WRC Paired Watershed 2013

A WRC Paired Watershed Conference:

Key Findings on the Environmental Impact of Contemporary Forest Practices

Presentation Abstracts

Abstracts are in order of presentation

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Stream Temperature Pattern and Process in the Trask Watershed Study: Pre-Harvest

Maryanne Reiter, Sherri Johnson and Peter James

Abstract

The Trask Watershed Study is a multi-disciplinary, long-term research project in the Oregon Coast Range that is designed to examine the effects of current forest management practices on aquatic ecosystems. Extensive physical (e.g., water quantity and quality, channel morphology) and biological data (e.g., primary productivity, macro-invertebrate communities, amphibian movement and fish populations and behavior) has been collected in both the small and large watersheds since 2006 and will continue until 2016. One of these key parameters we have been collecting at multiple scales is stream temperature. Understanding the variability in stream temperature patterns and processes prior to harvest in both small non-fish headwater streams and downstream in larger fish-bearing basins allows us to anticipate potential responses to harvest and subsequent potential changes in biota. Using the pre-harvest stream temperature data we examine variability in maximum and minimum temperatures across the 15 small headwater streams. We also examine how well both small treatment streams and the larger downstream basins correlate to un-harvested reference streams to determine the best match to compare post-harvest response. Finally we examine how stream temperature patterns vary longitudinally in the downstream direction through time.

Short-term responses of suspended solid sediments and turbidity from contemporary road crossings in headwater streams of the Trask river watershed, Oregon

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Abstract

Road-related turbidity and suspended sediments is a concern for both commonly occurring and higher magnitude storm events with the potential to negatively affect in-stream biota. Here, we present preliminary results that address whether forest road crossings deliver fine sediments into streams. Specifically, we evaluate evidence of sediment routing before/after road interventions (including new roads and road upgrades - surfacing with gravel) and above/below road crossing within forest harvest units. We hypothesize that newly constructed and upgraded roads will increase turbidity and suspended sediments where roads are hydrologically connected to streams. This response will be heightened during high intensity precipitation. We measured suspended sediment and turbidity above and below road crossing and before (June 2010-Apr 2011) and after (July 2011-June-2012) road upgrades using ISCO samplers in five headwater streams from small-sized watersheds (5-36 ha). We complemented this information with available data from hydrology (four flume stations) and precipitation (two climate stations) during the same time periods. We examined statistical differences of in-stream turbidity and concentrations of suspended sediments below and above road crossing and characterized the behavior of sites before and after road upgrades.

Headwater riparian habitat: prime real estate for birds.

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Abstract

Management strategies along headwater streams typically focus on aquatic resources, but riparian forests also are habitat for many terrestrial wildlife species. Increasing the understanding of mechanisms that underlie the riparian associations of these species can help integrate management of aquatic and terrestrial environments in headwater forests. We investigated the diets of and food availability for four bird species associated with riparian habitats in the headwaters of the Trask River, in northwestern Oregon. We tested the hypotheses that 1) emergent aquatic insects were a food source for insectivorous birds in headwater riparian areas, and 2) the abundance of arthropod prey did not differ between streamside and upland areas during the bird breeding season. We found that adult aquatic insects represented a relatively small proportion of available prey abundance and biomass and were present in less than 1% of the diet samples from the four riparian-associated bird species. Nonetheless, arthropod prey, comprised primarily of insects of terrestrial origin, was more abundant in streamside than upland samples. We concluded that food resources for birds in headwater riparian areas are primarily associated with terrestrial vegetation, and that bird distributions along the gradient from streamside to upland may be related to variation in arthropod prey availability. Because distinct vegetation may distinguish riparian from upland habitats for riparian-associated birds and their terrestrial arthropod prey, we suggest that understory communities be considered when defining management zones for riparian habitat.

The role of location: Responsiveness of stream-living fish populations to relatively fixed site characteristics and dynamic environmental regimes

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Abstract

The evolution of concepts in stream ecology has resulted in a collective recognition that location within a landscape matters to aquatic biota. Although it is known that location-related conditions have implications for aquatic biota, the contribution of location that most greatly influences a population has yet to be understood. Stream-living fish populations in headwater stream locations are affected by a juxtaposition of influences between more dynamic environmental regimes (i.e., flow, temperature, turbidity) and relatively fixed site-specific physical characteristics of streams also referred to as the physical 'habitat template' (e.g., channel geomorphology, instream habitat). Simulation experiments using the inSTREAM individual-based coastal cutthroat trout (*Oncorhynchus clarkii clarkii)* population model explored the role of environmental regimes and a habitat template for four headwater streams in the Trask River Watershed. We paired the suite of historic environmental regimes (i.e., flow, temperature, turbidity) from each site with the habitat template from each site (i.e., channel shape, velocity shelter availability, spawn gravel availability, distance to hiding refuge) using a full factorial design resulting in 16 different scenarios for both summer and winter over 4 years. We present evidence demonstrating that the role of the habitat template predetermines population dynamics by setting hierarchical boundaries to alternative environmental regimes. Our findings suggest that the habitat template needs to be considered when examining the effects from land-use or climate change. These results highlight the need to better understand site-specific differences among similar locations, especially in headwater streams.

The Alsea Watershed Study and Alsea Watershed Study Revisited

George Brown, George Ice, John Stednick, Jeff Light, Cody Hale, Jeff McDonnell, Stephen Schoenholtz

Abstract

The original Alsea Basin Logging and Aquatic Resources Study (1959-1973) was established in response to public and legislative concerns about the impact of timber harvesting and road construction on salmon. It was the first paired watershed study in North America to document these impacts.

The study design utilized one watershed (Flynn Creek) as an untreated control for the duration of the study. Deer Creek was roaded and harvested with three small patch clearcuts covering about 25% of the basin. Harvest boundaries were kept 50 feet or more from the stream banks. The small clearcuts received a light slash fire following logging. Needle Branch was roaded and completely clearcut without stream protection buffers and, following logging, was burned with a very hot slash fire and channel cleaned of debris, which typified the logging practices of the day. Before and after treatments, streamflow, water quality and aquatic resources were carefully monitored on all three watersheds.

Changes in streamflow, water quality and aquatic resource populations were small after road construction and logging in Deer Creek, even with the very narrow stream protection buffers.

Large changes in water quality and suspended sediment were recorded after clearcutting without stream protection and the hot slash fire in Needle Branch.
Temperature and suspended sediment levels returned to pretreatment levels within five years. Cutthroat trout numbers decreased significantly.

This historic study was a catalyst for the adoption of the Oregon Forest Practices Act and rules. Those early findings demonstrated the value of riparian protection in protecting water quality, fish and other aquatic organisms.

The new study utilizes the same paired watershed design to determine the impacts of contemporary forest practices under current rules on water quality and fish.

Dissolved Oxygen Response to Forest Management in the Alsea Watershed Study Revisited

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Abstract

The original Alsea Watershed Study found dissolved oxygen (DO) concentrations at or near saturation in the control (Flynn Creek) and patchcut and buffered (Deer Creek) watersheds. DO concentrations in some reaches of the clearcut and unbuffered watershed (Needle Branch) were found to be substantially below saturation following the 1966 harvest. The depressed concentrations were thought to result from a combination of increased biochemical oxygen demand, reduced solubility due to stream heating, increased biological activity, and reduced reaeration. The Alsea Watershed Study Revisited (AWSR) returns to the same watersheds and provides an assessment of physical, chemical, and biological response to contemporary forest practices.

During the pre-treatment phase of the AWRS low DO concentrations were observed in Needle Branch in the summer and fall. These low concentrations coincided with low flow periods. At these times flow becomes "discontinuously perennial" and portions of the stream network go subsurface. We now believe that despite having some of the highest reaeration rates ever measured, certain reaches of Needle Branch are prone to depressed DO concentrations. For some reaches, surface flow during critical late season periods is largely composed of recently emerged groundwater or hyporheic water. Both original study and AWSR findings show high spatial variability in DO concentrations. The fish team reports that fish populations in Needle Branch are "clumpy" in their distribution. This may reflect movement toward reaches with higher DO concentrations and help explain the ability of fish to thrive in this environment.

While Flynn and Deer Creeks are always near saturation at the main gauging stations, some reaches of Needle Branch experience DO concentrations well below saturation, dropping to 2 to 4 mg/L during periods of minimum discharge each year. This occurred even before recent management activities. Despite supporting resident trout and salmon spawning and rearing, some reaches of Needle Branch cannot achieve state water quality criteria even without forest management. This is a natural phenomenon, probably observable in many headwater streams.

Nutrient response to harvesting with contemporary forest practice regulations: The Alsea Watershed revisited

John D. Stednick, Colorado State University
Cody Hale, George Ice, Diana Cook, Jeff Light, and Jeff McDonnell

The original Alsea Watershed Study measured water quality before and after logging. For Deer Creek with patchcuts and streamside vegetation buffers, there were no changes in water quality post-harvesting. Needle Branch was harvested without streamside buffers and the slash burned. Nitrate concentrations increased from 0.70 to a maximum of 2.10 mg/L, and returned to pretreatment levels by the 6th year after logging. The loss of nitrogen was negligible when compared to the nitrogen capital (soils and vegetation) and loss of terrestrial productivity was not anticipated.

Of note in the early study was the calculated nitrogen flux from the control watershed Flynn Creek. Flynn Creek averaged a nitrate flux of 28kg/ha/yr compared to Needle Branch which went from 4 to over 15kg/ha/yr after harvesting. Deer Creek generally remained constant at 27kg/ha/yr.

Additional water quality monitoring in the study watersheds identified spatial and temporal variations in stream water quality. Of particular note is the influence of landscape elements including vegetation, soils, slope, and hydraulic conductivity as related to water quality, particularly nitrogen. Also the first significant fall storm flushes oxidized nitrogen from the soil profile and results in higher stream water nitrate concentrations.

The Alsea Watershed Study Revisited (AWSR) provides an assessment of water quality response to contemporary forest practices. Nested watersheds in Needle Branch, including immediately below the harvest unit (NBU) and the original gauge (NBL) were compared for water quality changes. During the pre-treatment monitoring, nutrient concentrations at NBU were generally higher but paralleled concentrations at NBL. Surprisingly, after harvesting, nitrate concentrations increased to levels seen in the original study. Total phosphorus concentrations did not respond to harvesting and were higher at NBL, and remain below the recommended standard of 50µg/L. Nitrogen and phosphorus exports in the organic fraction were negligible for all watersheds.

Herbicides in Needle Branch Streamwater

Jeff Louch, Ginny Allen, George Ice, NCASI
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Abstract

Glyphosate, aminomethylphosphonic acid (AMPA), imazapyr, sulfometuron methyl, and metsulfuron methyl were measured in Needle Branch streamwater during and after application of herbicide(s). Application rates were 681 g/ac glyphosate (a.e.), 85 g/ac imazapyr (a.e.), 64 g/ac sulfometuron methyl (a.i.), and 17 g/ac metsulfuron methyl (a.i.), and all herbicides were applied by helicopter in a single tank mix. Samples were collected at three sites: NBH (at the fish/no-fish interface in the middle of the harvest unit), NBU (at the bottom of the harvest unit), and NBL (well downstream).

AMPA, imazapyr, sulfometuron methyl and metsulfuron methyl were not detected in any sample at 15 ng/L, 0.6 µg/L, 0.5 µg/L and 1 µg/L, respectively. However, a clear pulse of dissolved glyphosate manifested at NBH during the application (baseflow conditions). This pulse maximized at ≈50 ng/L and persisted for two to three hours. An associated pulse was not detected (<20 ng/L) at NBL, and no samples were collected at NBU due to equipment malfunction. Subsequent baseflow samples collected three days after treatment (DAT) showed ≈25 ng/L dissolved glyphosate at all three sites, and all sites were <20 ng/L at 19 DAT. Samples collected during the first storm event (8 DAT) showed a clear pulse of dissolved glyphosate at NBU, but not at NBH or NBL. The maximum concentration observed during this pulse at NBU was 115 ng/L, and the pulse persisted for about six hours. During the next storm event (10 DAT) a clear pulse of dissolved glyphosate manifested at NBH, but not at NBU or NBL. The maximum concentration observed was 42 ng/L, and this pulse persisted for about ten hours. Results from all subsequent storm events showed dissolved glyphosate at <20 ng/L in all samples. A limited number of analyses on suspended sediment (SS) showed that SS held *de minimis* masses of glyphosate and AMPA.

These results show that exposure of aquatic organisms to herbicides from applications conforming to modern best management practices are short lived and low concentration (<1 µg/L).

Fish Population Response to Harvesting with Contemporary Forest Practice Alsea Watershed Study Revisited

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Abstract

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* are the most widely distributed native salmonid in the forested watersheds of western Oregon. The initial Alsea Watershed Study demonstrated negative impacts on the abundance of cutthroat trout due to logging practices of the day. Here we report on abundance, size, growth, and condition of coastal cutthroat trout before and after logging under the current forest management practice regulations using a before, after, control, impact (BACI) study design with Flynn Creek and Needle Branch as the control and impact streams respectively. Relative abundance estimates are from a census of pool habitats using single-pass electrofishing and relative growth is from the recapture of individuals implanted with passive integrated transponder tags. A significant increase in age 1+ cutthroat trout biomass and abundance was observed post-harvest in Needle Branch relative to Flynn Creek ($p=0.04$ and 0.01 respectively). There was also a significant shift in the spatial distribution of cutthroat biomass in Needle Branch ($p=0.04$) in an upstream direction post-treatment suggesting that increases in cutthroat trout were spatially linked to the location of the harvest unit. There was no evidence for a treatment effect on mean fork length or the 90th percentile of fork length for age 1+ cutthroat trout ($p=0.32$ and 0.24 respectively). This result was supported by an absence of evidence for a treatment effect on relative growth rate. There was some evidence for a decline in mean fork length of age 0 trout post-treatment in Needle Branch ($p=0.07$). Condition factor (Fulton's K) changed significantly with treatment for only cutthroat trout 75-104 mm fork length ($p=0.05$) showing an increase in condition in Needle Branch relative to Flynn Creek.

Local and downstream impacts of contemporary forest harvesting practices on watershed hydrology

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Abstract

The hydrological impacts of forest management remains a primary concern to resources managers yet much of our understanding about these effects comes from historic paired watershed studies conducted up to four decades ago. While these early studies play a critical role in the development of current best management practices and forest harvesting practices, results do not necessarily reflect the effects of modern forest harvesting. In this presentation we show results of a study conducted at the decade-long Hinkle Creek Paired Watershed Study that examines the local and downstream impacts of forest harvesting on streamflow. Streamflow was measured at the outlet of six (4 treatment|2 reference) headwater catchments and two (1 treatment|1 reference) 3rd –order watersheds. Regression-based change detection models were developed between reference and treated catchments using mean monthly streamflow, instantaneous maximum peak flow, and storm quick flow. Contemporary forest harvesting practices, defined by the Oregon Forest Practice Rule, were used to clear-cut harvest trees in four experimental headwater catchments, while reference catchments remained untouched. Forest harvesting treatments were initiated in the experimental headwater catchments in 2005 (1st entry) removing trees from 13% to 65% of catchment area following a fifteen to eighteen month calibration period. A second harvest entry (2008) removed trees from an additional 12% in unmonitored catchments within the treated 3rd –order watershed. Significant increases in monthly streamflow that were generally proportional to area harvested were found in 3 of the 4 headwater catchments and in the 3rd order treatment watershed; significant increases in peak flow and quick flow were found only in the headwater catchments; and a statistically significant decrease in storm quick flow was found in the 3rd – order treatment watershed. However, the magnitude and significance of harvesting impacts on hydrology in the treatment catchments varied by unique pairing of reference catchments.

Local and downstream impacts of contemporary forest practices on sediment yield.

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Abstract

Statistically significant increases in sediment yield, as suspended sediment, were detected as a consequence of timber harvest in the South Fork Hinkle Creek. These increases were detected at the small, headwater watershed scale as well as the large watershed scale. Unlike the increases in water yield, these increases were not consistent with the literature. The results of the seminal paired watershed studies showed very large increases in sediment yield, often as much as two or three times greater than sediment yields before timber harvest. The results from contemporary forest practices are much more muted and the increases are in the range of 20 to 30 percent increases in sediment yield. The increases are in order with and correlate well with the increases in water yield.

That the increases in sediment yield are a result of increased stream power due to increases in water yield is a reasonable hypothesis to put forward to explain these observations. The greatest improvement in forest practices over the past several decades were directed toward reducing the impacts of timber harvest on sediment yield. These improvements include; clearcut size limits and adjacency constraints, improved yarding systems (in this case slackline, skyline cable systems), the prescription of buffer strips, changes in site preparation practices, and the construction, maintenance, and connectivity of roads. These improvements in conjunction with the known erosion processes that governed sediment yield in Hinkle Creek over the last decade make the stream power hypothesis viable.

A problem with this hypothesis is that it is inherently a self-fulfilling prophecy. The collection, reduction, and analysis of sediment data require the collection, reduction, and analysis of discharge. The calculation of sediment yield requires discharge so it is impossible to not have sediment yield correlated with water yield. A challenge for the next step in the analysis of these data is to normalize for discharge and investigate whether or not the increased sediment yield was a result of increased stream power or whether or not the erosion rate of the watershed increased.

The Influence of Contemporary Forest Management on Stream Nutrient Concentrations in an Industrialized Forest in the Oregon Cascades

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Abstract

Nutrient concentrations were measured in eight streams from October 2002 to September 2011 to assess nutrient response to contemporary forest practices at Hinkle Creek. This period of time included a two-year pre-treatment calibration between control and treatment watersheds, a fertilization treatment of both basins in October 2004, and a post-treatment period from 2005 to 2011. Stream water samples were analyzed for nitrogen, phosphorus, calcium, sodium, potassium, magnesium, sulfate, chloride, and silicon as well as specific conductance, pH, and alkalinity. Programmable water samplers were used to take water samples during fall freshets in November 2009 to assess the stream water discharge versus $NO_3 + NO_2$ concentration relationship.

All treatment watersheds showed a statistically significant increase in $NO_3 + NO_2$ concentrations after clearcutting ($p < 0.001$). The slope of the streambed through the disturbance was a stronger predictor of the magnitude of the response than was the magnitude of disturbance. Ammonia and organic nitrogen displayed notable increases after harvest treatment, but these increases were attributed to increases in the control watersheds. Phosphorus showed a response to timber harvest in one headwater stream. The remaining nutrients showed a small decrease in the control and treatment watersheds for the period after harvest. The storm response results showed that $NO_3 + NO_2$ concentrations in stream water increase with discharge during small storms that occur after periods of negligible precipitation.

Concentrations of $NO_3 + NO_2$ observed during the calibration period were similar to concentrations observed in an old-growth forest in the H.J. Andrews, suggesting that nutrient processing within the Hinkle Creek watershed had returned to levels that existed prior to its initial harvest sixty years ago. This finding helps to assess long-term impacts of shorter rotation timber harvest of regenerated Douglas-fir stands characteristic of industrialized timber harvest in Oregon.

Effects of stream adjacent logging on downstream populations of coastal cutthroat trout.

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Abstract

Here we evaluate the response of a headwater fish community to forest management using a before, after, control, impact (BACI) study design. Annual fish abundance and biomass estimates are from a census of pool and cascade habitat units over the fish-bearing portion of both the reference and treatment catchments. Movement, survival, and growth were estimated from the monitoring and recapture of salmonids marked with passive integrated transponder (PIT) tags. Sampling consisted of an annual electrofishing and marking event during the low-flow period (2001-2011), and beginning in the winter of 2003, there were three annual mobile antenna PIT-tag survey events in December, March, and June. Additionally, continuously operating swim-through antennas were located at the downstream end of each stream segment. The study calibration phase occurred 2001-05. Treatment-1 (2006-2008) consisted of stream adjacent logging without retention of standing tree buffers with harvest units occurring in channels upstream from channel sections inhabited by fish. During Treatment-2 (2009-2011), there was stream adjacent logging with standard buffers as prescribed by current forest practice regulations. Analysis occurred at two spatial scales, tributaries only and catchments. Overall, very few detectable changes in habitat or biologic parameters were observed in conjunction with either treatment. Despite limited inferential power, it appears the current Oregon Forest Practices Rules provide adequate short-term protection from acute negative effects to aquatic systems in previously-harvested catchments of western Oregon.

The impact of timber harvest on stream temperature at a watershed scale: A case study from Hinkle Creek.

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Abstract

One of the overarching objectives of the Hinkle Creek Paired Watershed Study was to investigate the impact of contemporary forest practices on stream temperature for non-fish-bearing streams and the cumulative impacts downstream on the fish-bearing tributaries and the main stem. Clearcuts adjacent to non-fish-bearing streams that were logged using slackline, skyline yarding systems resulted in statistically significant increases and decreases to maximum daily stream temperatures. The average daily maximum temperature increased by as much as 1.1°C and decreased by as much as 1.5°C. The absence of the magnitude of the hypothesized increase and the decrease in maximum daily stream temperatures was attributed to shade provided by a layer of logging slash over the streams and harvest related increases in summer low flows. Statistically significant decreases in minimum daily temperature were detected for all of the treatment streams. No change in stream temperature was detected at the mouth of the treatment watershed. On a watershed scale, the net effect of the first harvest entry was to decrease the average daily stream temperature 0.5°C.

Clearcuts adjacent to the fish-bearing tributaries and the main stem resulted in statistically significant increases and decreases to maximum daily stream temperatures. The average daily maximum temperature increased by as much as 2.5°C and decreased by as much as 0.8°C. Statistically significant increases and decreases were also detected in minimum daily stream temperatures. The largest increase in average maximum daily stream temperature (4.5°C) and the average minimum daily stream temperature were associated with the dam break flood that occurred in BB Creek during the 2009 WY. On a watershed scale, the net effect of the second harvest entry was to increase the average daily stream temperature by 0.5°C. There was no empirical evidence that the changes in stream temperature detected at the scale of individual stream reaches were propagated downstream. Furthermore, when the processes that are involved with the downstream propagation of stream temperature are studied, in Hinkle Creek, they do not support the hypothesis that temperature impacts can be translated downstream. The two processes

most responsible for this hypothesis in Hinkle Creek are the advected heat due to groundwater influx and the celerity and residence time of the water in the stream.

Long-term Studies of Macroinvertebrate Responses to Harvest in Hinkle, Alsea and Trask watersheds

Judith Li, William Gerth, Janel Sobota, Richard Van Driesche, and Doug Bateman

Abstract

Our studies of stream invertebrate responses to contemporary timber practices compared treated to control sites prior to and following harvest at Hinkle, Alsea and upper Trask watersheds. In each watershed the BACI study design and robust replication has been crucial in accounting for natural variations in macroinvertebrate distributions while examining patterns of change in response to harvest. As these basins vary physically in association with regional and geologic differences, initially we observed distinctive invertebrate assemblage composition for each watershed. In addition the proportion of chironomid midges and total benthic densities were higher at Alsea and Trask headwaters than at Hinkle. Our ability to detect responses to harvest within basins was enhanced when we found no pre-harvest differences in macroinvertebrate densities, percent chironomids, or taxa richness between control and treatment reaches of similar size at Hinkle and Trask watersheds. However significant invertebrate community differences were observed between the two Alsea tributaries, likely due to differences in tributary sizes or other physical and chemical differences.

At South Fork Hinkle headwater and mainstem sites taxa richness decreased, percent chironomids and rates of adult aquatic emergence increased locally, adjacent to harvest activities, but no changes in invertebrates were detected downstream. Though benthic invertebrate densities increased at headwater sites post-harvest, there were no detectable density differences at mainstem sites. Prey consumption by trout, whose densities at mainstem sites increased following harvest, possibly explained the lack of change observed for invertebrate densities. As post-harvest studies begin on the Trask, we are also measuring benthic biomass to evaluate changes in stream productivity, and collecting season-long aquatic emergence to track potential life history changes following harvest. In Alsea streams early results suggest that harvest effects may be more difficult to detect because of greater pre-harvest variability in invertebrate responses and the study's smaller scale. Results from the broader landscape studies at Hinkle and the Trask will provide important context for interpreting responses in the Alsea watershed.

A synthesis of the impacts of contemporary forest practices on aquatic ecosystems at a watershed scale: A case study from Hinkle Creek.

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Abstract

The Hinkle Creek Paired Watershed Study was initiated to carry out two overarching goals: to investigate the environmental impact of contemporary forest practices on non-fish-bearing streams and downstream in tributary and main stem fish-bearing streams. The study watersheds are located in the foothills of the southern Oregon Cascades, support a harvest-regenerated, 60-year old Douglas-fir forest, and are wholly owned and managed by Roseburg Forest Products. The study involved two harvest entries: the first harvest entry included 152 ha (382 acres) in five clearcuts adjacent to non-fish-bearing streams and the second harvest entry included 131 ha (324 ha) in four clearcuts adjacent tributary and main stem fish-bearing streams.

Statistically significant increases in water yield, summer low flows, peak flows, and storm flows were detected as a consequence of timber harvest and the subsequent silvicultural activities. The increases in water yield and the subsequent recovery of these processes are consistent with the literature. Statistically significant increases in sediment yield were also detected. The increases in sediment yield were not consistent with the literature; however they were highly correlated with the observed increases in water yield. Statistically significant increases and decreases were detected in maximum and minimum daily stream temperatures in the non-fish-bearing tributaries, fish-bearing tributaries, and the main stem as a

consequence of the two harvest entries. For all stream reaches, the changes in stream temperature could reasonably be explained by the changes in the energy budget associated with that stream reach. The hypothesized increases in maximum daily stream temperatures in the non-fish-bearing tributaries was not realized primarily as a result of shade-producing logging slash over the streams and harvest related increases in summer low flow. The cumulative effects, or downstream propagation, of stream temperature impacts, were not realized. The hypothesized downstream impacts were not realized primarily because of advected heat due to groundwater influx and the celerity and residence time of the water in the streams. Statistically significant increases in nitrogen were detected as a consequence of the timber harvest and the subsequent silvicultural activities. Nitrogen was the only nutrient that responded to the silvicultural activities. The harvest units in place in 2001 and the fertilization that occurred in 2004 impacted the analysis of the nitrogen data. The increases and subsequent recovery of nitrogen concentrations is consistent with the literature.

In Hinkle Creek the pacific giant salamander was the only amphibian that was abundant enough to study. The abundance of Pacific giant salamanders was studied for two years prior to and two years after the first harvest entry. In the two years after the first harvest entry, the data did not support the hypothesis that there was any change in the abundance of salamanders. Aquatic invertebrates were sampled within the harvest units, in the tributary streams below the harvest units, and in the main stem. After the first harvest entry, the density of benthic invertebrates increased, the percent chironomids increased, and species richness decreased within the harvest units. No change was detected in aquatic invertebrates downstream of the harvest units in the tributaries or the main stem. After the second harvest entry, changes in the aquatic invertebrates were detected in the tributaries and the main stem where the plots were associated with harvest units. Changes were not detected in aquatic invertebrates away from the harvest units. No impacts were detected in abundance, size, or growth of salmonids (primarily cutthroat trout) as a consequence of the first harvest entry adjacent to the non-fish-bearing streams. Increases in abundance, length and growth of salmonids were detected after the second harvest entry that was adjacent to the fish-bearing tributary streams and the main stem. The increases in abundance, length, and growth were most readily observed for 1+ cutthroat trout and young of the year trout in the tributary streams and the upper main stem.