two watersheds being harvested with even-aged management (**Figure 5**). Five sub-basins had 20% or more of basin area harvested on steep and potential unstable hillslopes.

## ***Discussion***

The evaluation of habitat condition (i.e. stream gradient and riparian vegetation) and sediment delivery potential provides a means for identifying sub-basins with the highest conservation value and those that have the best potential for restoration. This approach can provide a broad screening of sub-basins that can assist in prioritizing restoration efforts. One approach to screening watersheds assigns a ranking to sub-basins based on existing habitat and potential for sediment delivery. The rankings for habitat would be based on the measured values for riparian vegetation, upland vegetation, and stream gradient. The rankings for sediment delivery potential would be a combination of road related hazards and timber harvesting. The decision rule for classifying sub-basins can be determined through a 3 x 3 matrix that identifies a basins restoration potential (**Table 5**). For example, a basin with a high habitat rating (good vegetation and suitable channel conditions) and a medium or high sediment delivery rating would have good restoration potential. Whereas; a sub-basin with both good habitat and a low sediment delivery rating would have high conservation potential (**Figure 6**).

| | | **Sediment Delivery Potential** | | |
|---|---|---|---|---|
| **Riparian Habitat Indicators** | | *Low* | *Medium* | *High* |
| | *Poor* | **A**<br>Limited restoration potential. Requires long term restoration of riparian habitat | **B**<br>Limited restoration potential. Requires long term restoration of riparian habitat and sediment reduction. | **C**<br>Limited restoration potential. Requires long term restoration of riparian habitat and sediment reduction. |
| | *Adequate* | **D**<br>Near term restoration possible with improved riparian habitat | **E**<br>Near term restoration possible with reductions in sediment and improved riparian habitat | **F**<br>Requires long term sediment reduction and riparian habitat improvements |
| | *Good* | **G**<br>Good Conservation Potential | **H**<br>Short term restoration possible with sediment reduction | **I**<br>Requires long term sediment reduction |

**Table 5**. Decision rule for evaluating the restoration potential of sub-basins.

*Conclusions*

The watershed analysis for this study resulted in a database that describes the amount and extent of habitat, and allows for a consistent comparison of stream morphology and riparian vegetation conditions among sub-basins. The main processes addressed in this study include stream channel morphology, vegetation condition (riparian and upland), hillslope erosion, road hazards and the amount and location of timber harvesting. The results suggest that a large portion of the total stream miles contain low gradient reaches that are potentially available for salmon. However, a much smaller portion of the low gradient reaches are bordered by late seral (< 10%) or mature forest stands (23%) that provide canopy cover and potentially contribute to stream habitat conditions through recruitment of large woody debris.

The methods developed for this study provide a comprehensive, coarse grained (i.e. level 1) assessment of watershed sub-basins. This map-based assessment provides a useful tool to evaluate forest practices across a larger landscape, but does not take the place of more detailed field observation that are required for project specific watershed restoration. The results reflect the pattern of land use across two watersheds and suggest that the configuration of existing habitat versus potential sediment sources can provide a basis for a land management plan that would maximize the conservation and restoration of salmonid habitat across the entire watershed.

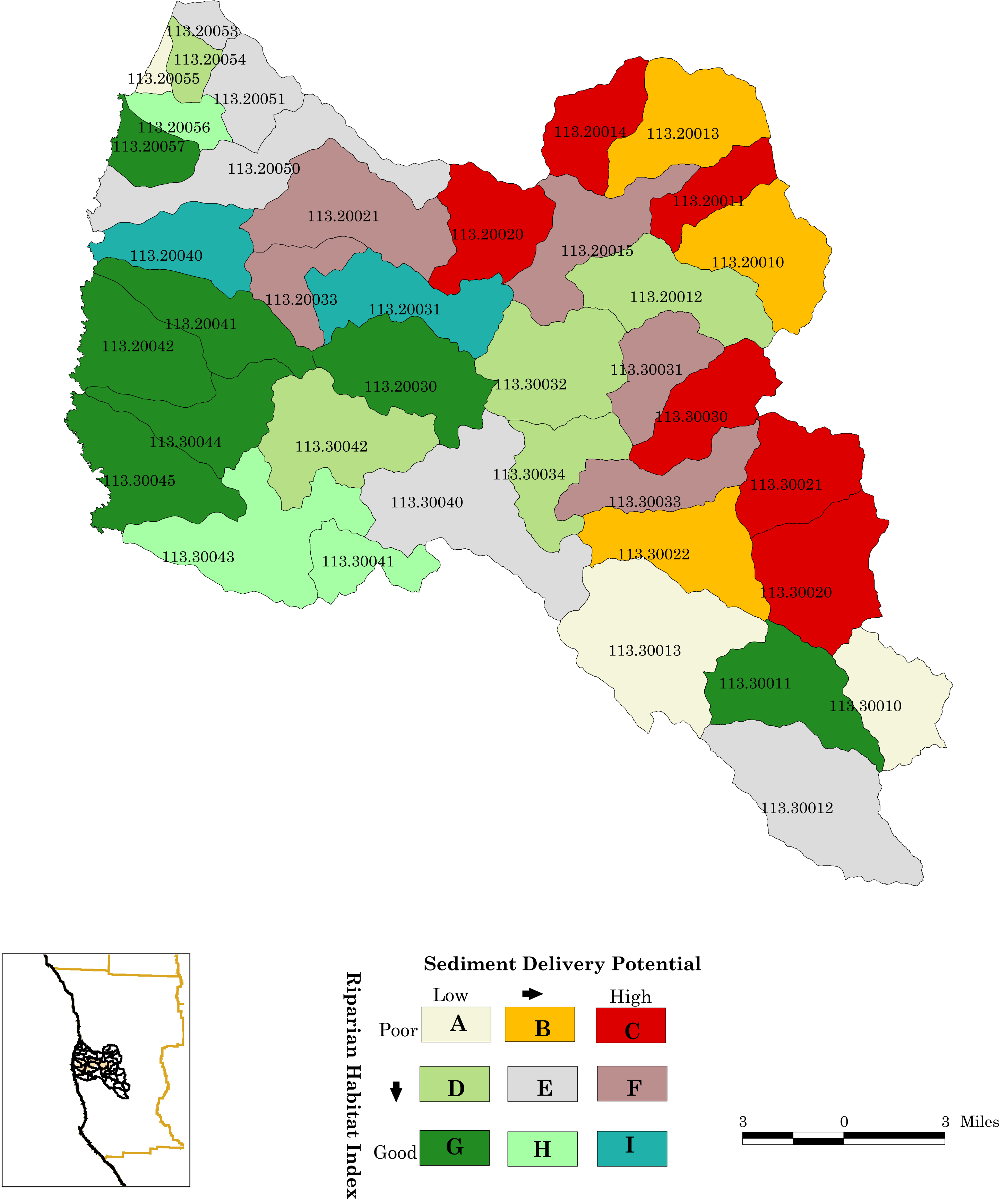


Figure 6:
Noyo and Big River Watersheds: Restoration Potential

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