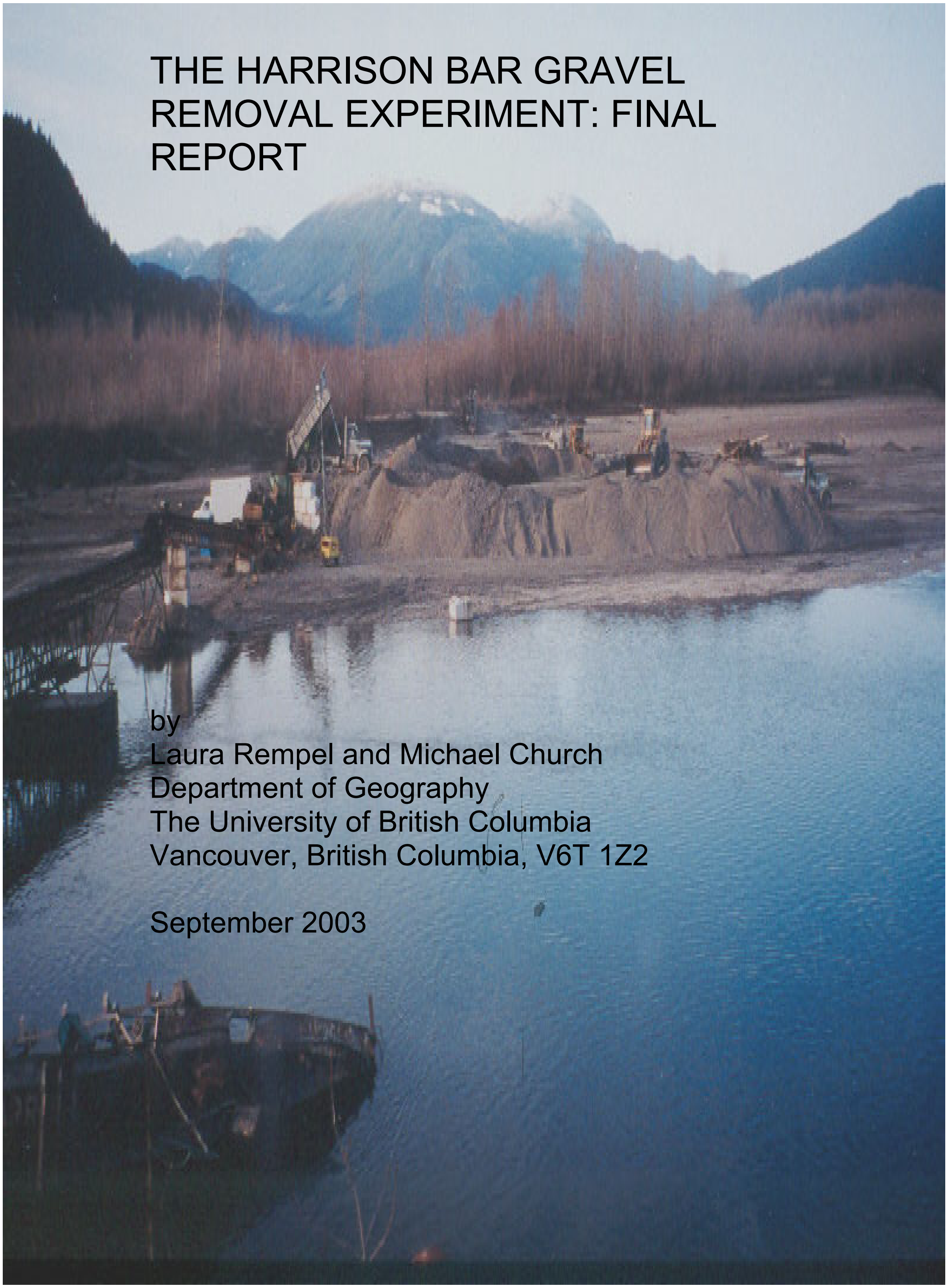

THE HARRISON BAR GRAVEL REMOVAL EXPERIMENT: FINAL REPORT

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Executive Summary

There is increasing concern that the natural processes of bed aggradation and seasonal flooding pose an unacceptable risk to the people and investment along lower Fraser River. As a result, gravel mining from within the main channel is currently being investigated as part of an effective strategy to reduce flood risk. For many decades, Fraser River has been exploited by the local aggregate industry as a source of gravel for construction and industrial purposes. However, observations from other rivers where gravel extraction occurs have found that mining can induce major morphological and ecological changes.

This report summarises research that examined the short-term (over three freshet cycles post-mining) physical and ecological impacts of an experimental gravel removal at Harrison Bar, Fraser River. The lower corner of Harrison Bar was chosen for bar scalping because it had been the site of persistent sediment deposition over the past 15 years and flood security in the vicinity was being compromised. The removal operation took place in February 2000 and involved scalping 70,000 m^3 of gravel from the surface of the exposed gravel bar at low flow. Systematic monitoring began in August 1999, prior to the removal, and continued for 18 months following the removal. Four components of the river system were examined: bar topography, physical habitat characteristics, the macroinvertebrate assemblage; and fish species assemblages and distributions with respect to habitat availability at Harrison Bar.

Data were collected at the scalped site (Har-S) and three upstream reference sites (upper Harrison Bar, Foster Bar, Carey Bar) that were chosen for their physical similarity to Har-S. Sampling for benthic invertebrates occurred twice before and eight times after bar scalping. Fish sampling by beach seine took place three times before and eight times after scalping. Topographical surveys of the removal area took place prior to scalping, immediately after, and on three occasions after subsequent freshet events (2000, 2001, 2002) to document changes in bar configuration and to estimate sediment replenishment to the removal area.

Sediment was extracted to an average depth of less than 1 m at Har-S, producing notable instantaneous changes. The scalped area was left topographically simple with unconsolidated fine gravel and sand replacing a coarse and relatively stable bar surface. Average sand cover increased from 11% to 32% and median grain size decreased from 25 mm to 13 mm. Also notable was the decrease in grain size of the coarsest fraction (D_{95}) from 66 mm to 40 mm. The proportion of the area of lower Harrison Bar at greater than 8 m elevation was reduced from 71% to 4% and the area >9 m elevation was reduced from 24% to 0%.

These physical changes were relatively short-lived: two subsequent freshets of below-average discharge in 2000 and 2001 transformed the loose and sandy surface into a moderately coarse substrate with negligible sand cover. Median grain size (D_{50}) increased to 35 mm and the coarsest fraction (D_{95}) increased in size along the water's edge but remained lower than prior to scalping (82 mm versus 91 mm).

The below-average freshets of 2000 and 2001 produced negligible volumetric change at the scalped site (8311 m^3 net erosion over the lower bar); however, topographical changes were notable and resulted in deposition of an isolated gravel bar at the lower corner and erosion of a summer channel that flowed diagonally across the lower bar. The channel had irregular geometry with high habitat diversity. Some rebuilding of high bar area was observed in 2000 and 2001: the proportion by area of lower Harrison Bar >9 m surface elevation was 15% after freshet in 2001 compared with 0% immediately after scalping. However, a loss in high bar habitat remained evident as the area of lower Harrison Bar >9 m elevation prior to scalping was 24%.

The above-average freshet in 2002 deposited 27,630 m^3 of sediment over lower Harrison Bar. Considering volumetric change within the boundaries commonly surveyed in all years, 31% of the scalped volume was replenished over three freshets. The lower bar was further transformed into an irregular surface of variable elevation that offered greater topographical variability in comparison with pre-scalp conditions. However, the proportion of area over lower Harrison Bar >9 m elevation remained 6% less than before scalping (18% post-scalping versus 24% before scalping, corresponding to 44,750 m^2 and 58,925 m^2, respectively). The range of flows over which the loss of high bar habitat was most significant was between 4000 and 7000 m^3/s. These flows typically occur between May and August, during the period when fish are rearing in the gravel reach.

At flows less than 3000 m^3/s, lower Harrison Bar offered higher habitat diversity and smaller-sized habitat units after scalping. Bar edge remained the most common habitat type, however, units were shorter in length and spaced between open nooks. The increase in habitat diversity was observed both along the main channel edge and within a summer channel that crossed the lower corner of Harrison Bar. The new channel increased the amount of wetted area available for fish and presented a variety of habitat types including eddy pool, open nook, and bar edge. Recently, the channel appears to be infilling, however, it provided valuable aquatic habitat in the short-term after scalping as the bar was changing toward its new configuration.

The characteristics of bar edge units, the most common habitat type in the gravel reach, changed at Har-S after scalping in comparison with the three reference sites. The short-term change was statistically significant and was interpreted to be a shift towards reduced bank slope and sandier substrate. The change was only observed during summer months.

Asymmetrical analysis of variance (ANOVA), the most rigorous approach available to detect environmental impacts, was used to determine whether or not bar scalping had a significant impact on benthic invertebrates and juvenile fish at lower Harrison Bar.

Asymmetrical ANOVA was applied to five parameters characterizing juvenile fish at the removal site compared with the three reference sites: total density, proportion of salmonid species, species richness, Simpson's diversity, and Simpson's evenness. When data from all habitat types were pooled at the bar-scale, only evenness recorded a short-term impact at Har-S: values were more variable at Har-S after scalping compared with reference sites. An examination at the habitat-scale limited to bar edge units found a significant short-term impact in the proportion of salmonid species at Har-S. In this case, salmonid representation (consisting of chinook and chum salmon) was *higher* at Har-S than reference sites in winter and spring post-scalping. Statistical power to detect an impact was low for all analyses, however, it was higher for bar-scale analyses due to the larger number of beach seine samples.

Six parameters characterizing the invertebrate community were examined by asymmetrical ANOVA: total density, proportion of mayflies, stoneflies, caddisflies (EPT), taxon richness, the number of EPT taxa, Simpson's diversity, and Simpson's evenness. Results of the analyses were identical when data were examined at the bar-scale (all habitats) or habitat-scale (bar edge only). A short-term significant impact was detected for 3 of 6 parameters. Total density and the proportion of EPT were lower at Har-S in May and August after scalping compared with reference sites. Evenness was more variable after scalping at Har-S. Statistical power was relatively high for these analyses.

An examination of the abundances of the seven most common invertebrate taxa found a significant short-term reduction at Har-S due to scalping for two taxa: Chironomidae and Oligochaeta. A significant change for Baetidae was also detected, however, abundance of the common mayfly increased at Har-S after scalping. Statistical power to detect an impact was moderate for those taxa for which an impact was not detected.

Invertebrate density at the scalped site was lower than reference sites immediately after mining in April 2000 and remained lower until August 2000, less than one freshet cycle. Lower invertebrate density at the scalped site suggested that physical conditions may have been less favourable than at other gravel bars affected by spring flooding. The rate of sediment transport across Harrison Bar was likely higher due to the loose substrate framework left by scalping, and these conditions may have deterred settlement by some taxa. The fact that all impacts associated with the invertebrate community due to scalping were short-lived is consistent with observations that the fine gravel/sand surface at lower Harrison Bar was transitory, lasting only through the first freshet.

We are unable to rule out the possibility that the improvement in habitat diversity at flows <3000 m^3/s after scalping was fortuitous. In other circumstances, post-scalp sedimentation patterns might have sustained or even further simplified the existing topography. It does appear certain that processes of sediment transport and deposition assisted site recovery because the scalped surface of Harrison Bar became topographically complex after one freshet event. However, an above-average freshet was necessary for substantial sediment deposition and areas of high surface elevation to rebuild. We expect that sediment replenishment will be necessary for a removal site to continue to offer high quality habitat that favours recolonization by benthic invertebrates and rearing by fish. A large removal in 1995 from the upstream head of nearby Foster Bar has continued to degrade in the absence of sediment deposition since scalping and habitat quality has been notably impacted.

Eight recommendations, summarized below, are given for future gravel removals based on the experience gained in this study in order to minimize the likelihood of negative morphological and ecological change. Minimum sampling requirements are also listed for future monitoring studies along with a discussion on ways to improve statistical power to detect an impact.

1. *Site selection and planning for future removals should give due consideration to the need to preserve areas of high bar habitat as well as local patterns of sediment transport and the likelihood of gravel replenishment to the site.*
2. *In general, the removal volume at a site should not exceed the best estimate of local gravel deposition in a year of mean annual flood discharge (derived from volumetric or sediment transport estimates). This is to ensure that physical changes to a site fall within the range of change that might be observed at a non-removal site in a large freshet.*
3. *The haul road surface should be mechanically scarified once a removal operation is complete and prior to freshet.*
4. *It is important to preserve bars within the gravel reach exclusively as reference sites to allow for comparisons between scalped and undisturbed reference sites*.
5. *Future removals should be treated as "experiments" with a structured monitoring program.*
6. *When the goal of a monitoring program is to examine mining impacts using statistically rigorous methods, due consideration must be given to the timing of permit approval to allow necessary pre-scalp samples to be collected.*
7. *There remains a need to learn about the ecological and morphological impacts of linear excavations, bar edge scalping, and riffle dredging.*
8. *There remains a need to learn about the cumulative impacts of multiple removals or single but large removals, as well as the response to gravel mining over an extended period of long-term monitoring.*

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1.0 Introduction

1.1 Background

The distribution of sediment along stream channels determines the pattern and form of the channel, and is itself a function of flow regime and upstream sediment supply. In steep gradient systems, large cobbles and boulders are major structural elements along the channel while gravel and smaller sized sediment are transported downstream. As gradient drops and the flow becomes less powerful, gravel is deposited and accumulates to form bars. The tendency for sediment to accumulate as bars and islands in moderate and low gradient channels creates outstanding habitat for various fish species and aquatic organisms.

Sediments are important not only to a stream's ecosystem; they are highly desirable for construction and industrial purposes. Road and highway construction, septic systems, and concrete are only a few uses for the valued material. Alluvial gravel (from rivers) is particularly desirable because of its high quality and ease of removal. A variety of extraction techniques may be used in rivers depending on the size of channel, the annual hydrograph and depositional pattern of the material. In most cases, material is scalped from exposed bar surfaces at low flow, removed by in-stream suction dredging, or extracted from off-channel floodplain deposits (Kondolf et al. 2001). In many systems, historical extraction volumes have greatly exceeded the natural rate of replenishment in many systems. This has happened in part because of a misperception that large volumes of gravel stored in the riverbed corresponded with high rates of gravel influx (Kondolf et al. 2001). Alluvial gravel mining is now regulated in most industrialised countries, although the demand for aggregate continues to grow.

Morphological studies characterizing the physical impacts of gravel mining are reasonably common (e.g., Lagasse 1986, James 1999). Collins and Dunne (1990) summarised observations from several rivers in the United States with extensive mining activity. Gravel extraction from several rivers in California has been reviewed in detail by Kondolf (1994, 1998a, 1998b). The physical impacts of river engineering and gravel extraction on European rivers (Sear and Archer 1998, Surian 1999) and several coastal streams in British Columbia (Sutek and Kellerhals 1989, reviewed by Church et al. 2001) have been described as well.

Far fewer studies have examined the ecological impacts of gravel extraction, despite growing concern that mining damages aquatic habitat. Most ecological studies have been short in duration (usually one season) and conducted in channels with a lengthy history of gravel mining (e.g., Brown et al. 1998). For these studies, no data from true "control" sites or from mined sites prior to extraction are available with which to compare conditions at the impacted site. As well, many studies have neglected to document the mining history (frequency and volumes removed) and sediment transport regime of the channel, making it difficult to draw conclusions and transfer results to other systems.

Ecological studies on rivers with a prolonged history of gravel mining may provide insight into the chronic effects resulting from persistent extraction. But there remains a significant gap in our knowledge of the short-term impacts on aquatic habitat quality and the pattern of response of organisms. To date, no known study has tracked a removal operation with time series data of pre-impact and post-impact sampling to examine the short-term ecological effects of mining.

This report summarises research that examined the short-term physical and ecological impacts of gravel mining at Harrison Bar, Fraser River. The site was chosen for an experimental gravel removal conducted in February 2000 and was part of a larger study examining the ecology of this large, snowmelt-dominated river. The removal operation involved scalping sediment from the surface of the exposed gravel bar at low flow. No in-stream dredging or wet scalping along the edge of Harrison Bar occurred, and the site had no prior history of gravel extraction. Three areas of information were the focus of the study: physical habitat characteristics before and after mining; fish species assemblages and distributions before and after mining with respect to habitat availability at Harrison Bar; and the macroinvertebrate assemblage and its short-term response to mining.

Herein, the term gravel extraction is used interchangeably with mining, and is defined as the removal of coarse sediment (sand, gravel, cobble) for the purpose of aggregate recovery for profit, for river management, or both. In order to place this study in context and identify its limits of application, we propose three phases of system response to gravel extraction in Fraser River (**Table 1**). Our study has examined the first two phases only: instantaneous and short-term impacts of bar scalping. Proper examination of the long-term ecological and morphological responses to bar scalping would require a prolonged monitoring program that possibly examined additional parameters.

Table 1. Proposed phases of river system response to gravel extraction in Fraser River.

PHASE	DESCRIPTION
Instantaneous	*During removal activities and on the rising limb of the discharge hydrograph* as the bar is first inundated. The surface sediment is loose and of small calibre, hence the rate of fine sediment transport is relatively high.
Short-Term	*Extending from first inundation over several subsequent flood cycles* as the bar sediment redevelops a coarse surface layer and the river has the opportunity to replenish sediment at the removal site. Bar-scale adjustments in topography occur and fluvial process begin to modify the site: bar elevation rebuilding to initiate island formation; sediment recruitment and fluvial processes redistributing material to recreate habitat units; secondary channels developing and incising across the bar; and the spectrum of useable habitat types becoming available over the range of discharges.
Long-Term	*Continuing over a prolonged cycle of freshets* as morphological and ecological adjustment take place. Fluvial processes (described above) continue to modify the site. Adjustments in channel form extending upstream and downstream from the removal site may occur.

1.2 Governing Variables

There is an overall lack of scientific information on gravel mining impacts to stream communities. It is expected that ecological impacts are mostly transmitted by way of physical alterations to river habitat. However, the extent of physical habitat change necessary to elicit an ecological response is unknown. As well, the degree of impact and trajectory of ecological response are uncertain. Several physical factors are known to exert a strong influence on the distribution of organisms and the structure and function of stream communities (**Table 2**). Integrating observations of these factors with ecological data collected over the course of this impact study was intended to assist in identifying and understanding the ecological response to gravel mining. These factors, referred to as "governing variables" because of their governing role in structuring aquatic communities, were incorporated into the data collection activities at Harrison Bar.

1.3 Fraser River Context

Fraser River drains 232,000 km^2 of south and central British Columbia. Much of the river system is steep and, consequently, significant amounts of sediment are mobilized and transported from the upper basin. Once the river enters the Lower Mainland, it encounters a rapidly declining gradient that forces the deposition of much of this coarse sediment load. Significant quantities of gravel and sand are deposited in the channel zone between Laidlaw and Mission (averaging 285,000 m^3/yr since 1952, Church et al. 2001) to form, on a large scale, an alluvial fan. Hence, the reach is referred to as "the gravel reach". Mountainous terrain and channel dyking confine lateral growth of the alluvial fan; consequently it is prograding (extending downstream) and aggrading (building vertically) as a result of annual sediment deposition. On a local scale, the gravel deposits split the flow into multiple channels that shift with bar growth and bank erosion.

Fraser River exhibits a "wandering" plan-form in the gravel reach with multiple channels separated by bars and islands (cf. Neill 1973, Desloges and Church 1989). Upstream, the cobble-bed channel is single-thread and confined by mountainous terrain whereas, downstream of Mission, the sand-bed reach is also mostly single-thread and confined by dyking (**Figure 1**). Within the gravel reach, a range of channel sizes and habitat types provide varied combinations of velocity, depth, and substrate that together support a diverse assemblage of fish species. Backwaters and off-channel bays provide rearing habitat for many species, and vegetated bank edges along the channels and islands provide riparian habitat where cover, terrestrial insects, nutrients and microhabitat features are available. It is no coincidence that the gravel reach supports at least 28 species of fish and Fraser River itself is one of the great salmon producing rivers in the world (Northcote and Larkin 1989).

The Fraser basin is also home to 65% of BC residents, roughly 2.5 million people. At least 87% of these people are concentrated along lower Fraser River downstream of Hope (The 2001 Census of Canada, www.bcstats.gov.bc.ca). Associated with the high density of people living along the river are a variety of land use pressures that threaten the integrity and function of its ecosystem. With the concentration of people and investment along lower Fraser River, there is increasing concern that the natural processes of bank erosion and seasonal flooding pose an unacceptable risk. Riprap has been placed along more than 63 km of bank line between Hope and Mission in an effort to control erosion (Church et al.

2001), and concerns of overbank flooding have led to dyke construction and the isolation of more than 100 km of side channels (Rosenau and Angelo 2000). However, with continuing gravel deposition within the reach, there is concern that rising streambed and water levels will eventually compromise the security provided by the dykes. Gravel mining from within the main channel is now being investigated as an effective strategy to reduce the flood risk and, in certain circumstances, counter erosion.

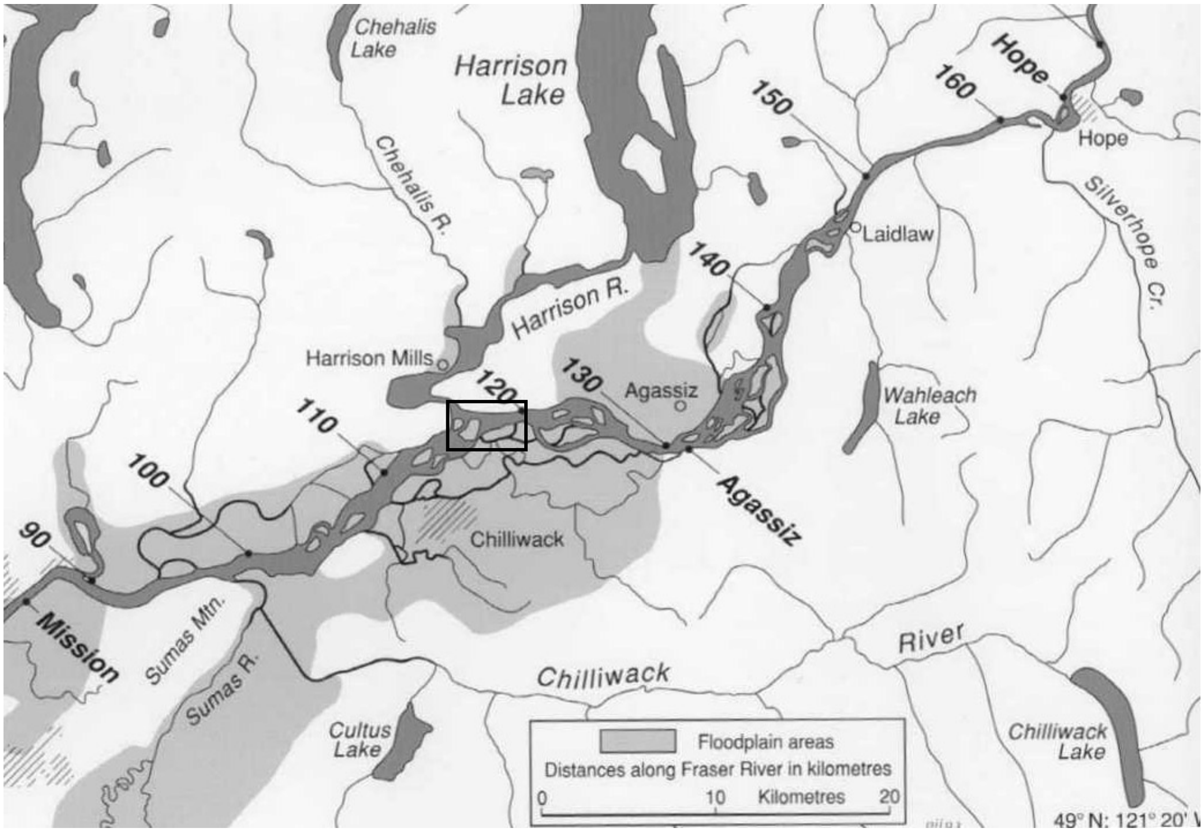


Figure 1. Location map of lower Fraser River. The gravel reach extends from river km 90 at Sumas Mountain to river km 150 near Laidlaw. The study area, including Harrison Bar, is located within the black box.

For many decades, Fraser River has been exploited by the local aggregate industry as a source of high quality gravel for the Lower Mainland. At least 4.6 million cubic metres of gravel have been mined since 1964 (Weatherly and Church 1999), and we expect there were many other unrecorded removals based on historical air photographs (e.g., Big Bar in 1974). The majority of gravel mining has been by dry bar scalping in the main channel between January and March of a given year. Mining is now considered by some to be an economically profitable strategy to mitigate against flooding and bank erosion. However, government regulatory agencies have recognized the potentially negative impacts to fish habitat and have become more restrictive in allowing gravel removal. A temporary moratorium on gravel mining from Fraser River was in place for three years (1998-2001) to allow scientific studies to proceed and to draft a long-term management plan. This report presents results from one component (short-term impacts) of the scientific studies.

Table 2. Governing variables that influence the structure and function of biological communities in rivers.

Variable	Nature of Influence	Direction of Influence	References
Discharge	• *High discharge events* are necessary for sediment transport and bar development	+	Kellerhals and Church 1989, McLean et al. 1999
	• *Moderate, predictable flood events* are associated with high species richness and may be an environmental cue for animal life cycle events	+	Robinson et al. 1992, Death and Winterbourn 1995
	• *Flashy, high velocity flood events* may dislodge insects and disrupt the distribution of fish	–	Harvey 1987, Cobb et al. 1992, Holomuzi and Biggs 2000
Water Depth	• *Range of depths* supports multiple life stages and higher species richness	+	Allen 2000, Rempel et al. 2000
	• *Near-shore areas of shallow water* have high primary productivity, are inhabited by invertebrates, and are used by fish for rearing	+	Rosemond 1994, Rempel et al. 1999, Allen 2000
	• Steeply sloped banks reduce the availability of near-shore habitat	–	Kellerhals and Church 1989
Water Velocity	• *Range of velocity conditions* and flow types supports higher species richness	+	Townsend et al. 1987
	• *High velocity* places energetic stress on organisms and limits species interactions	–	Feminella and Resh 1990
Substrate	• The distribution of *coarse sediment (gravel and cobble-sized material)* influences the spatial distribution of aquatic organisms	+	Rice et al. 2001
	• *Large stones* promote *substrate stability* and reduce the risk of insects being dislodged from the channel bed during floods	+	Malmqvist and Otto 1987, Oldmeadow 2001
	• *Stable substrates* increase species richness, abundance, and the likelihood for species interactions (predation, competition)	+	Fuller and Rand 1990, Townsend et al 1997
	• *High surface roughness* improves the retention of leaf litter and detritus, and provides refuge for insect during floods	+	Culp et al. 1983, Cobb et al. 1992, Lancaster and Hildrew 1993
	• *High concentrations of fine sediment* can smother benthic organisms and reduce primary productivity	–	Culp et al. 1986, Wood and Armitage 1997
Topography	• *Variable bar topography* provides a greater number of habitat types	+	Kemp et al. 1999

2.0 Gravel Removal – Methods and Analysis

2.1 Site Selection

Site selection for the experimental removal was done in consultation with several agencies (former BC Assets & Lands Corporation, former BC Ministry of Environment, Lands & Parks – Fish & Wildlife and Water Management Divisions, Fisheries & Oceans Canada). The main scientific criterion for choosing the site was that it had no prior history of gravel extraction. A second criterion was that the site be situated within a zone of perceived flood risk. Several sites met these criteria and were considered for the experimental removal; however, lower Harrison Bar was chosen for the following reasons.

1. There was a perceived need to increase channel capacity at the mouth of Harrison River, which would reduce the risk of increasing flow into Minto Channel.
2. The site was deemed "geomorphologically safe"; bedrock protects neighbouring banks and would limit the magnitude of morphological changes that might be set in train.
3. The site was accessible for removal operations and subsequent monitoring activities. It was also in close proximity to commercial gravel markets.
4. Harrison Bar had been a site of recent major sediment deposition; the entire bar surface was exposed relatively early on the declining limb of the discharge hydrograph.
5. Reasonable background knowledge of the fish and benthic invertebrate community was available from Harrison Bar.
6. Northwest Hydraulic Consultants had previously evaluated the site for gravel mining by bar scalping and a shallow channel excavation (NHC 1995).

Harrison Bar is situated on the south side of the main channel opposite the Harrison River confluence. At this location the river is set against the north bank before making a 90˚ turn as flow impinges against Harrison Knob. The backwater effect induced by the addition of Harrison River flow and the sharp bend has contributed to significant gravel deposition and bed level change on Harrison Bar over the past twenty years (**Table 3**). Gravel deposition in the past 15 years has averaged 112,800 m^3/yr (cell 31 and 32).

Table 3. Sediment volume changes and bed level changes in the vicinity of Harrison Bar (from Church et al. 2001). Refer to Figure 2 for cell locations.

Cell	1952 – 1984			1984 - 1999		
	Bed Level Change (m)	Gravel (10^3 m^3)	Sand+Gravel (10^3 m^3)	Bed Level Change (m)	Gravel (10^3 m^3)	Sand+Gravel (10^3 m^3)
31	-0.29	-166	-291	+1.63	+1,075	+1,651
32	-0.09	+162	-121	+0.69	+617	+897

The scalped area of lower Harrison Bar (Har-S) is outlined in **Figure 2**. The upper portion of Harrison Bar along with two additional gravel bars (Carey and Foster) was designated as a control, or reference site. The upstream portion of Harrison Bar (Har-R), Carey Bar (Car-R), and the lower portion of Foster Bar (Fos-R) have no known history of gravel mining and their upstream proximity to the scalping site meant that they shared physical characteristics with respect to channel morphology and gradient, sediment transport regime, and substrate texture. The three reference sites and scalping site were also similar in the array of habitat types available for fish over most levels of discharge.

Although Calamity Bar was included originally as a reference site, it was excluded from data analysis and reporting because its position immediately downstream of the removal area and Harrison River confluence was thought to make it an unsuitable reference site.

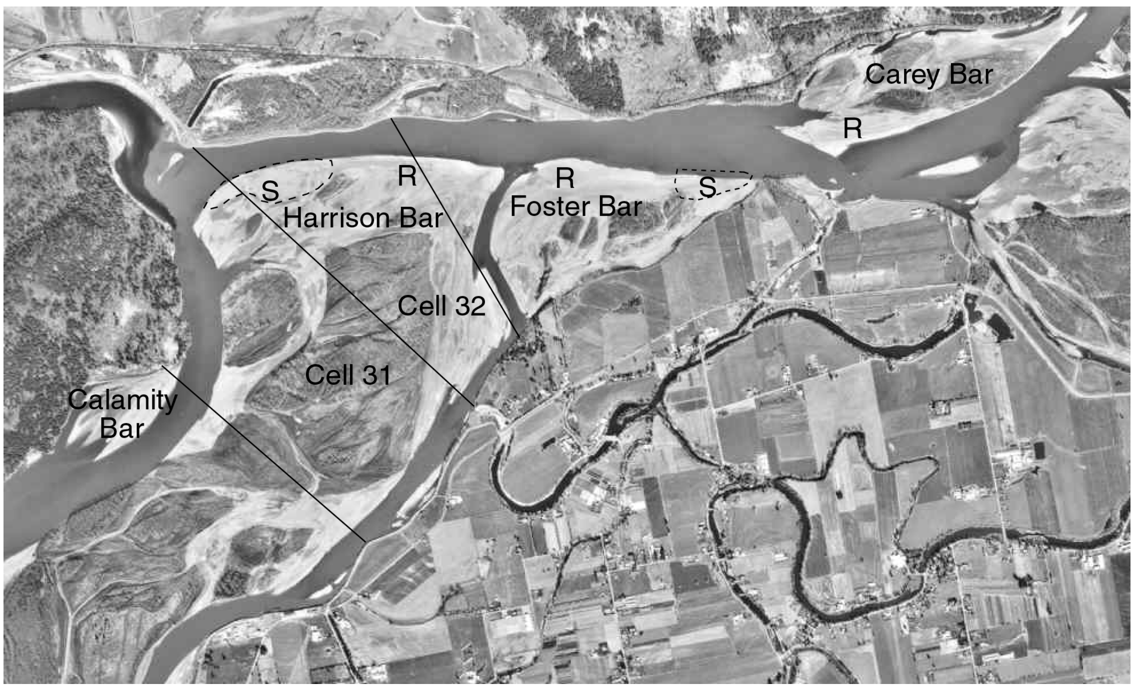


Figure 2. Reach of lower Fraser River where the experimental gravel removal at Harrison Bar took place. Reference areas (R) and the scalping site (S) are indicated. Upper Foster Bar was the site of bar scalping in 1995. Photograph taken March 27, 1999.

Upper Foster Bar (Fos-S) was included in the sampling program to examine site characteristics several years after gravel mining (**Figure 2**, see Appendix B). Fos-S was mined in February 1995 by dry bar scalping and approximately 300,000 tonnes of sand and gravel were removed (Tunbridge and Tunbridge). Three topographic surveys conducted after scalping, between 1995 and 2003, indicated that only 9% of the removal volume has replenished the site (Appendix B). Data collected at Fos-S are not presented in the report but are available upon request. We summarize general observations made at Foster Bar in **Section 4.0** and Appendix B for comparative purposes because the removal at Foster Bar and the trajectory of physical and ecological response appear to have differed from Harrison Bar.

2.2 Gravel Mining at Harrison Bar

A target removal volume of 100,000 m^3 was set for Harrison Bar to approximately equal the mean annual volume of aggregate previously removed from the gravel reach (Weatherly and Church 1999) and, for experimental purposes, to promote the likelihood of the removal yielding a detectable ecological response. Material was removed by bar scalping. Hence, the results could be compared to sites where past scalping has occurred and might be used to predict the outcome of future scalping proposals.

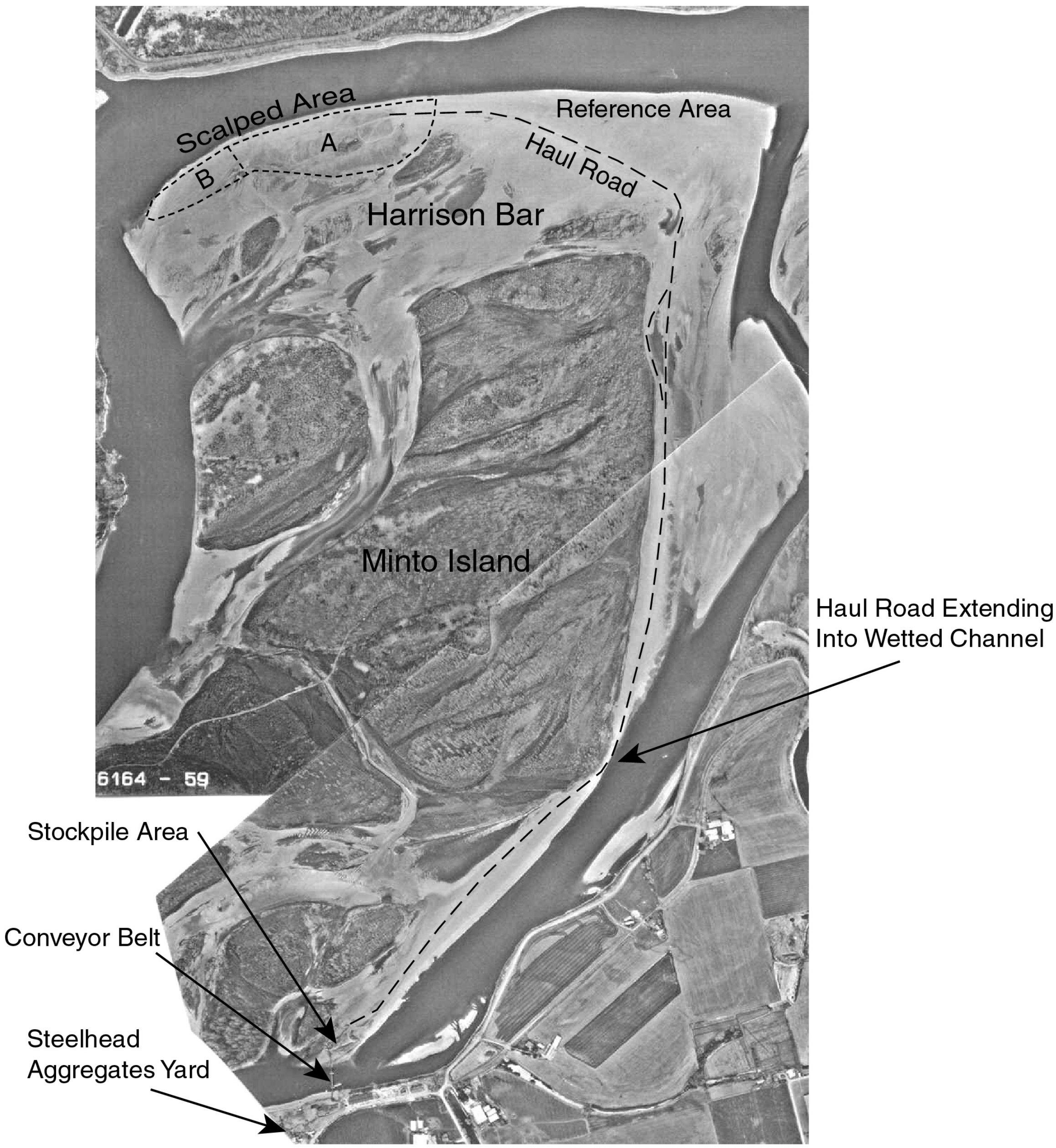


Figure 3. Minto Island showing the scalped area on Harrison Bar, haul access road, stockpiling area, conveyor belt, and Steelhead Aggregates Ltd yard. Photograph taken March 10, 2000**.**

Appendix A provides a photographic record of Harrison Bar during the removal operation. Access to the site for haul trucks and a front-end loader was via a graded haul road from the stockpiling area (**Figure 3**). The removal site consisted of two areas referred to as "A" (~200 x 400 m) and "B" (~100 x 200 m) (**Figure 3**), which were separated by a narrow gravel berm. A 1-m buffer strip was left along the water's edge in Area A whereas the downstream corner of Area B was scalped directly to water line in a trough-shape to ensure positive drainage.

Steelhead Aggregates Ltd. removed approximately 70,000 m^3 of sand and gravel between February 26 and March 17, 2000. Fisheries & Oceans Canada (DFO) granted approval for a 2-day extension beyond the March 15 deadline in order to complete site restoration works. Discharge at Hope remained stable during the operation and averaged 707 m^3/s. The sequence of removal activities was as follows.

A barge stationed at the Steelhead yard transported machinery, dump trucks, and vehicles across Minto Channel to Minto Island for the duration of the removal. Personnel were transported daily to and from Minto Island by powerboat. A haul road was established and graded from the stockpiling area on Minto Island to the removal site on February 26 (**Figure 3**). An 85 m portion of the road was required to extend into the wetted channel and was constructed by placing a bed of angular riprap in the water using a front-end loader until it was about 0.3 m above water level. A grader then packed sand and gravel onto the riprap base to build up and stabilize the road.

Material was scalped from the surface of the removal area and loaded into dump trucks by a front-end loader. Each truck had a haul capacity of approximately 10 m^3 and transported gravel from the removal site to a stockpiling area on Minto Island. A large conveyor spanning Minto Channel was then used to transfer gravel from the stockpile to the Steelhead yard. The conveyor belt operated continuously during the removal period and the scalping operation followed a 24-hour schedule in order to maximize the removal volume by the March 15 deadline. Large floodlights were used to illuminate the site at night. Despite this intensive program, only 70% of the target removal volume could be scalped by the deadline.

After completion, the site was graded at a 2% slope towards the main channel to ensure positive drainage and that no depressions or low areas could strand fish. Machinery and trucks were removed from the site between March 15 and 17, 2000. The haul road was left hard-packed rather than scarified and loosened (standard procedure) in order to examine the change in grain size and degree of compaction after flooding.

2.3 Monitoring Activities - Conceptual Approach

The sampling design and chosen monitoring activities were intended to address the following sequence of questions.

1. How did the **bar-scale physical characteristics** of Harrison Bar differ between pre-scalp conditions and those after scalping, and after two subsequent freshet events?
2. Did the **availability of habitat types** change at Harrison Bar after scalping?

3. How did the **physical characteristics of habitat types** differ at Harrison Bar between pre-scalp and post-scalp periods? Were habitat characteristics comparable with reference sites before and after scalping?
4. Of the habitat types available at Harrison Bar, did they host a similar **assemblage and density of fish** before and after scalping? Was the habitat-specific fish assemblage at Harrison Bar comparable with reference sites before and after scalping?
5. Did the **density and assemblage of benthic invertebrates** at Harrison Bar differ between pre-scalp and post-scalp periods? Were these metrics comparable with reference sites before and after scalping?
6. Did the **prey choice** of juvenile fish rearing in the reach differ between the scalp and reference sites before and after scalping?

The conceptual approach followed a BACI-design (Before-After-Control-Impact; Stewart-Oaten et al. 1986) whereby measurements are collected several times before and several times after an impact takes place from a control and impacted site. BACI is a commonly used acronym, however, its original authors admit that the term "reference site" is usually more appropriate than "control site" (Stewart-Oaten and Bence 2001). Herein, we use the term reference site because conditions at a site remained subject to seasonal modification by river processes. We modified the BACI-design to include three reference sites rather than one single site because of the spatial variability of the system. Including three reference sites also was more favourable for data analysis of fish and invertebrate data. Selecting reference sites that resembled as closely as possible the physical characteristics at the scalped site was an important consideration. The three chosen reference sites (Har-R, Fos-R, and Car-R) are believed to have met this criterion because of their proximity to Har-S and their similarity with respect to channel morphology, gradient, sediment transport regime, and substrate texture. Being situated upstream, each reference site also was unaffected by possible changes at Har-S after the removal.

The BACI design was first introduced as a solution to the problem of assessing the environmental effects of an unreplicated disturbance such as gravel mining where the location is not randomly assigned (Green 1979, Stewart-Oaten et al. 1986). This situation poses difficult statistical problems, identified by Hurlbert (1984), where the main goal is to determine whether the state of the impacted site differs significantly from what it would have been in the absence of the disturbance. Ideally, such a study would proceed as an experiment with a number of replicate sites (i.e., gravel bars), each randomly assigned to one of two treatments (i.e., scalping or no scalping), and then applying standard statistical analyses. However, this ideal situation rarely occurs. More often, and in the case of scalping at Harrison Bar, the location is not randomly determined and replication is not feasible.

Because the state of Harrison Bar in the absence of mining could not be observed post-scalping, an estimate was needed of what that state would have been to compare with the observed condition. The BACI approach accomplished this by collecting samples at both the scalped site and nearby reference sites simultaneously (as nearly as possible). Replication was achieved by collecting the samples from all sites on a number of dates both before and after scalping. Differences between the reference and scalped sites prior to mining were taken to be an estimate of the difference expected in the period after mining had the removal not occurred. This design allows for natural differences between the reference and scalped locations, and for changes during the before and after periods that influenced all sites in the same way (e.g., differences in discharge and water temperature between sampling periods).

Figure 4 illustrates the approach with a simple example (from Stewart-Oaten et al. 1992). In case A, mean density is greater in the control area than in the impacted area and the average difference between impact and control does not change significantly from before to after (bottom panel), indicating that there has been no detectable impact. Case B illustrates a situation in which the disturbance has reduced density at the impacted site, leading to an increase in the difference from before to after the impact.

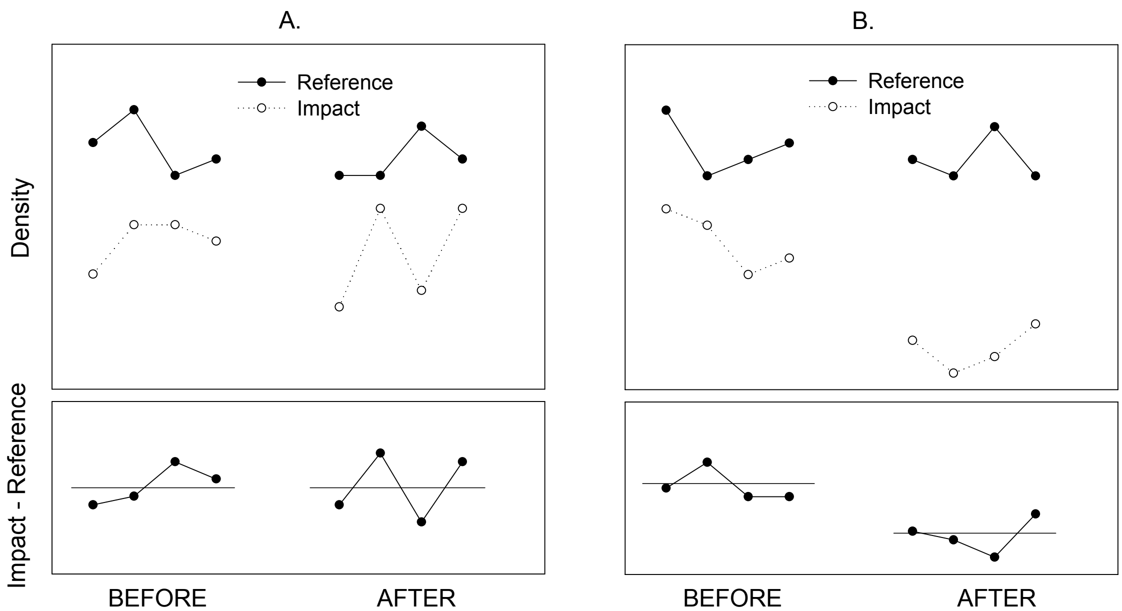


Figure 4. Hypothetical data collected using the BACI design. (A) Average density is greater in the reference area than in the impact area. The average difference in abundance between impact and reference does not change significantly from before to after (bottom panel), indicating that there has been no impact. (B) Case where the disturbance has reduced density at the impact site, causing a change in the difference from before to after (adapted from Stewart-Oaten et al. 1992).

Figure 4 also illustrates a critical weakness of the BACI design: it provides no means to estimate the variability of the possible outcomes at impact or reference sites, so that it becomes impossible to ascertain what a truly significant change at the impact site might be. On this basis, the design has been heavily criticized. The problem is addressed in an extension of the BACI design by Underwood (1991, 1993, 1994), in which variance is dealt with by introducing multiple reference sites. This strategy leads to an asymmetrical analysis of variance in which sources of environmental variance are assessed from the observations at the reference sites. Details are given in **Section 2.6**.

2.4 Monitoring Activities - Timing and Hydrology

Pre-removal sampling for fish and benthic invertebrates began in August/September 1999 as part of a larger study examining the ecology of lower Fraser River. At this time, the removal was not anticipated and consequently sampling effort at some sites was incomplete for the design requirements of the study. Only limited data were gathered from upper Harrison Bar and Foster Bar.

The Harrison Bar experimental removal was approved in January 2000 and systematic monitoring of the scalp and reference sites began in February 2000, prior to scalping. Sampling was repeated following the removal over 18 months beginning in April 2000 when the rising water level began inundating the scalped area. Monthly sampling was scheduled originally but the sampling frequency was scaled back after May 2000 to be more cost effective. The revised sampling schedule was intended to coincide with the timing of key life cycle stages of invertebrates and juvenile fish (**Table 4**). Sampling in February, March, and November targeted invertebrate larvae that typically mature through the winter and emerge as terrestrial adults by late March (**Figure 5**). Sampling in July through September targeted juvenile fish rearing in near-shore habitats as well as newly hatched invertebrate larvae. In total, invertebrate sampling occurred twice before and eight times after scalping. Sampling for juvenile fish occurred over three periods before and eight periods after scalping.

Table 4. Sampling schedule for juvenile fish (F) and benthic invertebrates (B). The shaded cell marks the timing of bar scalping and the period when night (N) sampling for fish occurred.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999								F	F, B			
2000		F, B	N	F, B	F, B			F, B	F, B		F, B	
2001	B	F, B						F	F, B			

Sampling in some months occurred at lower elevations than the limit of bar scalping (e.g., January and February 2001). These samples were important for characterizing the time-series sequence of ecological and physical responses to mining and to assist in the interpretation of patterns detected in other months. They were also useful because the bar-scale response to mining was uncertain; it was possible that the impacts of scalping might extend laterally and cause the bar to unravel, especially given the lateral instability of wandering rivers. We recognize, however, that because summer sampling for fish and benthic invertebrates was carried out within the removal boundary, these samples may more likely reveal an impact due to bar scalping. Hence, they are given greater emphasis in data interpretation.

Referring to **Figure 5**, bar scalping at Harrison Bar took place at low flow in March 2000 and was followed by two high flow episodes in spring of 2000 and 2001. It was only during these two periods of high flow that sediment transport occurred and any gravel replenishment to the removal site could take place (McLean et al. 1999). Whereas the low flow periods in 2000 and 2001 were similar with respect to discharge and duration, the freshet in each year differed. Flooding followed a unimodal pattern in 2000 with peak discharge (8000 m^3/s on July 6) less than the mean annual flood discharge of 8766 m^3/s (McLean et al. 1999). The flood hydrograph was bimodal in 2001, with discharge reaching 6940 m^3/s on June 6, subsequently dropping to a low of 4180 m^3/s on July 19, and peaking again on July 23 at 7210 m^3/s. Maximum discharge in each year occurred later than average; peak flow typically occurs by mid June (McLean et al. 1999).

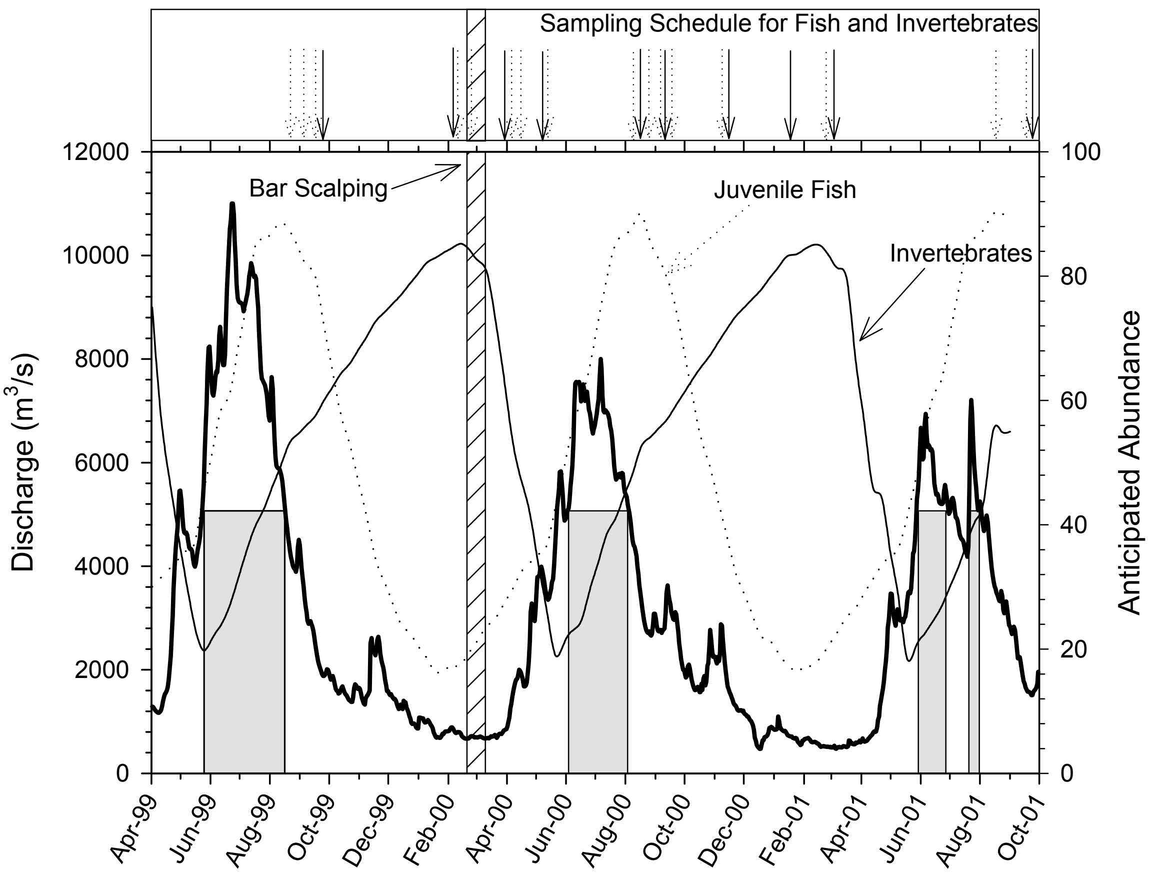


Figure 5. Discharge hydrograph of Fraser River at Hope over the duration of the experiment. Shaded boxes indicate the main periods of bed material movement (McLean et al. 1999). Generalized curves showing the anticipated relative abundance of aquatic invertebrates and juvenile fish (modified from Hynes 1970) are overlain on the hydrograph. The panel above indicates the approximate timing of fish (dotted lines) and invertebrate (solid lines) sampling. The hatched box represents the timing of scalping at Harrison Bar.

Field data collection was completed in September 2001 but it is worth noting that freshet in 2002 was above average and peaked on June 21 at 10,066 m^3/s. Lower Harrison Bar was re-surveyed after this freshet in March 2003 to determine topographical change and patterns of sediment deposition. These survey data have been incorporated into the report.

2.5 Monitoring Activities - Field Methods

2.5.1 Sedimentology

2.5.1.1 Before Scalping

Major sedimentary units were delineated by ground observation in the removal and reference areas on February 8, 2000. Pre-scalp sediment sampling (sub-surface and surface) was stratified within the units to reduce the effect of spatial variability on estimates of grain size. This method follows recommendations of Wolcott and Church (1991). Two such units (areas of relatively uniform sediment texture) were identified in each of the removal and reference areas (**Figure 6**)

Sub-surface sediment sampling at Harrison Bar took place on February 8 and 14, 2000. A single bulk sample was taken from each major sedimentary unit in the removal and reference areas following methods of Church et al. (1987). Total weight of each sample met the 0.1% criterion bulk sample standard (cf. Church et al. 1987) to ensure a grain size distribution representative of the true bed sediment. This weight averaged 537 kg for each of the four bulk samples. The grain size distribution of samples from the removal area characterized the calibre of material removed by scalping.

Surface materials were sampled with greater effort because it is the surface sediment in which macroinvertebrates live, that spawning and rearing fish encounter, and that defines the boundary hydraulic roughness. Surface sediment sampling was stratified by sedimentary units and followed either the Wolman or photographic technique. Each method (described below) provides a robust characterization of the grain size distribution at a site (Church et al. 1987). **Table 5** summarizes sediment sampling effort over the course of the experiment.

Table 5. Number of surface sediment samples collected at Harrison Bar. W: Wolman method, P: photo method.

Site	February 2000	April 2000	September 2000	September 2001
Mined Area	4 (W)	3 (W)	5 (W)	12 (P)
Reference Area	4 (W)	0	5 (W)	9 (P)

In February 2000, one sample was collected from each of the two sedimentary units in the removal and reference areas, and 2 additional samples were taken near the water's edge in each area (**Figure 6**). Wolman samples were collected by measuring the B-axis of 400 stones picked at a fixed spacing along a line-transect. Stone spacing always exceeded the size of the largest stone observed within the sedimentary unit and was standardized at 75 cm for most Wolman samples. This spacing ensured that the size of successively sampled stones was independent. Stones were measured using templates of standard grain size categories (Wentworth classification, Church et al. 1987) from which cumulative frequency curves were constructed. Wolman samples also assessed the overall proportion of the surface area covered with sand. The frequency curve of the gravel-sized fraction was used to determine median grain size (D_{50}) and two distribution percentiles to indicate the size of the coarse (D_{95}) and fine (D_5) material present.

2.5.1.2 After Scalping

Three Wolman samples were collected immediately after scalping in late March 2000 from the removal area (**Table 5**), including one along the road surface. The small number of samples was adequate because scalping had left a loose and uniformly graded matrix of surface and sub-surface material. The reference area was not sampled because no change to the site had occurred.

After freshet in September 2000, five Wolman samples were collected from the removal area, including one from the road surface. Five samples were also collected from the reference area. Samples were spatially distributed across the bar surface to correspond with major sedimentary units (**Figure 6**).

Surface sediment sampling in September 2001 followed a photographic method; 12 photographs in the removal area and 9 photographs in the reference areas were taken. The photographic method was calibrated by Dr. S. Rice (Geography, Loughborough University) and described in Church et al. (2000). Briefly, the technique is based on geometrical arguments that posit an inverse relation between the size of the stones that occur on a surface and the number of those stones present per unit area. An initial calibration data set for the gravel reach consisted of 83 Wolman samples paired with vertical photographs of a 0.5 x 0.5 m quadrat laid down within the Wolman sampling grid. The number of visible stones in each photograph was counted and the plot of grain-size data (Wolman samples) against stone counts (photographs) yielded consistent relations between stone count ($\#/m^2$) and D_5, D_{50}, and D_{95}. Linear regression on log-transformed variates yielded calibration functions that are applicable to counts obtained from other sites. This calibration allows many size estimates to be obtained rapidly from photographs taken over large areas in the field. Its disadvantage is laborious office time counting stones from the photographs.

2.5.2 Bar Topography

Tunbridge & Tunbridge (Ltd) were retained to survey lower Harrison Bar on February 3, 2000. This survey preceded all removal operations and included areas “A” and “B” of the excavation. The removal area was re-surveyed on March 20, 2000, immediately after scalping, to determine the volume of gravel removed. Tunbridge & Tunbridge repeated the survey over the lower bar on February 19, 2001 and October 5, 2001, and most recently on March 28, 2003. The latter three surveys captured changes in topography over the lower bar and quantified sediment recruitment to the scalped area following subsequent freshet events.

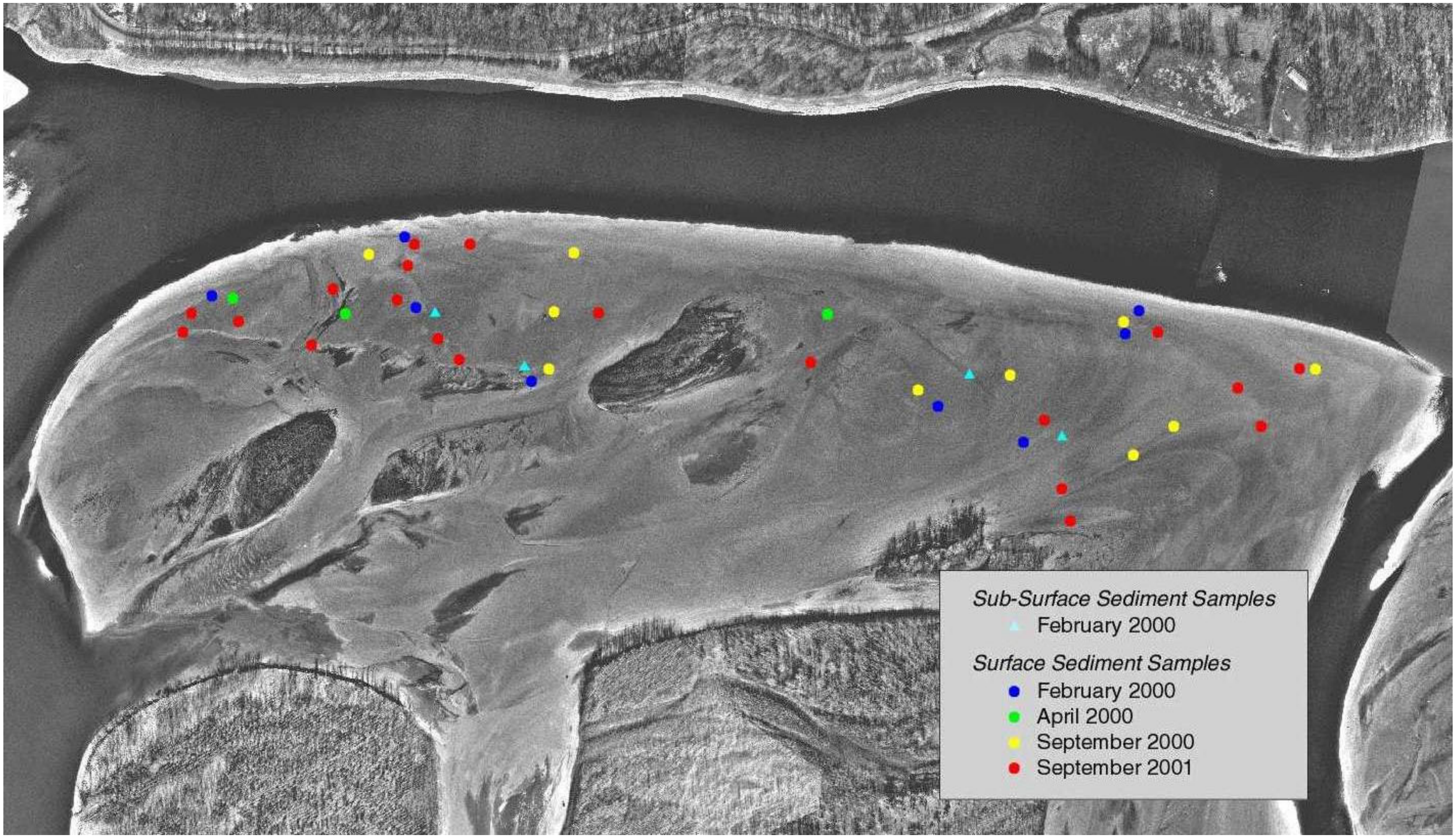


Figure 6. Sediment sampling locations at Harrison Bar. Photograph taken March 7, 2001.

2.5.3 Habitat Mapping

Habitat mapping followed Level Three of the Morphological and Habitat Classification of the Lower Fraser River Gravel-Bed Reach (Church et al. 2000). The classification was applied to the scalped and reference sites and differentiated *habitat types* that represent rearing habitat for juvenile fishes. Habitat units are most accurately identified by ground surveys but can be delineated from aerial and oblique photographs by a trained technician (Rempel and Church 2002).

Fourteen habitat types (**Table 6**) are recognized as physically and ecologically distinct in the gravel reach (Church et al. 2000). All habitats have a likelihood of occurring within each of three channel types (main, side, summer) and at each site. The habitats differ with respect to morphological, sedimentary, and hydraulic characteristics, which implies that no single technique is effective for sampling fish. The seven habitat types most appropriately sampled by beach seine are indicated with an * in **Table 6**. (Beach seine sampling is described in Section 2.5.4). These habitats are alluvial in origin, having been formed by fluvial processes of sediment deposition and erosion, and are associated with the perimeter of gravel bars. The habitat types commonly associated with bars are depicted in **Figure 7**.

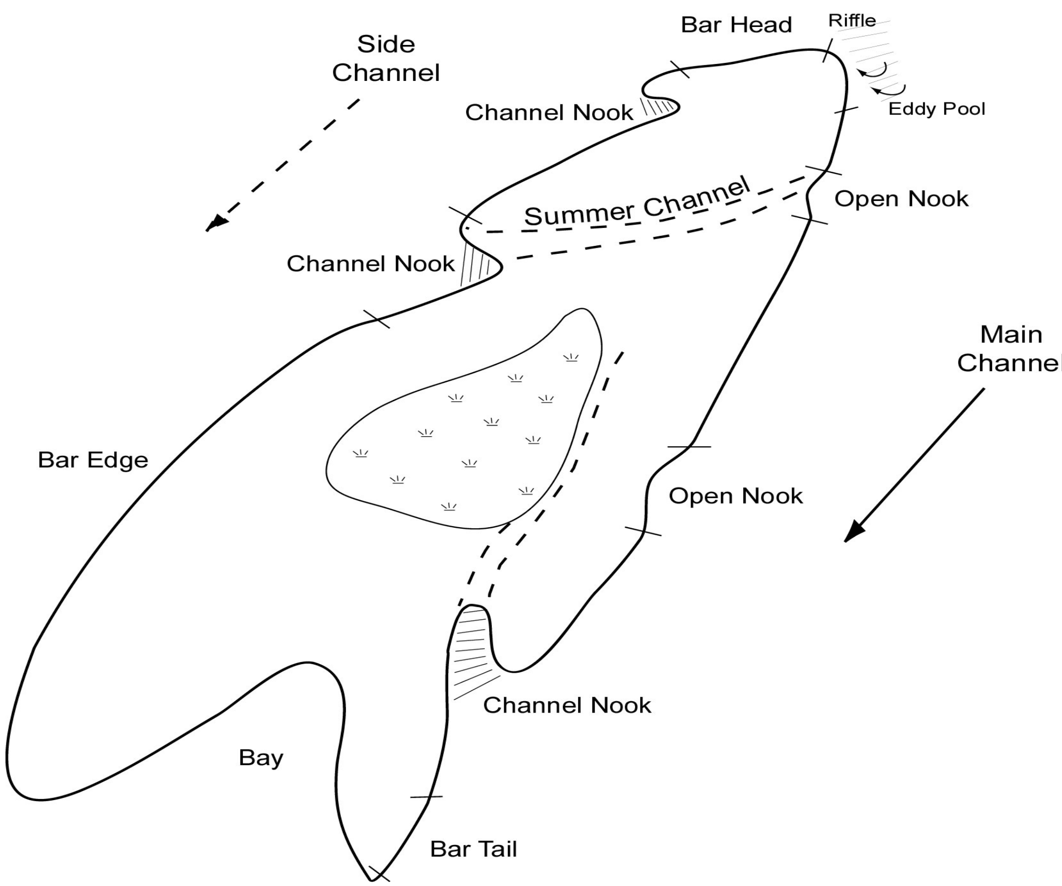


Figure 7. Schematic of the 3 channel types and 8 alluvial habitat types found associated with gravel bars of lower Fraser River (after Church et al. 2000).

Table 6. Level *III* of the habitat classification (after Church et al. 2000). Habitat abbreviations are given in parentheses. Habitat types in *italics* are hypothetical only because they have not been sampled. An * denotes alluvial habitat types effectively sampled by beach seine.

HABITAT TYPE	DEFINITION
Bar Head (BH)*	Upstream end of a gravel bar. Surface substrate is characteristically coarse and flow velocity is usually high (erosional) but can be a back eddy (depositional).
Riffle (RI)	High-gradient area of shallow, fast water flowing over well-sorted substrate that often has granular structures and is stable. The flow is rough. Common at bar heads.
Eddy Pool (EP)*	Area bounded by fast, rough water that creates a back eddy in the lee of the flow. Common on the inside edge of riffles and at the upstream end of some bar head habitats. Bank slope is invariably steep and the substrate is usually embedded cobble.
Bar Edge (BE)*	Any length of bar edge not occurring at the head or tail of a bar that is oriented parallel to the flow and subject to constant and consistent flow forces. A range of velocities and substrate types is possible. Riparian influence is variable.
Bar Tail (BT)*	Downstream end of a gravel bar, usually with moderate flow velocity. The habitat is often depositional and surface substrate consists of smaller cobbles and gravels.
Open Nook (ON)*	Shallow indentation along a bar edge of reduced velocity and variable substrate that is openly connected to the channel with no sedimentary barrier (unlike channel nook). An ephemeral habitat that often disappears with a relatively small change in water level.
Channel Nook (CN)*	Dead-end channel or narrow embayment of standing water and concave geometry. Substrate material usually consists of sand/silt and embedded gravel.
Large Bay (BA)*	Semi-enclosed area with no flow velocity and fine bed material (sand/silt). Occurring on the lee side of large sediment accretions that are deposited in the shape of a crescent-dune.
Cut Bank (CB)	Eroding bank of fine sediment that is steeply sloped or vertical. Dense riparian vegetation is often present. Large woody debris is common and flow conditions are variable.
Rock Bank (RB)	Natural rock bank, possibly with openings and cracks, that is invariably steep. The water is deep immediately offshore and currents are either fast or form a back eddy.
Artificial Bank (RP)	Bank is invariably steep and consisting of riprap or rubble rock that may have significant openings within its structure. The water is usually deep and fast immediately offshore.
Open Water (OP)	Open area with no direct influence from bank or bar edge features or riparian vegetation. Velocity and substrate characteristics are variable.
Bar Top (BT)	*Bar top surface inundated only during high flow with reduced velocity and shallow water depth relative to open water and the thalweg. Substrate is variable.*
Vegetation (VG)	*Area of flooded island and bank vegetation where velocity is reduced and substrate is relatively fine. Submerged only at very high flow.*

In this study, habitat mapping was applied to Harrison Bar before and after gravel mining to examine differences in habitat availability. Because availability varies with discharge, multiple comparisons over a range of water levels were desired. Habitat availability around Harrison Bar was compared at three water levels using a combination of photo interpretation and ground surveys: low flow in winter and two levels of moderate discharge in summer (<3000 m^3/s). Only those habitats with connectivity to the main channel (no isolated ponds) were mapped. In all photographs, Harrison Bar was split into two halves of approximately equal perimeter length that corresponded roughly with the upstream reference area and the downstream scalped area.

No photographs depicting high discharge were available for comparison. However, topographic survey data were used to speculate on the change in habitat availability at Har-S before and after scalping.

Low flow conditions were assessed using aerial photographs flown in March in 1999, 2000, and 2001 when discharge was approximately 700 m^3/s. Habitat units were identified and counted based on the photographs and follow-up ground surveys. The length of each unit around the perimeter of Harrison Bar was measured from air photographs.

Oblique photographs depicting moderate summer flow in 1995, 1999, and 2000 were provided by Dr. V. Galay (Northwest Hydraulic Consultants). Photos were taken from a fixed-wing aircraft flown approximately 1000 m above the ground. L. Rempel took photographs by the same method in September 2001. River discharge at the time of photography was similar in 1995 and 2000 (2680 m^3/s and 2844 m^3/s, respectively), and in 1999 and 2001 (1950 m^3/s and 1580 m^3/s). These two pairs of photographs represented comparable water levels before and after scalping and were used to classify habitat units and compare summer availability at two discharges.

Habitat mapping from oblique photographs was conducted based on counts of units around the bar perimeter because distortion in the oblique photographs prevented lengths from being measured accurately. For all years except 1995, photo interpretation was followed by ground surveys to confirm the location and identity of habitat units. For 1995 photographs, habitat typing was carried out using photographs only. This method has been shown to be reliable (Rempel and Church 2002).

2.5.4 Fish Sampling And Habitat Characterization

The distribution and abundances of juvenile fish were examined using a beach seine net (12.5 m x 2 m, 6 mm knotless mesh). Various capture techniques (gill netting, minnow trapping, and electro-shocking) had been evaluated previously and beach seining provided the most consistent catch data, as well as being practical in all alluvial habitat types. Its major limitation was that sampling extended to a maximum depth of 1.2 m, the maximum depth one can safely work in chest waders.

Although the beach seine was easily deployed in all habitat types and performed in a consistent and reliable manner, its capture efficiency may have varied depending on a variety of factors including habitat type, species of fish, fish size, time of year, and time of day. Each of these factors has been suggested to bias fish sampling devices (Bayley and Dowling 1993). For example, Parsley et al. (1989) found beach seine capture efficiency was reduced over large cobbles in comparison to sand in Columbia River, and bottom-dwelling species such as prickly sculpin were captured with lower efficiency than water-column species such as redside shiner. Some authors recommend attempting to quantify this bias and applying a correction factor to catch data (e.g., Parsley et al. 1989); however, Holland-Bartels and Dewey (1997) demonstrated that corrections to compensate for gear bias and environmental conditions are difficult and can be inaccurate because the error of the adjusted data remains high.

We did not quantify the capture efficiency of our beach seine, in part because we believe that turbidity during most months of seining minimized sampling bias, and also because the biases introduced by physical differences between habitat types and species-specific traits were variable and difficult to estimate. Fish density will be underestimated if fish either *evade* the net (under the lead line or around the outside edge) or *escape* through its mesh. To minimize fish evasion of the net, each seine was executed swiftly and only relatively short lengths of beach were sampled at a time. The catch data were discarded for any seine in which the net became snagged. Despite these efforts, it remains probable that bottom-dwelling fish managed to evade the net in some instances, particularly over coarse substrate. Highly agile and fast-swimming fish may have evaded the net in some instances as well. The problem of fish escaping through the net pertains only to very small individuals (<20 mm) whose species identification would be difficult to determine, and to small individuals of longnose dace that are highly streamlined and could pass through the mesh.

To date, no studies have examined the effect of turbidity on beach seine efficiency. However, turbidity has been shown to decrease the reactive distance of fish (Sweka and Hartman 2001), and Gregory and Levings (1998) demonstrated that turbidity in Fraser River reduced the encounter rate between predacious adult fish and juvenile chinook salmon. Gregory and Levings (1998) also reviewed evidence that fish living in turbid water are active throughout the day and benefit from turbidity providing protective cover, which reduces the risk of occupying near-shore areas. Beach seines conducted by L. Rempel for a separate study supported these findings: summer fish density in daytime beach seines was similar or higher than at night whereas winter density averaged 3 times higher at night (unpublished data). Based on this collection of evidence, we believe that turbidity during most months of sampling (April through September) minimized bias and helped to provide realistic estimates of fish density. Clear water in winter months (October – March) likely contributed to an underestimate of fish density, however, relative comparisons between sites during winter months should remain valid because density in all likelihood was underestimated by a common factor at all sites.

Sampling by beach seine depended on habitat types being present and accessible at each site. Although all habitats had a likelihood of occurring at all sites and at all water levels, more often some habitats were absent at a site during sampling. Consequently, sampling effort varied between sites and effort was not stratified equally among habitat types. For example, the perimeter of Harrison Bar prior to scalping was simple and consisted mostly of bar edge habitat. Overall, common habitat types (e.g., bar edge) were sampled with greater frequency than uncommon ones (e.g., eddy pool); an attempt was made to sample fish from all available habitats during each sampling period. Fish sampling sites are shown in **Figure 8**.

A 17' aluminium-welded boat with an outboard jet engine, on loan from the former BC Ministry of Fisheries, was used to travel on the river between sites. Sampling by beach seine occurred within habitat units by dragging the net in a downstream direction along the shoreline. Samples were collected over a distance of 10-50 m, depending on the length of the habitat unit. Fish became trapped in the net, which was then hauled on shore. The contents were promptly examined and all fish were immediately transferred to holding buckets containing fresh river water. Refer to **Figure 5** and **Table 4** for the sampling schedule.

Once collected, all fish were identified to species according to McPhail and Carveth (1994) and counted. A minimum of 15 fishes representing each species in the haul were measured for fork length (mm) and weighed (g). Twenty-four species of fish were identified during the study (Appendix C), including 10 salmonid species, white sturgeon (red-listed in British Columbia) and 5 blue-listed species (mountain sucker, coastal cutthroat trout, bull trout, Dolly Varden, and brassy minnow).

Observations and measurements of the physical characteristics of habitat units were made at all beach seine sites. Water velocity and depth were measured at nine points within the seine area using a wading rod and Marsh-McBirney velocity meter. The surface sediment was visually classified for degree of embeddedness and percent representation by major grain size classes: sand (<2 mm), gravel (2 – 64 mm), cobble (64 – 128 mm), and large cobble (>128 mm). Embeddedness reflects the degree to which dominant sediments were embedded in the surrounding framework material. The slope angle of the bank was calculated as the sine-function of beach seine maximum depth divided by seine width. Water temperature at the mid-point in the seine area was measured using a hand-held thermometer and the presence and type of nearby vegetation were noted.

2.5.4.1 Night Sampling for Juvenile Fish

A question of interest was whether scalping affected near-shore fish over the course of the operation (e.g., noise, vibration). Because daytime sampling in February and March yielded very few fish at all sites, night sampling was scheduled and Steelhead Aggregates Ltd. provided a vehicle for transportation around Harrison Bar. Har-S and Har-R were sampled on March 13, 2000 between 20:30h and 23:00h. No additional reference sites could be sampled because the boat was not equipped with running lights for night operation. Bar edge habitat was sampled at four locations within the scalped area and two locations within the reference area. Heavy equipment had ceased operating at this time; however, removal activities had been underway a few hours earlier and had been operating on a 24-hr schedule for 15 days prior.

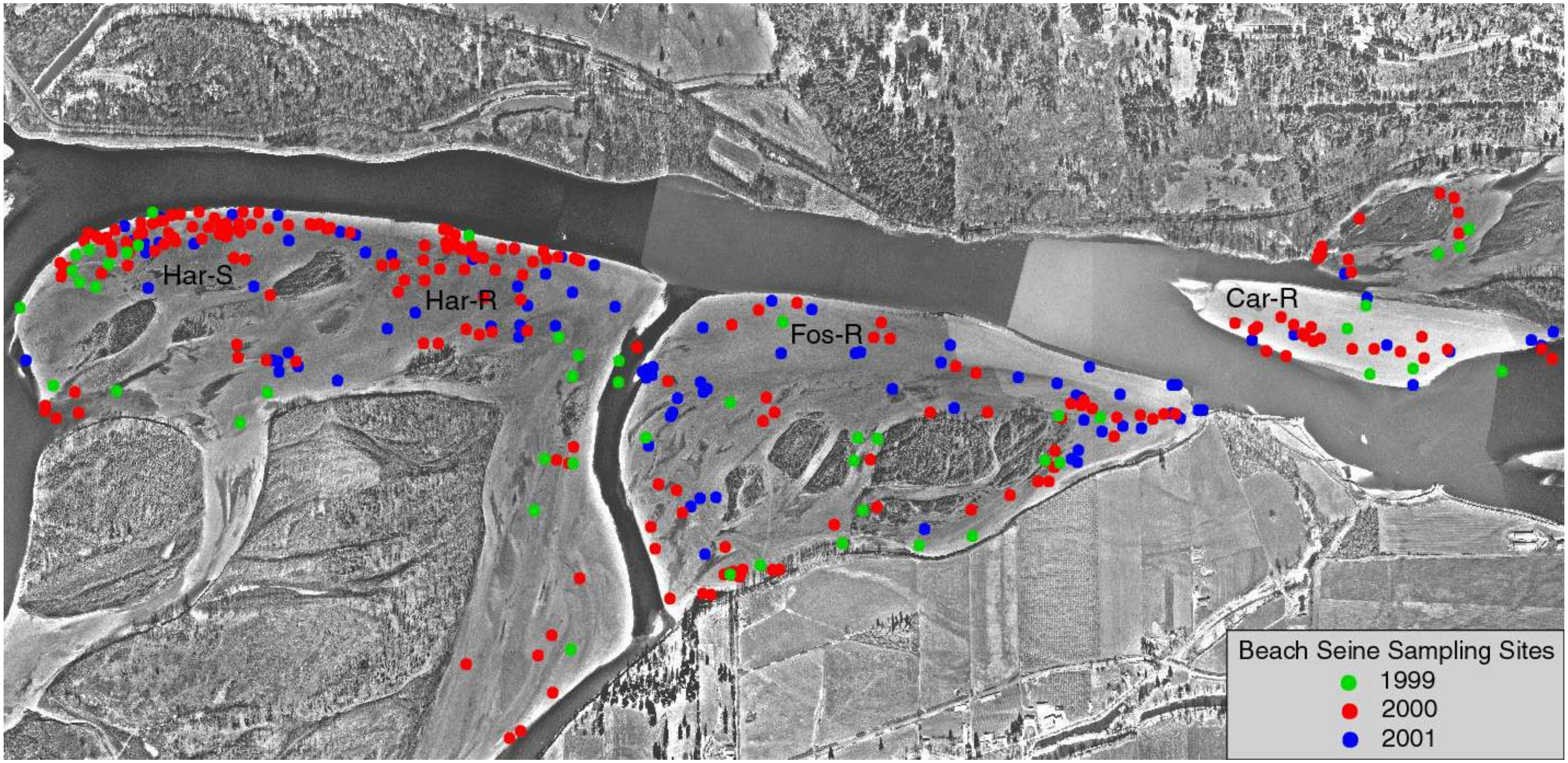


Figure 8. Locations where juvenile fish were collected by beach seine at scalped (S) and reference (R) sites over 3 years. Scalping took place at Harrison Bar (Har-S) in February 2000. Photograph taken March 7, 2001.

2.5.5 Benthic Invertebrate Sampling

Benthic invertebrates were collected near-shore using a Surber net (500-µm mesh, 0.09 m^2) at approximately 20 cm water depth. The substrate was disturbed vigorously by hand to a depth of 5 –10 cm and benthic material was washed into the net by the current of the river. (The Surber net cannot be used in areas of standing water.) Refer to **Figure 5** and **Table 3** for the sampling schedule, and **Figure 9** for sampling locations.

Similar to fish sampling, samples in some months were collected below the lower limit of gravel mining (e.g., January and February 2001). These samples were important to collect because it was unknown how scalping might modify the physical characteristics of the bar (e.g., lateral erosion) and how such changes might transmit to benthic populations. Species richness and invertebrate abundance are highest in winter months immediately before the animals emerge to reproduce; an impact to populations at this stage of the life cycle would be detrimental to the success of the next generation. Nevertheless, emphasis for data interpretation was given to samples collected from within the removal boundary at Har-S in 2000 and 2001 (i.e., those collected between April and November).

Sampling effort at a given site was stratified by habitat type and a minimum of three replicate samples was collected within each represented habitat unit. Replicates were taken 5 to 10 m apart and sequentially in an upstream direction to ensure that each location was undisturbed by prior sampling. Collecting replicate samples from all sampled locations is recommended sampling protocol because the distribution of invertebrates is inherently variable (Plafkin et al. 1989, Cao et al. 2002). The total number of samples collected at a site varied between months because the number of habitat types changed as water levels fluctuated. Bar edge habitat was present and sampled at all sites in all months whereas sampling effort in bar head and bar tail habitat types varied between sampling episodes.

Water depth and velocity were measured at the location of each Surber sample using a Marsh-McBirney velocity meter and graduated wading rod. The surface sediment was visually classified for the percentage representation of major grain size classes (sand, gravel, cobble, large cobble), and the degree of embeddedness. Each of these parameters has been shown to influence invertebrate distributions (Rempel et al. 2000).

Samples were preserved in 4% formalin and later processed in the DFO Laboratory, Cultus Lake. Samples were first wet-sieved (250-µm mesh) and then sorted using a dissecting microscope. The entire contents of each sample were sorted for animals; no sub-sampling occurred. Invertebrates were preserved in 70% isopropanol and later identified to the lowest possible taxonomic level according to Merritt and Cummins (1996). Additional references used were Wiggins (1996), Stewart and Stark (1988), Fitzpatrick Jr. (1983), Bland and Jacques (1978), and Borror and DeLong (1964). Mayflies, stoneflies, and caddisflies were identified to genus; dipterans to either family or subfamily (Chironomidae); beetles and true bugs to family; oligochaetes, leeches, crustaceans, and mites to class; and nematodes to phylum. Taxa were assigned the following functional feeding group (FFG) categories after Merritt and Cummins (1996): collector-gatherers (CG), scrapers (SC), collector-filterers (CF), predators (PR), shredders (SH), and parasites (PA). These categories are based on the general mechanism used by each taxon to feed. A list of taxonomic groups identified in this study and their feeding classification is provided in Appendix D.

2.5.6 Fish Stomach Content Analysis

A sub-sample of captured fish was sacrificed for stomach content analysis on several sampling dates. These fish were overdosed with anaesthetic (MS-222), followed by a sharp blow to the spinal cord, and then preserved in 10% formalin. Only data for juvenile chinook salmon (*Oncorhynchus tshawytscha*) are presented in this report. This species is known to use the gravel reach extensively for rearing (Levings and Lauzier 1991).

Samples were processed at the DFO Laboratory at Cultus Lake. Each fish was lightly dried and weighed with the stomach intact and weighed again after stomach removal. Visible parasites were removed from the fish and their net weight subtracted from the total weight. Following methods of Murphy and Willis (1996), the esophagus and stomach cavity were removed from all fish; no material was collected below the pyloric caeca (where the intestine leaves the stomach). Stomach contents were washed into a petri dish and distinguishable prey material picked with a dissecting microscope (20x lens). For animal prey, identification and counts were based primarily on head capsules but included major body parts resistant to digestion. Sources listed in Section 2.5.5 were used for taxonomic identification. Algae, seeds, and plant material were identified and counted as well.

A volumetric estimation of prey items was made in addition to count-based estimates. First, the stomach contents of a fish were separated according to major prey classes and each group was placed on plasticized graphing paper (2-mm grid). The vertical height of each group was kept constant (approximately one body thickness) and the horizontal spread was estimated as the number of cells covered on the paper. All groups were then placed together in a graduated 12-ml vial and centrifuged for 18 minutes to obtain the total prey volume. The volume of each prey group was then estimated by back-calculation based on the ratio of total number of squares covered and total prey volume.

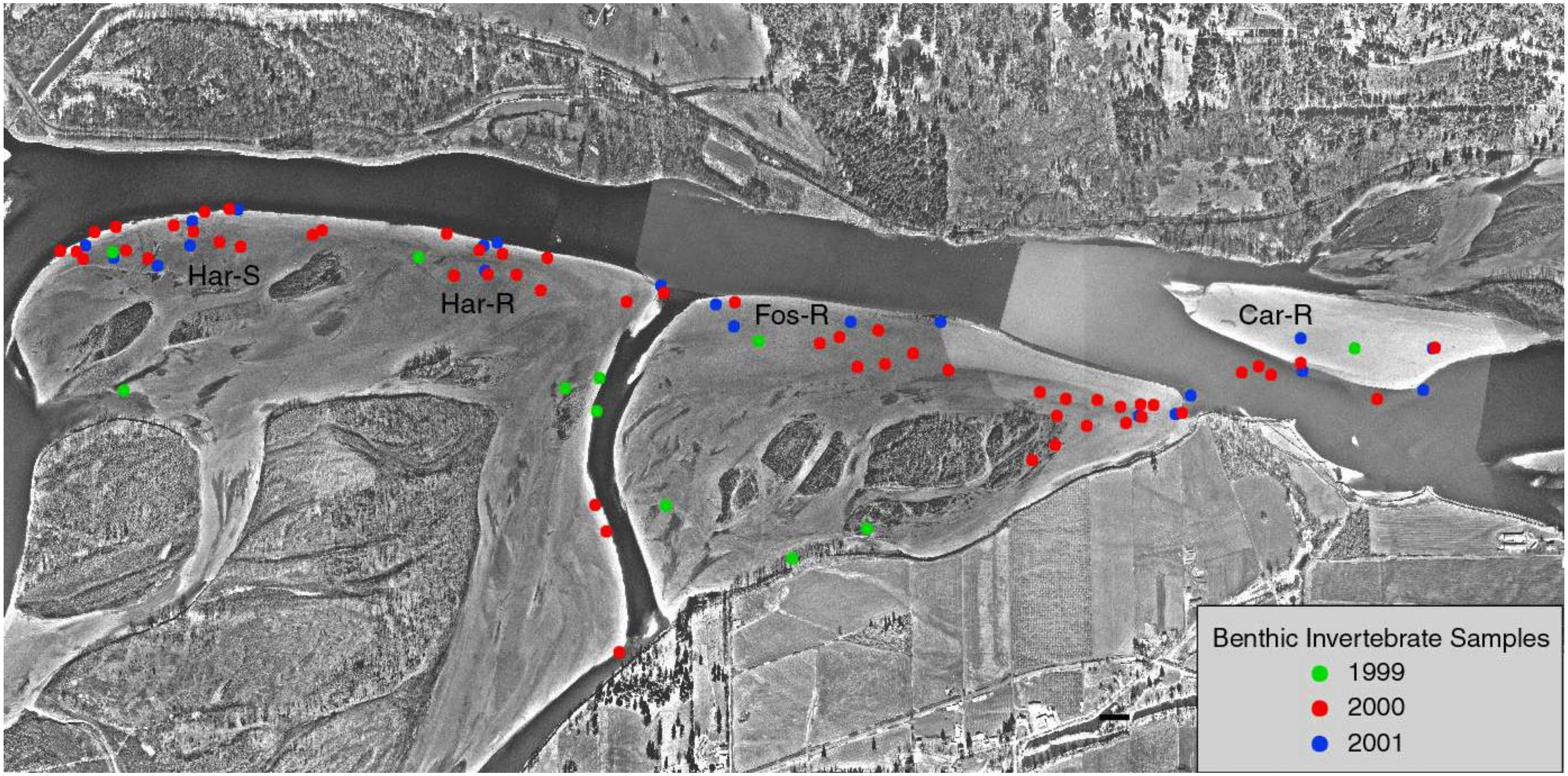


Figure 9. Locations where benthic invertebrate samples were collected at scalped (S) and reference (R) sites over 3 years. A minimum of three replicate Surber samples was collected at each of the marked locations. Scalping at Harrison Bar (Har-S) occurred in February 2000. Photograph taken March 7, 2001.

2.6 Data Analysis

The sequence of analyses was chosen to address the six questions listed in **Section 2.3**. Several of these questions were answered following a common statistical approach, referred to as asymmetrical analysis of variance (ANOVA), which was developed by A. J. Underwood to detect environmental impacts (Underwood 1991, 1992, 1994). The method is an extension of standard ANOVA and the procedure is described briefly below. The practical mechanics of the analysis are outlined in Underwood (1993) and detailed breakdowns of the analyses are provided in appendices **E** through **K**.

Asymmetrical ANOVA is an extension of the BACI design that requires repeated sampling at multiple reference locations in order to achieve spatial replication. Including multiple reference sites establishes a measure of sampling variance, lacking in simple BACI designs, so that observed changes may be tested rigorously for significance. The design is "asymmetrical" because only the reference condition is replicated (there are not replicate treatment sites). Sampling on multiple occasions before and after treatment (i.e., scalping) achieves temporal replication. According to the analysis, an impact is defined as some difference (negative or positive) in the *change* of mean abundance (or other parameter of interest), or time-course of mean abundance, at the treatment site from before to after treatment compared with such changes from before to after at the reference sites (see **Figure 4**). Thus, there must be a statistical interaction in the difference between the treatment and reference locations from before to after the disturbance.

The analysis is carried out as four standard ANOVAs that systematically isolate the variance contributed by the treatment site, before and after treatment, to the total variance in the observations. Standard statistical software can carry out the analyses (Systat v.9 was used for this study). From these four analyses, the asymmetrical ANOVA is calculated by simple subtractions and additions of the component sums of squares. The detection of an impact is complex because it may show up in different ways depending on the spatial and temporal consistency of the data being measured. Underwood (1993) provides a useful flowchart for proceeding through a set of questions and statistical tests to address whether or not an impact has occurred (**Figure 10**). The answer to the question at each branch of the flowchart determines the sources of variation and degrees of freedom used to calculate an F-value.

In this study, the treatment effect was gravel removal by bar scalping at Har-S. The sequence of questions outlined in **Figure 10** was followed to determine whether or not a detectable impact occurred.

If there is a significant temporal interaction among reference sites after scalping (A, **Figure 10**), the test for a different temporal pattern at Har-S will not be very sensitive (few degrees of freedom in the denominator). However, this condition reflects the fact that there are large natural variations over time from one site to another. Accordingly, a specific impact would have to be large for it to push the system beyond its capacity to recover. As Underwood (1993) points out, populations in a naturally variable environment likely are resilient and can recover rapidly from disturbances.

When scalping is found to cause a short-term interaction between Har-S and the reference sites (A2 or B2, **Figure 10**), the conclusion is that the temporal trend at Har-S was outside that found naturally at the reference sites. For this interpretation to be realistic, there must be no corresponding change in the interactions from before to after scalping among the reference sites. Otherwise, the evidence must be interpreted to mean that there has been a widespread change that affected all sites. It must also follow that the change in this temporal interaction between Har-S and the reference sites was coincident with the timing of scalping. The number of observations made prior to the disturbance improves the sensitivity of this analysis. An inadequate number of sampling episodes before scalping, particularly when variance is large, will afford the analysis few degrees of freedom and prevent it from definitively showing that the impact was coincident with scalping, leading to indeterminate results.

A more rigorous test for impact (more degrees of freedom in the denominator) can be carried out when short-term temporal interactions among reference sites are small and non-significant (B, **Figure 10**) and a short-term interaction between Har-S and the reference sites is not detected (B1, **Figure 10**). An impact is then evaluated at the larger time-scale of Before versus After (C and D, **Figure 10**). For an impact to be detected, there must be an interaction in the difference between Har-S and the reference sites before scalping compared with the difference after scalping. Otherwise, the final conclusion is that scalping did not produce a detectable impact.

Underwood (1993) describes the importance of choosing an appropriate sampling frequency to detect an ecological impact. He advises that the timing and frequency of sampling is best determined by logical thought about the processes operating and consideration of the life histories of the organisms and the consequent rates of change of abundances. There is thus no set rule for guiding sampling programs. We sampled for fish over three periods prior to scalping and for benthic invertebrates on two dates prior to scalping; although we recognize that additional pre-scalp sampling episodes were desirable, the imposed planning timeline and available resources determined the limits of the sampling program. The analysis is as rigorous as our data allowed.

Another issue raised by Underwood (1993) is serial correlation between sampling periods. In analysis of variance, serial effects in data should be explicitly incorporated into the analysis or eliminated. Seasonal effects were incorporated in our analysis as a time-factor. The possibility remains for persistence to influence fish samples taken in adjacent months at certain stages in the sampling program (e.g., August and September 2000). However, these samples collected in succession were intended to search for specific discontinuities in the data and to identify specific potential effects of central interest; hence, all these data have been retained in the analysis.

A critical value of $p = 0.05$ was chosen for asymmetrical analyses. This value represents the probability of committing a Type I error and rejecting the null hypothesis even when it is true (i.e., falsely detecting an impact). The probability of a Type I error is increased when carrying out multiple analyses on the same dataset and the Bonferroni correction factor is usually applied in such cases to overcome the problem (0.05 / # contrasts, Zar 1984). However, a p-value >0.05 is sometimes chosen for impact assessment because failing to detect a real impact may have severe economic and social consequences that are possibly non-recoverable (Underwood 1993). Our choice of $p = 0.05$ represents a compromise between inflating the risk of a Type I error by performing multiple analyses on the same dataset, and wanting to ensure that any real impact was detected.

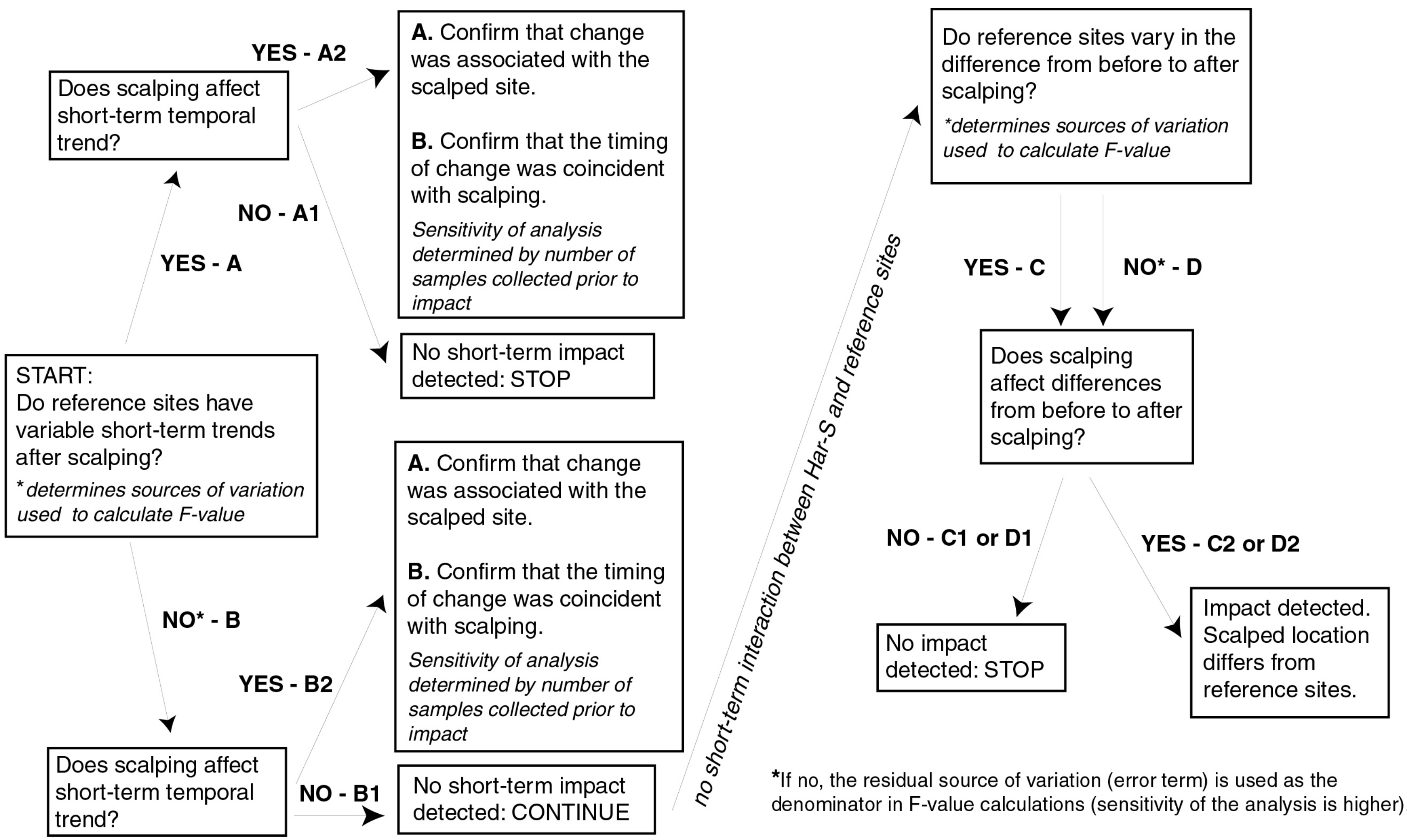


Figure 10. Sequence of questions for Underwood's asymmetrical ANOVA to detect an impact (from Table 6, Underwood 1993). The answer to each question determines the sources of variation and degrees of freedom used to calculate the F-value.

One practical limitation of our sampling program was that the occurrence of habitat types at a site varied with discharge. Although all habitats had a likelihood of occurring at all water levels, more often some habitats were absent at a site during sampling. Missing data creates an unbalanced design that poses a statistical challenge for analysis. Following Underwood's (1997) recommendation, we overcame this statistical problem by replacing the missing data with "dummy values" using the mean of the other reference sites on that date. These values generated no variance and contributed nothing to the sum of squares. The residual degrees of freedom in each analysis were adjusted to compensate for the missing values.

A challenge for studies examining environmental impacts whose results may influence management decisions is the need to quantify the power of the analysis to detect an impact. A null-result (i.e., a non-significant impact) can be generated from a small or non-effect, but may also occur when the power of the analysis to detect a real impact is very low. This mistake is referred to as a Type II error.

The ability of a statistical test to detect an impact depends on several factors: the effect size (or magnitude of the impact), the natural variability of the data, and the number of independent sampling events (Osenberg et al. 1994). A severe impact is always more readily detectable, but the sensitivity of an analysis to detect an impact can be improved by increasing sample size, either in the number of replicates per sample (which increases precision of the estimated mean value), or the number of control sites, or the number of sampling episodes (Underwood 1993). Determining the most effective sampling strategy that returns the most discriminating results will depend on the temporal and spatial structure of variance in the data. Large variability both in space and time characterized the data collected for this study. As is discussed further in **Section 4.5**, the most effective strategy in this situation may be to increase sampling replication rather than increase the number of sampling episodes or reference sites, in order to improve the estimates of mean values, hence improve the ability of the analysis to discriminate among them.

The *power* of a statistical test is defined as its capacity to reject, when appropriate, a null hypothesis (Underwood 1993). This is the complement of a Type II error; therefore, power is defined as (1 - Probability of Type II error). Standard ANOVA has a straightforward method to determine power between group means given a specified significance level, sample size, and estimate of variance (see Zar 1984). Underwood (1993) has developed a similar method for power analysis to complement the asymmetrical ANOVA, which we have applied here. It is most desirable to estimate power prior to initiating an impact study, which then allows for design and sampling modifications to increase power (Peterman 1990), but that exercise requires preliminary estimates of variance (usually determined by prior sampling). Power also can be estimated for an ANOVA already performed when no impact was detected in order to determine how likely the test was to detect a difference.

Following Underwood (1993), power was estimated for each analysis in this study that failed to detect a significant impact. (Note that calculation of power is not relevant when a significant impact is detected, Peterman 1990). A breakdown of the power calculations is presented in the appropriate appendices (**F** – **K**) and the mechanics of the calculation are described in Appendix E. Power analysis produced a number between 0 and 1 that represents the probability of detecting an impact when it actually occurs.

2.6.1 Sedimentology

The grain size distribution of surface sediment was compared before and after scalping based on samples truncated to retain sizes >4 mm. This coarse sediment fraction was important to consider because it determines the ultimate stability of the bed at a particular place. The proportion of sand covering the surface was estimated as well, and was of interest from an ecological perspective because fine sediment affects primary production, modifies the architecture of macroinvertebrate habitat and, in part, determines the spawning quality of the bed.

We compared the grain size distributions of Wolman samples collected in February 2000 to samples from September 2000 (after scalping) by the Kolmogorov-Smirnov (K-S) goodness of fit test (Zar 1984). The test is suited to continuous data grouped by size class and determines if a particular sample distribution differs from an expected distribution. In this case, the expected distribution for post-scalp samples was a match with pre-scalp data. The critical value of the K-S test was found to be impractically sensitive for Wolman samples: two distributions with >5% difference between any grain size class were statistically unique. For a 400-stone Wolman sample grouped according to 11 size classes, this translated into a critical difference of <20 stones for any given class. Based on this criterion, even replicate samples collected simultaneously within a sedimentary unit were statistically different. We chose an alternate critical value based on the maximum difference *naturally* found between replicate Wolman samples collected from within a homogeneous sedimentary unit. Samples collected in February 2000 were used; the maximum difference between replicate samples taken from the water edge was 51 stones and the maximum difference from within the inner bar sedimentary unit was 45 stones. The average, 48 stones, was chosen as the adjusted critical value for K-S comparisons of grain size distributions between Wolman samples in February and September 2000.

A single-factor analysis of variance (ANOVA) was used as a complement to the K-S test to compare several metrics derived from surface sediment samples. Comparisons were made between samples collected on one date before (February 2000) and two dates after scalping (September 2000, 2001). Separate analyses were run for each of two sedimentary units: the water edge and inner bar. Four parameters were examined after meeting assumptions of normality (Shapiro-Wilks test) and homogeneity of variance (Levene's test): arcsine-transformed proportion of sand, log (D_5), D_{50}, and D_{95}. The critical value was adjusted by the Bonferroni method because multiple significance tests were performed on the same data (0.05 / 4 contrasts = 0.0125). Otherwise, the risk of committing a Type I error and incorrectly rejecting the null hypothesis would be overly inflated.

It should be noted that the exact locations sampled before freshet were not revisited in April 2000, September 2000 and September 2001. Rather, sample sites in all months were chosen to correspond with distinguishable sedimentary units following methods of Wolcott and Church (1991). Using this strategy, sampling on all dates was adequate to characterize the surface sediment texture across Harrison Bar and sample sites were sufficiently close together for valid comparisons to be made between months.

2.6.2 Bar Topography

Tunbridge & Tunbridge (Ltd) provided surface elevation data from each of their five surveys. With these data, we first examined the spatial pattern of sediment deposition by plotting bar surface elevation along several cross-sections.

Second, we estimated volumetric changes at Harrison Bar by producing topographic surface grids from each of the surveys using the TOPOGRID command in Arc/Info (5-m grid spacing). The TOPOGRID command was used previously to produce a realistic bed surface model for the entire gravel reach of Fraser River (Church et al. 2001). The TOPOGRID command is applied to an area designated by a *boundary* within which there must be a sufficient density of elevation measurements to produce a smooth surface. Hence, it was important that elevation data for each survey were well distributed within the boundary to minimize interpolation error. After each survey was converted to topographic surface grids, the CUTFILL command in Arc/Info was used to determine volumetric differences between two surfaces.

A complicating factor was that some surveys did not overlap the boundaries of the removal area along the waterline (**Figure 11**). These discrepancies were due to differences in river discharge between surveys and changes to the bar perimeter over time. Whereas the survey in March 2000 corresponded approximately with the removal boundary, surveys in October 2001 and March 2003 excluded a sizeable area around the lower corner.

To overcome this problem, we established three boundaries within which volumetric comparisons between surveys were made (**Figure 12**). *Site A* and *Site B* boundaries approximately corresponded with the original removal boundary. The *Lower Bar* boundary represented the largest relevant area of all surveys. Only survey data from February 2000, March 2000, and February 2001 could be compared within *Site A* and *B* boundaries, whereas all survey dates could be compared within the *Lower Bar* boundary.

Finally, we examined the change in topography at Harrison Bar by calculating the relative proportion of bar surface area that was at or above a given elevation. These calculations were based on the grid surfaces. Hypsometric curves, which describe the relation between bar surface area and elevation, were produced from each surface grid to facilitate comparisons between surveys.

The topographic surface grid of Harrison Bar, before and after scalping, was related to river discharge in order to determine the minimum discharge at which the entire bar surface was completely submerged. This question was of interest because shallow, near-shore habitat is important to juvenile fish for rearing but becomes relatively scarce during freshet when the water is high. The lowering of bar surface elevation by scalping may have resulted in a loss of near-shore and bar top habitat during this hydrologically stressful period. The relation between water surface elevation and discharge was established based on gauge readings from the Canadian Pacific Railway Bridge at Harrison Mills (corrected to geodetic datum) and discharge data at Hope.

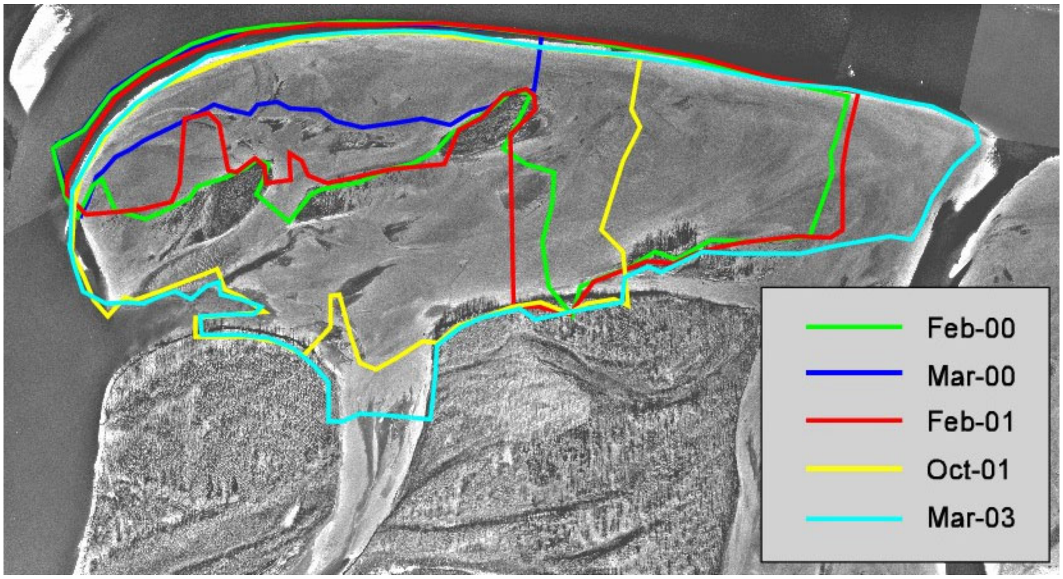


Figure 11. The approximate extent of surveys conducted by Tunbridge & Tunbridge at Harrison Bar on 5 dates between and after scalping. The survey in March 2000 corresponded approximately with the removal boundary. Photograph taken March 7, 2001.

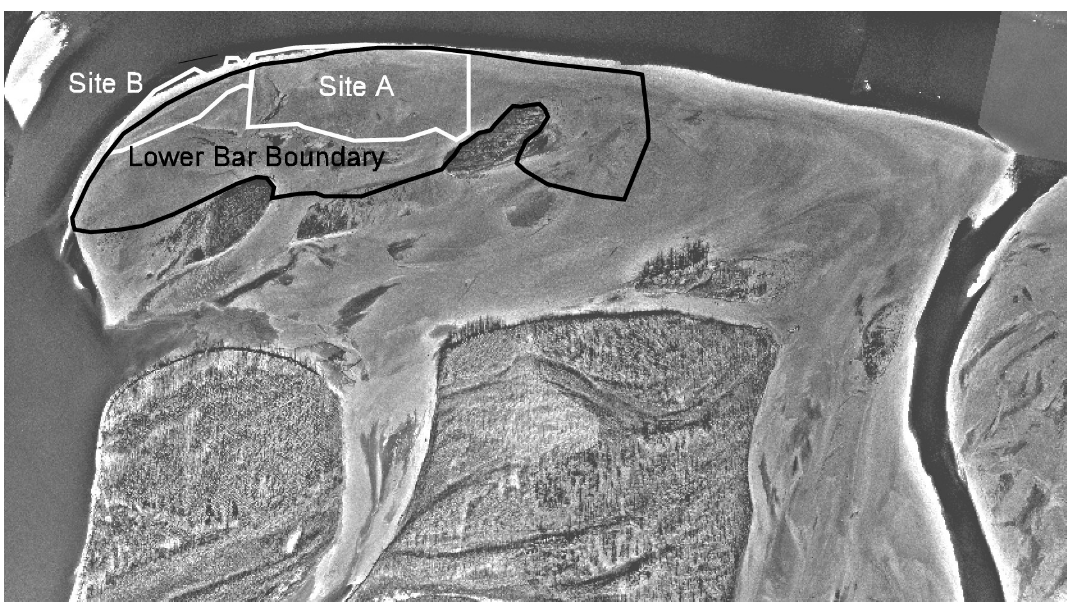


Figure 12. The three boundaries within which calculations of volumetric change between survey dates were made. Photograph taken March 7, 2001.

2.6.3 Habitat Availability and Physical Characteristics

Habitat-specific analyses followed two lines of examination. First, habitat mapping was used to determine *if the availability of habitat types changed* at Harrison Bar after scalping. For stereo photographs depicting low flow conditions in March, the number and length of each habitat unit were determined based on a combination of air photograph interpretation and ground truthing. Habitat value was estimated as the total number of each habitat type multiplied by the mean density of juvenile fish captured in the habitat by beach seine over 3 years of sampling (1999 to 2001). An alternate measure of habitat value was calculated as the total length of each habitat type multiplied by mean density. Only fish data collected at low flow (November through April) were used in the density estimates for March photographs.

Perspective distortion in oblique photographs from summer months prevented accurate length measurements of habitat units. Hence, only the count-based estimate of habitat value was calculated for each habitat type (number of units x mean fish density). Fish data collected during summer months (July through August) between 1999 and 2001 were used in the estimates of fish density for oblique photographs.

The second line of examination served to determine *if the physical characteristics of habitat types changed* at Har-S after scalping (difference between sampling periods) and if conditions were comparable with reference sites (difference between sites). These questions were important because it is not only necessary for habitat units to be available, but the physical characteristics of units must be favourable for fish to occupy them. The physical characteristics at reference sites were taken to represent favourable conditions, and the characteristics of bar edge habitat were compared between the scalped area and reference sites based on observations from beach seine sampling. Only bar edge habitat was sampled prior to scalping at Har-S and all reference sites. Bar edge also was the dominant habitat per unit bar length in the gravel reach. Two methods of analysis were used, the first examining physical factors individually. Four factors were of interest: bank slope, mean velocity, dominant substrate type, and substrate embeddedness. The factors were assigned categorical groupings and data were tabulated as the percent of beach seines matching each category at the scalped and reference sites.

A second method, principal components analysis (PCA), was used to summarize total variation in the physical data set and reduce the number of variables to a subset of linear, orthogonal axes representing the dominant physical gradients. These PC-axes were then used to examine habitat differences over time and between sites by considering the relation among all physical factors simultaneously. PCA had the advantage of considering all physical variables together, but the disadvantage of yielding multivariate PC-axes that were not as readily interpretable. PCA was applied to bar edge habitat data using a correlation matrix. Variables were first tested for normality (Shapiro-Wilks test) and homogeneity of variance (Levene's test), and the appropriate transformation applied. The following variables were included: bank angle ($\log_{10}$-transformed), mean depth, maximum depth, mean velocity, maximum velocity, and the proportions of cobble, gravel and sand (each arcsine-transformed). PC-axes with an eigenvalue >1 were considered to represent dominant physical gradients.

Asymmetrical analysis of variance (ANOVA), outlined by Underwood (1993) and described in **Section 2.6**, was applied to each of the first three PC-axes (eigenvalue >1) to determine if the physical characteristics of bar edge units changed as a result of scalping at Harrison Bar. Separate analyses of each PC-axis were valid because the axes are orthogonal, and therefore independent of each other.

2.6.4 Juvenile Fish

The following parameters, or metrics, were calculated to assess differences in the fish community between Harrison Bar and the reference sites before and after scalping. Evaluating a combination of metrics was intended to provide assurance of a thorough impact assessment. Recall that reference sites were to serve as a standard against which the scalped portion of Harrison Bar was compared. Formulae are from Krebs (1998).

1. **Total Density (N)**: total number of fish captured in a beach seine haul divided by sampling area (# / 10 m^2).
2. **Salmonid Index**: the proportion of all individuals belonging to the family Salmonidae (see Appendix C).
3. **Species Richness**: total number of unique species captured in a beach seine.
4. **Simpson's Diversity (*D'*)**: $1 - D = 1 - \sum_{i=1}^{s} p_i^2$ where p is the proportion of individuals of the i^{th} species. *D* refers to Simpson's Index. The index provides more weighting for common species and reflects the probability of picking 2 fish at random that are different species. Values range from 0 to 1.
5. **Simpson's Evenness (*E*)**: $E = \frac{1}{D} * s$ where *D* is Simpson's Index (see above) and *s* is the number of unique species. Values range from 0 to 1 and the index is relatively unaffected by rare species in the sample. The metric quantifies how evenly the abundance of fish is distributed among all species in the sample.

The experimental removal was carried out over a large area of lower Harrison Bar, which implied that the appropriate spatial unit for examining scalping impacts was the gravel bar. However, field experience suggested that gravel bars are an agglomeration of smaller habitat units that differ in physical and ecological character. Proceeding to analyze data grouped at the bar scale would pool this habitat-specific variability, thereby inflating the error variance if the habitat types in fact differ, and possibly reduce statistical power to detect a significant impact. However, considering only a sub-set of the data grouped by habitat type would reduce sample size and would not directly address impacts at the bar-scale unit. We chose to carry out identical statistical analyses at the bar scale (i.e., all habitat types pooled) and habitat unit scale (i.e., bar edge habitat) to resolve this dilemma. Habitat-specific comparisons between sites examined bar edge only because no other habitat types were sampled at all sites during all periods of sampling.

Comparisons of bar-scale and bar edge samples were made based on a combination of (1) graphical examination and (2) asymmetrical analysis of variance (ANOVA) outlined by Underwood (1993) and described in **Section 2.6**. Prior to analysis, each variable was tested for normality (Shapiro-Wilks test) and homogeneity of variance (Levene's test). To meet these conditions, total density and Simpson's Evenness were log-transformed, the salmonid index was arcsine-transformed, and species richness and Simpson's Diversity did not require transformation. Total density was expressed as #/10 m^2 because very small values can be problematic for ANOVA. We have chosen to graphically depict normal-transformed variables to reflect the scale on which statistical analyses were based.

There were six cases of missing bar edge data over the course of sampling: Car-R August 1999; Car-R and Fos-R February 2000; Fos-R September 2000; Car-R November 2000; and Car-R August 2001. There were three missing observations for the bar-scale analysis: Car-R and Fos-R February 2000; and Car-R August 2001. Following Underwood (1997), we replaced the missing data with "dummy values" using the mean of the other reference sites on that date. The residual degrees of freedom were adjusted to compensate for the missing values.

2.6.5 Benthic Invertebrates

The following metrics were calculated to assess differences in the benthic invertebrate community between Harrison Bar and the reference sites before and after scalping.

1. **Total Density (N)**: total number of benthic organisms in a Surber sample divided by sampling area. Sampling area was 0.09 m^2 for all benthic samples.
2. **Taxa Richness (*s*)**: total number of unique taxonomic groups in a sample.
3. **EPT Richness (s')**: total number of unique taxonomic groups belonging to the Orders Ephemeroptera, Plecoptera, and Tricoptera.
4. **EPT Index**: the proportion (%) of all individuals belonging to the Orders Ephemeroptera, Plecoptera, and Tricoptera.
5. **Simpson's Diversity (*D'*)**: see above
6. **Simpson's Evenness (*E*)**: see above

Similar to the analysis of juvenile fish, the appropriate spatial scale for examining scalping impacts was the gravel bar. However, previous experience indicated that the distribution of invertebrates is significantly correlated with hydraulic and sedimentary conditions (Rempel et al. 2000), which vary at the habitat-scale. In recognition of both possible scales of impact, we carried out identical statistical analyses at the bar scale (i.e., all habitat types pooled) and habitat scale. Habitat-specific comparisons between sites before and after scalping examined only bar edge because bar head and bar tail habitats were not present at all sites on all dates before and after scalping.

Comparisons of bar edge and bar-scale data were made based on a combination of (1) graphical examination and (2) the asymmetrical analysis of variance outlined by

Underwood (1993). Refer to **Section 2.6** for details of the ANOVA. Variables were first transformed to meet assumptions of normality (Shapiro-Wilks test) and homogeneity of variance (Levene's test). Total density and Simpson's Evenness were log-transformed, EPT index was arcsine-transformed, and the remaining metrics did not require transformation. Graphical presentations of the data depict normal-transformed variables to reflect the scale on which statistical analyses were based.

There were two cases of missing bar edge data over the course of sampling: Fos-R May 2000; and Car-R September 2000. One case was missing for the bar-scale analysis, Fos-R in May 2000. Following Underwood (1997), we replaced the missing data with "dummy values" using the mean of the other reference sites on that date. The residual degrees of freedom were adjusted to compensate for the missing values.

Asymmetrical ANOVA was also applied to examine population-level metrics by comparing densities of common taxonomic groups (representing greater than 1% of the total invertebrates collected) between sites before and after scalping. Seven groups met this criterion: the mayflies Baetidae, Heptageniidae, and Ephemerellidae; the stonefly Capniidae; the midge Chironomidae; nematodes, and oligochaetes. Samples from all habitat types were included and invertebrate densities were log-transformed prior to analysis to meet assumptions of normality (Shapiro-Wilks test) and homogeneity of variance (Levene's test). A goal for this analysis was to gain insight into patterns of recolonization by invertebrates of a scalped gravel bar. Those groups identified to genus/species were merged into family-level groupings because most families were represented by one common genus and possibly several uncommon genera. Several authors have found the family-level of identification sufficient for bio-monitoring purposes and for detecting site impairment due to physical, toxicological or biological disturbance (Bournaud et al. 1996, Reece et al. 2001).

A final qualitative analysis examined functional metrics, specifically proportions of functional feeding groups (FFG), to evaluate community structure at the scalped and reference sites. When compared to reference sites, a shift in the dominance of a particular feeding group at the scalped site may indicate a community responding to a change in food source.

2.6.6 Fish Stomach Contents

The stomach contents of juvenile chinook salmon (*Oncorhynchus tshawytscha*) were examined to determine variability in diet choice among sites and if prey choice at Har-S after bar scalping differed from reference sites. Sample size varied significantly between sites because the fish were collected for a separate study. *O. tshawytscha* measuring between 50 and 100 mm (fork length) were included and only those collected in bar edge, bar head and bar tail habitat types of the main channel were used in the analysis.

Qualitative comparisons between samples collected in summer 1999, 2000 and 2001 were made based on the percent composition *by volume* of prey types. The method quantifies different food types in directly comparable units and therefore indicates the relative importance of prey items to the diet. For most prey types, food value is roughly proportional to weight or volume (Murphy and Willis 1996).

3.0 Results

3.1 Sedimentology

3.1.1 Pre-Scalping

Gravel bars are generally characterized as having coarser surface sediment at the bar head and finer sediments downstream toward the bar tail. Furthermore, at any location on a bar, the surface is typically coarser than the bulk deposit beneath because the finer materials are systematically removed from the surface by water washing.

At Harrison Bar, the grain-size distribution of sub-surface sediment was similar between the scalped and reference areas prior to mining (**Figure 13**). Approximately 95% of each sample by weight was finer than 16 mm and 50% of each sample was finer than 5.6 to 8 mm. Har-S had a higher proportion of fine sediment <4 mm, approximately 20 to 30%, compared with 15-20% in the reference area. This result is consistent with the upstream position of the reference site.

Surface grain size prior to scalping exhibited a fining trend from the water edge toward the inside bar top (**Figure 14**a, **Figure 15**a), consistent with less powerful and less frequent current washing on the bar top. The moderately sloped beach face was coarser and had a low proportion of sand (< 3%). Absolute sediment size also declined downstream, chiefly in the water edge D_{50}. This trend is consistent with the sub-surface indication that a similar total range in grain sizes was present in both areas. The median grain size on the inner bar top was similar between Har-S and the reference area. Average sand coverage was relatively high on both the scalping (11%) and reference (17%) surfaces (**Figure 16**a), but was locally very variable, reflecting the vagrant nature of sand deposition and persistence in the gravel reach.

3.1.2 Post-Scalping

After the removal and prior to the 2000 freshet, the scalped surface had a higher proportion of sand (average cover 32%, **Figure 16**b) and the grain size distribution was notably finer. Average D_{95} dropped from 66 mm to 39 mm and average D_{50} dropped from 25 mm to 13 mm (**Figure 17**). This fining reflects disruption of the surface layer to expose finer bulk materials beneath.

After freshet in September 2000, sand cover in both the reference and scalped areas was substantially lower (**Figure 16**c). The reduction in sand was observed both along the water edge and the inner bar top. Gravel sizes in the reference area decreased slightly whereas the scalped area coarsened and, in places, was again similar to conditions before scalping ($16<D_{50}<31$ mm, $41<D_{95}<77$ mm). Surface sediment texture within Har-S was also comparable to reference sites in September 2000 (Carey Bar: D_{50} = 26 mm, D_{95} = 49 mm). However, the coarsest fractions appear not to have been replenished along the water edge of Har-S after one freshet (**Figure 17**), where D_{95} after freshet (77 mm) was less than before scalping (102 mm).

The freshet of 2001 produced only modest changes to surface sediment texture at Harrison Bar. The percent sand cover increased in the upper removal area whereas the reference areas showed little change in sand cover. The gravel grain size distributions in both areas were highly similar as well. Median grain size at Har-R was virtually unchanged and Har-S showed some coarsening, with average values increasing from 22 mm to 25 mm (**Figure 17**).

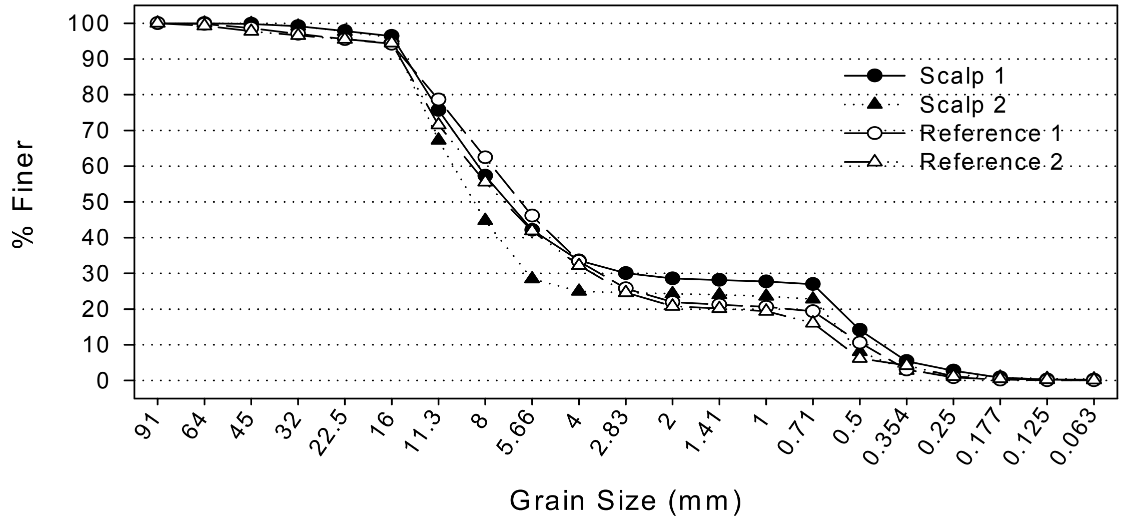


Figure 13. Cumulative grain-size distribution of sub-surface sediment samples collected from the scalped and reference areas prior to scalping in February 2000.

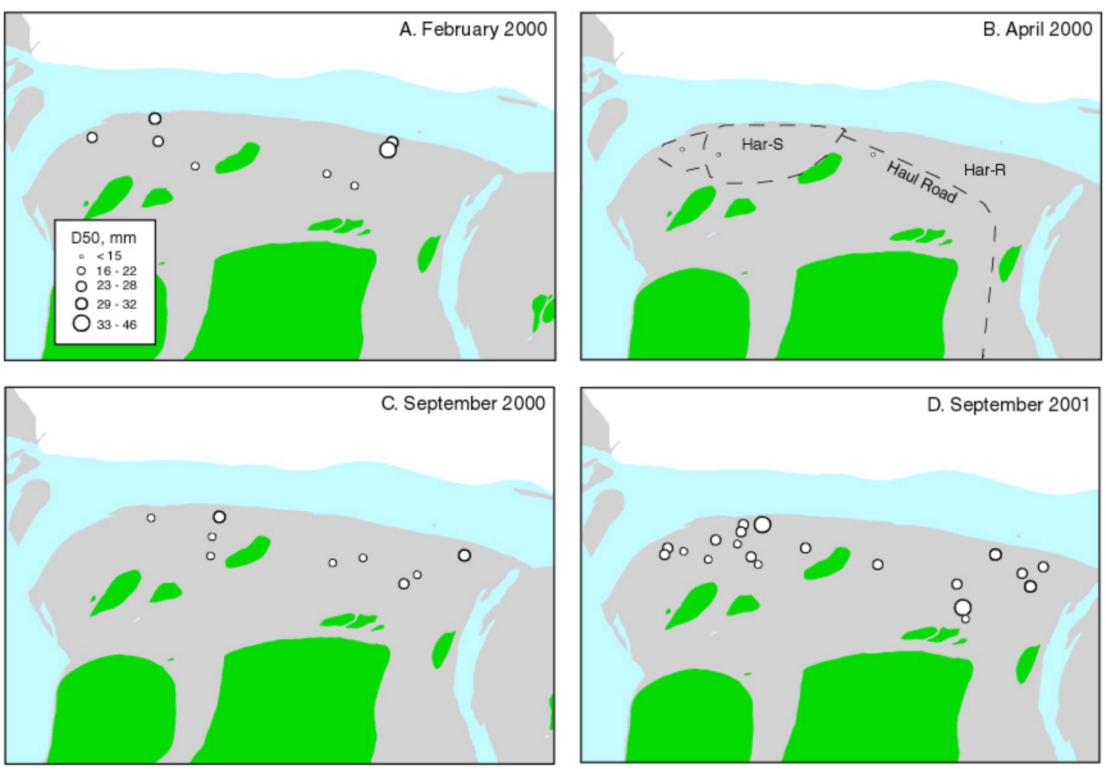


Figure 14. Surface gravel D_{50} (mm) at Wolman and photographic sites where sediment sampling occurred at Harrison Bar on 4 dates before (A) and after (B-D) scalping. Size range categories were chosen to highlight natural breaks in the data.

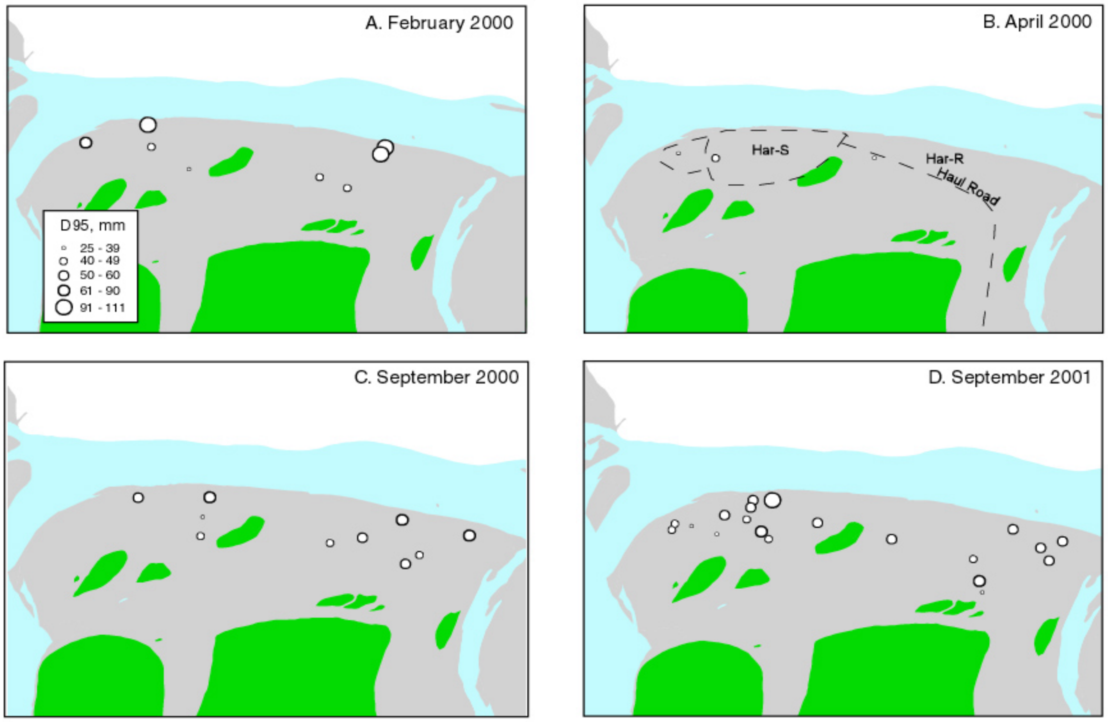


Figure 15. Surface gravel D_{95} (mm) at Harrison Bar on 4 dates before (A) and after (B-D) scalping. Size range categories were chosen to highlight natural breaks in the data.

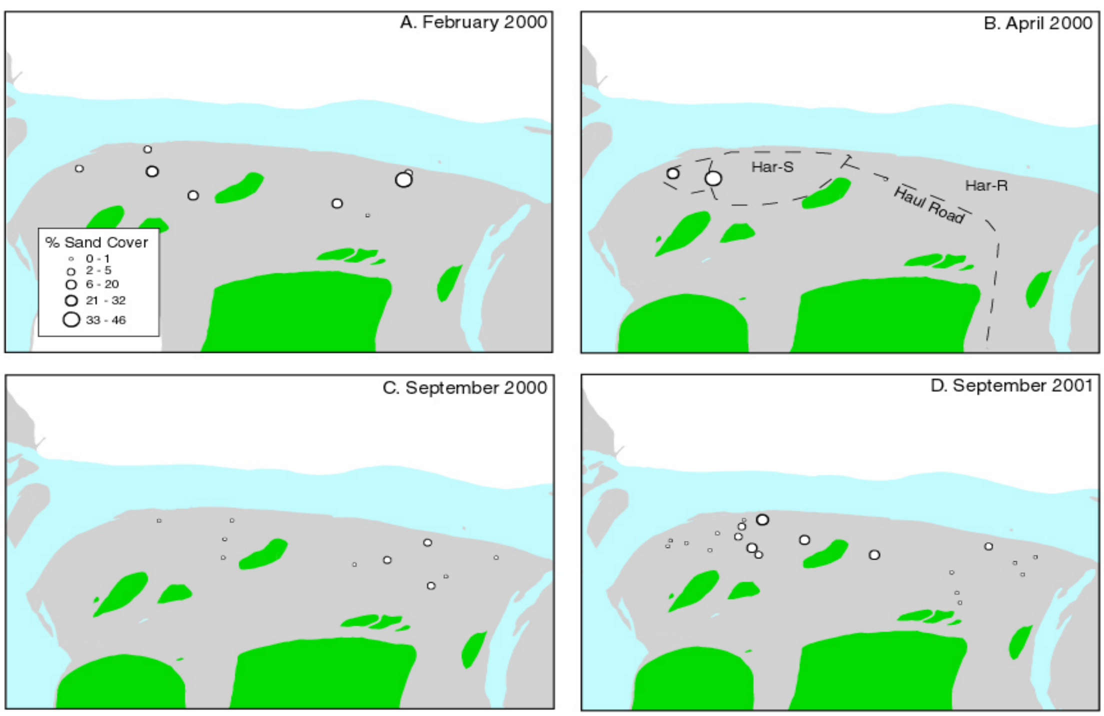


Figure 16. Percentage sand cover at Harrison Bar on 4 dates before (A) and after (B-D) scalping. Size range categories were chosen to highlight natural breaks in the data.

Comparing grain size data collected in February 2000 prior to scalping (**Figure 17**), the median grain size in September 2001 was virtually identical at Har-S both at the water's edge and inner bar. The coarsest size fraction (D_{95}) was less than the average pre-scalping value at the water's edge, but a reduction over this period was observed at Har-R as well. A similar change in the reference and scalped areas suggests that sediment recruitment through two below-average freshets may be responsible for the particular outcome. Sand content in both areas was less in September 2001 as compared to pre-scalping values.

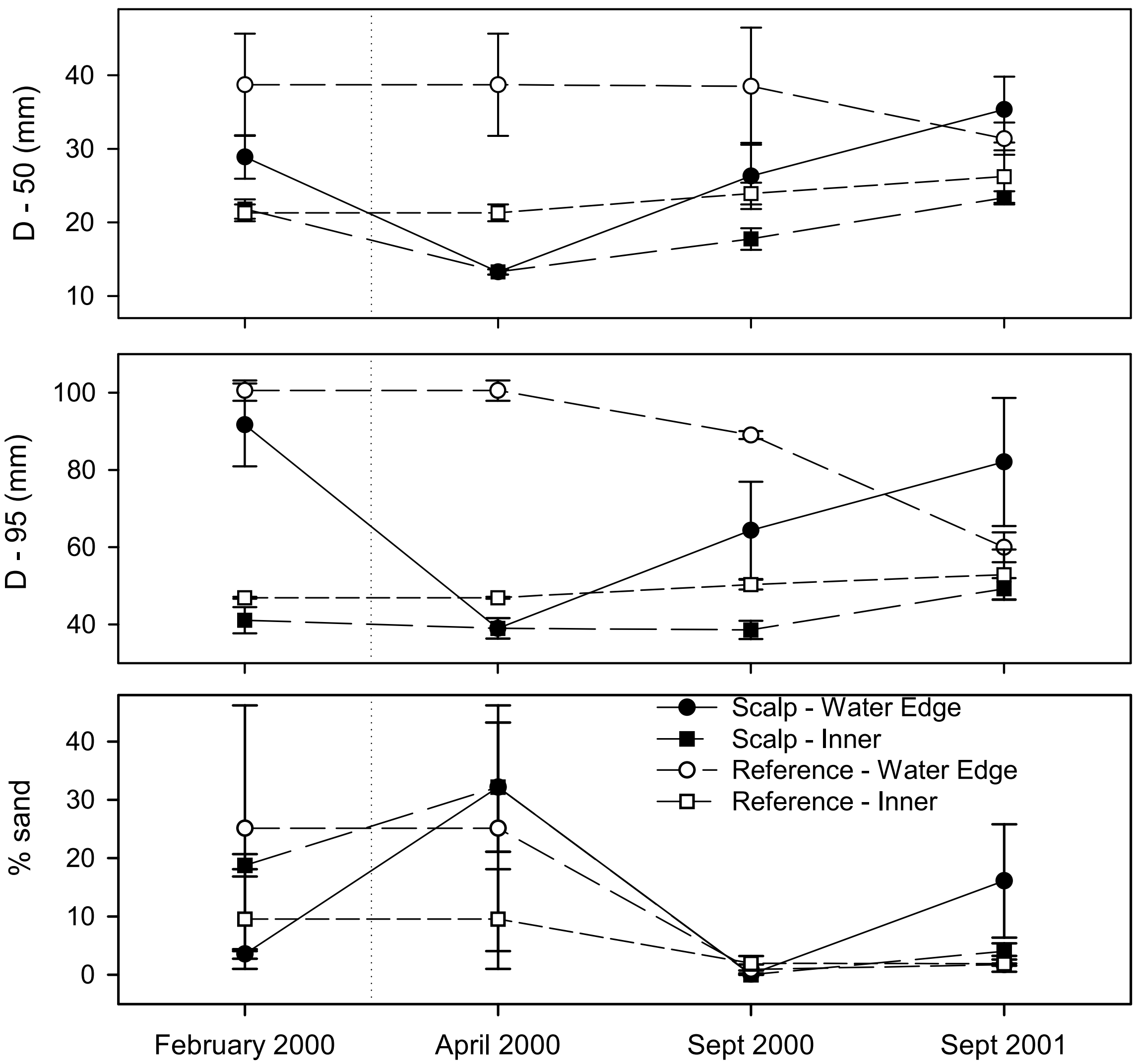


Figure 17. Surface sediment characteristics (mean ± SE) in the scalped and reference areas of Harrison Bar before and after bar scalping. Mining took place prior to sampling in April 2000.

Sediment texture along the access road did not recover to pre-scalping conditions after two freshet events. It was left hard-packed after bar scalping and obvious crushing of the coarse sediment had occurred. The surface had low sand content (<1%) and grain sizes were fine (D_{50} = 4 mm, D_{95} = 25 mm). Sediment texture along the entire road surface was consistent post-scalping. The freshets of 2000 and 2001 deposited sediment in isolated patches over the road and in these areas the hardened surface appeared to have broken up. But other areas remained compact and were blanketed with sand. These areas could be discerned from air photographs taken in March 2001 and, to a lesser degree, from oblique photographs taken in August 2001.

The Kolmogorov-Smirnov (K-S) test was used to compare grain size distributions of Wolman samples collected in February (before scalping) and September 2000 (after scalping and flooding). Samples from September 2001 were not included because they were collected by the photographic method and lacked distribution information. The K-S critical difference between samples was 48 stones. The maximum difference of samples along the water edge was 110 stones, and differences from two sets of samples collected from the inner bar were 84 and 68 stones. Thus, the K-S test found a significant difference in grain size distributions before and after one freshet post-scalping along the water edge and inner bar.

Results of one-factor ANOVA examining differences between sampling dates were more conservative than the K-S test (**Table 7**). This analysis included Wolman samples and surface samples collected in September 2001 by the photographic method. Only the proportion of sand in samples collected from the inner bar differed after scalping, with higher sand content before scalping than on both sampling dates after scalping.

Table 7. Results of separate single-factor ANOVA analyses contrasting surface sediment samples over 3 dates. The critical value was 0.0125, corrected by Bonferroni's method for multiple contrasts. Asterisk * denotes a significant difference. Residual values are in brackets.

Parameter	df	MS	F	*p*
Water Edge				
Proportion Sand	2 (3)	0.04 (0.05)	0.83	0.52
D_5	2 (3)	0.2 (0.07)	2.74	0.21
D_{50}	2 (3)	43.3 (57.8)	0.75	0.54
D_{95}	2 (3)	384.3 (724.9)	0.53	0.64
Inner Bar				
Proportion Sand	2 (3)	0.1 (0.003)	33.31	0.009*
D_5	2 (3)	0.02 (0.006)	3.07	0.19
D_{50}	2 (3)	19.3 (11.5)	1.67	0.32
D_{95}	2 (3)	33.5 (40.2)	0.83	0.52

3.2 Bar Topography

The *Lower Bar Boundary* of Harrison Bar, as delineated in **Figure 12**, had a relatively simple morphology prior to mining, consisting of two flat, open areas that dipped moderately steeply over coarse gravel beaches into the main channel (**Figure 18**, **Figure 19**). These open areas were separated from the vegetated islands in the centre of the bar by a summer channel containing complex chute and lobe features. Average surface elevation was 8.36 m and maximum elevation was 11.64 m (**Table 8**). Morphology in the reference area (Har-R) was equally simple: a large flat-topped area dipping gently to the side channel on its left (south) and more steeply to the main channel on its right (north).

Scalping removed the moderately steep beach face from the upper scalped area (Area A), producing a low gradient slope (1-2%) running without interruption from the low water edge to a high point in front of the central islands (lines 2 and 3, **Figure 18**). Within removal Area B, scalping left a low-lying basin (line 4, **Figure 18**) separated from the upstream scalped area by a low berm. Area B joined the main channel opposite the Harrison River confluence as a trough-shaped tongue. Removal volumes in Area A and B were 49,484 m^3 and 19,586 m^3, respectively, and totalled 69,070 m^3. The maximum vertical depth of extraction was approximately 2 m (along the inner boundary of removal area A), and average surface elevation was reduced by over 1 m (**Table 8**).

The modest freshet of 2000 produced negligible volumetric change in Area A (715 m^3 erosion) and deposited 3,838 m^3 of sediment within Area B (**Table 9**). This material was seen as exposed gravel bar surrounded by a relatively deep summer channel intersecting the lower corner of the bar (**Figure 19**). The area of deposition in Area B corresponded with line 5 of **Figure 18**. Over the entire lower bar, a net loss of 6,635 m^3 was recorded after the 2000 freshet. This loss is reflected in the average and maximum bar surface elevation (**Table 8**).

Table 8. Surface elevation (m) characteristics of lower Harrison Bar (total area: 247,825 m^2). Scalping took place immediately following the Feb-00 survey. River discharge (m^3/s) was estimated at Hope.

Survey #	Date	Discharge	Mean	Maximum	Minimum	SD
1	Feb-00	888	8.36	11.64	5.67	0.71
2	Mar-00	733	8.14	11.64	5.67	0.75
2*	Mar-00	733	7.16	9.71	5.48	0.98
3	Feb-01	521	8.12	10.89	6.05	0.78
4	Oct-01	1320	8.13	11.93	5.76	0.81
5	Mar-03	900	8.25	11.99	5.60	0.81

*determined within removal area boundary only (Site A and Site B)

We calculated negligible volumetric change over the lower bar after the even lower 2001 freshet (1,676 m^3 net erosion, **Table 9**), however, some topographic changes were observed within the removal area. There was deposition both in Site A (where maximum surface elevation increased to >9 m) and Site B (where maximum elevation increased to >8 m), including some infilling of the summer channel (**Figure 19**).

Topographic changes over lower Harrison Bar were most notable following the large freshet of 2002, which deposited a net sediment volume of 27,630 m^3. Flood discharge peaked at 10,066 m^3/s on June 21. Sediment deposition occurred across the inner and middle scalped area (lines 3 and 4, **Figure 18**), as well as the lower area (line 5, **Figure 18**). Erosion was noted along the downstream corner on the apex of the bend.

Comparing the *Lower Bar Boundary* of Harrison Bar between February 2000 and March 2003, there was a net loss of 42,913 m^3 of sediment. Given a scalped volume of 62,232 m^3 within the lower bar boundary, 31% of the removed volume appears to have been replenished after 3 freshets. All of this material was deposited during the most recent and largest freshet. Whereas scalping lowered mean bar surface elevation by 22 cm, sediment deposition by the 2002 freshet restored average bar surface elevation to within 9 cm of the pre-scalped surface (**Table 8**).

Bar scalping resulted in a shift in the elevation profile of the *Lower Bar Boundary* of Harrison Bar (**Figure 20**a). Approximately 24% (or 58,925 m^2) of the lower bar area was >9 m elevation before scalping, which declined to 14% (or 35,300 m^2) after scalping and after one freshet in September 2000 (**Table 10**). Deposition resulting from flooding in 2001 and 2002 increased the bar area >9 m to 18%, or 44,750 m^2. This increase is reflected in a positive shift of the elevation profile towards the pre-scalped state (**Figure 20**a). The proportion of bar area >8 m elevation was 71% prior to scalping, 4% immediately after scalping, and 57% after the freshet of 2002. Based on the relation between water surface elevation at Harrison Bar and discharge at Hope (**Figure 21**), the entire bar surface surveyed in 2003 would be inundated at a discharge of 10,760 m^3/s. The pre-scalp surface would have been inundated completely at 10,200 m^3/s. With consideration to the elevation-area relation, 24% of the lower bar area remained exposed at flows of 4,960 m3/s whereas only 18% of the post-scalp surface in 2002 was exposed at this flow.

Despite no long-term reduction in maximum surface elevation, there remained a net loss of bar area between 8.5 and 10 m elevation (**Figure 20**b), which becomes inundated between 3,960 and 6,960 m^3/s. This range on the declining limb of the discharge hydrograph corresponds with the period of hatching and rearing for fish in the gravel reach. The reduction in area of the 9-9.5 m elevation class was particularly notable.

Table 9. Volumetric (m^3) comparisons between surveys conducted at Harrison Bar. Scalping occurred within areas A and B following the February 2000 survey. ne: not estimated.

Survey Comparisons	Area A (71,975 m^2)	Area B (19,670 m^2)	Lower Bar* (247,825 m^2)
Feb-00 vs Mar-00	*fill*: 0 **net loss: -49,484**	*fill*: 0 **net loss: -19,586**	*loss*: -63,881 *fill*: +1,648 **net loss: -62,232**
Feb-00 vs Feb-01	*loss*: -50,697 *fill*: +498 **net loss: -50,199**	*loss*:-15,797 *fill*: +49 **net loss: -15,748**	*loss*: -89,200 *fill*: +20,3328 **net loss: -68,868**
Mar-00 vs Feb-01 (2000 freshet)	*loss*: -14,233 *fill*: 13,519 **net loss: -715**	*loss*:-3,791 *fill*: +7,629 **net fill: +3,838**	*loss*: -47,476 *fill*: +40,840 **net loss: -6,635**
Feb-01 vs Oct-01 (2001 freshet)	ne	ne	*loss*: -28,414 *fill*: +26,737 **net loss: -1,676**
Oct-01 vs Mar-03 (2002 freshet)	ne	ne	*loss*: -23,348 *fill*: +50,978 **net fill: +27,630**
Feb-00 vs Mar-03	ne	ne	*loss*: -81,317 *fill*: +38,400 **net loss: -42,913**

*Inconsistencies arise amongst the units because the "Lower Bar" excludes a small portion of Areas A and B, which was not consistently surveyed. See Figure 11.

Table 10. Bar area (m^2) and percentage (%) of the total area at greater than three surface elevations for the *Lower Bar Boundary* of Harrison Bar (247,825 m^2 total area).

Date	>8 m		>8.5 m		>9 m	
	m^2	**%**	**m^2**	**%**	**m^2**	**%**
Feb-00 (pre-scalping)	175,725	71	111,750	45	58,925	24
Mar-00 (post-scalping)	9,775	4	1,625	1	0	0
Feb-01 (2000 freshet)	135,900	55	80,225	32	35,300	14
Oct-01 (2001 freshet)	136,950	55	80,975	33	38,250	15
Mar-03 (2002 freshet)	141,250	57	94,250	38	44,750	18

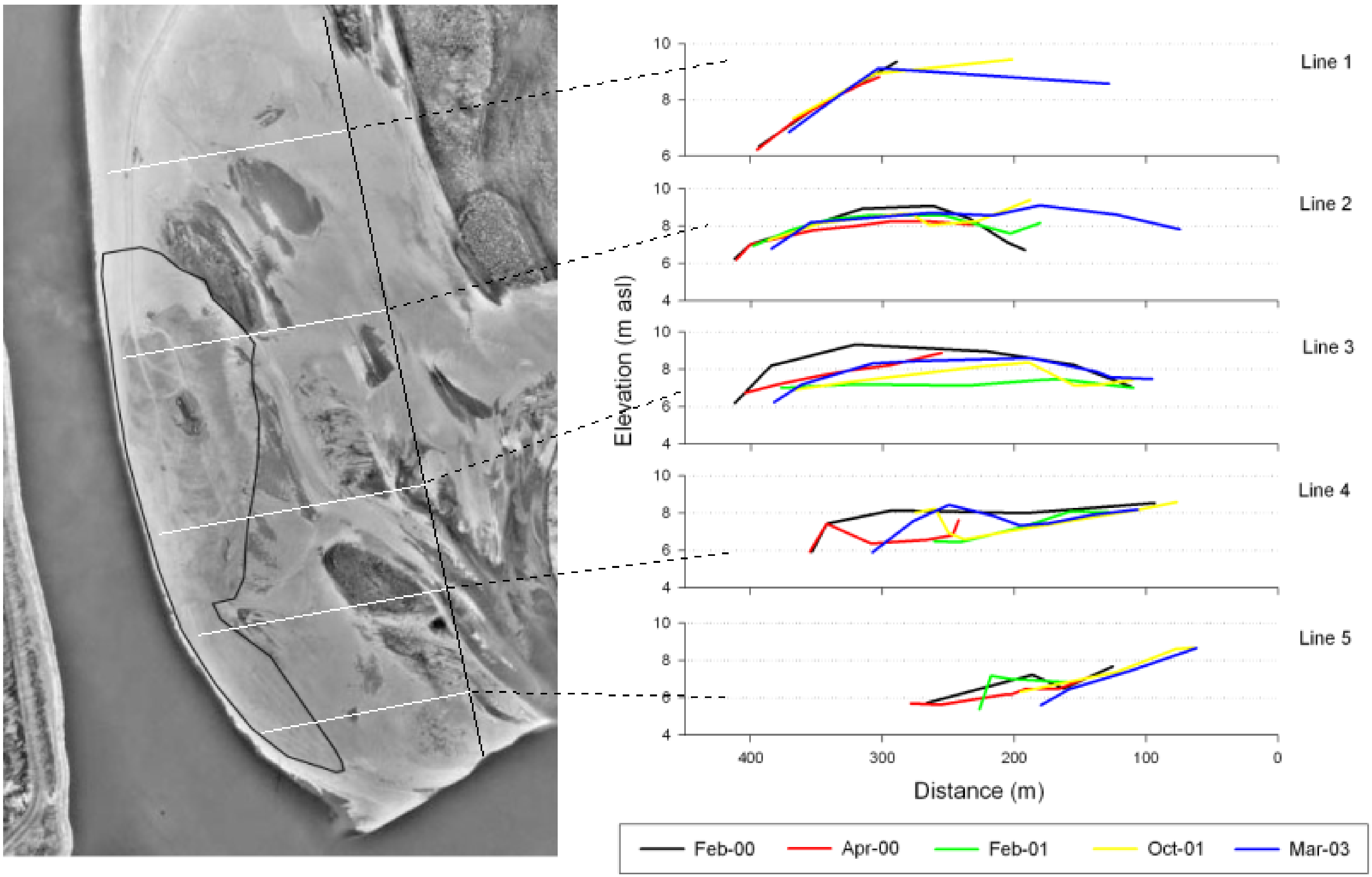


Figure 18. Site photograph (March 2000) showing elevation plots along five cross-sections based on surveys from 1 date before and 4 dates after scalping at Harrison Bar. The removal area is delineated on the photograph (taken March 9, 2000).

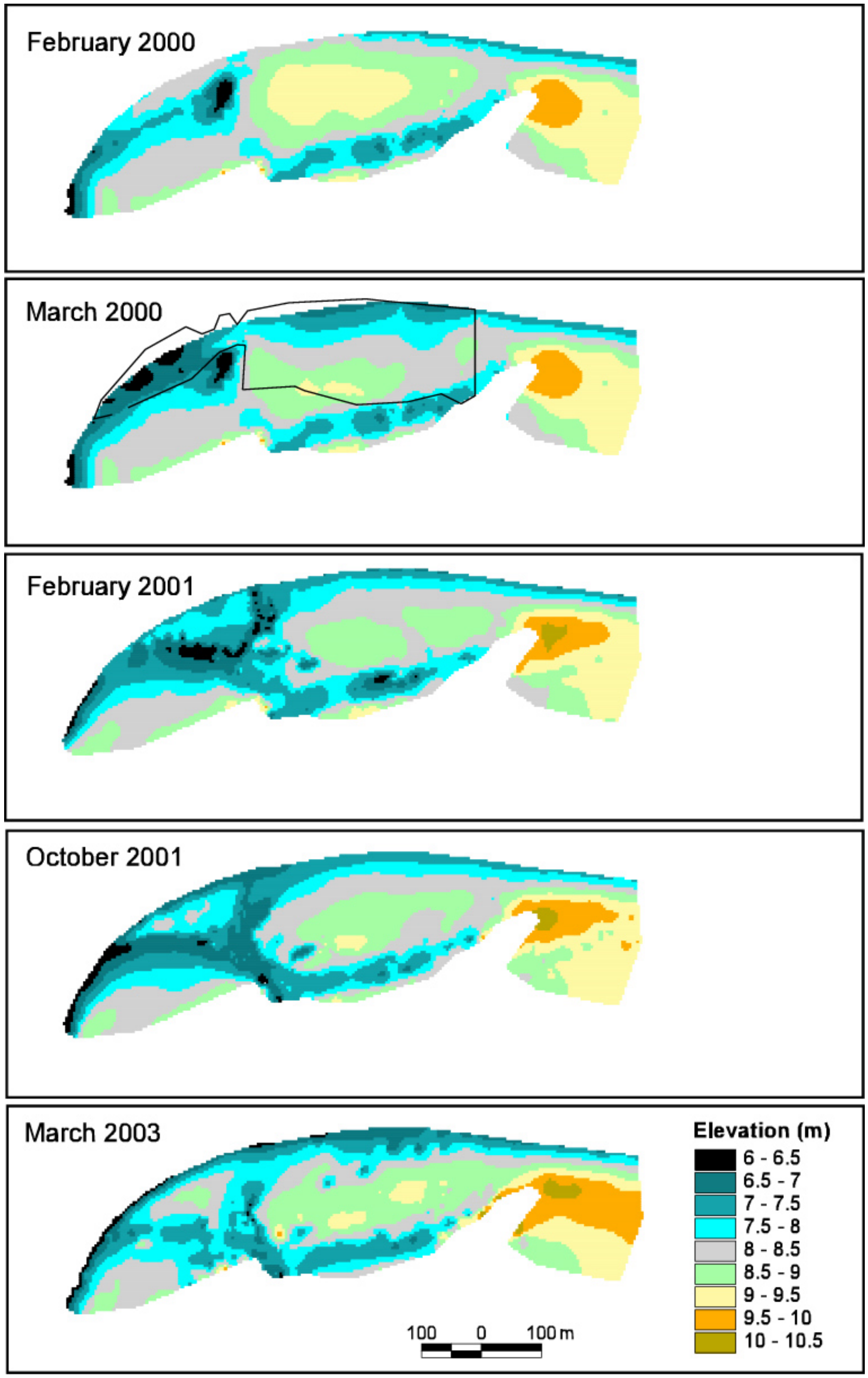


Figure 19. Topographic images portraying surface elevation classes at Harrison Bar. The images were based on repeated surveys of Harrison Bar once before scalping and on 3 dates following freshet events post-scalping. The perimeter outlined in March 2000 delineates the scalp boundary.

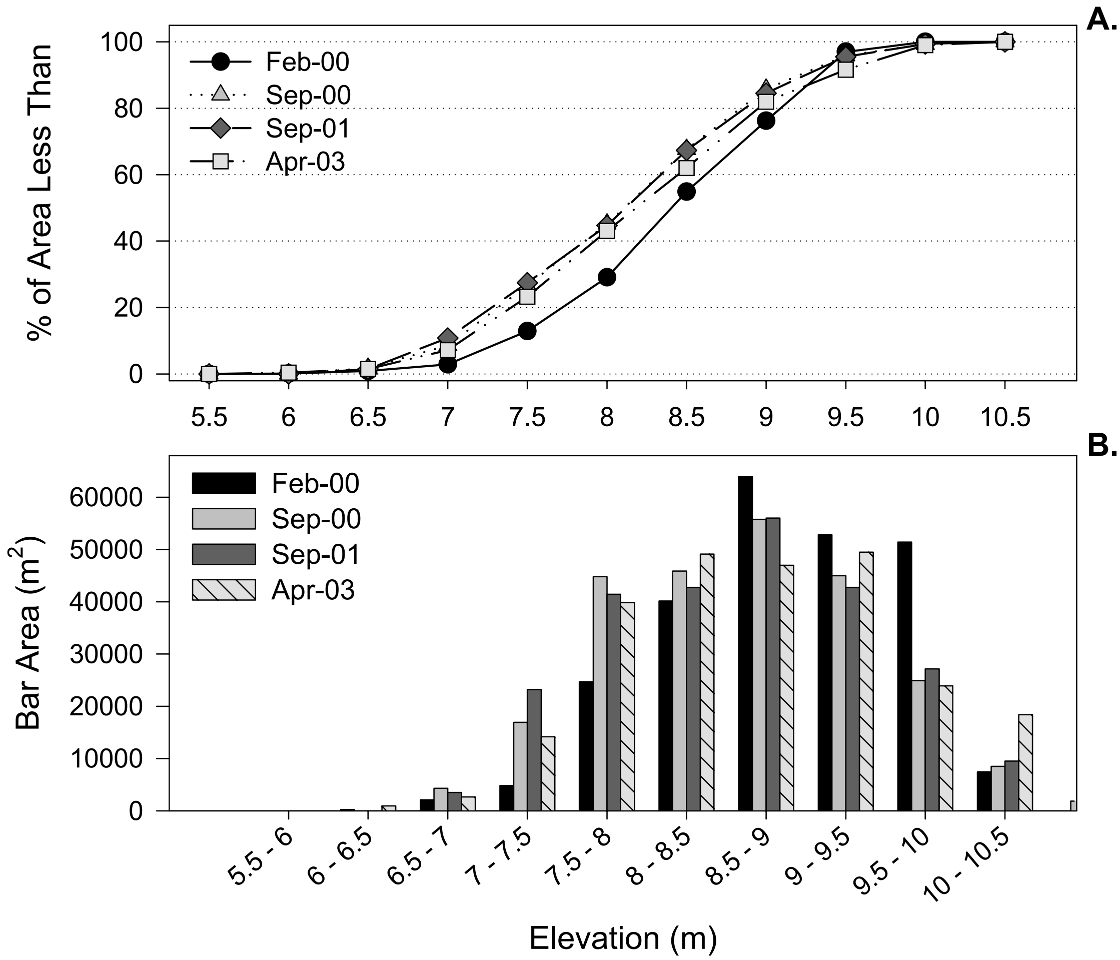


Figure 20. Area-elevation relation within the *Lower Bar Boundary* of Harrison Bar, based on topographic surface modeling before scalping (Feb-00) and after three freshets.

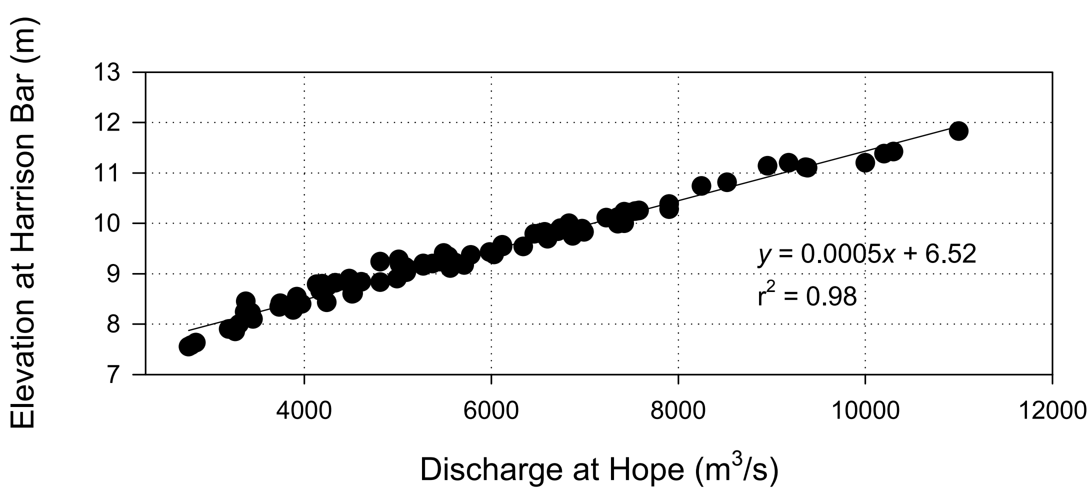


Figure 21. Discharge-elevation relation at Harrison Bar based on gauge data from the CPR Bridge at the mouth of Harrison River (1995 – 2002).

3.3 Habitat Availability and Physical Characteristics

3.3.1 Photographic Mapping

The availability of habitat units at low flow (500 - 860 m^3/s discharge) remained similar in the reference area of Harrison Bar between 1999 and 2001 (**Figure 22**). Within the scalped area, only minor changes were observed in the array of habitats available between 1999 and 2000 prior to gravel mining. Air photographs taken in March 2001 after one freshet since scalping revealed a higher number (6 units) of habitat units around lower Harrison Bar. Two distinct open nooks developed at the midpoint of the scalped area. Riffle, bar edge, and bar tail units were observed around the downstream corner.

Habitat value, *estimated as the total count of each habitat type multiplied by average fish density*, remained virtually unchanged in the reference area between 1999 and 2001. In contrast, habitat value within the scalp area was lower in 2000 (.26) than in 1999 (.51, **Table 11**). Gravel mining was not responsible for this change because the bar flank was unmodified by scalping in the 2000 photograph. In March 2001 and after one freshet post-scalping, habitat value within the scalped area increased to .73. Substituting total counts with lengths of habitat types produced similar results. Although the direction of change in habitat value is noteworthy, the change is not considered to be significant given the natural variation in habitat availability around gravel bars.

Based on oblique photographs, habitat availability in the reference area showed little change between August 1995 and 2000 (**Figure 23**). A total of four habitat units were present in each year. Within the scalped area, the number of habitat units increased from 6 to 15 units. The increase in units resulted mostly from a new summer channel that intersected the lower corner of the removal area, making available bar edge, channel nook, eddy pool and open nook habitats. Average unit size in 2000 was also smaller, allowing the bar flank to accommodate a higher number of units overall.

A comparison of photographs taken before and after gravel mining in September 1999 and 2001 found little change in the reference area and a low number of habitat units overall (**Figure 24**). Within the scalped area there were 4 units before and 6 units after mining. It is worth noting that discharge at the time of photography in 2001 was almost 400 m^3/s lower than in 1999. On-site sampling 5 days before the photography when discharge was 1780 m^3/s (and more comparable to the 1999 photograph) found the summer channel conveying flow and offering a high number and variety of habitats for juvenile fish. Hence, habitat availability post-scalping has been under-represented in this photographic comparison.

Habitat value increased in both the reference and scalped areas between 1995 and 2000 (**Table 12**). On both dates, the scalped portion had higher habitat value and the post-scalp bar offered a greater variety of habitat types in August 2000 than before scalping. The difference was due in part to the summer channel that intersected the lower corner of the bar. The channel enriched habitat availability at intermediate flows and was likely the consequence of lowering the bar top by scalping and shaping the lower removal area as a trough. The lower corner was subject to flows over a longer period of the summer, but also to stronger flows near freshet peak. Whereas habitat value in the reference area decreased between September 1999 and 2001, it increased within the scalping area over the same period from 0.84 to 1.70 mostly due to the presence of open nook. Because the number of units overall was low, these changes are not significant but suggest a direction of change.

Table 11. Habitat value in the reference and scalped areas of Harrison Bar. Photographs in each year were taken in March when discharge was less than 900 m^3/s. ND: no data available.

Habitat	March 1999 *(pre-scalp)*		March 2000 *(pre-scalp)*		March 2001 *(post-scalp)*	
	Har-R	**Har-S**	**Har-R**	**Har-S**	**Har-R**	**Har-S**
Bay	0	0	0	0	0	0
Bar Edge	.08	.08	.08	.08	.08	.16
Bar Head	.13	0	.13	0	.13	0
Bar Tail	0	0	0	0	0	.10
Cut Bank	0	0	0	ND	0	0
Channel Nook	0	.43	0	0	0	0
Eddy Pool	0	0	0	0	0	0
Open Nook	0	0	0	.18	0	.35
Riffle	.12	0	.13	0	0	.12
Total	**.33**	**.51**	**.33**	**.26**	**.21**	**.73**

Table 12. Habitat value in the reference and scalped areas of Harrison Bar. Discharge in each pair of years was approximately equal.

Habitat	August 1995 *(pre-scalp)*		August 2000 *(post-scalp)*		September 1999 *(pre-scalp)*		September 2001 *(post-scalp)*	
	Har-R	**Har-S**	**Har-R**	**Har-S**	**Har-R**	**Har-S**	**Har-R**	**Har-S**
Bay	0	.38	0	0	0	0	0	0
Bar Edge	.10	.10	.10	.59	.10	.10	.10	.20
Bar Head	.09	0	.09	.09	0	0	.09	0
Bar Tail	0	.16	0	.16	0	.16	0	.16
Cut Bank	0	0	0	0	0	0	0	0
Channel Nook	0	0	0	.90	0	.45	0	.45
Eddy Pool	.29	0	0	.29	0	0	0	0
Open Nook	0	1.52	.76	2.28	.76	0	0	.76
Riffle	.13	.13	.13	.13	0	.13	0	.13
Total	**.61**	**2.30**	**1.08**	**4.45**	**.86**	**.84**	**.19**	**1.70**

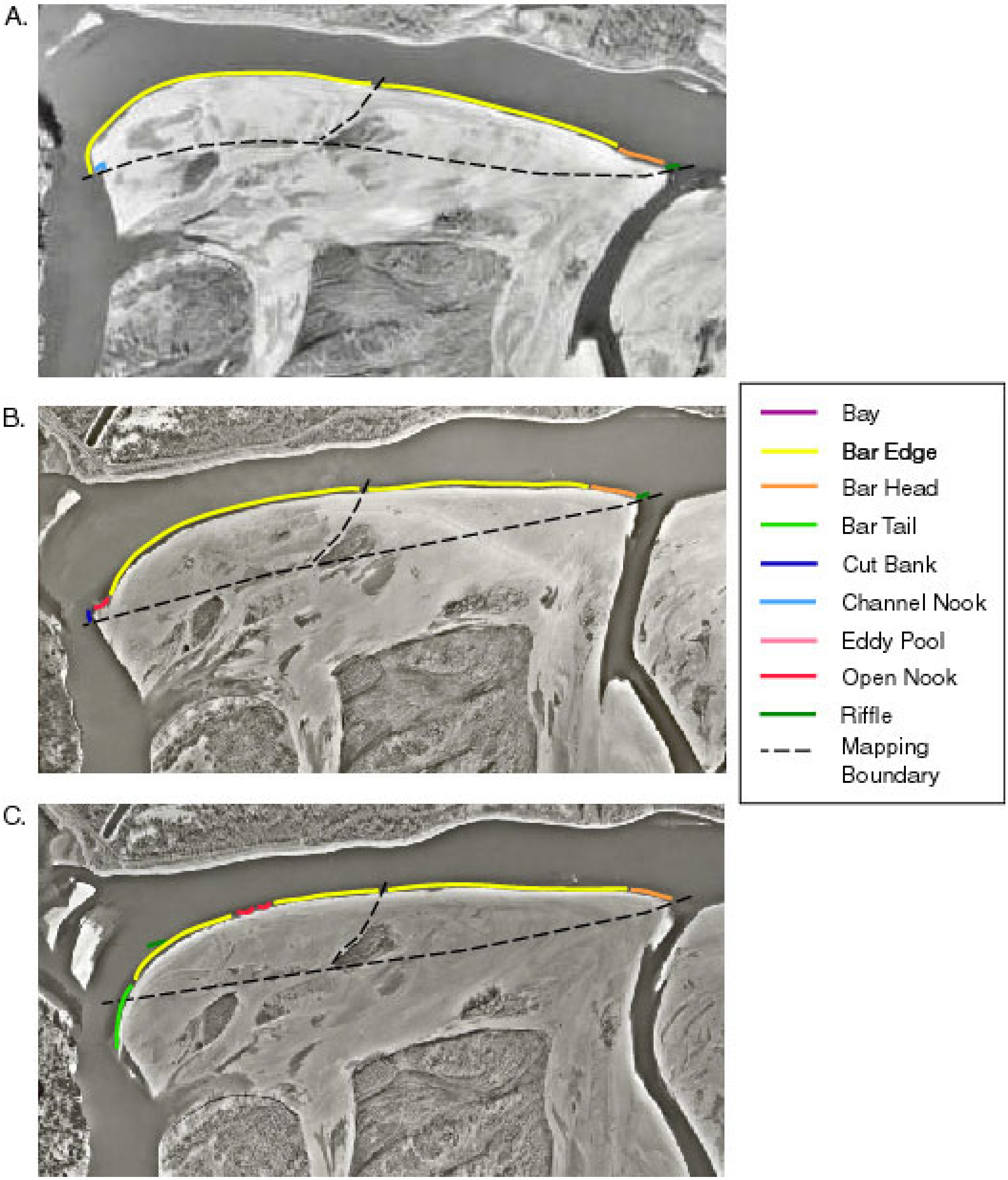


Figure 22. Habitat units around Harrison Bar on (A) March 27 1999 (discharge: 860 m^3/s); (B) March 10 2000 (discharge: 677 m^3/s); and (C) March 7 2001 (discharge: 502 m^3/s).

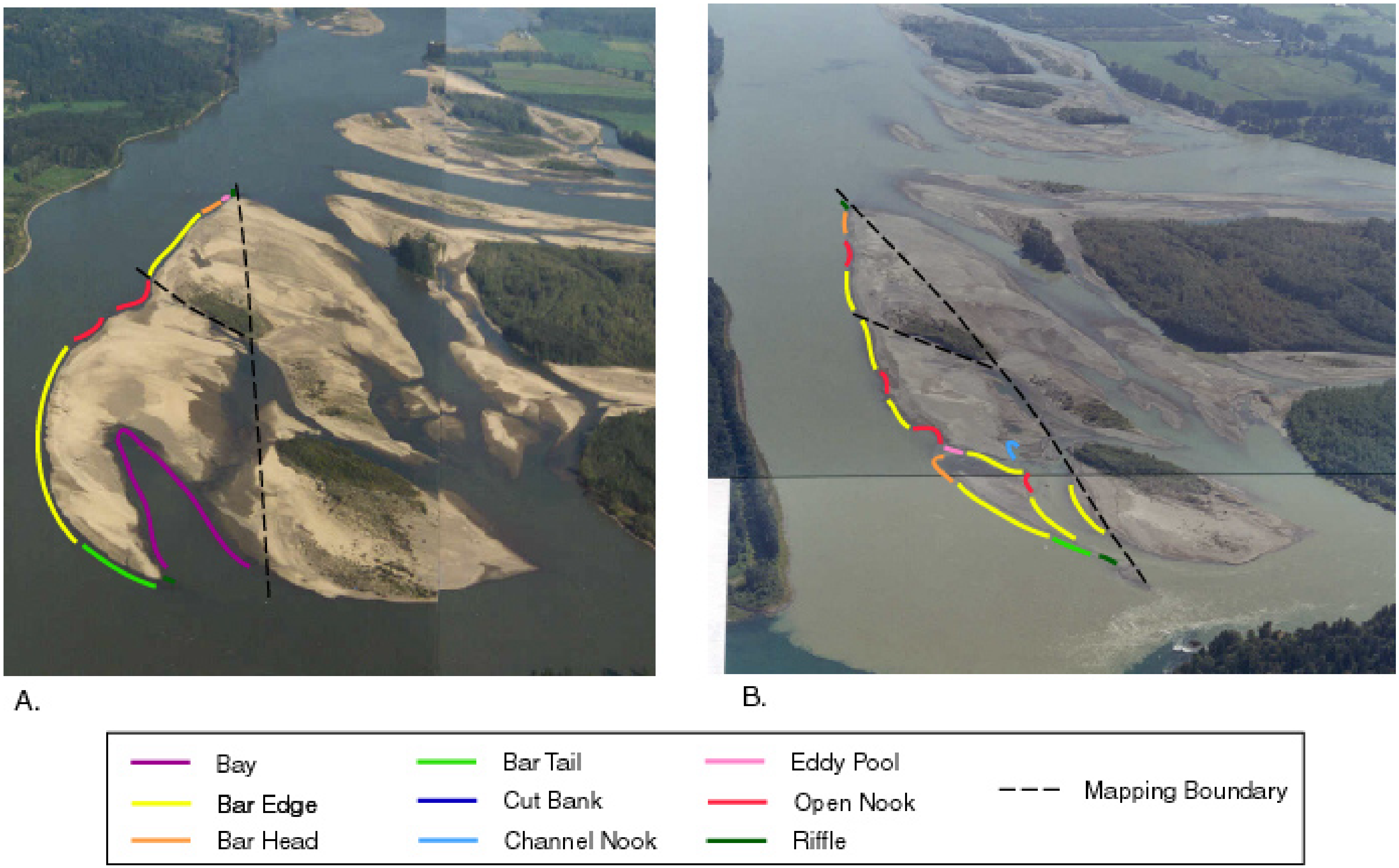


Figure 23. Habitat units around Harrison Bar on (A) August 30, 1995 (discharge: 2680 m^3/s) and on (B) August 21, 2000 (discharge: 2844 m^3/s). One freshet event had occurred since scalping in February 2000.

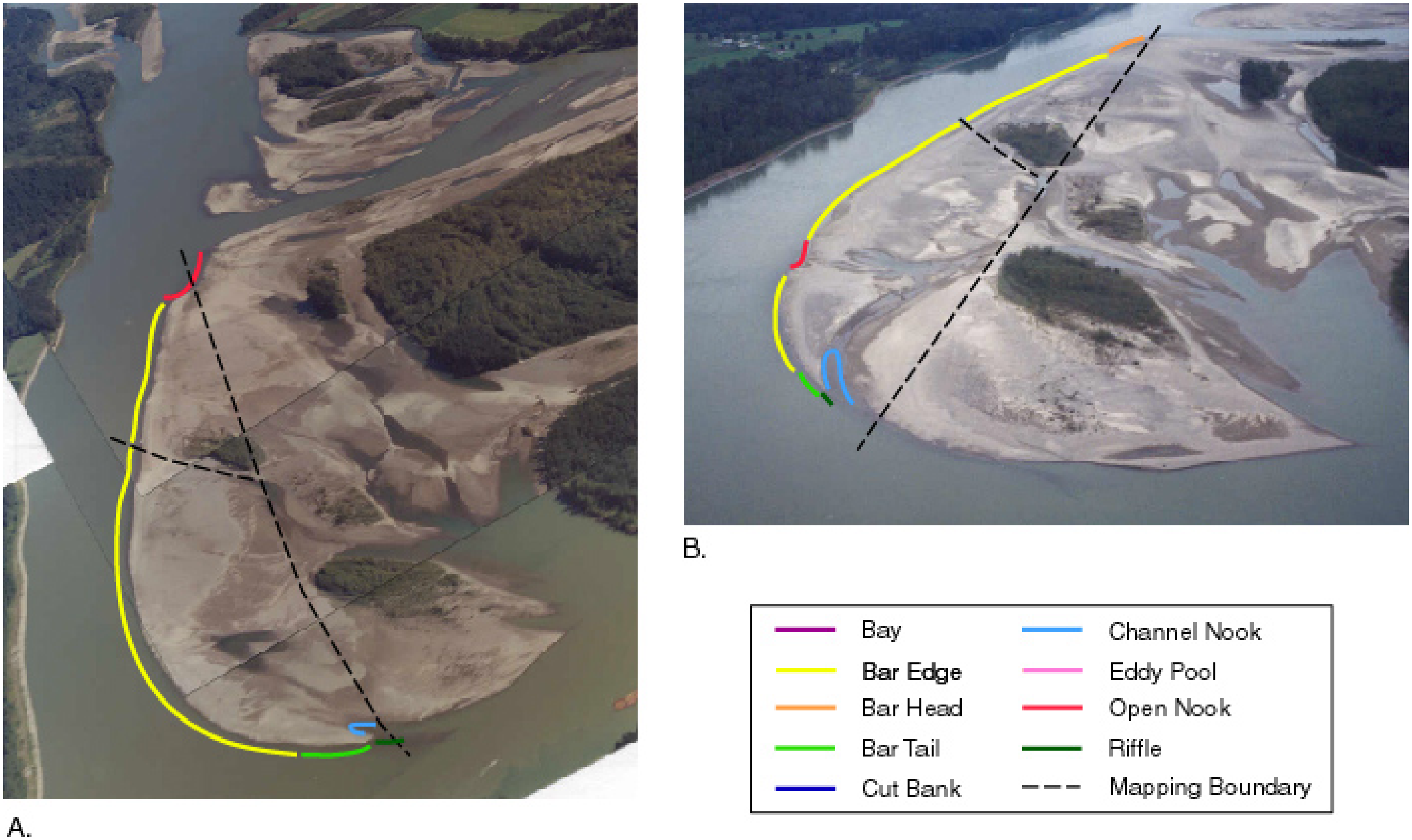


Figure 24. Habitat units around Harrison Bar on (A) September 27, 1999 (discharge: 1950 m^3/s) and on (B) September 20, 2001 (discharge: 1580 m^3/s). Two freshet events had occurred between the gravel removal and photography in 2001.

3.3.2 Physical Contrasts Between Habitat Types

Bar edge habitat was most commonly characterized as having moderate velocity (5 – 50 cm/s), a moderate bank slope less than 5º, and mixed gravel/cobble substrate with low to moderate embeddedness (**Table 13**). Exceptions to these generalized conditions were occasionally found, however, observations made in each year were relatively similar between site groups. Mean velocity decreased after scalping at Har-S while conditions at the reference sites remained relatively consistent in each year. Bank slope fluctuated between low and moderate at all sites and only one steeply sloped bar edge unit was observed at a reference site. The dominant substrate at Har-S was consistently a gravel/cobble mix, and cobble-sized sediment decreased in representation at the reference sites between 1999 and 2001.

Table 13. Bar edge habitat characteristics at Har-S and reference sites (Car-R, Har-R, Fos-R), based on summer sampling between July and August. Values represent the number of beach seine samples (%) matching the particular class (# samples in parentheses).

	1999 *(pre-scalp)*		**2000** *(post-scalp)*		**2001** *(post-scalp)*	
Mean Velocity	**Har-S** (5)	**Reference** (3)	**Har-S** (8)	**Reference** (19)	**Har-S** (2)	**Reference** (10)
< 5 cm/s	0	0	0	10	0	0
5 – 25 cm/s	20	33	12	16	100	30
26 – 50 cm/s	60	33	50	16	0	50
51 – 80 cm/s	20	33	13	47	0	20
> 80 cm/s	0	0	25	11	0	0
Bank Slope						
Low (<2.5º)	20	33	62	11	50	20
Moderate (2.5-5º)	80	67	38	84	50	80
High (<5º)	0	0	0	5	0	0
Dominant Substrate						
Sand	0	33	0	10	0	0
Gravel	60	0	50	32	50	90
Cobble	40	67	50	58	50	10
Lg. Cobble	0	0	0	0	0	0
Substrate Embeddedness						
Low	40	0	75	63	0	60
Moderate	60	67	25	32	100	40
High	0	33	0	5	0	0

Principal components analysis (PCA) of bar edge habitat characteristics accounted for 90.5% of the total variation in the first three PC axes. PC1 explained 44.3% of the variation and represented a hydraulic gradient of increasing water depth, bank angle, and velocity. PC2 accounted for 25.6% of the variation and was correlated with cobble and gravel to represent a gradient of coarse sediment. PC3 explained 20.6% of the variation and was correlated with sand, representing a gradient of fine sediment. The loading of each physical variable on the PC-axes is given in **Table 14**. Asymmetrical ANOVA found a significant short-term impact due to scalping along the hydraulic gradient represented by PC1 (**Table 15**). Graphical examination suggested that the timing of impact was coincident with scalping (**Figure 25**a) but statistical analysis was unable to confirm this because of the limited number of sampling periods prior to mining. Sedimentary gradients represented by PC2 and PC3 were not affected significantly by scalping, although power of the analysis to detect an impact was low.

Table 14. Factor loadings from Principal Components Analysis of bar edge habitat units. Variables significantly correlated with PC-axes are highlighted in bold.

Variable	PC 1	PC 2	PC 3
Cobble	-0.63	**0.71**	-0.26
Gravel	0.29	**-0.88**	-0.35
Sand	0.55	0.08	**0.78**
Bank Angle	**-0.81**	-0.31	0.44
Average Depth	**-0.82**	-0.27	0.42
Average Velocity	**-0.73**	-0.26	-0.27
Eigenvalue	2.66	1.53	1.24
% Variation Explained	44.3	25.6	20.6

Table 15. Results of the asymmetrical ANOVA examining impacts of scalping on the physical characteristics of bar edge habitat units.

Variable	Do reference locations have variable short-term trends after scalping? (A or B)	Does scalping affect short-term temporal trend?	Do reference locations vary in difference from before to after scalping? (C or D)	Does scalping affect differences before or after?	Conclusion	p-value	Power
Hydraulic Gradient (PC 1)	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-
Coarse Sediment Gradient (PC 2)	No	No	No	No	No impact detected	0.72	0.004
Fine Sediment Gradient (PC 3)	No	No	No	No	No impact detected	0.48	0.04

Details of analysis given in Appendix F.

Figure 25a shows a seasonal shift at Har-S along PC1 relative to reference sites from shallow and lower velocity conditions in summer months to deeper and faster flowing water in winter. The shift was observed over three summers of sampling but only in May 2000 did PC1 scores for Har-S fall outside the range of conditions observed at the reference sites (based on 95% confidence intervals). May 2000 corresponded to the period when flooding began to inundate the scalped site. The difference in hydraulic conditions between reference sites and Har-S was less in August and September 2000 on the declining limb of the hydrograph, and PC1 values in September 2001 were similar to those in September 1999 at reference sites and Har-S. A shift in the relation between site groups along PC2 or PC3 was not observed (**Figure 25**b, c), and the sites had similar PC-values on all dates before and after scalping.

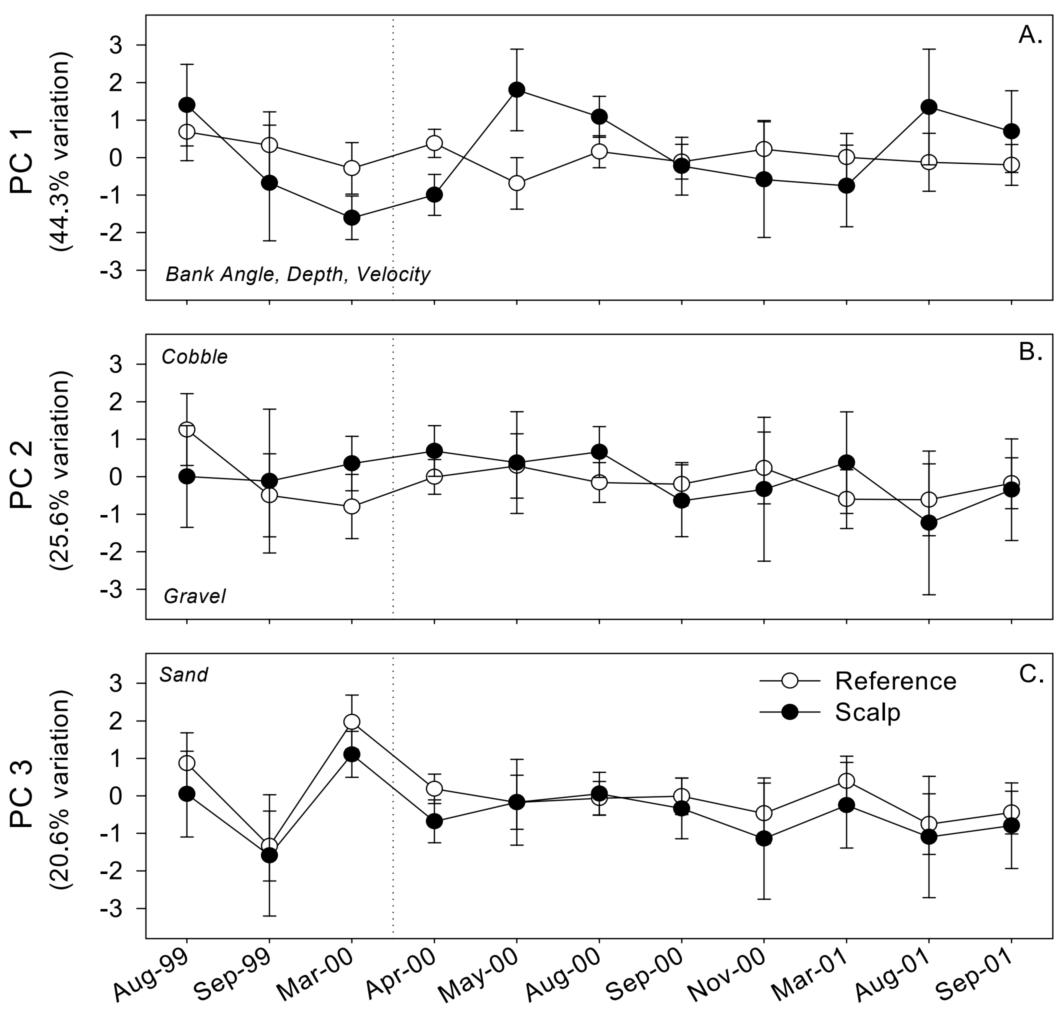


Figure 25. Mean factor scores (± 95% confidence interval) for reference sites and the scalped site, derived from principal components analysis of bar edge habitat characteristics. The proportion of variation explained by each PC-axis is given and the variables most highly correlated with each axis are listed in italics. Bar scalping took place after sampling in March 2000 (indicated by dotted line).

3.4 Juvenile Fish

3.4.1 Night Time Bar Scalping Observations

Night sampling by beach seine on March 13, 2000 assessed whether or not removal activities reduced the presence of fish along the bar edge. Sampling at Har-R and Har-S found a higher percentage of fish belonging to the family Salmonidae in the reference area of Harrison Bar than in the scalping area (**Figure 26**). Species richness and fish density were higher at Har-R as well, but values at Har-S fell within the range observed at Har-R.

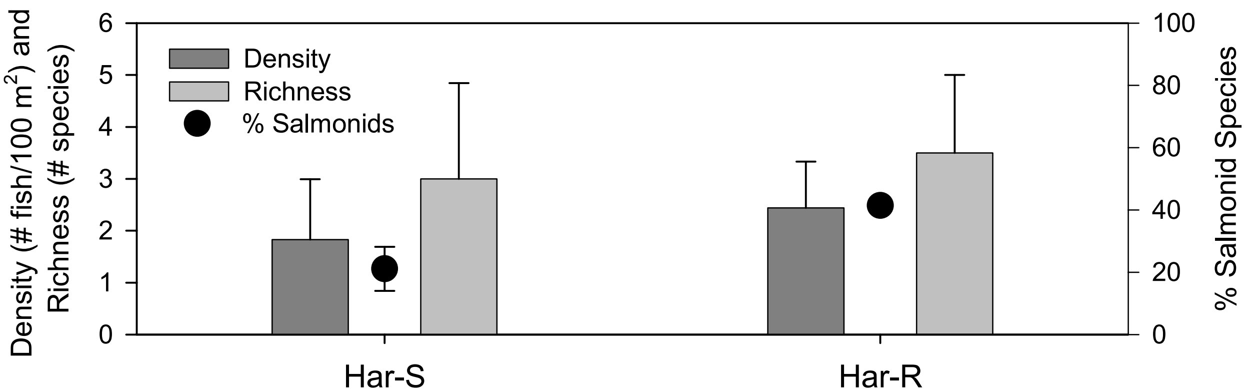


Figure 26. Average (± SE) catch data from night time beach seines in bar edge habitat at the scalped site (Har-S) and reference site (Har-R) in March 2000. Four seines were conducted at Har-S and two were conducted at Har-R.

The average length of chinook salmon captured in night time beach seines was higher at Har-R than at Har-S but the sample size at Har-R was low (two fish measuring 40 and 104 mm). The lengths of chum salmon, coastrange sculpin (*Cottus aleuticus*), and leopard dace (*Rhinichthys falcatus*) were similar at both sites in night beach seines (**Figure 27**).

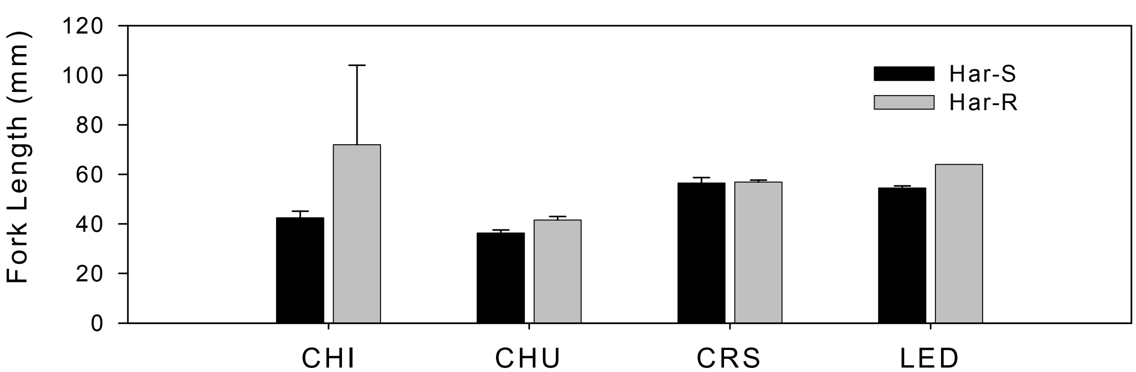
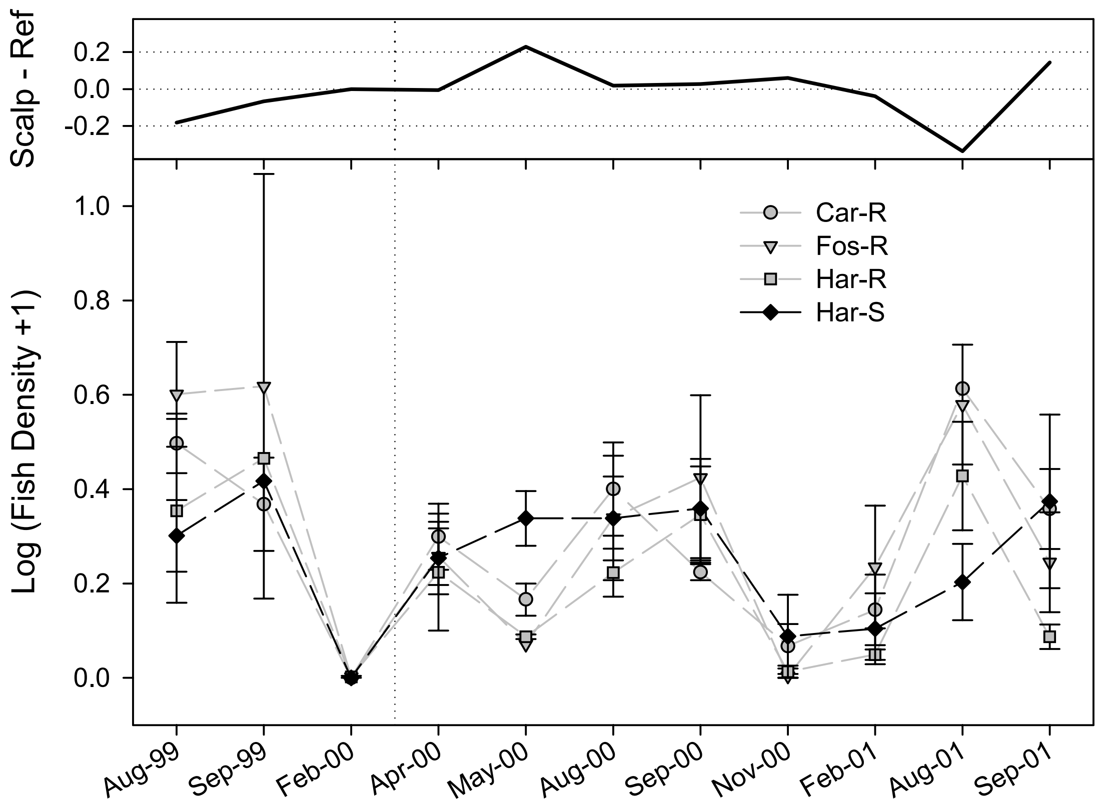


Figure 27. Average (± SE) fork length of fish captured at night by beach seine at Har-S and Har-R in March 2000. Species codes listed in Appendix C.

3.4.2 Bar-Scale Examination

A total of 12,094 fish were captured at Har-S and the reference sites by beach seine between August 1999 and September 2001. The number of beach seines varied among months (**Figure 28**) due to a variety of factors including sampling constraints and safety. Limited sampling took place during winter months (November through March) because few fish were encountered. Density averaged 0.24 fish/10-m^2 in winter 2000 and 2001 combined (**Figure 28**). Limited sampling also took place during peak freshet (May, June) when high velocities and water levels created dangerous conditions for sampling.



6	2	7	12	4	15	9	2	5	5	3	Har-S
14	11	5	27	5	29	21	6	18	13	22	Reference Sites

Figure 28. Average (± SE) fish density (#/10 m^2) based on beach seines in all habitat types conducted in 3 months before and 8 months after scalping at Harrison Bar. The number of beach seines in each month is listed in the box below. Vertical dotted line denotes the timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of the reference site values.

Fish density was variable among sites on most sampling dates throughout the study but sites followed a similar seasonal trend, with highest fish density between April and September and lowest density in winter months (**Figure 28**). In all months after scalping except February and August 2001, density at Har-S was equal or greater than the average density at reference sites (upper panel **Figure 28**) and no significant impact due to scalping was detected (**Table 16**). Fish density was most variable among sites in summer 1999 when unusually large numbers of redside shiner (*Richardsonius balteatus*) leopard dace (*Rhinichthys flacatus*) occupying open nook and bar edge habitats were collected at Fos-R. The increase in density from February to April 2000 was partly attributed to chum salmon fry (*Oncorhynchus keta*) migrating downstream. The stomachs of these fish were always full and consisted mostly of adult and larval chironomids, zooplankton, and mayflies. These observations indicated that chum fry were using habitat in the gravel reach for feeding and justified the species' inclusion in data tabulations.

Also in April 2000, a significant number of adult marine stickleback (*Gasterosteus aculeatus trachurus*) was collected in beach seines. These fish were migrating upstream to spawn and, although the spawning area is uncertain, spawning likely does not occur within the main channel of the gravel reach (Dr. Don M^{c}Phail, personal communication). For this reason, the species was excluded from data tabulations. By including marine stickleback, average density would have increased from 0. 9 to 2.0 fish/10-m^2 in April 2000. Highest densities of marine stickleback in April 2000 were found at the scalped site, occupying newly created open nook and channel nook habitat in the lower corner of removal Area B.

Table 16. Results of the asymmetrical ANOVA examining impacts of gravel mining on juvenile fish metrics at the bar scale (all habitats combined).

Variable	Do reference locations have variable short-term trends after scalping? (A or B)	Does scalping affect short-term temporal trend?	Do reference locations vary in difference from before to after scalping? (C or D)	Does scalping affect differences before or after?	Conclusion	p-value	Power
Total Density	No	No	No	No	No impact detected	0.37	0.18
Salmonid Index	No	No	No	No	No impact detected	0.27	0.08
Species Richness	No	No	No	No	No impact detected	0.68	0.37
Simpson's Diversity	No	No	No	No	No impact detected	0.49	0.26
Simpson's Evenness	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-

Details of analysis in Appendix G.

The proportion of fish belonging to the family Salmonidae was highly variable among sites during all periods of sampling by beach seine. Har-S had consistently lower salmon representation than reference sites before scalping, but a higher than average value during sampling in May 2000 (**Figure 29**). Virtually all these fish were chinook salmon occupying bar edge and bay habitat within the former removal area. The proportion of salmon species was low at Har-S relative to all reference sites during summer and autumn sampling in 2000, but showed a sharp increase again in February 2001, when chum salmon and mountain whitefish (Prosopium williamsoni) were collected. After one year post-scalping in 2001, the proportion of salmon species at Har-S was similar to reference sites both in summer and winter. The power to detect an impact due to scalping in the proportion of salmon was low, presumably due to the large amount of variance occurring both through time and space among reference sites.

Species richness at Har-S was similar to reference sites in most months of sampling and averaged approximately 4 species per beach seine (**Figure 30**). After scalping, values at Har-S were similar to reference sites during all periods except September 2000 and August 2001, when richness was below average. Richness was extremely low in winter months in comparison with spring and summer, during which period values were relatively consistent among sites and months. It followed that power to detect an impact was moderate and no impact due to bar scalping was found (**Table 16**).

Species diversity, measured as Simpson's diversity, showed a temporal pattern similar to species richness. Seasonal differences between winter and spring/summer were dramatic and were observed consistently at all sites (**Figure 31**). Diversity was lower at Har-S than reference sites in summer 1999 before scalping and remained lower immediately after scalping in April and May 2000. However, samples in all periods after August 2000 had similar diversity at the scalped site compared with reference sites. No impact due to bar scalping was detected (**Table 16**).

Simpson's evenness did not show a strong seasonal trend, unlike most other metrics evaluated. Average evenness at Har-S was highly variable both before and after scalping in relation to the mean value observed at reference sites (upper panel, **Figure 32**). Evenness was higher at Har-S in August 1999, 2000, and 2001 compared with reference sites, but varied considerably in the intervening periods. A significant impact due to bar scalping was detected by asymmetrical ANOVA but the small number of sampling episodes before scalping gave the analysis inadequate power to confirm if the timing of change at Har-S was coincident with scalping (**Table 16**).

The analyses carried out above were based on a relatively large number of samples (242 in total) because beach seines conducted in all habitat types were pooled together. A larger sample size afforded the analysis a higher number of degrees of freedom (i.e., power) from which to detect an impact. However, we expected that analyses conducted at the habitat-unit scale might be more sensitive because the variance due to habitat differences was accounted for rather than being incorporated into the error term of the analysis. (A total of 124 beach seines were conducted in bar edge units.) These analyses are presented below.

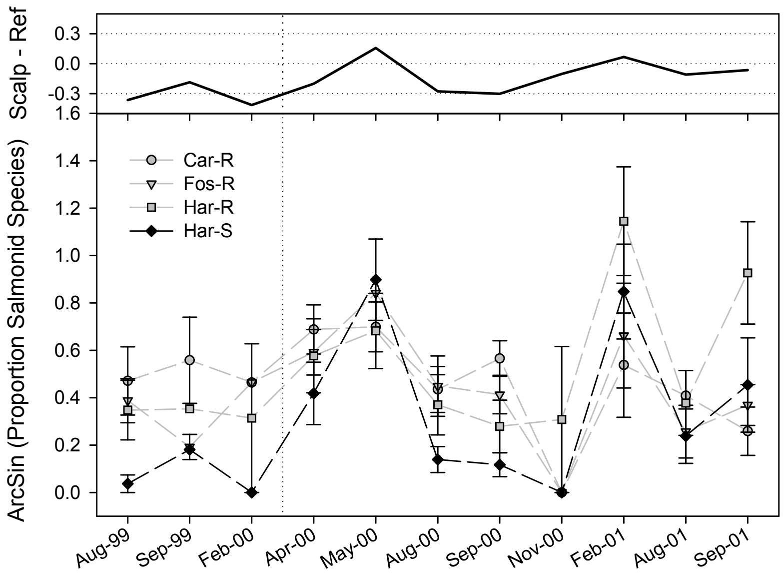


Figure 29. Average (± SE) proportion of salmonid species in all habitats conducted in 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

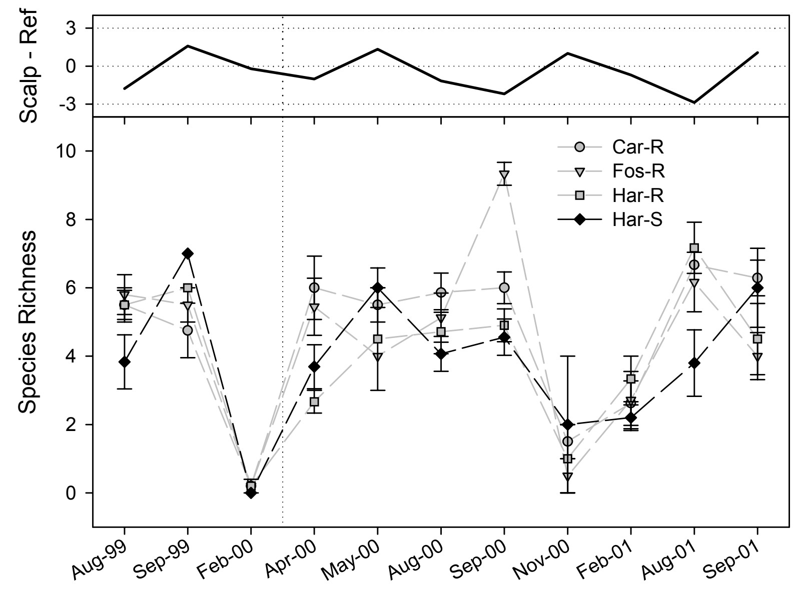


Figure 30. Average (± SE) number of unique species in all habitats during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

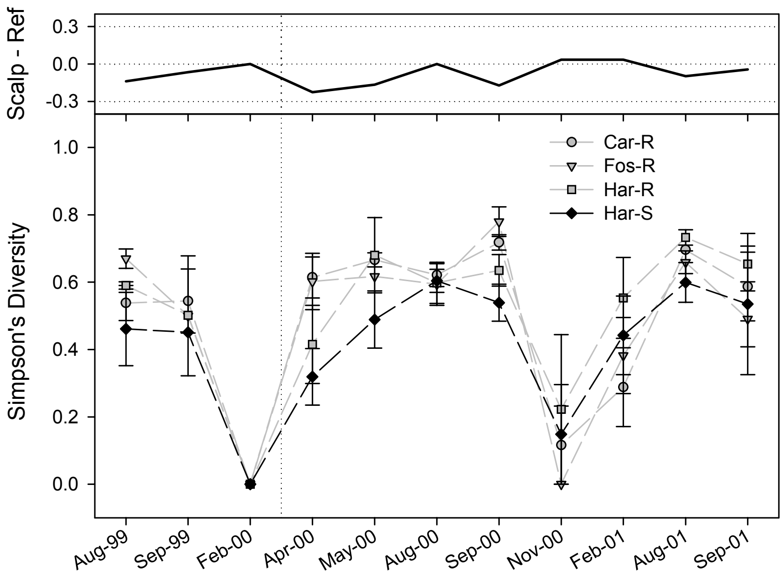


Figure 31. Average (± SE) Simpson's diversity in all habitats during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

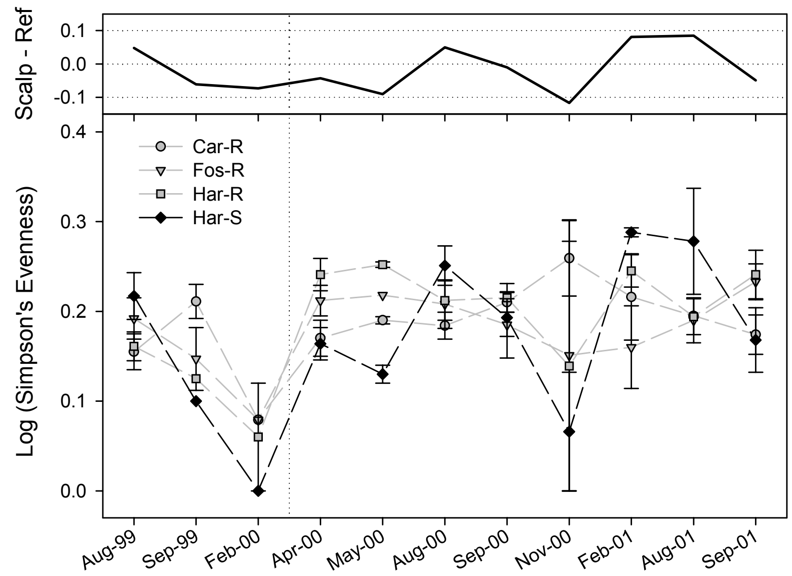


Figure 32. Average (± SE) Simpson's evenness in all habitats during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

3.4.3 Habitat-Scale Examination: Bar Edge Units

Fish density within bar edge habitat was most variable among sites in summer 1999 (**Figure 33**). A single bar edge beach seine at Car-R in September 1999 had unusually high numbers of mountain sucker (*Catostomus platyrhynchus*), chinook salmon, and redside shiner. All sites had very low density in winter months before and after scalping. Whereas Har-S had similar density relative to reference sites before mining, density was highly variable in subsequent months (upper panel, **Figure 33**). Higher than average density at Har-S in May 2000 consisted mostly of chinook salmon and leopard dace. Lower than average density at Har-S in August 2001 was due to an absence of northern pikeminnow (*Ptychocheilus oregonensis*), redside shiner, and peamouth chub (*Mylocheilus caurinus*), which were abundant at all reference sites in the same month. The asymmetrical ANOVA did not detect a significant impact at Har-S due to scalping (**Table 17**), however, statistical power was low. Contrasting power between this habitat-scale analysis and the whole-bar analysis suggested that isolating bar edge units did not improve the sensitivity of the analysis as compared with the gain in power contributed by a larger sample size at the whole-bar scale.

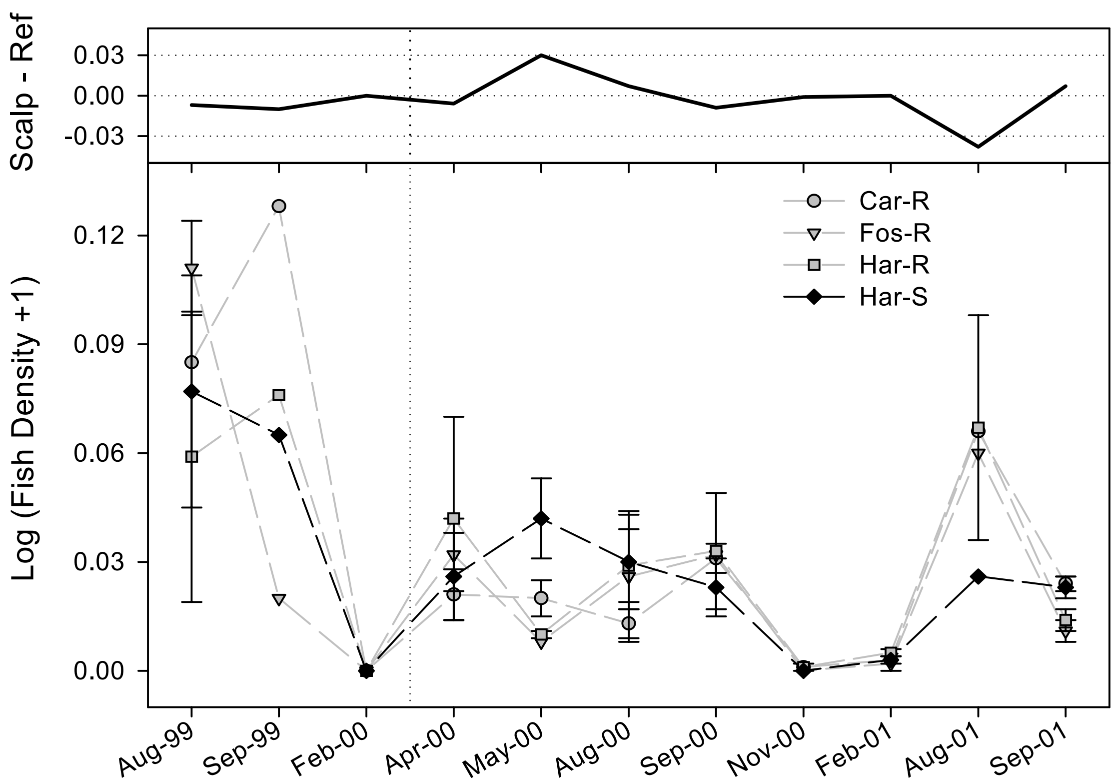


Figure 33. Average (± SE) fish density (#/10 m^2) based on beach seines in bar edge habitat conducted in 3 months before and 8 months after scalping at Harrison Bar. Vertical dotted line denotes the timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

Table 17. Results of asymmetrical ANOVA examining impacts of scalping on juvenile fish at the habitat scale (bar edge habitat only).

Variable	Do reference locations have variable short-term trends after scalping? (A or B)	Does scalping affect short-term temporal trend?	Do reference locations vary in difference from before to after scalping? (C or D)	Does scalping affect differences before or after?	Conclusion	p-value	Power
Total Density	No	No	No	No	No impact detected	0.66	0.042
Salmonid Index	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	0.01	-
Species Richness	No	No	No	No	No impact detected	0.67	.09
Simpson's Diversity	No	No	No	No	No impact detected	0.87	.004
Simpson's Evenness	No	No	No	No	No impact detected	1.00	.07

Details of analysis in Appendix H.

The proportion of fish belonging to the family Salmonidae was consistently lower at Har-S than at reference sites in all months of sampling prior to bar scalping (**Figure 34**). The average value increased sharply at Har-S between February and May 2000 before dropping abruptly in August 2000. May 2000 beach seines at Har-S contained a high number of chinook salmon. Although most reference sites followed a similar temporal trend as Har-S in 2000, the change in salmonid representation was more dramatic at Har-S over this period and a short-term impact was detected by asymmetrical ANOVA (**Table 17**). Graphical analysis indicated that the timing of the change was coincident with scalping, however, statistical analysis could not confirm this because of an inadequate number of pre-scalp sampling episodes. Salmonid species were relatively common at Har-S in each month sampled in 2001. Whereas the proportion of salmonids at Har-S was comparable in summer months between 1999 and 2000 and lower than reference sites, it was higher than reference sites in August and September 2001and higher than previous years. In general, chinook salmon was the most common salmonid species at all sites and in all months.

The number of unique species in beach seines was consistent among sites in the months prior to scalping at Harrison Bar and showed a strong seasonal trend (**Figure 35**). Species richness increased between winter and spring at all sites and in both years after scalping. Har-S had higher than average species richness in May 2000 and notably lower richness than reference sites in August 2001 due to an absence of northern pikeminnow, redside shiner, and peamouth chub, which were abundant at all reference sites. No significant impact due to bar scalping was detected at Har-S based on values of species richness (**Table 17**). Similar with total density, statistical power to detect an impact was lower when bar edge units were isolated for analysis.

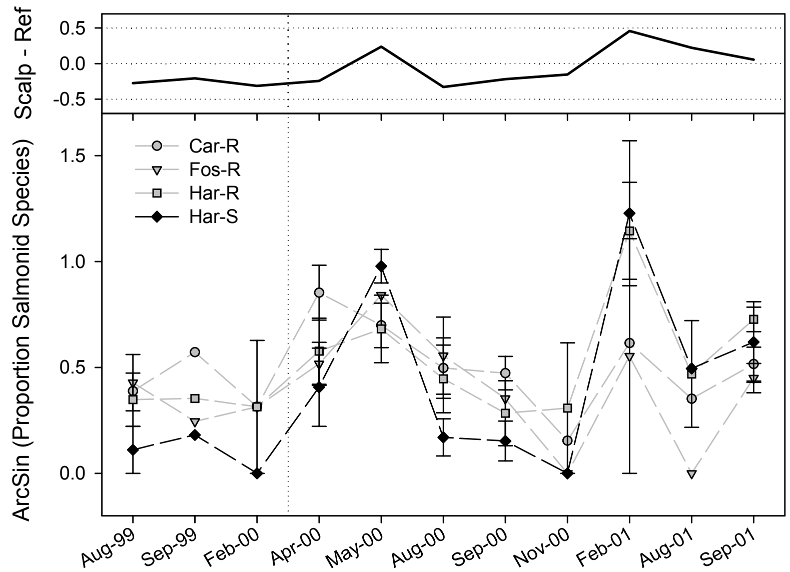


Figure 34. Average (± SE) proportion of salmonid species based on beach seines in bar edge habitat conducted in 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

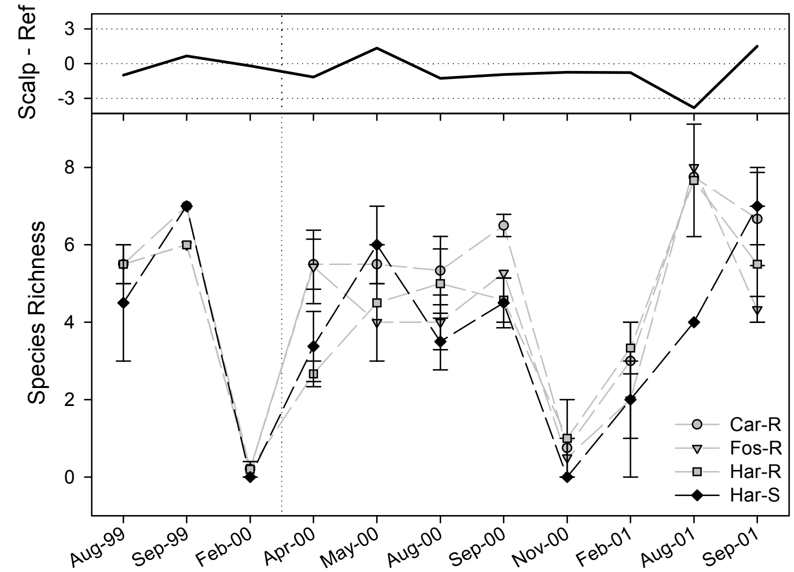


Figure 35. Average (± SE) number of unique species in bar edge habitat during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

Simpson's diversity showed a temporal pattern similar to that of species richness. Whereas seasonal differences were notable, differences among all sites in each month of sampling were relatively small (**Figure 36**). Not surprisingly, no significant impact due to scalping was detected based on Simpson's diversity (**Table 17**). In most months before and after bar scalping, diversity at Har-S was lower than the average of reference sites. Considering summer months only, reference sites had similar species diversity in all years while Har-S showed an increasing trend from 1999 to 2001. Only in summer 2001 was diversity higher at Har-S than the average of reference sites.

Species evenness was highly variable among sites and between sampling periods (**Figure 37**). Har-S exhibited the greatest variability of all sites, but this variation was in part a reflection of the low sample size in winter months. No impact due to bar scalping was detected based on estimates of species evenness at the bar edge habitat scale (**Table 17**).

For both Simpson's diversity and evenness, the estimated power to detect an impact was low, and considerably lower than when all habitat types were pooled at the bar-scale for analysis. Clearly, the isolation of bar edge units did not reduce variance to the same degree that an increase in degrees of freedom improved statistical power when all habitat types were pooled. We suspect, however, that this result may be unique to bar edge because it has variable physical characteristics compared with most other habitat types such as open nook or eddy pool. These latter habitat types are less common in the gravel reach, and the number of beach seines carried out in these habitat types was insufficient for asymmetrical ANOVA.

3.4.4 Species-Specific Contrasts – Bar Edge Habitat

Bar edge summer densities of commonly occurring fish species were notably variable among years (**Figure 38**). Several species, especially leopard dace and redside shiner, were substantially more abundant in 1999, although the reason for lower densities in 2000 and 2001 is uncertain. The same beach seine net was used throughout the study (necessary repairs were made after each summer) and sampling techniques were consistent in each year. A similar difference in density after summer 1999 was observed at other sites sampled for a different study, indicating it was not a site-specific phenomenon.

Juvenile chinook salmon density increased at Har-S from before to after scalping, but was generally lower than at reference sites in each year. Leopard dace showed the most dramatic decline in density between years, from an average of 0.084 fish/m^2 in 1999 to 0.014 fish/m^2 and 0.022 fish/m^2 in 2000 and 2001, respectively. A substantial reduction in the density of redside shiner between years was observed as well but, in each year, density at Har-S was comparable with that at reference sites. Northern pike minnow (*Ptychocheilus oregonensis*) density was similar between Har-S and reference sites prior to scalping but was lower at Har-S in the two summers after scalping. In contrast, largescale sucker (*Catostomus macrocheilus*) density was higher at Har-S relative to reference sites after scalping. Mountain sucker (*Catostomus platyrhynchus*) was uncommon at Har-S throughout the study but was observed at reference sites in variable densities in each summer.

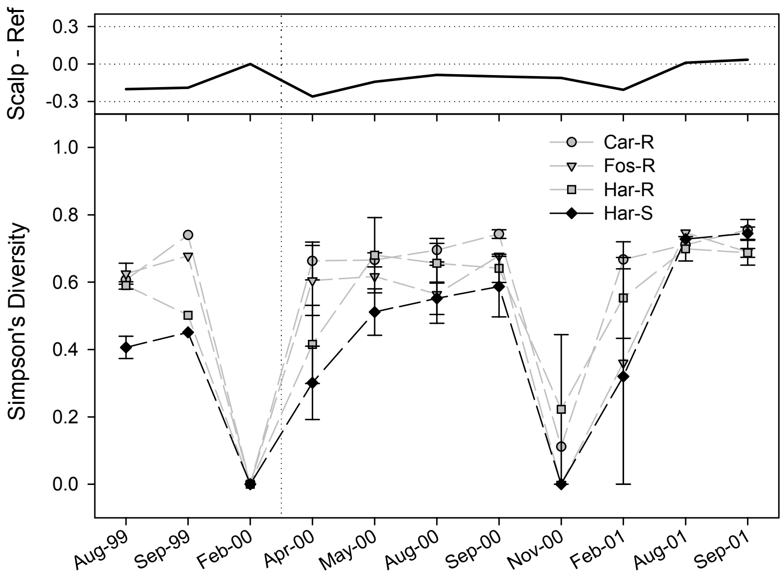


Figure 36. Average (± SE) Simpson's diversity in bar edge habitat during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

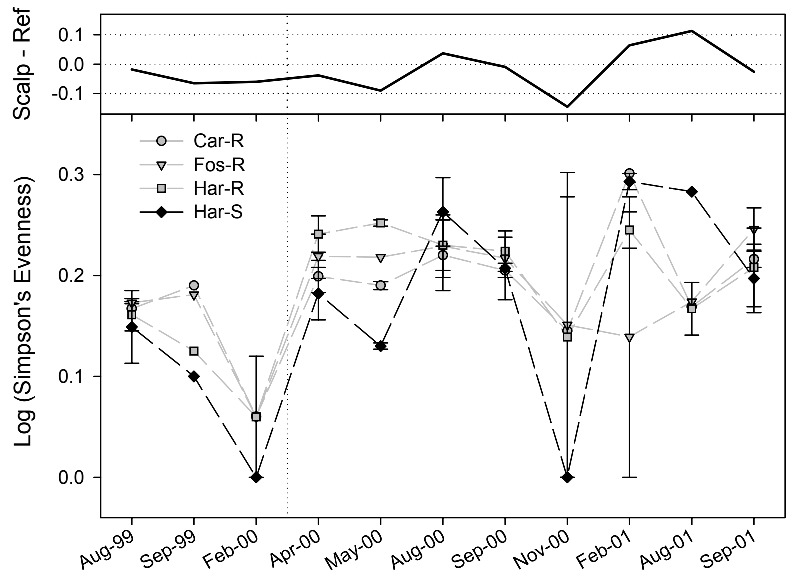


Figure 37. Average (± SE) Simpson's evenness in bar edge habitat during 3 months before scalping and 8 months after scalping at Harrison Bar. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

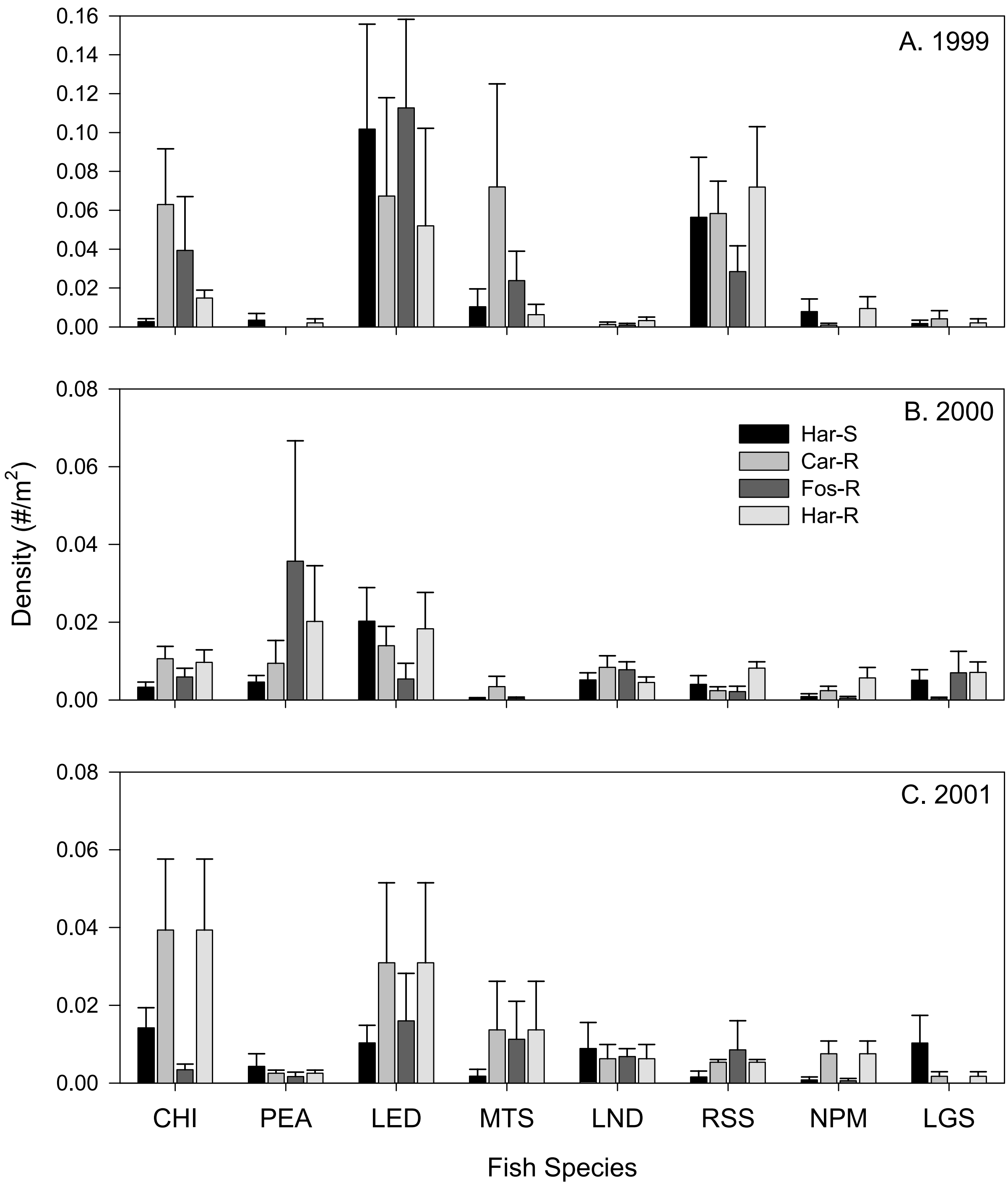


Figure 38. Average (± SE) density of common fish species collected within bar edge habitat during summer months in 1999 (before scalping) and summer two years after scalping. Bar scalping occurred at Har-S in March 2000. Species codes are listed in Appendix C.

3.5 Benthic Invertebrates

The asymmetrical ANOVA to examine scalping impacts on benthic invertebrates yielded identical results for all variables analyzed at the bar-scale and the scale of bar edge habitat units. However, statistical power to detect an impact was higher for habitat-scale analyses of bar edge units. We present graphical data and statistical results based on the habitat-scale only (bar edge habitat). Detailed reporting of ANOVA results is in Appendix I (whole bar) and J (bar edge units only).

3.5.1 Habitat-Scale Examination: Bar Edge Units

A total of 85,704 benthic invertebrates were collected at Har-S and three reference sites between September 1999 and September 2001 (11 sampling episodes). Invertebrate density varied according to season at all sites, with February samples containing more than 4 times the density of animals as in August and September (**Figure 39**). Year to year variability was evident as well: average density in September 2000 was 4 times lower than in September 1999 and 9 times lower than in September 2001. We speculate that a sudden rise in discharge in early September 2000 (refer to **Figure 5**) may be the cause of low average density in these samples: either the higher discharge flushed invertebrates from the surface sediment or there was insufficient time for invertebrates to colonize the temporarily inundated bar edge prior to samples being collected. In either case, August 2000 samples would be more representative of late summer conditions and more appropriately compared with September samples from other years.

Har-S had average density similar to that of reference sites prior to scalping but lower density following scalping in May and August 2000. This difference is reflected in the top panel of **Figure 39**. Asymmetrical ANOVA detected a short-term impact at Har-S (**Table 18**), but lacked statistical power to confirm that the impact was coincidental with scalping because of the small number of sampling episodes before scalping. Samples in May and August 2000 were collected within the removal boundary and from sediment previously disturbed by scalping. On all sampling dates after August 2000, density at Har-S was higher than the average of reference sites. Notably high density at Har-S in January 2000 consisted of high numbers of Chironomidae and the mayfly Baetidae. Average density in February 2000 at Har-S fell within the range observed at reference sites prior to scalping (**Figure 39**). After scalping in February 2001, the same pattern was observed although densities were higher at most sites.

The average proportion of invertebrates belonging to the orders Ephemeroptera, Plecoptera, and Tricoptera (EPT) was highest in samples from Har-S before scalping and values remained higher than reference sites immediately after scalping in April 2000 (upper panel, **Figure 40**). A significant impact was detected by asymmetrical ANOVA (**Table 18**). Har-S had the highest April value (53%), with samples containing a high proportion of the mayfly *Ameletus* sp. Samples from all sites in April 2000 contained a large number of *Ameletus* sp. The proportion of EPT at Har-S in May 2000 was lower than at all reference sites, however, the difference between reference sites and Har-S was relatively small in all months after May 2000 (upper panel, **Figure 40**). The %EPT at Har-S in September 2001 was lower than before scalping in 1999 but fell within the range observed at reference sites. Winter samples collected in February 2000 had a similar %EPT at all sites, ranging between 4% at Har-R and 19% at Har-S. After scalping, the average % EPT at Har-S in February 2001 was higher than at most reference sites (15%) and comparable to samples collected in February 2000 (19%).

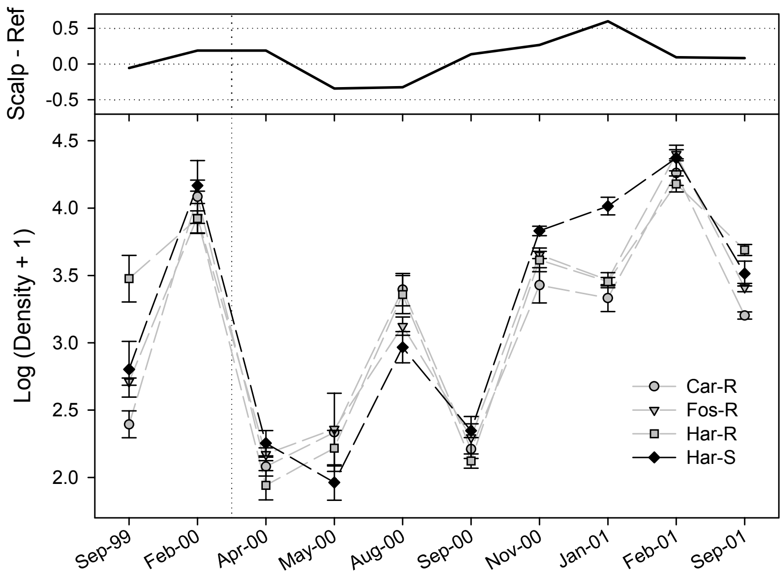


Figure 39. Average (± SE) density of benthic invertebrates collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

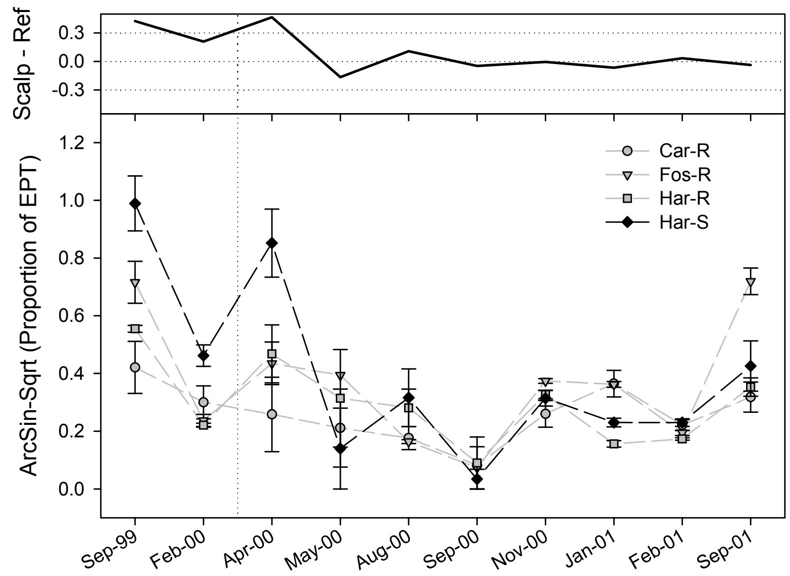


Figure 40. Average (± SE) proportion of Ephemeroptera, Plecoptera, and Tricoptera collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

Table 18. Results of the asymmetrical ANOVA examining impacts of scalping on benthic invertebrate community at Harrison Bar. (EPT: Ephemeroptera, Plecoptera, Tricoptera)

Variable	Do reference locations have variable short-term trends after scalping?	Does scalping affect short-term temporal trend?	Do reference locations vary in difference from before to after scalping?	Does scalping affect differences before or after?	Conclusion	p-value	Power
Invertebrate Density	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-
% EPT	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-
Taxa Richness	Yes	No	-	-	No short-term impact detected	0.39	0.54
# EPT taxa	Yes	No	-	-	No short-term impact detected	0.21	0.67
Simpson's Diversity	Yes	No	-	-	No short-term impact detected	0.35	0.62
Simpson's Evenness	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-

Details of analysis in Appendix I.

Taxonomic richness followed a seasonal cycle similar to density; winter samples collected between November and February had the highest number of unique taxa (**Figure 41**). Richness at Har-S was consistent between February 2000 and 2001, averaging approximately 13 taxa. February values at Har-S in both years were slightly higher than the average at most reference sites (upper panel, **Figure 41**). Over three sampling periods after scalping, Har-S had lower richness than reference sites but this difference was not statistically significant (**Table 18**) and no significant impact due to scalping was detected. Power to detect an impact was 0.54 compared with 0.23 when all habitat types were pooled for analysis. Comparing richness in summer months between years, Har-S was higher than reference sites in 1999, comparable after scalping in 2000, and lower than reference sites in 2001.

The number of EPT taxa in samples followed temporal patterns similar to that of taxonomic richness at all sites (**Figure 42**). EPT richness was highest in winter months and Har-S had higher values than the average of reference sites both before and after scalping. A notable reduction in the relative number of EPT at Har-S in May and August 2000 samples was not statistically significant and no impact due to scalping was detected (**Table 18**). The power to detect an impact was high (0.67), and approximately double the power attained when all habitat types were pooled for analysis (0.34).

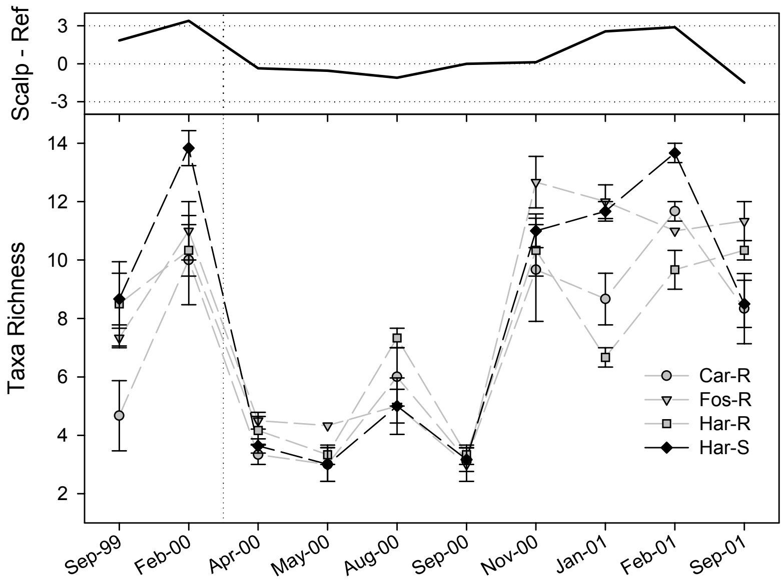


Figure 41. Average (± SE) taxon richness in samples collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

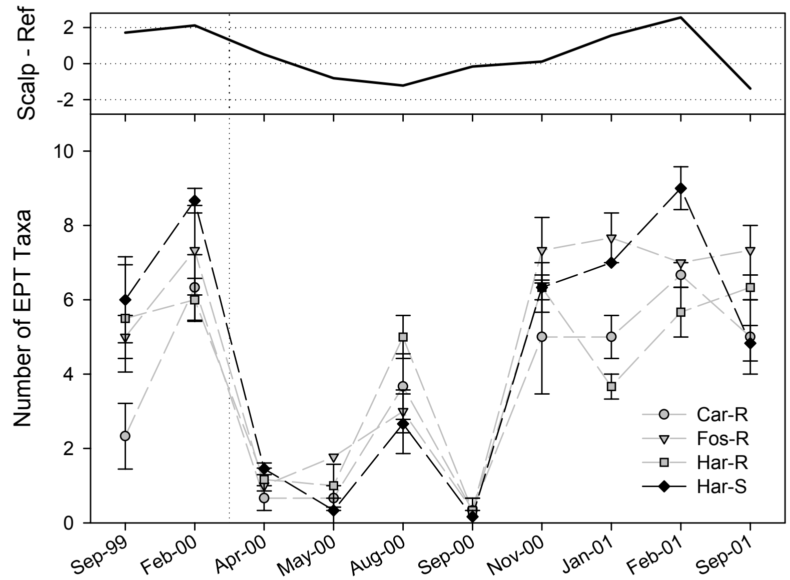


Figure 42. Average (± SE) number of taxa belonging to the Orders Ephemeroptera, Plecoptera, and Tricoptera in samples collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

Species diversity averaged 0.69 at Har-S in September 1999 prior to scalping (**Figure 43**) and reference sites had values ranging from 0.41 to 0.64. A reduction in diversity between September 1999 and February 2000 was observed at all sites. While all sites increased in diversity between February and April 2000, the increase was smallest at Har-S. Between May and November 2000, diversity at Har-S was higher than the average of reference sites (upper panel, **Figure 43**). Diversity was lowest at Har-S in January 2000, when densities of Chironomidae and Baetidae were high. All sites showed very little change in diversity between February 2000 and 2001. However, comparing September 1999 to 2001 revealed a decrease in diversity at Har-S and Car-R and values at Har-S were less than the average of all reference sites. No impact due to bar scalping was detected based on the analysis of diversity and statistical power (0.62) was relatively high (**Table 18**). Power was 0.49 when all habitat types were pooled for analysis.

Changes in evenness at Har-S relative to the reference sites over the duration of the study were similar to those of diversity (**Figure 44**). In all months except January 2000, evenness was highly similar at Har-S and at the reference sites. Evenness was highest in the months immediately after scalping at most sites, including Har-S, and evenness was lowest at all sites in the winter months of 2000 and 2001. The numerical dominance of the chironomid Orthocladiinae contributed to low evenness values in February of both years. Year to year differences in September values were observed at all sites and September 2000 values were higher than 1999 or 2001 values at all sites. Asymmetrical ANOVA revealed a short-term impact due to bar scalping at Har-S, although the analysis lacked temporal resolution to confirm if the change was coincident with the timing of removal because of the small number of sampling episodes prior to scalping (**Table 18**).

Power to detect an impact due to bar scalping in the analysis of invertebrate data was higher when bar edge units were isolated from bar head and bar tail. This is in contrast to the analysis of fish data in which power was greatest when all habitat types were pooled and sample size was large (242 versus 124 samples in bar edge units). The difference in sample size was smaller for invertebrate data, 197 samples collected at the whole bar scale versus 155 collected within bar edge units. For invertebrate analyses, isolating bar edge units appeared to reduce habitat-specific variance that was otherwise included in the error term of the analysis, thereby increasing power to detect a change. It should be noted that power was higher for analyses of invertebrate data compared with fish data, regardless of the spatial scale of examination (i.e., whole bar or bar edge only).

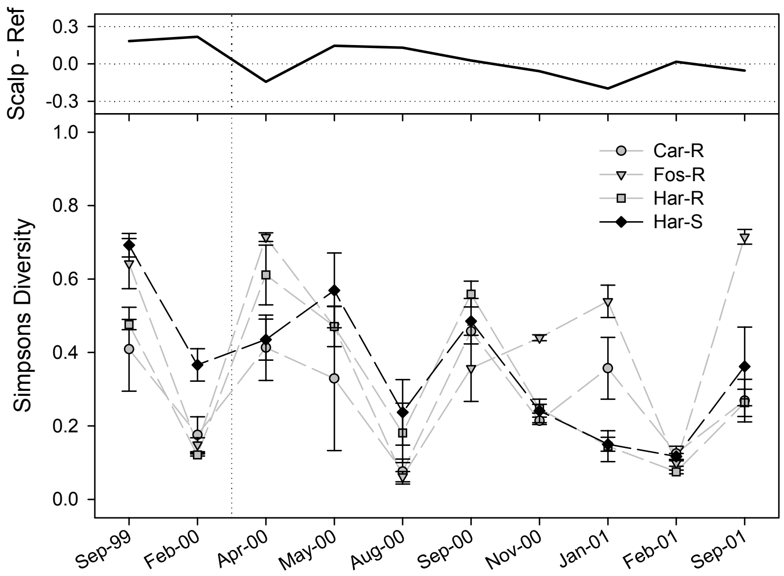


Figure 43. Average (± SE) Simpson's Diversity of samples collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

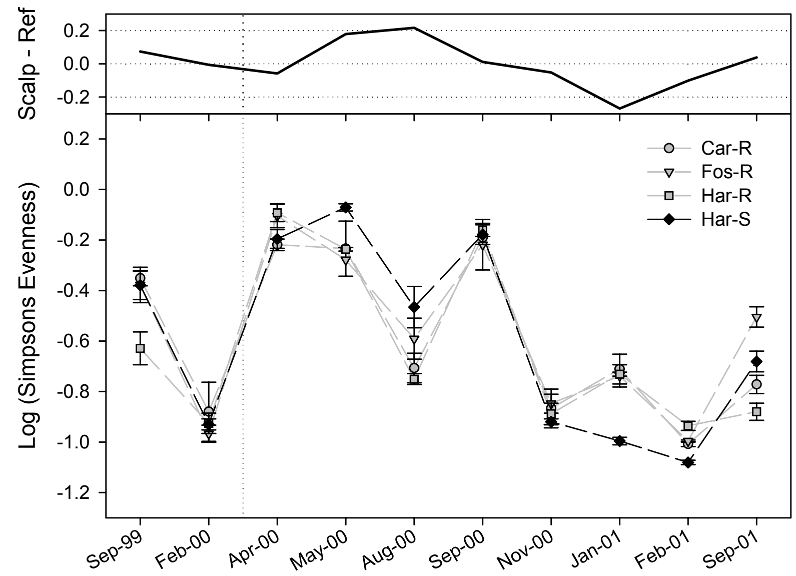


Figure 44. Average (± SE) Simpson's Evenness of samples collected in bar edge habitat on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

3.5.2 Population-Level Examination

Seven family groups each represented greater than 1% of the total invertebrates collected. Of these, the mayfly Baetidae showed strong seasonal trends in abundance that reflected life history events. Abundance was highest in February of each year and lowest in spring after aquatic larvae had emerged into their adult terrestrial form (**Figure 45**). Abundance was also low in September 2000, but the decline between August and September 2000 was possibly the result of the sudden rise in discharge in early September that may have either flushed invertebrates from the near-shore zone of gravel bars or not allowed sufficient time for invertebrates to colonize the newly flooded area.

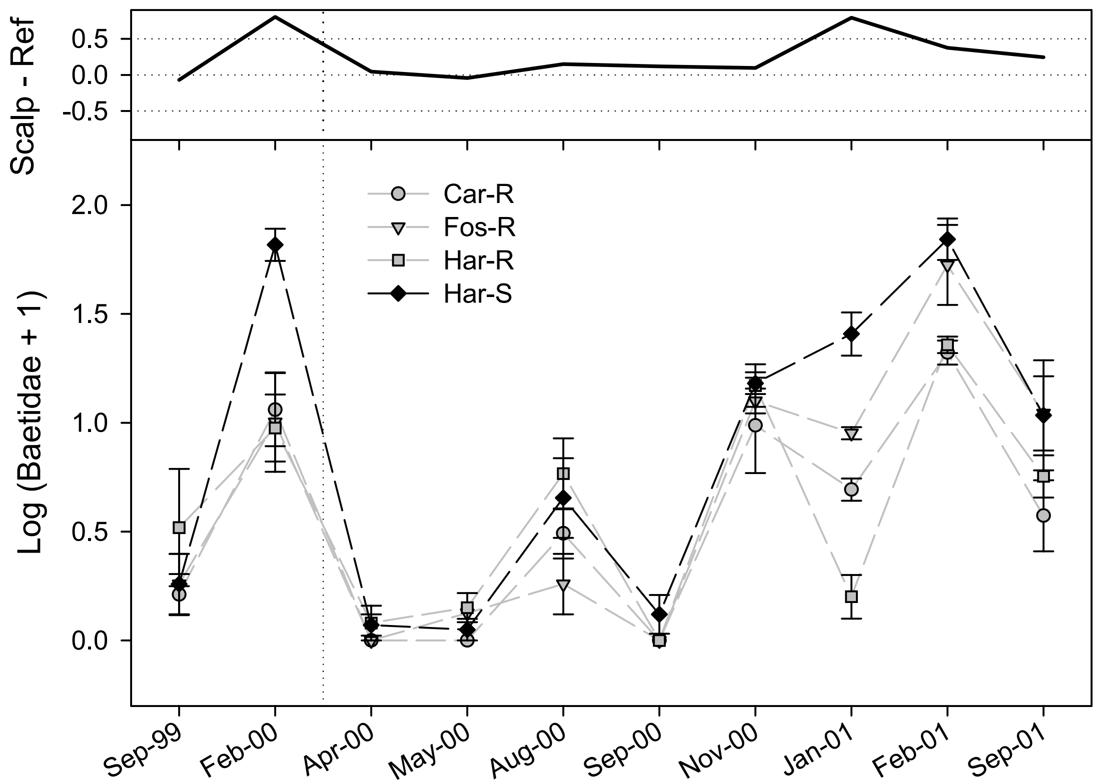


Figure 45. Average (± SE) number of Baetidae mayflies in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols connect successive sampling episodes at a site and should not be interpreted to represent a trend in the inter-sampling period. Upper panel values are the scalped site value minus the average of reference site values.

In all months after scalping, Baetidae abundance at Har-S was approximately equal to or higher than the average at all reference sites. No notable change in abundance at Har-S was observed between February 2000 and 2001; however, Har-S had a substantially higher abundance of Baetidae than most other reference sites in 2001. Whereas abundance declined between

November 2000 and February 2001 at all reference sites, it increased at Har-S. This deviation between the scalped and reference sites in February 2001 was statistically significant and resulted in the detection of a significant impact at Har-S (**Table 19**), albeit an increase in abundance that occurred almost a year after scalping.

Chironomids belonging to the sub-family Orthocladiinae were the most numerous taxon in most samples on all dates. This is consistent with previous studies of Fraser River benthos in the gravel reach (Rempel et al. 1999). Average abundance fluctuated in a similar manner at all sites during the study, and dramatic shifts in abundance reflected life history events (e.g., emergence between February and April 2000). Prior to scalping, Har-S had lower than average Chironomid abundance in September 1999 and higher than average abundance in February 2000 (**Figure 46**). Har-S had lower than average abundance immediately after scalping and higher than average abundance after September 2000. The temporal trend at reference sites was consistent after scalping whereas a significant short-term interaction between Har-S and the reference sites was detected (**Table 19**). Comparing February 2000 to 2001, chironomid abundance at all sites was virtually unchanged.

Table 19. Results of asymmetrical ANOVA examining impacts of scalping on the abundances of common benthic invertebrate families.

Variable	Do reference locations have variable short-term trends after scalping?	Does scalping affect short-term temporal trend?	Do reference locations vary in difference from before to after scalping?	Does scalping affect differences before or after?	Conclusion	p-value	Power
Baetidae	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	0.03	-
Chironomidae	No	Yes	-	-	*Short-term impact detected at Har-S but uncertain if coincident with scalping*	<0.001	-
Capniidae	No	No	No	No	No impact detected	0.71	0.07
Heptagenidae	Yes	No	-	-	No short-term impact detected	0.29	0.79
Ephemerellidae	Yes	No	-	-	No short-term impact detected	0.98	0.15
Nematoda	Yes	No	-	-	No short-term impact detected	0.74	0.18
Oligochaeta	Yes	No	-	-	No short-term impact detected	0.40	0.81

Details of analysis in Appendix K.

The stonefly Capniidae was the only common taxon for which, according to Underwood's (1993) analysis, the temporal trend at reference sites was consistent after scalping and no short-term interaction between Har-S and the reference sites was found (**Table 19**). This allowed a more rigorous examination of an impact due to bar scalping at the larger time-scale of Before versus After (refer to **Figure 10**). According to asymmetrical ANOVA, no significant impact was detected in the abundance of Capniidae from before to after bar scalping, although power was low (**Table 19**). Large seasonal differences in abundance were apparent and these differences were relatively consistent among sites (**Figure 47**). Capniidae were virtually absent from samples collected during spring and summer of 2000. Whereas abundance at Har-S was lower than all reference sites in September 1999 prior to scalping, it was higher than reference sites in September 2001. Har-S also maintained a higher than average number of Capniidae in February of both years. The same pattern held for Perlodidae, another stonefly that was less common than Capniidae in samples. Capniidae are shredders feeding on coarse particulate organic matter whereas members of the family Perlodidae are mostly predators.

The mayfly family Heptageniidae was mostly represented by *Rhithrogena* sp. and *Cinygmula* sp., both of which cling to the surface of stable stones for feeding on detritus. Family abundance was variable at all sites among sampling dates (**Figure 48**). Whereas Har-S had higher relative abundance prior to scalping, Heptageniidae were less common at Har-S in spring and summer immediately after scalping. Abundance at all sites, however, was low during these months. No significant short-term impact at Har-S was detected with high statistical power (**Table 19**), and abundance was higher at Har-S than the average of reference sites in samples collected in November 2000 and all later sampling dates.

Abundances of Ephemerellidae were similar to those of Heptageniidae during the study. The family was represented mostly by *Ephemerella* sp., which is a collector-gatherer that feeds on detritus and algae. A comparison between September sampling events showed lowest abundance in 2000 and comparable values at most sites in 1999 and 2001 (**Figure 49**). Ephemerellidae abundance was highly variable among sites on all sampling dates in 2001. The group was absent from the majority of samples in April 2000. No significant short-term impact at Har-S was detected (**Table 19**).

Nematodes are parasitic worms whose abundance showed a strong seasonal trend (**Figure 50**). Nematodes were common at all sites in winter months and virtually absent during summer. All sites had highly similar abundances among dates in the first twelve months of sampling both before and after scalping. However, there was variability among all sites during winter of 2000 and 2001. Abundances at Har-S were similar to reference sites on all dates throughout the study except January 2001, when abundance was lower than the average value of reference sites. No impact due to scalping was detected based on nematode abundance (**Table 19**).

In this study, the families Naididae and Tubificidae comprised the class of Oligochaeta, otherwise known as aquatic worms. The families were not differentiated for analysis because their identification at certain life stages was uncertain. The abundance of oligochaetes was highly variable among sites on most dates and no strong seasonal trend was apparent (**Figure 51**). Har-S had below average abundance in September 1999 but abundance was similar to reference sites in February 2000, prior to scalping. Abundance remained lower than at reference sites immediately after scalping, but was higher than at reference sites in the fall and winter of 2000. On no date after scalping did oligochaete abundance at Har-S fall outside the range of values at reference sites and power to detect an impact was high (**Table 19**).

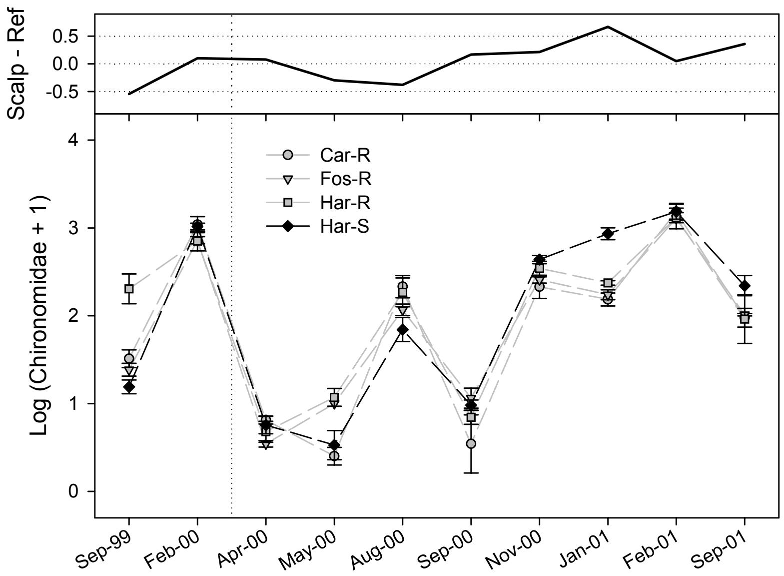


Figure 46. Average (± SE) number of Chironomidae midges in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

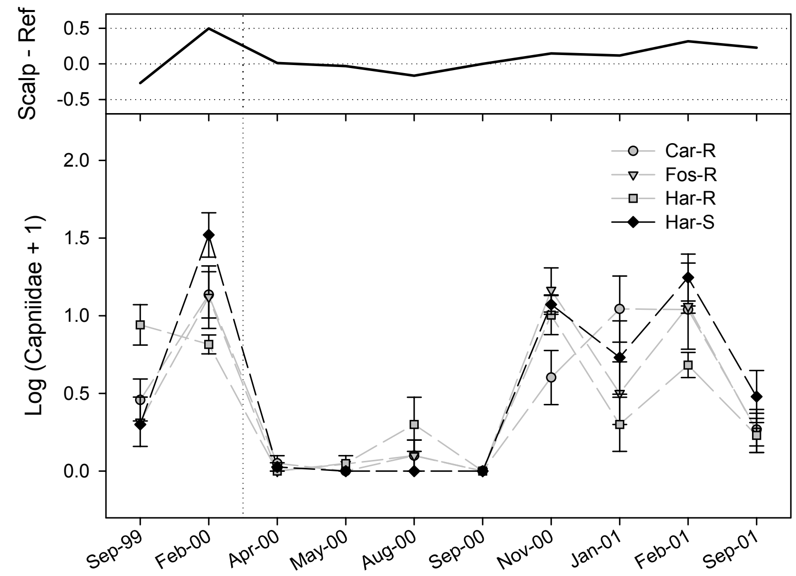


Figure 47. Average (± SE) number of Capniidae stoneflies in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

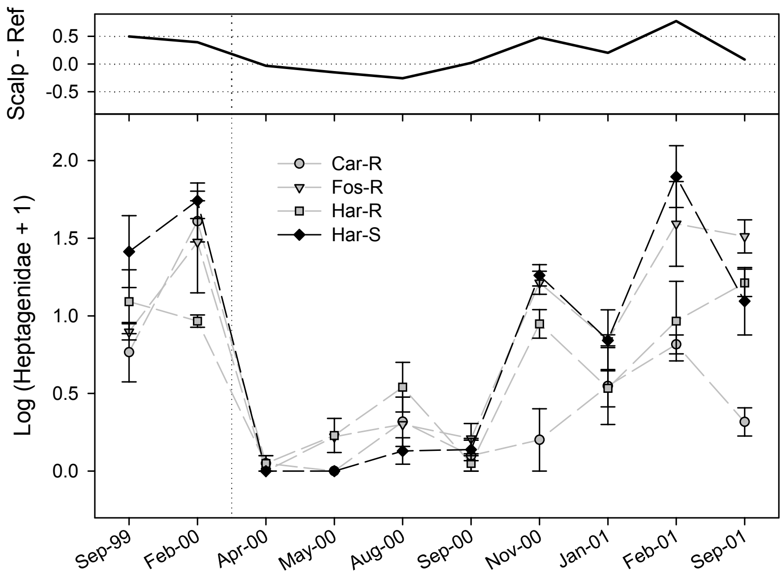


Figure 48. Average (± SE) number of Heptageniidae mayflies in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

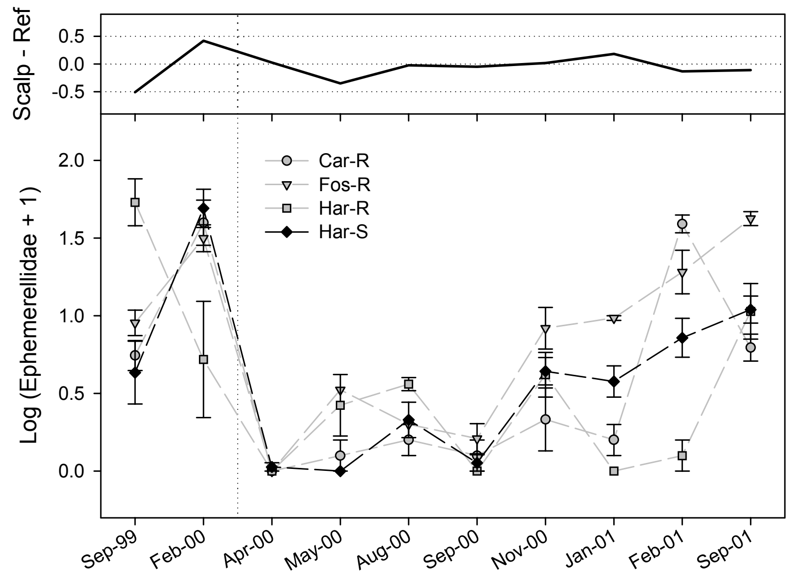


Figure 49. Average (± SE) number of Ephemerellidae mayflies in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

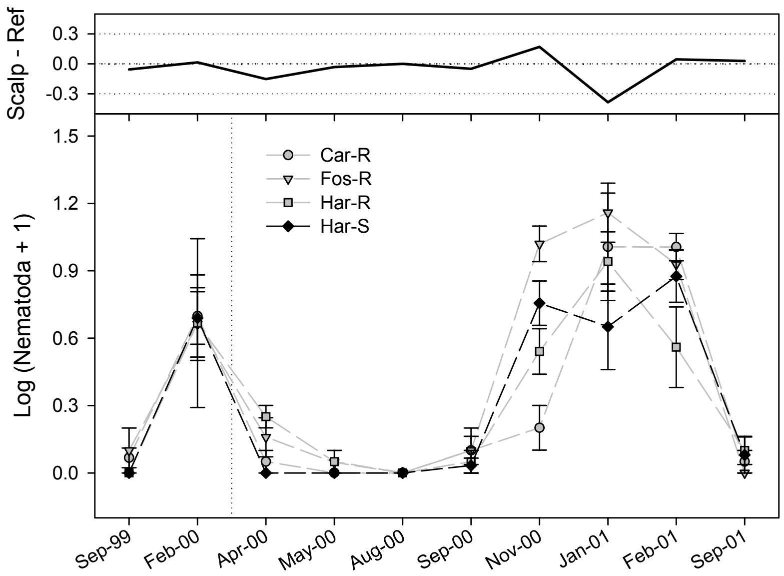


Figure 50. Average (± SE) number of nematodes in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

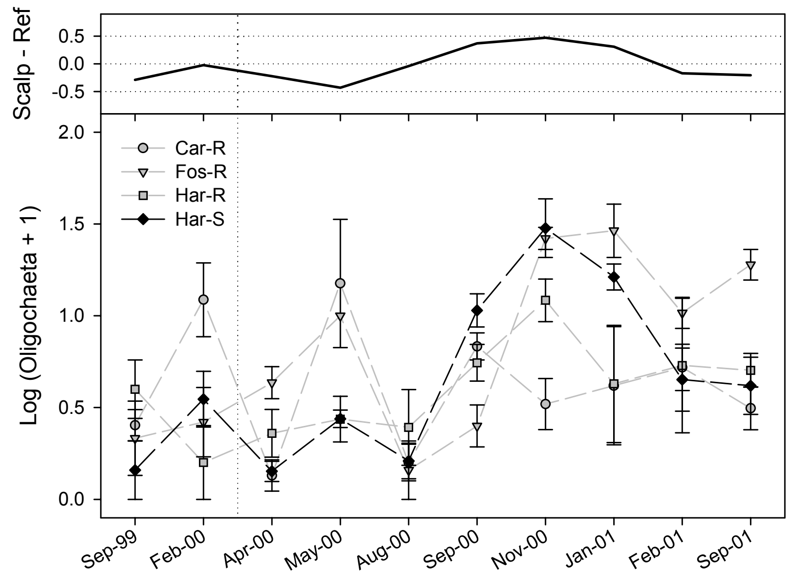


Figure 51. Average (± SE) number of oligochaetes in samples collected on 2 dates before and 8 dates after scalping at Har-S. Vertical dotted line denotes timing of scalping. Hatched lines joining symbols reflect the uncertain temporal trend between dates. Upper panel values are the average of reference site values subtracted from the scalped site value.

3.5.3 Functional Parameters

Predators, collector-filterers, shredders and parasites each represented less than 10% of individuals caught in most samples throughout the study. Scrapers were typically the second most common feeding group represented, averaging 17% in samples. The proportion of scrapers was variable between dates; samples collected in April and September 2000 had notably higher proportions of scrapers than other months. Collector-gatherers (CG) feeding on fine particulate organic matter were the most common feeding group represented in most samples.

The proportionate breakdown of feeding groups at Har-S revealed the dominance of CG on most dates (**Figure 52**). Predators, mostly stoneflies and chironomids of the sub-family Tanypodinae, were common in September 1999 (representing 16% of invertebrates) but in no other month. Samples in August 2000 and September 2001 were highly similar whereas September 2000 samples consisted of a high proportion of scrapers (primarily Oligochaeta). Despite a substantial difference in the density of invertebrates between September and February, the proportionate representation of feeding groups was similar. February samples collected before and after scalping had highly similar proportions of each feeding group represented. Scrapers, mostly *Ameletus* sp., represented 53% of all invertebrates in April 2000 immediately after scalping while CG were the second-most common feeding group.

The reference site Carey Bar was dominated by CG on most sampling dates (**Figure 53**). As at Har-S, scrapers (primarily Oligochaeta) were particularly common in April and September 2000 (>50%), but represented less than 10% of invertebrates in other months. Contrasting Carey Bar with Har-S revealed a high degree of similarity in all months. The pattern observed at Carey Bar was representative of conditions at other reference sites on all dates.

3.6 Fish Stomach Contents

Juvenile chinook salmon consumed a variety of prey, the most common types representing both nymph (aquatic) and adult (terrestrial) stages of many invertebrate taxa found in Surber samples (**Table 20**). The most abundant prey types by volume were generally consistent between years for a given site. Mayfly nymphs (Ephemeroptera) and chironomids were the most abundant groups in stomachs collected from Har-S and Har-R in each year. In contrast, a relatively low volume of Ephemeroptera was consumed at Car-R. Instead, chironomids (nymph and adult) and Hymenoptera (wasps, bees, ants) were consumed in high proportions. The large majority of chironomids found in stomachs from all sites were Orthocladiinae, which also represented the large majority of invertebrates collected in Surber samples at these sites. Plant material, including seeds and algae, was uncommon in the stomachs of chinook salmon. Piscivory was also rare, as indicated by the low proportion of fish parts in stomachs.

3.7 Summary of Biophysical Results

A large number of observations from a variety of data sources have been presented herein. **Table 21** summarises these data in order to synthesize pattern and trends, as well as to facilitate discussion.

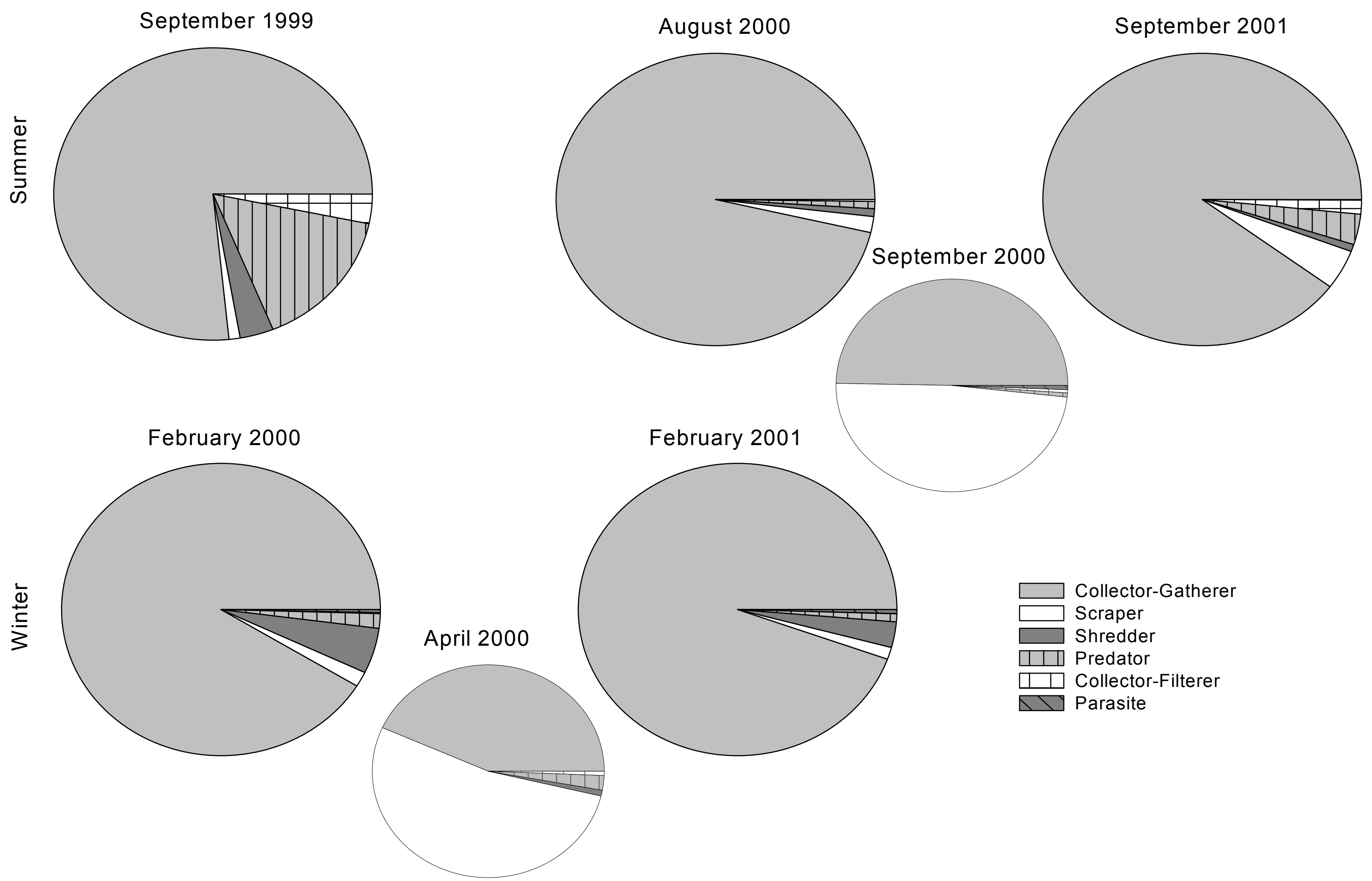


Figure 52. Average proportion of feeding groups in samples collected from the scalped portion of Harrison Bar (Har-S) on 7 dates. Scalping occurred immediately after sampling in February 2000.

Figure 53. Average proportion of feeding groups in samples collected from Carey Bar (reference site) on 7 dates.

Table 20. Mean proportion by volume (% total stomach volume +/- SE) of prey items in stomachs of chinook salmon. Data were collected between July and September in each of three years at a scalped (S) and reference (R) sites. Scalping occurred after sampling in 1999. Shaded cells highlight common prey items (>20%).

Prey Item	Har-S			Car-R			Har-R		
	1999	*2000*	*2001*	*1999*	*2000*	*2001*	*1999*	*2000*	*2001*
# of Stomachs	2	7	3	19	16	3	3	6	3
% Body Wt as Stomach	5.4 ± 0.1	6.1 ± 0.4	11.8 ± 1.6	6.7 ± 0.3	7.7 ± 0.7	9.9 ± 1.1	4.7 ± 0.7	6.5 ± 0.2	8.2 ± 1.5
Mean Fish Length (mm)	76.0 ± 2.8	70.1 ± 1.7	67.7 ± 4.8	63.3 ± 1.3	64.8 ± 0.9	79.3 ± 3.7	74.7 ± 2.5	73.3 ± 2.9	74.0 ± 1.7
Sand	0	0	0	0	0	0	0	0	0
***Ephemeroptera* (A)**	0	0	0	2.7 ± 1.6	0	0	0	0	0
***Ephemeroptera* (N)**	25.6 ± 1.6	47.8 ± 16.7	16.8 ± 16.8	11.5 ± 5.1	0.4 ± 0.3	7.4 ± 4.6	12.0 ± 2.9	3.1 ± 1.1	22.6 ± 11.6
***Plecoptera* (A)**	0	0	0	0	0	0	0	0	0
***Plecoptera* (N)**	0	2.4 ± 1.9	0	0	0.7 ± 0.5	0	0	1.2 ± 1.2	0.8 ± 0.6
***Trichoptera* (A)**	0	0.9 ± 0.9	8.2 ± 4.5	5.3 ± 5.3	0.2 ± 0.2	26.1 ± 16.7	0	0	8.4 ± 8.4
***Trichoptera* (N)**	1.7 ± 1.4	0	1.6 ± 1.6	0.3 ± 0.3	0	0	1.8 ± 0.4	1.0 ± 1.0	2.7 ± 2.7
***Diptera* (A)**	0	1.3 ± 0.9	1.3 ± 1.3	15.4 ± 5.9	3.5 ± 1.1	4.9 ± 2.5	0	0	2.0 ± 2.0
***Diptera* (N)**	0	0.2 ± 0.2	1.1 ± 1.1	0	0.2 ± 0.1	0	0	0	0.7 ± 0.7
***Chironomidae* (A)**	4.8 ± 1.3	28.1 ± 13.3	60.3 ± 8.3	20.4 ± 5.5	57.3 ± 10.8	47.7 ± 11.9	0.3 ± 0.3	82.7 ± 7.4	28.9 ± 14.8
***Chironomidae* (N)**	66.4 ± 1.4	9.7 ± 4.2	0	8.5 ± 4.4	23.2 ± 10.4	0.1 ± 0.1	66.1 ± 9.3	1.7 ± 1.1	9.0 ± 9.0
***Hymenoptera* (A)**	0	0.4 ± 0.4	1.8 ± 0.9	17.7 ± 6.2	9.4 ± 6.4	11.4 ± 2.8	0	0.9 ± 0.6	2.0 ± 2.0
Other Aquatic Inverts	0	0	0	0.3 ± 0.3	0	0	0	3.9 ± 1.8	0.2 ± 0.2
Terrestrial Inverts	0.3 ± 0.3	8.1 ± 3.8	8.9 ± 4.7	10.2 ± 3.2	3.2 ± 1.2	2.5 ± 1.0	0.2 ± 0.2	1.2 ± 0.6	21.1 ± 17.5
Fish Parts	0	0	0	0	0.54 ± 0.38	0	0	4.2 ± 4.2	0
Invertebrate Parts	0	0	0	0	0	0	0	0	0
Invertebrate (A)	0	0	0	0.4 ± 0.4	0	0	0	0	0
Invertebrate (P)	0	0	0	0	0.5 ± 0.5	0	14.0 ± 14.0	0	0
Invertebrate (N)	0	0	0	4.0 ± 4.0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0
Algae	0	0	0	0.4 ± 0.4	0	0	0	0	0
Plant Seeds	1.0 ± 1.0	0	0	3.0 ± 2.5	0.1 ± 0.1	0	5.7 ± 5.7	0.2 ± 0.2	0.7 ± 0.7
Plant Material	0.4 ± 0.4	1.1 ± 1.1	0	0.5 ± 0.4	0.7 ± 0.6	0	0	0	0
Zooplankton	0	0	0	0	0	0	0	0	0
Unidentified	0	0	0	0	0	0	0	0	2.0 ± 2.0

A = Adult N=Nymph P=Pupae

Table 21. Summary of physical and biological observations made at Harrison Bar. Scalping took place in February 2000. Monitoring occurred over eighteen months between September 1999 and 2001.

Attribute	1999 – Before Scalping	2000 to 2002 – After Scalping
Bar Scale – Physical Characteristics		
Topography within Lower Bar boundary (247,825 m^2), which includes removal area (91,645 m^2)	• Simple morphology with two flat open areas that dipped moderately steeply to the main channel	• Island development on upper bar: Increased surface elevation >10 m upstream of removal boundary over an open area with a shallow sloping beach face • Increase in morphological complexity in middle bar: Range of surface elevations present and varied topography • Erosion around the outer corner directly opposite Harrison River confluence
	• Average bar elevation (Feb-00): 8.4 m Maximum bar elevation: 11.6 m	• Average bar elevation (Mar-03): 8.3 m Maximum bar elevation: 11.9 m • Reduction in total bar area greater than 8 m surface elevation (Mar-03):
	• 71% of surveyed area >8 m 45% of surveyed area >8.5 m 24% of surveyed area >9 m	• 57% of surveyed area >8 m 38% of surveyed area >8.5 m 18% of surveyed area >9 m
Sediment Recruitment	• Not applicable	• Approximately 50% of scalped volume replenished after 3 freshets (over lower bar, including removal area) • Net deposition (3,123 m^3) in removal area but net erosion over entire lower bar (6,590 m^3) in 2000 • Negligible deposition (914 m^3) over lower bar in 2001 • Net deposition of 34,915 m^3 over lower bar in 2002 (above-average flood discharge) • Erosion across the outer mid-bar flank, deposition in the inner mid-bar area as a shallow sloping gravel sheet • Deposition in the lower scalped area as an isolated high bar surrounded by a summer channel, erosion in the summer channel flowing diagonally across lower bar
Substrate Texture	• Scalped area: Interior area with gravel-sized surface material, coarse cobble-sized beach face • Scalped area: Sand coverage = 11% D_{50} = 25 mm D_{95} = 66 mm	• Scalped area 2000: Sand coverage = 0.1% D_{50} = 22 mm D_{95} = 51 mm • Scalped area 2001: Sand coverage = 5% D_{50} = 25 mm D_{95} = 54 mm • No change in interior of scalped area with gravel-sized surface material. • Decrease along beach face of scalped area in size of coarsest cobbles. • Haul road remained hard-packed and blanketed with sand after two freshets
Habitat Availability	• Winter: 2-3 units, bar flank simple and dominated by bar edge habitat • Summer: 3-5 units, bar flank simple and dominated by bar edge habitat • Moderate habitat value in summer and winter (estimated as the sum of the number of habitat units available of a given type multiplied by habitat-specific average fish density)	• Increase in winter: 6 units, bar flank dominated by bar edge habitat • Increase in summer: 6-14 units, bar flank with variety of habitat types (mostly bar edge and open nook) • Increase in habitat value due to presence of open nooks along main channel flank and topographically complex summer channel

Attribute	1999 – Before Scalping	2000/01 – After Scalping
Habitat Scale – Physical Characteristics		
Bar Edge	• Moderate velocity (26-50 cm/s), moderate bank slope (<5º), clean gravel/cobble-sized substrate	• Short-term impact on rising limb of flood hydrograph with shift towards lower bank slope and sandy substrate • No long-term change: Moderate velocity (26-50 cm/s), moderate bank slope (<5º), clean gravel/cobble-sized substrate

Table 21. continued.

Attribute	1999 – Before Scalping	2000/01 – After Scalping
Bar Scale – Juvenile Fish Community (relative to average of reference sites)		
Density	• Lower than references sites in summer 1999; considerable variability among reference sites	• No Impact Detected: Similar in most months; higher in May-00 and lower in Aug-01
% Salmonids	• Lower than references sites	• No Impact Detected: Higher than reference sites in May-00, but lower in most other months
Species Richness	• Lower in summer, higher in winter; high similarity among reference sites	• No Impact Detected: Variable between months, always within range of values observed at reference sites
Species Diversity	• Similar to reference sites	• No Impact Detected: Lower than reference sites except during winter months 00/01
Species Evenness	• Variable among all sites including scalped site	• Short-Term Impact Detected: Variable between months; August and September values similar at Har-S from 1999 to 2001
Habitat Scale – Juvenile Fish Community (relative to average of reference sites)		
Density	• Similar to reference sites; considerable variability among reference sites	• No Impact Detected: Similar in most months; higher in May-00 and lower in Aug-01
% Salmonids	• Lower than all reference sites	• Short-Term Impact Detected: Higher in May-00 but lower in other months
Species Richness	• Similar to reference sites; highly similar among reference sites	• No Impact Detected: Higher than reference sites in May-00 and lower in Aug-01, similar in other months
Species Diversity	• Lower than all reference sites	• No Impact Detected: Lower than all reference sites in 2000, similar in summer 2001
Species Evenness	• Lower than all reference sites	• No Impact Detected: Variable between months relative to reference sites
Habitat and Bar Scale – Benthic Invertebrate Community (relative to average of reference sites)		
Density	• Similar to reference sites, strong seasonal pattern	• Short-Term Impact Detected: Lower than reference sites in May and Aug-00, higher in all subsequent months
% EPT	• Higher than reference sites	• Short-Term Impact Detected: Sharp increase in Apr-00, then similar to reference sites in subsequent months
Taxa Richness	• Higher than reference sites, strong seasonal pattern	• No Short-Term Impact Detected: Lower in spring/summer 2000, higher in subsequent months
EPT Richness	• Higher than reference sites, strong seasonal pattern	• No Short-Term Impact Detected: Lower in spring/summer 2000, higher in winter 2001
Simpson's Diversity	• Higher than reference sites	• No Short-Term Impact Detected: Similar to reference sites in most months
Simpson's Evenness	• Similar to reference sites	• Short-Term Impact Detected: Variable relation to reference sites between months
Bar Scale – Common Benthic Invertebrate Populations (relative to average of reference sites)		
Baetidae	• Similar in Sep-99, higher in Feb-00	• Short-Term Impact Detected: Similar or higher in all months; comparable Feb-00 to Feb-01, higher Sep-99 to Sep-01
Chironomidae	• Lower in Sep-99, similar in Feb-00	• Short-Term Impact Detected: Lower in May/Aug-00, higher in subsequent months
Capniidae	• Lower in Sep-99, higher in Feb-00	• No Impact Detected: Similar in all months post-scalping
Heptagenidae	• Higher than reference sites	• No Short-Term Impact Detected: Lower in summer 2000 and higher in all months after Sep-00
Ephemerellidae	• Lower in Sep-99, higher in Feb-00	• No Short-Term Impact Detected: Similar in all months
Nematoda	• Similar to reference sites	• No Short-Term Impact Detected: Similar in all months but lower in Jan-01
Oligochaeta	• Similar to reference sites	• Short-Term Impact Detected: Variable relation to reference sites between months
Habitat Scale – Fish Diet		
Prey Choice	• Mayfly nymphs and Chironomidae nymphs comprised majority of stomach contents by volume	• No Detectable Change: Mayfly nymphs and Chironomidae adults comprised majority of stomach contents

4.0 Discussion

4.1 Bar-Scale Physical Changes

Immediate physical changes to Harrison Bar as a result of gravel mining were substantial. Approximately 70,000 m^3 of sediment was removed to an average depth exceeding 1 m and from a large area (~600 m x 150 m), which corresponded to roughly 40% of the lower bar. Within the scalped boundary, the proportion of bar area at greater than 8 m elevation was reduced from 71% to 4% and the area >9 m elevation was reduced from 24% to 0%. The scalped area was left topographically simple and graded to a slope of approximately 2%. The evenly graded, homogeneous area of unconsolidated fine gravel and sand replaced a pre-existing coarse and relatively stable bar surface. Average sand cover increased from 11% to 32% and median grain size decreased from 25 mm to 13 mm. Also notable was the decrease in grain size of the coarsest fraction (D_{95}) from 66 mm to 40 mm.

The dramatic change in surface sediment texture due to scalping was relatively short-lived. Flooding in spring 2000 transformed the loose and sandy substrate into a moderately coarse surface with negligible sand cover. Sand cover in the scalped and reference areas of Harrison Bar was similar (~1%) after flooding, which indicated that a significant amount of sand was entrained from across the entire bar surface. Flooding in 2001 produced additional surface coarsening within the removal area, particularly along the water's edge where median grain size increased from 25 mm before scalping to 35 mm after scalping and after two freshets. The coarsest fraction (D_{95}) increased in size along the water's edge after scalping, but to a lesser extent: the grain size after two freshets remained lower than prior to scalping (82 mm versus 91 mm). The D_{95} grain size along the waterline of the reference area decreased over the same period.

Topographical changes after scalping of lower Harrison Bar occurred concurrently with sedimentary changes as a result of flooding. Flood discharge in 2000 and 2001 was below average and produced negligible volumetric change, both over the entire lower bar (8311 m^3 net erosion) and locally within the removal area (3123 m^3 net deposition). However, there was a relatively large and balanced exchange of sediment (deposition and erosion) over the lower bar in each freshet that resulted in topographical changes. It remains uncertain whether or not this amount of sediment exchange is typical of gravel bars in Fraser River or if the destabilized bar surface after scalping was more easily entrained. Topographical changes after two freshets included an increase in maximum bar surface elevation but a slight decrease in average bar elevation, deposition of an isolated gravel bar at the lower corner, and erosion of a summer channel that flowed diagonally across the lower bar. The channel had irregular geometry with high habitat diversity, and established a flow connection between the main channel and inner side channel during summer months. Some rebuilding of high bar area was observed during this period: the proportion of bar area >9 m elevation was 15% after freshet in 2001 compared with 0% immediately after scalping and 24% prior to scalping.

Flood discharge in 2003 was above average and deposited 27,630 m^3 of sediment over lower Harrison Bar, approximately 31% of the scalped volume. The material was deposited over much of the area including upstream of the removal boundary, where bar surface elevation increased to >10 m. Total bar area >10 m was in fact higher in 2003 than before scalping (2,450 m^2 versus 25 m^2, respectively). Two small, high points >9 m developed on the inside middle bar, and further deposition on the lower corner resulted in infilling of the summer channel at its top end. The bar surface was transformed from a simple and homogeneous surface into an irregular surface of variable elevation that offered greater topographical variability in comparison with pre-scalp conditions. Average bar surface elevation increased to within 11 cm of the average prior to scalping, and maximum bar elevation exceeded pre-scalp conditions by 35 cm in 2003. However, the proportion of bar area >9 m was 18%, which remained 6% less than before scalping. The range of flows over which the loss of high bar habitat was most significant was between 4000 and 7000 m^3/s, corresponding to bar surface elevations between 8.5 and 10 m. These flows typically occur between May and August, during the period when fish are rearing in the gravel reach.

It should be noted that total bar area >10 m elevation, which would become inundated at flows exceeding 8000 m^3/s, was higher in 2003 than prior to scalping. This high-bar area was situated immediately upstream of the removal boundary. We do not believe that scalping was responsible for the increase and speculate that the area of bar >10 m would have been at least as large in the absence of scalping because of the natural tendency for sediment deposition over Harrison Bar. Nevertheless, this finding demonstrates that vertical bar growth and island building can proceed in proximity to a removal operation so long as sediment continues to be recruited to the area.

Clearly, multiple freshet events of above-average peak discharge will be necessary for areas of high surface elevation to rebuild on Harrison Bar after scalping. Such events also appear necessary for notable sediment recruitment to the lower bar. Given the rapid increase in bed material transport at higher flows, this condition is apt to be general along the river.

4.2 Habitat Availability and Use By Fish

The lowering of bar surface elevation and reduction in total area of high bar 8.5 – 10 m directly reduced the amount of shallow water habitat available between 4000 and 7000 m^3/s. Areas >8.5 m elevation before scalping would now have deeper water and higher velocity during summer months, which includes the period when fish are rearing in the gravel reach. Such conditions are not favourable for most species of juvenile fish and, consequently, habitat availability over this range of flow was reduced as a result of scalping. Habitat value in the gravel reach has been shown naturally to decrease in summer months as discharge increases (**Figure 54**). The additional reduction in high elevation bar area as a consequence of scalping would have further reduced habitat value during a period when it is already limiting.

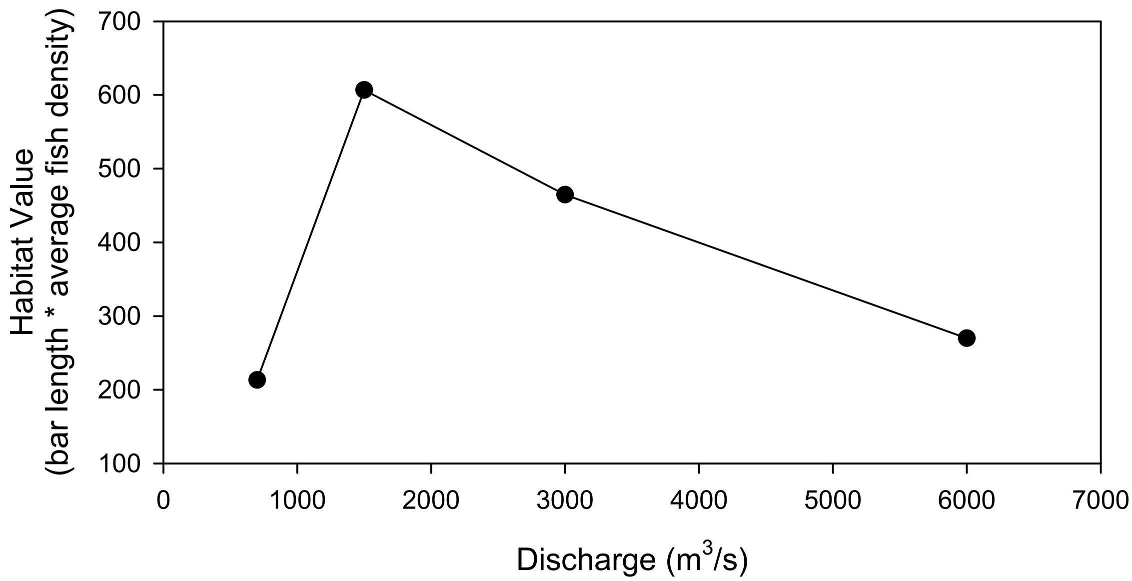


Figure 54. The relation between habitat value (total bar length * mean fish density grouped according to season) and discharge for bars in the gravel reach (adapted from Church et al. 2000).

The surface of lower Harrison Bar had greater topographic variability after scalping, which increased habitat diversity at flows less than 3000 m^3/s. The increase was not statistically significant, but the pattern of habitat diversification after scalping was consistent for several water levels examined by photography. Prior to scalping, the bar surface was an expansive, flat area of simple topography. Particularly at low flow, units of the most common habitat type, bar edge, were large (>700 m in length) and other habitat types were generally rare. Bar edge remained the most common habitat type at low flow one year after scalping, however, units were shorter in length and spaced between open nooks.

From the perspective of a fish, smaller and more diverse habitat units offer a wider choice in the range of habitat conditions available and support a greater number of species. This situation is energetically favourable because animals can disperse over short distances and select from a range of physical conditions and food sources (Rosenfeld and Boss 2001). It is also favourable for sustaining populations over the long term because reaches of river with high habitat diversity can support multiple life stages of animals with variable habitat requirements (Galat and Zweimüller 2001). In contrast, long-distance dispersal over extensive areas is necessary in a more simplified reach of river with few habitat types available (Nicolas and Pont 1997). Such a reach, ultimately, may lack the capacity to support some species of fish and high fish density (Ward et al. 2002).

The smaller size and greater diversity of habitat units after scalping was most notable during late summer months (discharge <3000 m^3/s) both along the main channel edge and within a summer channel that crossed the lower corner of Harrison Bar. The new channel increased the amount of wetted area available for fish and was host to a variety of habitat types including eddy pool, open nook, and bar edge. The channel conveyed flow through November 2000 but fresh sediment deposited by the 2001 freshet cut off flow into the channel after September 15, 2001. In 2002, the channel carried flow through August but was cut off prior to September 15. Although the channel appears to be infilling, it provided valuable aquatic habitat in the short-term after scalping as the bar was changing toward its new configuration.

Fish density, along with several other metrics characterizing the fish community, showed no detectable impact at lower Harrison Bar as a result of scalping. The statistical analyses were relatively sensitive because reference sites varied in a consistent manner over time. Density was lower in the scalped area *prior* to scalping relative to reference sites, but was higher in 7 of 8 periods of sampling post-scalping. This pattern was consistent regardless of whether the spatial scale of examination was the whole lower bar (all habitat types pooled) or bar edge units only.

There were 2 cases of 10 in which a significant impact was detected after scalping: Simpson's evenness and the proportion of fish belonging to the family Salmonidae. The former impact was detected at the bar scale and the latter result was obtained from the analysis of bar edge units only. In each case, the detected impact was short-lived (less than one freshet cycle). In the case of salmonid representation, average values before scalping were lower at the scalped site than all reference sites; however, there was a significant increase in salmonid representation at the scalped site in May 2000 and February 2001, after scalping. The significantly higher representation in May 2000 consisted of chinook salmon, whereas chum salmon fry were significantly more common at the scalped site in February 2001.

Diet choice by chinook salmon was relatively consistent among sites in each year of sampling, both before and after bar scalping. The majority of these fish originated from the Nechako and Stuart drainages (L. Rempel, unpublished data) and spent up to a year rearing in the gravel reach before migrating to the ocean. Stomach contents of chinook salmon collected during summer months included a range of aquatic and terrestrial insects, with nymph and adult chironomids making up the majority of food by volume in the stomachs of fish at all sites. Mayfly nymphs were common in the stomachs of chinook salmon from upper and lower Harrison Bar in most years as well, but had low representation in the stomachs of fish at Carey Bar.

4.3 Site Recolonization by Benthic Invertebrates

Benthic invertebrates recolonized lower Harrison Bar immediately after scalping as water inundated the site with the onset of freshet. Samples collected in April 2000 had above average density and included a high proportion of mayfly, stonefly, and caddisfly (EPT) nymphs. Several of these taxa (e.g., *Ameletus* sp.) are known to be highly mobile and have good swimming ability (Mackay 1992). These behavioural tactics are practical for survival in the gravel reach where the water edge shifts over several hundred meters across the surface of gravel bars during freshet (Rempel et al. 1999). However, subsequent months of sampling (May, August 2000) revealed lower than average invertebrate density and proportions of mayflies, stoneflies, and caddisflies at the scalped site. This reduction was statistically significant and indicated a short-term impact due to scalping at Harrison Bar. Recall that samples in these months were among those collected from sediment disturbed by scalping, whereas winter samples were collected at elevations below the removal boundary. In all months after August 2000, invertebrate density at the scalped site was higher than the average of reference sites.

Taxon richness, the number of EPT taxa, and species diversity showed variable trends after scalping at Harrison Bar and no short-term impact was detected due to scalping. Statistical power was relatively high for these analyses conducted both at the bar scale and within bar edge habitat units. The sensitivity of the analyses to detect an impact, however, was reduced because of the temporal variability observed at reference sites. Underwood (1993) states that a significant temporal interaction among reference sites after scalping indicates that an impact would have to be large to be ecologically "important". Presumably, populations are resilient to some disturbances in a variable environment, and an environmental impact "must be relatively large, otherwise it is simply within the population's capacity to recover". The fact that density, %EPT, taxon richness, and diversity were mostly similar at the scalped site in summer 2001 compared with pre-scalp conditions presumably indicates the system's capacity to recover from a modest removal of gravel from lower Harrison Bar.

Abundances of the most common mayfly, Baetidae, were higher at the scalped site than the average of reference sites on all dates before and after scalping. Abundance was significantly higher at the scalped site almost one year after scalping, in January 2001, and a short-term impact (positive) due to bar scalping was detected. Other common mayfly taxa (Ephemerellidae and Heptageniidae) showed a short-term decrease in abundance immediately after scalping but the decrease was not statistically significant and abundances were higher than reference sites after one summer post-scalping.

Chironomid midges (mostly Orthocladiinae) were the most abundant taxon at all sites in the gravel reach, and showed a significant reduction in abundance immediately after scalping. The impact was reflected in May and August samples that were collected from within the former removal boundary. Abundance was higher at the scalped site in all subsequent months of sampling relative to reference sites. Overall, a significant impact due to gravel mining was detected in the abundance of 3 of the 7 most common taxa in the gravel reach. The impact was short-lived for both taxa and was positive for the family Baetidae and negative for Chironomidae. Statistical power to detect an impact was moderate for those taxa for which an impact was not detected.

Lower taxon richness at the scalped site compared with reference sites immediately after mining suggested that physical conditions may have been less favourable than at other gravel bars affected by spring flooding. The rate of sediment transport across Harrison Bar was likely higher due to the loose substrate framework left by scalping, and these conditions may have deterred settlement by some taxa. But the disturbed surface sediment did not deter settlement by invertebrates such as *Ameletus* sp. The fact that all impacts associated with the invertebrate community due to scalping were short-lived, lasting up to one freshet cycle in duration, is consistent with observations that the fine gravel/sand surface at lower Harrison Bar was transitory, lasting only until the first freshet.

Recolonization by invertebrates of the scalped site depended on an abundant source population existing upstream. These animals would have arrived at Harrison Bar by a combination of passive and active drift in the flow as flooding inundated the site (Rader 1997). The term “drift” is given to the assemblage of animals found drifting in the flow, and previous drift sampling in the main channel of the gravel reach found high taxon richness (27 unique taxa on average) and moderate density (2.7 animals/m^3; L. Rempel, unpublished data). Drift samples consisted of a mixture of aquatic and terrestrial insects that would have dropped in from riparian areas. We do not know to what amount single or multiple scalping operations may reduce the source population of invertebrates in the gravel reach. But persistent removals extending throughout the gravel reach might reduce the source population and ultimately delay site recovery.

A dramatic shift in the proportions of functional feeding groups in April 2000 was not a signal of physical site disturbance but rather was driven by the life cycle of Orthocladiinae. Larval Orthocladiinae (collector-gatherers) hatch in late autumn (October/November) and mature through the winter months, emerging as terrestrial adults in March. They were significantly more abundant than all other taxa in March but were relatively rare in April. At this time, *Ameletus* sp. (scraper) had proportionately high abundance. A similar shift in dominance observed in September 2000 was due to an abundance of newly hatched oligochaetes (scrapers). The increase in Oligochaeta and shift from predominantly collector-gatherer taxa to scrapers was observed at all sites and was therefore independent of scalping. On all dates except April and September 2000, collector-gatherers feeding on fine particulate organic matter were the most common feeding group represented in samples. Previous benthic sampling in the gravel reach found collector-gatherers to be significantly more common than all other feeding groups combined (Rempel et al. 1999).

A notable observation from benthic sampling over three years in the gravel reach is that invertebrate abundance exhibited a high level of spatial variability. This pattern was prominent with Orthocladiinae; density was more than four times higher at Har-R than at all other sites in September 1999 and was almost twice as high at Fos-S than at other sites in February 2001. The abundances of other taxa such as Heptageniidae and Baetidae showed a similar degree of variability on some dates.

4.4 Synthesis and General Recommendations

Two freshets of below-average peak discharge resulted in some reorganization of surface sediment and adjustments in surface topography across lower Harrison Bar. However, an above average flood exceeding 10,000 m^3/s peak discharge was necessary for sediment recruitment and rebuilding of high bar habitat at the site. After two modest freshets and one large event, the proportion of bar area >9 m in elevation and inundated between 4000 and 7000 m^3/s remained 6% less than prior to scalping (44,750 m^2 versus 58,925 m^2 before scalping). Repeated topographic surveys were needed to detect this impact, which directly affected juvenile fish because the amount of shallow water habitat during summer months was reduced. Interestingly, a comparison of average and maximum bar surface elevation from before to after scalping found negligible differences. Only by comparing the elevation-to-area relation and then relating it to the specific range of flows over which fish would be affected was the impact to fish habitat identified.

The exchange of sediment by erosion and deposition over the bar surface appeared to assist in site recovery because the scalped surface of Harrison Bar was uniformly graded to a 2% slope but developed topographical variability after one freshet event. Topographical change continued over subsequent freshets and the transformation highlighted the role of sediment transport throughout the gravel reach in habitat creation and maintenance. Even in the absence of scalping, gravel bars undergo changes in sediment texture and configuration on an annual basis, creating alternating zones of sediment deposition and erosion that are relatively transient on the time scale of decades. Gravel deposits divert the flow around them and the fact that these deposits shift in space causes episodic lateral instability that is important for maintaining a diverse array of channel networks and habitats. On a local scale, sediment transport maintains fish habitat of high quality by producing topographic irregularities across a bar surface and by episodically reworking and cleaning the substrate.

Various factors operating both at the local and reach scales will influence the physical and ecological response to gravel mining; these factors likely vary between gravel bars. Foster Bar provides an example of the impact of bar scalping in the absence of sediment replenishment. In 1995, a substantial amount of gravel was removed from the bar head where flow patterns are predominantly erosional and the likelihood of gravel deposition is low. Removal depth averaged 3 m and, in the absence of sediment recruitment, bar surface elevation has degraded an additional 1 m over six years since scalping (see Appendix B). Scalping likely accelerated degradation by the removal of the coarse surface sediment layer. A change in flow patterns upstream of Foster Bar due to a change in channel alignment at Carey Point is partially responsible for the lack of coarse sediment recruitment and infiltration of fine sediment to the bar head. Bar topography has simplified and the habitat is of poorer quality compared with other sites in the gravel reach (L. Rempel, unpublished data).

These observations highlight the most significant impact of gravel mining: the loss of quality habitat units such as bar head, riffle, and eddy pool for use by fish and invertebrates. Current habitat conditions at Foster Bar are very simple (mostly bar edge) relative to other sites. Areas of clean, coarse sediment, which are typical at the upstream ends of gravel bars, are rare. Further degradation over the removal area since scalping has eliminated shallow, bar top habitat that is important for juvenile fish at high discharge. Although benthic invertebrate density was comparable with reference sites in localized areas with clean, coarse sediment, these areas were rare along the bar flank of upper Foster Bar after six years post-scalping.

On the basis of these findings, the following recommendations are presented for consideration in the planning of future removals in the gravel reach of Fraser River.

1. *Site selection and planning for future removals should give due consideration to the need to preserve areas of high bar habitat as well as local patterns of sediment transport and the likelihood of gravel replenishment to the site.*

Complex bar topography is essential for making available a variety of habitats at all levels of discharge. Although our analysis of habitat availability examined only a range of flows <3000 m^3/s, water levels fluctuate over several metres on the rising and declining limb of the flood hydrograph (McLean et al. 1999). Juvenile fish rearing in the reach depend on habitat being available over this entire range of flows. Strictly targeting areas of highest elevation to maximize removal depth is not recommended because of the importance of these areas for providing shallow zones of reduced hydraulic stress at high discharge. Scalping of lower Harrison Bar resulted in a reduction in the available area of shallow water between 4000 and 7000 m^3/s, and even after 3 freshet cycles the total area of high bar habitat had not recovered to its original pre-scalp extent.

2. *In general, the removal volume at a site should not exceed the best estimate of local gravel deposition in a year of mean annual flood discharge (derived from volumetric or sediment transport estimates). This is to ensure that physical changes to a site fall within the range of change that might be observed at a non-removal site in a large freshet.*

The impacts of bar scalping on the juvenile fish community and benthic invertebrate community were relatively short-lived. These results are not in themselves surprising given that approximately 285,000 m^3/yr of material is recruited to the gravel reach downstream of Agassiz, and an additional 2-3 million m^3/yr of material is redistributed locally (Church et al. 2001). Freshet therefore represents a major physical disruption on an annual basis to which organisms residing in the gravel reach are habituated. In comparison, the removal of 70,000 m^3 from lower Harrison Bar was relatively modest. Within the vicinity of Harrison Bar, gravel deposition in the past 15 years has averaged between 65,000 m^3/yr (based on gravel transport estimates; Figure 19 of Church et al. 2001) and 112,800 m^3/yr (based on volumetric calculations for gravel only; Table A2 of Church et al. 2001).

Underwood's (1993) prediction that populations residing in highly variable environments are resilient and can recover rapidly from disturbances appears to apply for the one-time gravel removal at Harrison Bar. The modest volume of gravel removed from a site that is geomorphologically favourable for sediment recruitment probably helped to achieve this goal at Harrison Bar. We recognize, however, that the improvement in habitat diversity after scalping may have been fortuitous. In other circumstances, post-scalp sedimentation might have sustained or even further simplified the topography, with consequent impacts on habitat quality and the abundances of animals.

3. *The haul road surface should be mechanically scarified once a removal operation is complete and prior to freshet.*

A location where the impact of gravel mining at Harrison Bar was less transient was along the road surface. It was left hard-packed after bar scalping and consisted mostly of fine, crushed gravel. Areas of road surface, compacted and blanketed with sand, remained discernible from photographs taken after two freshet events since scalping.

4. *It is important to preserve bars within the gravel reach exclusively as reference sites to allow for comparisons between scalped and undisturbed reference sites*.

Preserving multiple undisturbed bars as reference sites is absolutely necessary if the impacts of future removals are to be investigated following statistically rigorous methods. Very few gravel bars have escaped gravel removal and the value of these sites for future monitoring studies will increase as the pressure for bar scalping continues to grow.

5. *Future removals should be treated as "experiments" with a structured monitoring program.*

Results of the one-time gravel removal study at Harrison Bar cannot be generalized to all other removal operations within the gravel reach of Fraser River. Further studies are necessary to determine if the patterns of response by the physical habitat, fish, and benthic invertebrates are characteristic of removals at other sites. A monitoring program incorporating physical and ecological observations before and after mining should accompany future removals. Observations should address "structural" attributes of the fish community such as diversity and density, but should also emphasise "functional" attributes of the ecosystem by examining lower trophic levels and the energy base on which fish depend.

There is potential for this study to be used in conjunction with future removal studies as a time block in a repeated measures analytical framework. Each removal study would serve as an independent replicate for the analysis, allowing conclusions to be generalized beyond the site-scale to a larger area of the gravel reach. Such a design is more rigorous than asymmetrical ANOVA because the treatment effect is replicated. Prior consultation with a statistician is recommended to formulate the experimental framework and estimate the power of such a design to detect treatment effects at different levels of replication. Measures of variances estimated in this study will be useful in the early planning stages of future studies to determine the necessary sampling effort for a desired level of statistical power.

6. *When the goal of a monitoring program is to examine mining impacts using statistically rigorous methods, due consideration must be given to the timing of permit approval to allow necessary pre-scalp samples to be collected.*

The effectiveness of this study was limited by the short time period between permit approval and the start of removal operations. It was only fortuitous that sampling had been carried out at Harrison Bar and the three reference sites in August and September 1999, prior to bar scalping, as part of a different study. Typically, proponents interested in gravel mining initiate permit submission only months before scalping is to begin. Time for review by regulatory agencies is often several weeks or months and together, these factors result in an inadequate period for pre-removal data collection. The planning and approval processes must be modified if the desired outcome of a monitoring study is a rigorous statistical analysis of gravel mining impacts.

7. *There remains a need to learn about the ecological and morphological impacts of linear excavations, bar edge scalping, and riffle dredging.*

These techniques have not been evaluated but may be considered in the future for river management.

8. *There remains a need to learn about the cumulative impacts of multiple removals or single but large removals.*

The impacts of multiple removals likely are not simply additive, but rather multiplicative, and may not be immediately detectable. The results of this study should not be generalized to predict the outcome of these scenarios, nor should they be casually applied to others bars in the gravel reach without careful geomorphological consideration.

4.5 Sampling Recommendations

4.5.1 Statistical Power

Statistical power is a well-established concept (Zar 1984) that is being applied increasingly for studies in which the results have important implications for the management of fisheries or other natural resources (Peterman 1990). It is most appropriately carried out before initiating a study as a means to determine the necessary sampling effort for a desired level of power, given knowledge of the system's natural variance. Similarly, it can be used to solve for the minimum detectable effect size when the feasible sample size and natural variance are known. These applications of power analysis are highly useful in the planning of studies to ensure that resources are allocated most appropriately for data collection. The estimates of variance yielded by our study may be useful in this regard for future studies in the gravel reach of Fraser River.

Power analysis also can be used to interpret a statistical analysis of previously collected data that did not detect a difference among groups (as was done in this study). This application is termed retrospective power analysis, and has received strong criticism from some authors (Thomas 1997, Lenth 2001). The basis for these criticisms is that as the p-value increases, retrospective power analysis will decrease because it is simply a transformation of the p-value. It is argued that retrospective power calculations add no new information to an analysis, except to rationalize a non-significant result when it is not expected (Lenth 2001).

Despite these criticisms, we chose to calculate power for those analyses in which an impact due to bar scalping was not detected in order to help differentiate between a strong null-result and an analysis with low probability of revealing an effect. This application is of particular use to managers needing to make decisions and formulate policies based on study results. We believe that the low power values obtained for some analyses do not undermine the results of the asymmetrical ANOVA, but instead serve to reveal a high level of variance in the parameter being analyzed. This is because power is inversely related to the amount of residual variance unexplained in the analysis (see Appendix **E**).

The results of power analysis for the various fish metrics examined by asymmetrical ANOVA indicated low power when all habitats were pooled (0.08 to 0.37). Power was further reduced when sample size was lower and only bar edge habitat units were analyzed (0.001-0.09). These results indicated a large amount of variance in the data, both in space and time, relative to the amount of sampling effort. Natural variability inherent to fish distributions may reduce statistical power to detect impacts due to bar scalping (or due to another factor) without very great sampling effort. We expect that greater replication (larger number of beach seines at a site during each sampling episode) and a greater number of sampling episodes *before* gravel mining would have helped to better estimate the natural variance and thereby increase power to detect an impact.

Power to detect an impact was substantially higher for the analyses of benthic invertebrate metrics, ranging between 0.54 and 0.67 for bar edge units and 0.23-0.49 when all habitats were pooled (in contrast to fish results). Statistical power was also relatively high for the analysis of common taxon abundances (0.07-0.79). Because the distribution of invertebrates is also highly variable in space and time, we speculate that increased sampling replication would have improved statistical power to detect an impact. Sampling effort for invertebrates, in particular, comes at a high cost because of the laboratory processing time. Hence, desired statistical precision and the cost of laboratory processing time are conflicting but important factors to consider for future monitoring studies.

The most effective sampling strategy (i.e., the strategy that returns the most discriminating results for a given overall level of effort) will depend on the temporal and spatial structure of variance in the data. We briefly explored the properties of one variable analyzed by asymmetrical ANOVA to help establish a suitable sampling strategy for future studies given the high natural variance in Fraser River data. We chose to examine *invertebrate taxon richness* because no impact was detected and statistical power was approximately average. As well, a decline in richness at Har-S was noted immediately after scalping.

First, we simulated an increase in the effect magnitude in April 2000 immediately after scalping by systematically reducing taxon richness. Asymmetrical ANOVA was run three times, each time with taxon richness reduced at Har-S only (original values were successively reduced by a factor of 1 for three analyses from an average of 3 taxa/sample to 0 taxa/sample). Power increased from 0.23 (original), to 0.40 (minus 1), 0.65 (minus 2), and 0.84 (minus 3) based on the simulated data. The significance of each analysis was similar (no short-term impact detected), however, the power to detect an impact was substantially increased by an increase in effect magnitude.

Second, we examined the effect of an adding a fourth reference site to the analysis. Data from Calamity Bar were used because the site had been included in all monitoring activities. The additional reference site increased statistical power only marginally, from 0.23 to 0.31, based on original data. When both effect size was increased (as described above) and four reference sites were included, power substantially increased: 0.52 (minus 1), 0.76 (minus 2), and 0.91 (minus 3).

We also ran an analysis based on hypothetical data provided by Underwood (1993) to examine the effect of an unbalanced number of sampling episodes before and after the impact. Underwood's original data included an equal number (four) of observations collected before and after a simulated disturbance. We randomly eliminated two sampling episodes before the disturbance and power was virtually unchanged between the balanced and unbalanced sampling design. The variance among replicates in the example was lower than for Fraser River samples, but the exercise is nevertheless instructive because it suggests that our unbalanced design was not fatally weakened.

Collectively, these exploratory results suggested that when large-scale (i.e., bar to bar) spatial variability is great, the addition of another reference site may not improve resolution greatly. An additional reference site will improve power, however, when the effect size is very large. We expect that when there is high temporal variability, the addition of one or two sampling episodes may not greatly increase resolution. In such cases, it is probably most efficient to increase sample replication at each site in order to improve as much as possible the estimates of mean values, hence improving the ability of the analysis to distinguish among them. In this study, fewer post-scalp sampling periods and an increase in sample replication during each period may have improved overall statistical power. Of course, such insights can only be drawn once knowledge of the system's natural variance has been gained.

4.5.2 Minimum Sampling Recommendations

Substantial sampling effort and expense were undertaken for this study both in field data collection and laboratory processing time. This amount of effort may not be realistic for the monitoring of future removals; therefore, the following recommendations are made as *minimum* sampling requirements. If a statistically rigorous analysis is desired, we recommend consultation with a statistician to ensure that sampling effort will be adequately distributed given the natural level of variance quantified in our study.

- At least two reference sites undisturbed by bar scalping and other unnatural factors, and subject to the same flow conditions, should be included in all monitoring activities and sampled simultaneously with the removal site.
- At least two, and preferably three sampling episodes should be scheduled prior to gravel removal. These episodes should be spaced apart in time (preferably chosen at random) to ensure independence. Consideration should be given to the timing of key life cycle events (late winter for invertebrates emerging and spring/summer for fish rearing) to ensure that the animals of interest are present in the system. The same or greater number of sampling episodes should take place after the removal operation is complete. It is not necessary that the number of episodes matches with pre-impact sampling, but it may be desirable to match the timing of sampling episodes before and after impact. Post-removal sampling should extend over a minimum of one freshet cycle, and preferably one above-average freshet event, when the greatest degree of physical and biological change is likely to occur.

<u>Biological Sampling</u>

- Collect benthic invertebrates using a consistent and standard sampling technique (e.g., Surber net or kick net). Sample from only one habitat type or stratify effort equally among habitat types to minimize habitat-specific variability. Collect samples in groups of six replicates at a given location due to the inherent variability of invertebrate distributions. Taxonomic identification to family is adequate for most analytical purposes.
- Sample juvenile fish using a consistent technique (preferably by beach seine). Stratify effort by habitat type and collect a minimum of ten replicate samples from each sample unit during sampling episodes. Accurate catch estimates will require substantial effort due to the mobility of fish and habitat-specificity of their distributions. Additional sampling effort is recommended if budget allows.

<u>Physical Habitat Sampling</u>

- The grain size distribution of surface sediment should be characterized within the removal area and one reference area before mining and after one freshet, according to the Wolman or photographic method (Church et al. 2000). Sediment sampling should be carried out within identifiable sedimentary units at each site and these units categorized for each set of samples taken.

- Habitat mapping of the removal site should take place before and one freshet after mining at similar discharges. Mapping over a range of discharges is desired and should include at least one date of above average mean annual discharge (>3000 m^3/s). Mapping can be carried out by ground surveys or photographic analysis by a trained technician.
- Concurrent with fish sampling, descriptive information on habitat characteristics should be collected at fish sampling locations. This information should include surface sediment texture, embeddedness, near-shore and off-shore water velocity and depth, and bank slope.

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Appendix A. Photographic history of bar scalping at Harrison Bar.

Aerial view of scalping operation at Harrison Bar. Photograph taken March 7, 2000 (courtesy of Dr. V. Galay).

Ground view of scalping operation at Harrison Bar. Photograph taken March 7, 2000.

Stockpile area and conveyor belt used to transport gravel from Minto Island to Steelhead Aggregrates Ltd. yard. Photograph taken March 6, 2000 (courtesy of Dr. V. Galay).

Gravel stockpile and conveyor belt across Minto Channel (March 7, 2000).

Lower Harrison Bar pre-scalping (August 17, 1999) looking east toward Mt. Cheam.

Lower Harrison Bar post-scalping (March 26, 2000) looking west toward Harrison Knob.

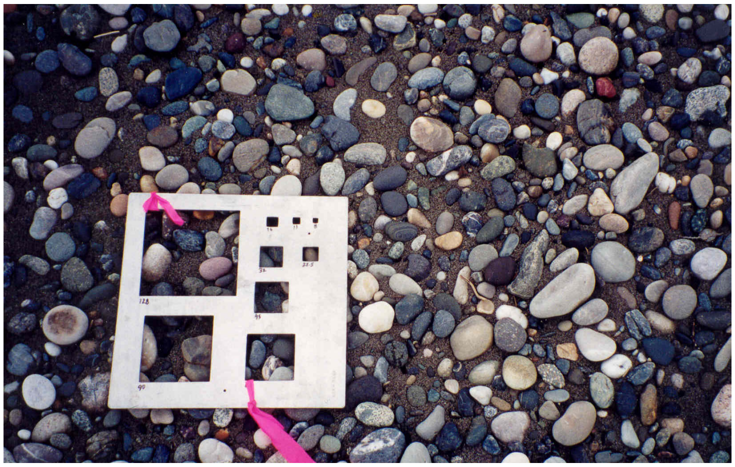
Lower Harrison Bar post-scalping as flood water inundated the site (May 9, 2000). View is east toward Mt. Cheam.

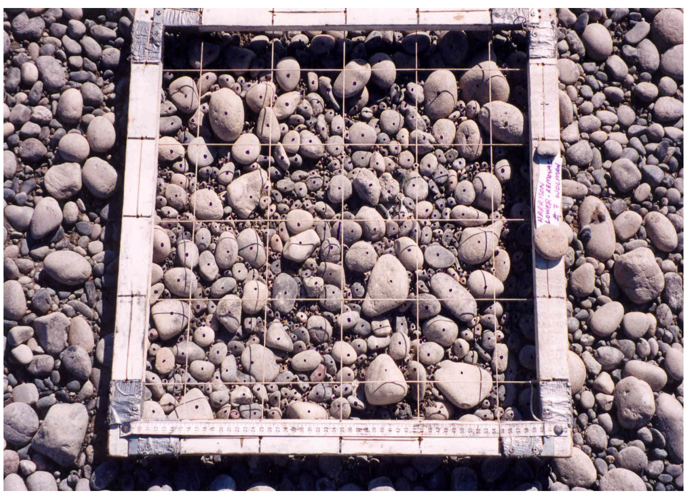
Lower Harrison Bar post-scalping and on the declining limb of the discharge hydrograph (August 17, 2000). View is east toward Mt. Cheam.

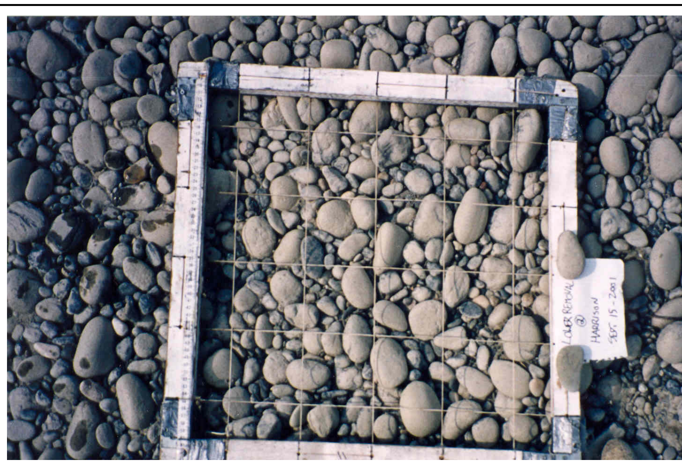
Summer channel intersecting across the scalped area of lower Harrison Bar, November 15, 2000. View is east toward Mt. Cheam.

Lower Harrison Bar post-scalping and after one freshet event (March 7, 2001). View is east toward Mt. Cheam.

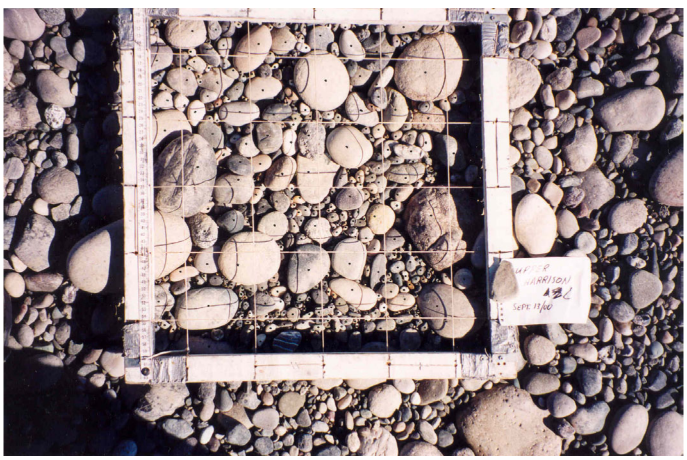
Sediment photos page 1

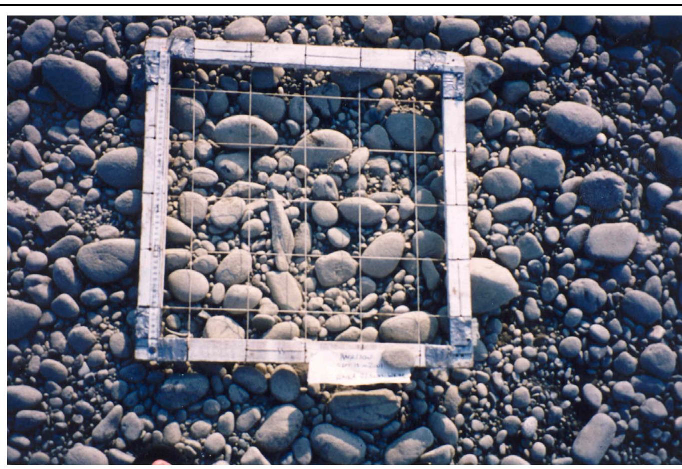






Sediment photos page 2





Sediment photos page 3

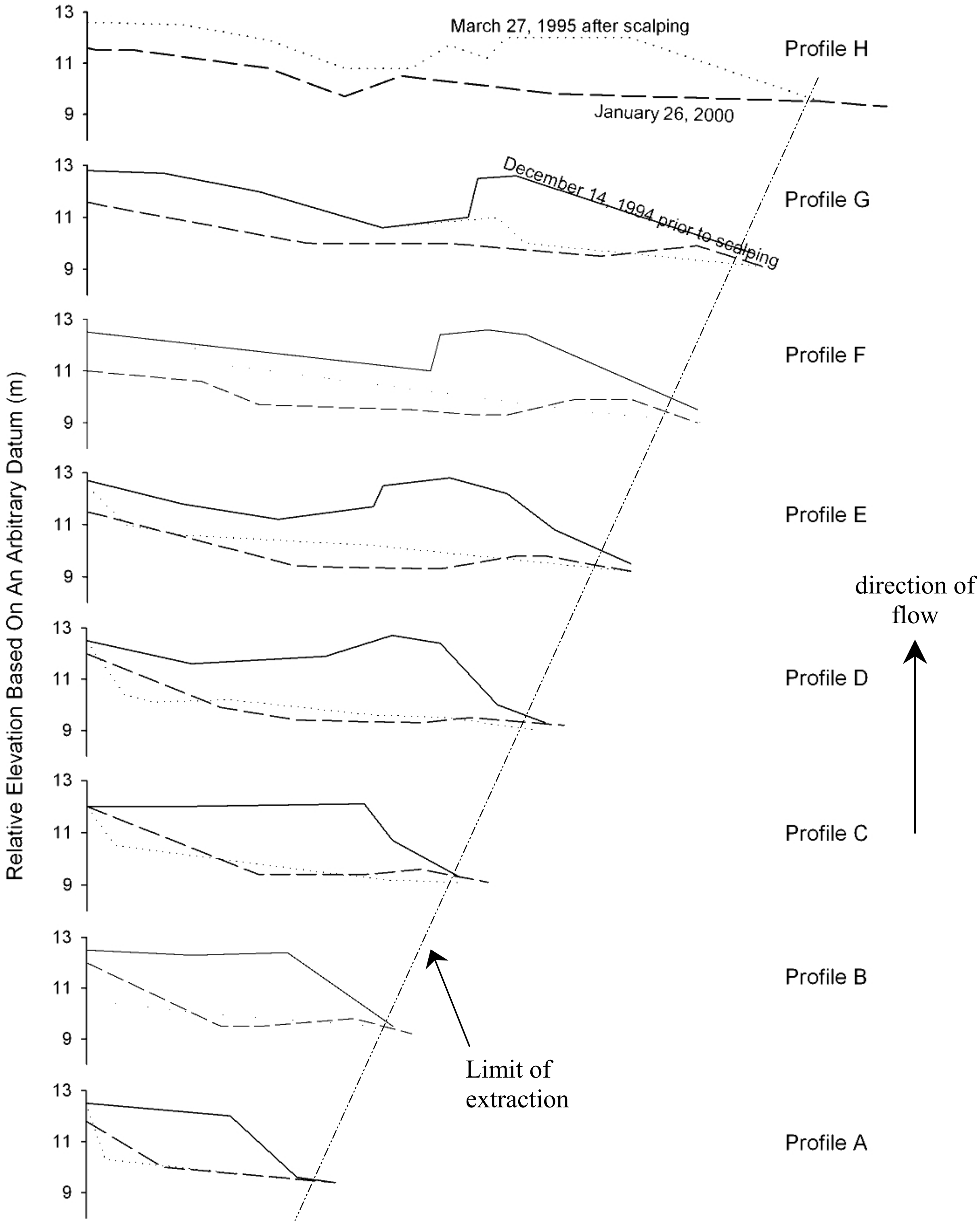
Appendix B. Record of scalping at Foster Bar (1995).

Bar scalping at Foster Bar. Photo taken March 2, 1995 (courtesy of Dr. V. Galay). Scalping took place in February/March 1995. Approximately 300,000 tonnes of gravel was removed.

A.

B.

Foster Bar (A) August 30, 1995 (photo courtesy of Dr. V. Galay) with scalped area inundated and (B) September 20, 2002, showing no sediment replenishment.



Planform view of cross-sections at Foster Bar (Tunbridge & Tunbridge Ltd) before, immediately after, and 5 years following bar scalping. Approximate horizontal scale 1:2500.

Appendix C. Twenty-five fish species collected in the gravel reach of Fraser River.

Family	Species	Common Name	3-Letter Code
Petromyzonidae	*Lampetra species*	Lamprey (species unknown)	LAM
Acipenseridae	*Acipenser transmontanus*	White sturgeon[R]	WST
Salmonidae	*Prosopium williamsoni*	Mountain whitefish	MWF
	Salvelinus confluentus	Bull char[B]	BUL
	S. malma	Dolly Varden[B]	DOV
	Oncorhynchus clarki	Cutthroat trout[B]	CUT
	O. mykiss	Rainbow trout	RBT
	O. gorbuscha	Pink salmon	PIN
	O. keta	Chum salmon	CHU
	O. kisutch	Coho salmon	COH
	O. nerka	Sockeye salmon	SOC
	O. tshawytscha	Chinook salmon	CHI
Cyprinidae	*Hybognathus hankinsoni*	Brassy minnow[B]	BRA
	Mylocheilus caurinus	Peamouth	PEA
	Ptychocheilus oregonensis	Northern pikeminnow	NPM
	Rhinichthys cataractae	Longnose dace	LND
	R. falcatus	Leopard dace	LED
	Richardsonius balteatus	Redside shiner	RSS
Catostomidae	*Catostomus columbianus*	Bridgelip sucker	BLS
	C. macrocheilus	Largescale sucker	LGS
	C. platyrhynchus	Mountain sucker[B]	MTS
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback	TSS
	G. aculeatus trachurus	Marine stickleback	MSB
Cottidae	*Cottus aleuticus*	Coastrange sculpin	CRS
	C. asper	Prickly sculpin	PRS

B: blue-listed
R: red-listed

Appendix D. Benthic invertebrate taxa collected in the gravel reach of Fraser River.

Invertebrates were identified to the lowest-possible taxonomic level, dependent on size and maturity of the individual and preserved condition. FFG refers to the functional feeding group classification based on Merritt and Cummins (1996). CG: collector-gatherer; SC: scraper; SH: shredder; PR: predator; CF: collector-filterer; PA: parasite. * identifies groups representing >1% of the total abundance of invertebrates collected; º identifies groups representing 0.5-1% of the total abundance of invertebrates collected; ‘ identifies groups representing 0.1-0.5% of the total abundance of invertebrates collected.

ORDER	FAMILY	SUB-FAMILY	GENUS	FFG
O. Ephemeroptera	*F. Baetidae		*Baetis sp.*	CG/SC
	*F. Heptageniidae		*Cinygmula sp.*	SC
			Epeorus sp.	SC
			Heptagenia sp.	CG/SC
			Rhithrogena sp.	CG/SC
	*F. Ephemerellidae		*Drunella sp.*	SC
			Ephemerella sp.	CG
	ºF. Ameletidae		*Ameletus sp.*	SC
	F. Leptophlebiidae		*Paraleptophlebiidae sp.*	CG
O. Plecoptera	*F. Capniidae		*Capnia sp*	SH
			Utacapnia sp	SH
	F. Chloroperlidae		*Plumiperla sp.*	PR
			Sweltsa sp	PR
	‘F. Nemouridae		*Ostrocera sp*	SH
			Podmosta sp.	SH
			Zapada sp.	SH
	F. Perlidae		*Agnetina sp.*	PR
			Claassenia sp.	PR
			Hesperoperla sp.	PR
	‘F. Perlodidae		*Isogenoides sp.*	PR
			Isoperla sp.	PR
			Skwala sp.	PR
	F. Leuctridae		*Despaxia sp.*	SH
	F. Pteronarcyidae		*Pteronarcella sp.*	SH
	ºF. Taeniopterygidae		*Taenionema sp.*	SH
O. Trichoptera	F. Brachycentridae		*Brachycentrus sp.*	CF
	F. Glossomatidae		*Glossosoma sp.*	SC

ORDER	FAMILY	SUB-FAMILY	GENUS	FFG
	F. Hydroptilidae		*Hydroptila sp.*	SC
	F. Limnephilidae		*Onocosmoecus sp.*	SH
O. Trichoptera	F. Lepidostomatidae		*Lepidostoma sp.*	SH
	ºF. Hydropsychidae		*Hydropsyche sp.*	CF
	F. Polycentropodidae		*Polycentropus sp.*	PR
	F. Rhyacophilidae		*Rhyacophilia sp.*	PR
O. Diptera	F. Athericidae		*Atherix sp.*	PR
	F. Blephariceridae		*Bibiocephala sp.*	SC
	*F. Chironomidae	*s.f.* Orthocladiinae		CG
		s.f. Tanypodinae		PR
		s.f. Chironominae	*Tanytarsini*	CF
			Chironomoni	CG
		s.f. Diamesinae		CG
	‘F. Ceratopogoniidae	*s.f.* Ceratopogoninae.		PR
	ºF. Empididae		*Chelifera sp.*	PR
			Hemerodromia sp.	PR
	‘F. Simuliidae		*Simulium sp.*	CF
	F. Tipulidae		*Antocha sp.*	CG
			Dicranota sp.	PR
			Erioptera sp.	CG
			Hesperconopa sp.	CG
			Limnophilia sp.	PR
			Ormosia sp.	CG
O. Coleoptera	F. Dytiscida		*Brachyvatus sp.*	PR
	Fam. Elmidae		*Heterolimnius sp.*	SC
	Fam. Gyrinidae			PR
	Fam. Hydrochidae		*Hydrochus sp.*	SH
	Fam. Hydrophilidae			PR
	F. Corixidae		*Corisella sp.*	PR
O.Homoptera			*Tricorixa sp.*	PR
O.Lepidoptera				SH
***Nematoda**				PA
***Oligochaeta**	Fam. Naididae			SC
	Fam. Tubificidae			SC
‘Acarina				PA

Appendix E. Asymmetrical ANOVA – Mechanics and Power Calculation

Mechanics

Underwood (1993) describes in thorough detail the mechanics of asymmetrical ANOVA, which is carried out by running four separate ANOVA procedures using any common statistical software. The procedure is described briefly below. Refer to appendices F through K to examine its application.

Three independent variables are involved in the analysis:

1. Before/After (B) – fixed categorical variable
2. Times – random categorical variable
3. Locations – fixed or random categorical variable

First (Table A in appendices), analyze all data as a fully orthogonal analysis of Before/After, Locations, and Times nested within Before/After [T(B)]. This analysis does not differentiate between the impacted and reference sites.

Second (Table B in appendices), analyze data as a three-factor analysis of all data from the reference locations only. The identical model as for analysis #1 is used, only selecting for reference sites.

Third (Table C in appendices), analyze data from all sites as a two-factor analysis and exclude sampling periods after the impact. Factor B (Before/After) is not included and Times is included as a non-nested factor.

Fourth (Table D in appendices), repeat analysis #3 but include only the reference sites.

From these four analyses, the entire asymmetrical ANOVA can be calculated by subtractions and additions of the component terms. The algebra is indicated in the appendices. Once the Source of Variation table is completed, use the flow chart below and proceed through a set of questions and statistical tests to address whether or not an impact has occurred. The answer to the question at each branch of the flowchart determines the sources of variation and degrees of freedom used to calculate an F-value. Refer to **Section 2.6** for further details.

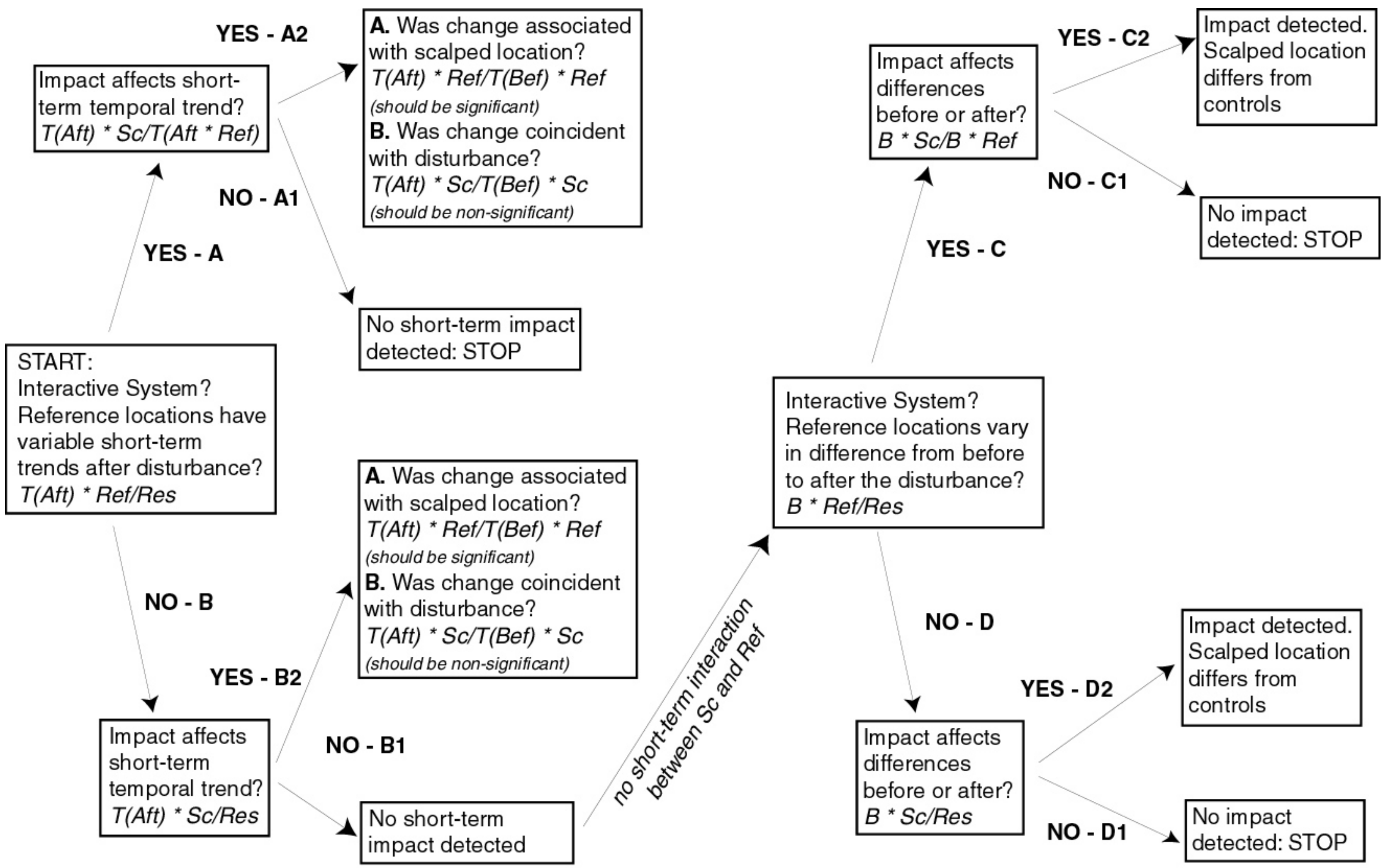
Power Calculation

The power of a statistical analysis is its capacity to detect a difference between groups when a difference actually exists. The calculation of power for asymmetrical ANOVA is straightforward, using values derived from the Source of Variation table and from the central distribution of *F* that is in common use.

First, determine 1+n□ = Mean Square [T(Aft) x Sc] / Mean Square [Residual]

Second, calcuate $F_{alt} = F_{crit}$ / (1+n□). F_{crit} is based on the degrees of freedom of (1+n□). df_1 for MS [T(Aft) x Sc]; df_2 for MS [Residual].

Third, estimate power based on F_{alt} using the distribution function of F: [(F_{alt}), df_1, df_2].



Sequence of questions and statistical tests of Underwood's asymmetrical ANOVA to detect an impact at a site with several reference locations (from Underwood 1993, Table 6). Sc: Scalp site. Ref: Reference sites. Res: Residual. B: Before. Aft: After. T: Time.

Appendix F. ANOVA results of Habitat Characteristics – Bar Edge Units

PC AXIS 1 (Hydraulic Gradient)

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	0.109	1	0.109	a1
Times(B)	10.180	9	1.131	a2
Locations	2.980	3	0.993	a3
B * L	2.400	3	0.800	a4
T(B) * L	43.725	27	1.619	a5
Residual	42.029	80	0.525	a6
Total	101.423	123		a7
B. Reference Locations on All Dates				
Bef/Aft - B	0.928	1	0.928	
Times(B)	7.272	9	0.808	
Locations	2.954	2	1.477	b1
B * L	0.044	2	0.022	b2
T(B) * L	11.900	18	0.661	b3
Residual	29.221	53	0.551	
Total	52.319	85		
C. All Locations Before Impact				
Times(B)	7.240	2	3.620	
Locations	2.106	3	0.702	
B * L	6.296	6	1.049	c1
Residual	2.332	13	0.179	
Total	17.974	24		
D. Reference Locations Before Impact				
Times(B)	2.053	2	1.027	
Locations	1.149	2	0.575	
B * L	1.685	4	0.421	d1
Residual	1.472	6	0.245	
Total	6.359	14		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.109	1	0.109
T(B)	a2	10.180	9	1.131
Location	a3	2.980	3	0.993
Impact vs Ref	a3-b1	0.026	1	0.026
Among Refs	b1	2.954	2	1.477
B * Location	a4	2.400	3	0.800
B * Impact	a4-b2	2.356	1	2.356
B * Ref	b2	0.044	2	0.022
T(B) * L	a5	43.725	27	1.619
T(Bef) * Location	c1	6.296	6	1.049
T(Bef) * Impact	c1-d1	4.611	2	2.306
T(Bef) * Ref	d1	1.685	4	0.421
T(Aft) * Location	a5-c1	37.429	21	1.782
T(Aft) * Impact	a5-c1-b3+d1	27.214	7	3.888
T(Aft) * Ref	b3-d1	10.215	14	0.730
Residual	a6	42.029	74	0.568
Total	a7	101.423	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	1.285	1.83	0.24
NO…				
2. Does scalping affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	6.845	2.14	p<0.0005
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,4	1.732	5.87	0.32
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,2	1.686	39.4	0.42
NO… change was not coincident with impact				

PC AXIS 2 (Coarse Sediment Gradient)

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	5.024	1	5.024	a1
Times(B)	30.489	9	3.388	a2
Locations	8.621	3	2.874	a3
B * L	3.399	3	1.133	a4
T(B) * L	13.377	27	0.495	a5
Residual	44.880	80	0.561	a6
Total	105.790	123		a7
B. Reference Locations on All Dates				
Bef/Aft - B	4.390	1	4.390	
Times(B)	23.538	9	2.615	
Locations	4.701	2	2.351	b1
B * L	2.930	2	1.465	b2
T(B) * L	10.484	18	0.582	b3
Residual	35.061	53	0.662	
Total	81.104	85		
C. All Locations Before Impact				
Times(B)	25.072	2	12.536	
Locations	6.567	3	2.189	
B * L	5.157	6	0.860	c1
Residual	8.742	13	0.672	
Total	45.538	24		
D. Reference Locations Before Impact				
Times(B)	19.136	2	9.568	
Locations	4.273	2	2.137	
B * L	5.006	4	1.252	d1
Residual	4.583	6	0.764	
Total	32.998	14		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	5.024	1	5.024
T(B)	a2	30.489	9	3.388
Location	a3	8.621	3	2.874
Impact vs Ref	a3-b1	3.920	1	3.920
Among Refs	b1	4.701	2	2.351
B * Location	a4	3.399	3	1.133
B * Impact	a4-b2	0.469	1	0.469
B * Ref	b2	2.930	2	1.465
T(B) * L	a5	13.377	27	0.495
T(Bef) * Location	c1	5.157	6	0.860
T(Bef) * Impact	c1-d1	0.151	2	0.075
T(Bef) * Ref	d1	5.006	4	1.252
T(Aft) * Location	a5-c1	8.220	21	0.391
T(Aft) * Impact	a5-c1-b3+d1	2.742	7	0.392
T(Aft) * Ref	b3-d1	5.478	14	0.391
Residual	a6	44.880	74	0.606
Total	a7	105.790	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	0.645	1.83	0.82
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	0.646	2.14	0.72
NO… no short-term impact detected				
3. Do reference sites vary in the difference from before to after?				
B * Ref / Residual	2,74	2.416	3.11	0.1
NO…				
4. Does impact affect difference from before to after impact?				
B * Imp / Residual	1,74	0.773	3.96	0.38
NO…no impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	0.646
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	3.310
Power (based on F-distribution)	0.004

PC AXIS 3 (Fine Sediment Gradient)

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.194	1	0.194	a1
Times(B)	13.764	9	1.529	a2
Locations	1.803	3	0.601	a3
B * L	0.230	3	0.077	a4
T(B) * L	21.796	27	0.807	a5
Residual	76.002	80	0.950	a6
Total	113.789	123		a7
B. Reference Locations on All Dates				
Bef/Aft - B	0.126	1	0.126	
Times(B)	13.386	9	1.487	
Locations	1.623	2	0.812	b1
B * L	0.222	2	0.111	b2
T(B) * L	10.366	18	0.576	b3
Residual	29.022	53	0.548	
Total	54.745	85		
C. All Locations Before Impact				
Times(B)	8.056	2	4.028	
Locations	1.023	3	0.341	
B * L	6.617	6	1.103	c1
Residual	2.404	13	0.185	
Total	18.100	24		
D. Reference Locations Before Impact				
Times(B)	10.357	2	5.179	
Locations	0.940	2	0.470	
B * L	1.938	4	0.485	d1
Residual	1.117	6	0.186	
Total	14.352	14		

Power Analysis

1+n0 = MS[T(Aft) * Impact] / MS[Residual]	0.939
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	2.277
Power (based on F-distribution)	0.034

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.194	1	0.194
T(B)	a2	13.764	9	1.529
Location	a3	1.803	3	0.601
Impact vs Ref	a3-b1	0.180	1	0.180
Among Refs	b1	1.623	2	0.812
B * Location	a4	0.230	3	0.077
B * Impact	a4-b2	0.008	1	0.008
B * Ref	b2	0.222	2	0.111
T(B) * L	a5	21.796	27	0.807
T(Bef) * Location	c1	6.617	6	1.103
T(Bef) * Impact	c1-d1	4.679	2	2.340
T(Bef) * Ref	d1	1.938	4	0.485
T(Aft) * Location	a5-c1	15.179	21	0.723
T(Aft) * Impact	a5-c1-b3+d1	6.751	7	0.964
T(Aft) * Ref	b3-d1	8.428	14	0.602
Residual	a6	76.002	74	1.027
Total	a7	113.789	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	0.586	1.82	0.87
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	0.939	2.13	0.48
NO… no short-term impact detected				
3. Do reference sites vary in the difference from before to after?				
B * Ref / Residual	2,74	0.108	3.11	0.9
NO…				
4. Does impact affect difference from before to after impact?				
B * Imp / Residual	1,74	0.008	3.96	0.93
NO…no impact detected				

Appendix G. Fish ANOVA results – Whole Bar Unit

FISH DENSITY

A. All Data				
Source of Variance	SS	df	MS	Term
Bef/Aft - B	0.019	1	0.019	a1
Times(B)	0.884	9	0.098	a2
Locations	0.184	3	0.061	a3
B * L	0.113	3	0.038	a4
T(B) * L	1.231	27	0.046	a5
Residual	14.965	198	0.076	a6
Total	17.396	241		a7
B. Exclude Impact Site				
Bef/Aft - B	0.056	1	0.056	
Times(B)	0.732	9	0.081	
Locations	0.171	2	0.086	b1
B * L	0.050	2	0.025	b2
T(B) * L	0.464	18	0.026	b3
Residual	9.304	139	0.067	
Total	10.777	171		
C. All Locations Before Impact				
Times(B)	0.292	2	0.146	
Locations	0.158	3	0.053	
B * L	0.121	6	0.020	c1
Residual	1.359	33	0.041	
Total	1.930	44		
D. Reference Locations Before Impact				
Times(B)	0.251	2	0.126	
Locations	0.118	2	0.059	
B * L	0.101	4	0.025	d1
Residual	1.311	22	0.060	
Total	1.781	30		

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.391
Degrees of Freedom	7,195
Falt = Fcrit / (1+n0) = 2.06 / (1+n0)	1.481
Power (based on F-distribution)	0.176

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.019	1	0.019
T(B)	a2	0.884	9	0.098
Location	a3	0.184	3	0.061
Impact vs Ref	a3-b1	0.013	1	0.013
Among Refs	b1	0.171	2	0.086
B * Location	a4	0.113	3	0.038
B * Impact	a4-b2	0.063	1	0.063
B * Ref	b2	0.050	2	0.025
T(B) * L	a5	1.231	27	0.046
T(Bef) * Location	c1	0.121	6	0.020
T(Bef) * Impact	c1-d1	0.020	2	0.010
T(Bef) * Ref	d1	0.101	4	0.025
T(Aft) * Location	a5-c1	1.110	21	0.053
T(Aft) * Impact	a5-c1-b3+d1	0.747	7	0.107
T(Aft) * Ref	b3-d1	0.363	14	0.026
Residual	a6	14.965	195	0.077
Total	a7	17.396	241	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,195	0.338	1.93	0.98
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,195	1.391	2.35	0.21
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,195	0.326	3.76	0.72
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,195	0.821	5.1	0.37
NO…no impact detected				

PERCENT REPRESENTATION BY SALMON

A. All Data				
Source of Variance	SS	df	MS	Term
Bef/Aft - B	0.610	1	0.610	a1
Times(B)	5.758	9	0.640	a2
Locations	0.713	3	0.238	a3
B * L	0.327	3	0.109	a4
T(B) * L	3.661	27	0.136	a5
Residual	25.510	198	0.129	a6
Total	36.579	241		a7
B. Exclude Impact Site				
Bef/Aft - B	0.234	1	0.234	
Times(B)	3.268	9	0.363	
Locations	0.077	2	0.039	b1
B * L	0.166	2	0.083	b2
T(B) * L	2.630	18	0.146	b3
Residual	20.304	139	0.146	
Total	26.679	171		
C. All Locations Before Impact				
Times(B)	0.032	2	0.016	
Locations	0.511	3	0.170	
B * L	0.115	6	0.019	c1
Residual	4.709	33	0.143	
Total	5.367	44		
D. Reference Locations Before Impact				
Times(B)	0.075	2	0.038	
Locations	0.023	2	0.012	
B * L	0.101	4	0.025	d1
Residual	4.668	22	0.212	
Total	4.867	30		

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.111
Degrees of Freedom	7,195
Falt = Fcrit / (1+n0) = 2.06 / (1+n0)	1.855
Power (based on F-distribution)	0.079

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.610	1	0.610
T(B)	a2	5.758	9	0.640
Location	a3	0.713	3	0.238
Impact vs Ref	a3-b1	0.636	1	0.636
Among Refs	b1	0.077	2	0.039
B * Location	a4	0.327	3	0.109
B * Impact	a4-b2	0.161	1	0.161
B * Ref	b2	0.166	2	0.083
T(B) * L	a5	3.661	27	0.136
T(Bef) * Location	c1	0.115	6	0.019
T(Bef) * Impact	c1-d1	0.014	2	0.007
T(Bef) * Ref	d1	0.101	4	0.025
T(Aft) * Location	a5-c1	3.546	21	0.169
T(Aft) * Impact	a5-c1-b3+d1	1.017	7	0.145
T(Aft) * Ref	b3-d1	2.529	14	0.181
Residual	a6	25.510	195	0.131
Total	a7	36.579	241	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,195	1.381	1.93	0.16
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,195	1.111	2.35	0.35
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,195	0.634	3.76	0.53
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,195	1.231	5.1	0.27
NO…no impact detected				

SPECIES RICHNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	12.077	1	12.077	a1
Times(B)	393.173	9	43.686	a2
Locations	2.368	3	0.789	a3
B * L	5.316	3	1.772	a4
T(B) * L	154.425	27	5.719	a5
Residual	733.625	198	3.705	a6
Total	1300.984	241		a7
B. Exclude Impact Site				
Bef/Aft - B	10.637	1	10.637	
Times(B)	323.943	9	35.994	
Locations	0.84	2	0.420	b1
B * L	4.693	2	2.347	b2
T(B) * L	92.76	18	5.153	b3
Residual	536.806	139	3.862	
Total	969.679	171		
C. All Locations Before Impact				
Times(B)	141.771	2	70.886	
Locations	0.682	3	0.227	
B * L	13.004	6	2.167	c1
Residual	68.433	33	2.074	
Total	223.89	44		
D. Reference Locations Before Impact				
Times(B)	92.801	2	46.401	
Locations	0.629	2	0.315	
B * L	1.101	4	0.275	d1
Residual	49.6	22	2.255	
Total	144.131	30		

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.890
Degrees of Freedom	7,195
Falt = Fcrit / (1+n0) = 2.06 / (1+n0)	1.090
Power (based on F-distribution)	0.371

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	12.077	1	12.077
T(B)	a2	393.173	9	43.686
Location	a3	2.368	3	0.789
Impact vs Ref	a3-b1	1.528	1	1.528
Among Refs	b1	0.840	2	0.420
B * Location	a4	5.316	3	1.772
B * Impact	a4-b2	0.623	1	0.623
B * Ref	b2	4.693	2	2.347
T(B) * L	a5	154.425	27	5.719
T(Bef) * Location	c1	13.004	6	2.167
T(Bef) * Impact	c1-d1	11.903	2	5.952
T(Bef) * Ref	d1	1.101	4	0.275
T(Aft) * Location	a5-c1	141.421	21	6.734
T(Aft) * Impact	a5-c1-b3+d1	49.762	7	7.109
T(Aft) * Ref	b3-d1	91.659	14	6.547
Residual	a6	733.625	195	3.762
Total	a7	1300.984	241	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,195	1.740	1.93	0.06
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,195	1.890	2.35	0.07
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,195	0.624	3.76	0.53
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,195	0.166	5.1	0.68
NO…no impact detected				

SIMPSON'S DIVERSITY

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.065	1	0.065	a1
Times(B)	1.122	9	0.125	a2
Locations	0.042	3	0.014	a3
B * L	0.032	3	0.011	a4
T(B) * L	1.894	27	0.070	a5
Residual	9.826	198	0.050	a6
Total	12.981	241		a7
B. Exclude Impact Site				
Bef/Aft - B	0.020	1	0.020	
Times(B)	0.690	9	0.077	
Locations	0.018	2	0.009	b1
B * L	0.008	2	0.004	b2
T(B) * L	1.143	18	0.064	b3
Residual	6.963	139	0.050	
Total	8.842	171		
C. All Locations Before Impact				
Times(B)	0.497	2	0.249	
Locations	0.003	3	0.001	
B * L	0.219	6	0.037	c1
Residual	1.819	33	0.055	
Total	2.538	44		
D. Reference Locations Before Impact				
Times(B)	0.197	2	0.099	
Locations	0.003	2	0.002	
B * L	0.035	4	0.009	d1
Residual	1.464	22	0.067	
Total	1.699	30		

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.607
Degrees of Freedom	7,195
Falt = Fcrit / (1+n0) = 2.06 / (1+n0)	1.282
Power (based on F-distribution)	0.261

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.065	1	0.065
T(B)	a2	1.122	9	0.125
Location	a3	0.042	3	0.014
Impact vs Ref	a3-b1	0.024	1	0.024
Among Refs	b1	0.018	2	0.009
B * Location	a4	0.032	3	0.011
B * Impact	a4-b2	0.024	1	0.024
B * Ref	b2	0.008	2	0.004
T(B) * L	a5	1.894	27	0.070
T(Bef) * Location	c1	0.219	6	0.037
T(Bef) * Impact	c1-d1	0.184	2	0.092
T(Bef) * Ref	d1	0.035	4	0.009
T(Aft) * Location	a5-c1	1.675	21	0.080
T(Aft) * Impact	a5-c1-b3+d1	0.567	7	0.081
T(Aft) * Ref	b3-d1	1.108	14	0.079
Residual	a6	9.826	195	0.050
Total	a7	12.981	241	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,195	1.571	1.93	0.08
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,195	1.607	2.35	0.13
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,195	0.079	3.76	0.92
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,195	0.476	5.1	0.49
NO…no impact detected				

SIMPSON'S EVENNESS

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	0.117	1	0.117	a1
Times(B)	0.126	9	0.014	a2
Locations	0.006	3	0.002	a3
B * L	0.007	3	0.002	a4
T(B) * L	0.255	27	0.009	a5
Residual	1.042	198	0.005	a6
Total	1.553	241		a7
B. Exclude Impact Site				
Bef/Aft - B	0.077	1	0.077	
Times(B)	0.045	9	0.005	
Locations	0.000	2	0.000	b1
B * L	0.006	2	0.003	b2
T(B) * L	0.083	18	0.005	b3
Residual	0.755	139	0.005	
Total	0.966	171		
C. All Locations Before Impact				
Times(B)	0.088	2	0.044	
Locations	0.005	3	0.002	
B * L	0.043	6	0.007	c1
Residual	0.138	33	0.004	
Total	0.274	44		
D. Reference Locations Before Impact				
Times(B)	0.037	2	0.019	
Locations	0.002	2	0.001	
B * L	0.014	4	0.004	d1
Residual	0.117	22	0.005	
Total	0.170	30		

Source of Variation	**Term**	**SS**	**df**	**MS**
B (bef-aft)	a1	0.117	1	0.117
T(B)	a2	0.126	9	0.014
Location	a3	0.006	3	0.002
Impact vs Ref	a3-b1	0.006	1	0.006
Among Refs	b1	0.000	2	0.000
B * Location	a4	0.007	3	0.002
B * Impact	a4-b2	0.001	1	0.001
B * Ref	b2	0.006	2	0.003
T(B) * L	a5	0.255	27	0.009
T(Bef) * Location	c1	0.043	6	0.007
T(Bef) * Impact	c1-d1	0.029	2	0.015
T(Bef) * Ref	d1	0.014	4	0.004
T(Aft) * Location	a5-c1	0.212	21	0.010
T(Aft) * Impact	a5-c1-b3+d1	0.143	7	0.020
T(Aft) * Ref	b3-d1	0.069	14	0.005
Residual	a6	1.042	195	0.005
Total	a7	1.553	241	

	df	**F**	**Fcrit**	**p**
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,195	0.922	1.93	0.52
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,195	3.823	2.075	<0.001
YES… short-term impact detected				
3A. Are changes associated with impact site?				
T(Aft) * Ref / T(Bef) * Ref	14,4	1.408	39.4	0.40
YES… changes are associated with scalped site				
3B. Timing of change was coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,2	1.409	948	0.48
NO… timing of change was not coincident with impact				

Appendix H. Fish ANOVA results – Bar Edge Unit

FISH DENSITY

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	0.070	1	0.070	a1
Times(B)	0.297	9	0.033	a2
Locations	0.008	3	0.003	a3
B * L	0.013	3	0.004	a4
T(B) * L	0.137	27	0.005	a5
Residual	0.779	80	0.010	a6
Total	1.304	123		a7
B. Exclude Impact Site				
Bef/Aft - B	0.060	1	0.060	
Times(B)	0.202	9	0.022	
Locations	0.008	2	0.004	b1
B * L	0.011	2	0.006	b2
T(B) * L	0.066	18	0.004	b3
Residual	0.428	53	0.008	
Total	0.775	85		
C. All Locations Before Impact				
Times(B)	0.172	2	0.086	
Locations	0.012	3	0.004	
B * L	0.054	6	0.009	c1
Residual	0.040	13	0.003	
Total	0.278	24		
D. Reference Locations Before Impact				
Times(B)	0.116	2	0.058	
Locations	0.012	2	0.006	
B * L	0.054	4	0.014	d1
Residual	0.025	6	0.004	
Total	0.207	14		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.070	1	0.070
T(B)	a2	0.297	9	0.033
Location	a3	0.008	3	0.003
Impact vs Ref	a3-b1	0.000	1	0.000
Among Refs	b1	0.008	2	0.004
B * Location	a4	0.013	3	0.004
B * Impact	a4-b2	0.002	1	0.002
B * Ref	b2	0.011	2	0.006
T(B) * L	a5	0.137	27	0.005
T(Bef) * Location	c1	0.054	6	0.009
T(Bef) * Impact	c1-d1	0.000	2	0.000
T(Bef) * Ref	d1	0.054	4	0.014
T(Aft) * Location	a5-c1	0.083	21	0.004
T(Aft) * Impact	a5-c1-b3+d1	0.071	7	0.010
T(Aft) * Ref	b3-d1	0.012	14	*0.001*
Residual	a6	0.779	74	0.011
Total	a7	1.304	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	0.081	1.93	0.99
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	0.964	2.35	0.46
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,74	0.522	3.76	0.60
NO…				
4. Does scalping affect differences from before to after?				
B * Imp / Residual	1,74	0.190	5.1	0.66
NO…no impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	0.964
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	2.219
Power (based on F-distribution)	0.042

PROPORTION REPRESENTED BY SALMON

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	0.808	1	0.808	a1
Times(B)	1.289	9	0.143	a2
Locations	0.173	3	0.058	a3
B * L	0.488	3	0.163	a4
T(B) * L	5.306	27	0.197	a5
Residual	12.981	80	0.162	a6
Total	21.045	123		a7
B. Exclude Impact Site				
Bef/Aft - B	1.109	1	1.109	
Times(B)	1.335	9	0.148	
Locations	0.081	2	0.041	b1
B * L	0.049	2	0.025	b2
T(B) * L	1.699	18	0.094	b3
Residual	10.32	53	0.195	
Total	14.593	85		
C. All Locations Before Impact				
Times(B)	0.202	2	0.101	
Locations	0.364	3	0.121	
B * L	0.302	6	0.050	c1
Residual	2.165	13	0.167	
Total	3.033	24		
D. Reference Locations Before Impact				
Times(B)	0.275	2	0.138	
Locations	0.061	2	0.031	
B * L	0.071	4	0.018	d1
Residual	1.44	6	0.240	
Total	1.847	14		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.808	1	0.808
T(B)	a2	1.289	9	0.143
Location	a3	0.173	3	0.058
Impact vs Ref	a3-b1	0.092	1	0.092
Among Refs	b1	0.081	2	0.041
B * Location	a4	0.488	3	0.163
B * Impact	a4-b2	0.439	1	0.439
B * Ref	b2	0.049	2	0.025
T(B) * L	a5	5.306	27	0.197
T(Bef) * Location	c1	0.302	6	0.050
T(Bef) * Impact	c1-d1	0.231	2	0.116
T(Bef) * Ref	d1	0.071	4	0.018
T(Aft) * Location	a5-c1	5.004	21	0.238
T(Aft) * Impact	a5-c1-b3+d1	3.376	7	0.482
T(Aft) * Ref	b3-d1	1.628	14	0.116
Residual	a6	12.981	74	0.175
Total	a7	21.045	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after scalping?				
T(Aft) * Ref / Residual	14,74	0.663	1.93	0.80
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	2.749	2.35	0.01
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,4	6.551	39.4	0.04
YES… changes are associated with scalped site				
3B. Was timing of change coincident with scalping?				
T(Aft) * Imp / T(Bef) * Imp	7,2	4.176	948	0.21
NO… change was not coincident with scalping				

SPECIES RICHNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	2.089	1	2.089	a1
Times(B)	291.578	9	32.398	a2
Locations	4.31	3	1.437	a3
B * L	1.124	3	0.375	a4
T(B) * L	62.743	27	2.324	a5
Residual	223.395	80	2.792	a6
Total	585.239	123		a7
B. Exclude Impact Site				
Bef/Aft - B	2.474	1	2.474	
Times(B)	219.268	9	24.363	
Locations	2.713	2	1.357	b1
B * L	0.561	2	0.281	b2
T(B) * L	36.63	18	2.035	b3
Residual	137.895	53	2.602	
Total	399.541	85		
C. All Locations Before Impact				
Times(B)	132.235	2	66.118	
Locations	0.334	3	0.111	
B * L	1.954	6	0.326	c1
Residual	6.3	13	0.485	
Total	140.823	24		
D. Reference Locations Before Impact				
Times(B)	85.253	2	42.627	
Locations	0.249	2	0.125	
B * L	0.473	4	0.118	d1
Residual	1.8	6	0.300	
Total	87.775	14		

Power Analysis

1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.166
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	1.834
Power (based on F-distribution)	0.093

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	2.089	1	2.089
T(B)	a2	291.578	9	32.398
Location	a3	4.310	3	1.437
Impact vs Ref	a3-b1	1.597	1	1.597
Among Refs	b1	2.713	2	1.357
B * Location	a4	1.124	3	0.375
B * Impact	a4-b2	0.563	1	0.563
B * Ref	b2	0.561	2	0.281
T(B) * L	a5	62.743	27	2.324
T(Bef) * Location	c1	1.954	6	0.326
T(Bef) * Impact	c1-d1	1.481	2	0.741
T(Bef) * Ref	d1	0.473	4	0.118
T(Aft) * Location	a5-c1	60.789	21	2.895
T(Aft) * Impact	a5-c1-b3+d1	24.632	7	3.519
T(Aft) * Ref	b3-d1	36.157	14	2.583
Residual	a6	223.395	74	3.019
Total	a7	585.239	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	0.856	1.93	0.61
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	1.166	2.35	0.33
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,74	0.093	3.76	0.91
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,74	0.186	5.1	0.67
NO…no impact detected				

SIMPSON'S DIVERSITY

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.356	1	0.356	a1
Times(B)	3.253	9	0.361	a2
Locations	0.179	3	0.060	a3
B * L	0.021	3	0.007	a4
T(B) * L	0.513	27	0.019	a5
Residual	2.8	80	0.035	a6
Total	7.122	123		a7
B. Exclude Impact Site				
Bef/Aft - B	0.234	1	0.234	
Times(B)	2.37	9	0.263	
Locations	0.032	2	0.016	b1
B * L	0.02	2	0.010	b2
T(B) * L	0.3	18	0.017	b3
Residual	1.692	53	0.032	
Total	4.648	85		
C. All Locations Before Impact				
Times(B)	1.346	2	0.673	
Locations	0.073	3	0.024	
B * L	0.064	6	0.011	c1
Residual	0.004	13	0.000	
Total	1.487	24		
D. Reference Locations Before Impact				
Times(B)	1.021	2	0.511	
Locations	0.018	2	0.009	
B * L	0.022	4	0.006	d1
Residual	0.002	6	0.000	
Total	1.063	14		

Power Analysis

1+n0 = MS[T(Aft) * Impact] / MS[Residual]	0.646
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	3.312
Power (based on F-distribution)	0.004

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.356	1	0.356
T(B)	a2	3.253	9	0.361
Location	a3	0.179	3	0.060
Impact vs Ref	a3-b1	0.147	1	0.147
Among Refs	b1	0.032	2	0.016
B * Location	a4	0.021	3	0.007
B * Impact	a4-b2	0.001	1	0.001
B * Ref	b2	0.020	2	0.010
T(B) * L	a5	0.513	27	0.019
T(Bef) * Location	c1	0.064	6	0.011
T(Bef) * Impact	c1-d1	0.042	2	0.021
T(Bef) * Ref	d1	0.022	4	0.006
T(Aft) * Location	a5-c1	0.449	21	0.021
T(Aft) * Impact	a5-c1-b3+d1	0.171	7	0.024
T(Aft) * Ref	b3-d1	0.278	14	0.020
Residual	a6	2.800	74	0.038
Total	a7	7.122	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	0.525	1.93	0.91
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	0.646	2.35	0.72
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,74	0.264	3.76	0.77
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,74	0.026	5.1	0.87
NO…no impact detected				

SIMPSON'S EVENNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.000	1	0.000	a1
Times(B)	0.070	9	0.008	a2
Locations	0.010	3	0.003	a3
B * L	0.005	3	0.002	a4
T(B) * L	0.214	27	0.008	a5
Residual	0.464	80	0.006	a6
Total	0.763	123		a7
B. Exclude Impact Site				
Bef/Aft - B	0.000	1	0.000	
Times(B)	0.079	9	0.009	
Locations	0.010	2	0.005	b1
B * L	0.005	2	0.003	b2
T(B) * L	0.160	18	0.009	b3
Residual	0.346	53	0.007	
Total	0.600	85		
C. All Locations Before Impact				
Times(B)	0.001	2	0.001	
Locations	0.001	3	0.000	
B * L	0.015	6	0.003	c1
Residual	0.042	13	0.003	
Total	0.059	24		
D. Reference Locations Before Impact				
Times(B)	0.001	2	0.001	
Locations	0.001	2	0.001	
B * L	0.009	4	0.002	d1
Residual	0.010	6	0.002	
Total	0.021	14		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.000	1	0.000
T(B)	a2	0.070	9	0.008
Location	a3	0.010	3	0.003
Impact vs Ref	a3-b1	0.000	1	0.000
Among Refs	b1	0.010	2	0.005
B * Location	a4	0.005	3	0.002
B * Impact	a4-b2	0.000	1	0.000
B * Ref	b2	0.005	2	0.003
T(B) * L	a5	0.214	27	0.008
T(Bef) * Location	c1	0.015	6	0.003
T(Bef) * Impact	c1-d1	0.006	2	0.003
T(Bef) * Ref	d1	0.009	4	0.002
T(Aft) * Location	a5-c1	0.199	21	0.009
T(Aft) * Impact	a5-c1-b3+d1	0.048	7	0.007
T(Aft) * Ref	b3-d1	0.151	14	0.011
Residual	a6	0.464	74	0.006
Total	a7	0.763	123	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,74	1.720	1.93	0.07
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,74	1.094	2.35	0.38
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,74	0.399	3.76	0.67
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,74	0.000	5.1	1.00
NO…no impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.094
Degrees of Freedom	7,74
Falt = Fcrit / (1+n0) = 2.14 / (1+n0)	1.955
Power (based on F-distribution)	0.073

Appendix I. Benthic ANOVA results – Whole Bar Unit

INVERTEBRATE DENSITY

A. All Data				
Source	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	4.391	1	4.391	a1
Times(B)	79.129	8	9.891	a2
Locations	0.301	3	0.100	a3
B * L	0.469	3	0.156	a4
T(B) * L	3.798	24	0.158	a5
Residual	8.346	157	0.053	a6
Total	96.434	196		a7
B. Exclude Impact Site				
Bef/Aft - B	3.816	1	3.816	
Times(B)	50.615	8	6.327	
Locations	0.258	2	0.129	b1
B * L	0.404	2	0.202	b2
T(B) * L	1.713	16	0.107	b3
Residual	5.828	105	0.056	
Total	62.634	134		
C. All Locations Before Impact				
Times(B)	10.507	1	10.507	
Locations	0.391	3	0.130	
B * L	1.033	3	0.344	c1
Residual	2.253	34	0.066	
Total	14.184	41		
D. Reference Locations Before Impact				
Times(B)	6.915	1	6.915	
Locations	0.391	2	0.196	
B * L	0.979	2	0.490	d1
Residual	1.954	27	0.072	
Total	10.239	32		

Source of Variation	**Term**	**SS**	**df**	**MS**
B (bef-aft)	a1	4.391	1	4.391
T(B)	a2	79.129	8	9.891
Location	a3	0.301	3	0.100
Impact vs Ref	a3-b1	0.043	1	0.043
Among Refs	b1	0.258	2	0.129
B * Location	a4	0.469	3	0.156
B * Impact	a4-b2	0.065	1	0.065
B * Ref	b2	0.404	2	0.202
T(B) * L	a5	3.798	24	0.158
T(Bef) * Location	c1	1.033	3	0.344
T(Bef) * Impact	c1-d1	0.054	1	0.054
T(Bef) * Ref	d1	0.979	2	0.490
T(Aft) * Location	a5-c1	2.765	21	0.132
T(Aft) * Impact	a5-c1-b3+d1	2.031	7	0.290
T(Aft) * Ref	b3-d1	0.734	14	0.052
Residual	a6	8.346	156	0.054
Total	a7	96.434	196	

	df	**F**	**Fcrit**	**p**
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	0.980	1.75	0.48
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	5.423	2.075	<0.00001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	0.107	39.4	0.99
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	5.373	948	0.32
NO… change was not coincident with impact				

PROPORTION REPRESENTED BY EPHEMEROPTERA, PLECOPTERA, TRICOPTERA

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	1.035	1	1.035	a1
Times(B)	3.515	8	0.439	a2
Locations	0.558	3	0.186	a3
B * L	0.306	3	0.102	a4
T(B) * L	1.834	24	0.076	a5
Residual	6.355	157	0.040	a6
Total	13.603	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.387	1	0.387	
Times(B)	1.899	8	0.237	
Locations	0.193	2	0.097	b1
B * L	0.065	2	0.033	b2
T(B) * L	0.695	16	0.043	b3
Residual	3.587	105	0.034	
Total	6.826	134		
C. All Locations Before Impact				
Times(B)	1.013	1	1.013	
Locations	0.473	3	0.158	
B * L	0.127	3	0.042	c1
Residual	0.720	34	0.021	
Total	2.333	41		
D. Reference Locations Before Impact				
Times(B)	0.528	1	0.528	
Locations	0.110	2	0.055	
B * L	0.016	2	0.008	d1
Residual	0.625	27	0.023	
Total	1.279	32		

Source of Variation	**Term**	**SS**	**df**	**MS**
B (bef-aft)	a1	1.035	1	1.035
T(B)	a2	3.515	8	0.439
Location	a3	0.558	3	0.186
Impact vs Ref	a3-b1	0.365	1	0.365
Among Refs	b1	0.193	2	0.097
B * Location	a4	0.306	3	0.102
B * Impact	a4-b2	0.241	1	0.241
B * Ref	b2	0.065	2	0.033
T(B) * L	a5	1.834	24	0.076
T(Bef) * Location	c1	0.127	3	0.042
T(Bef) * Impact	c1-d1	0.111	1	0.111
T(Bef) * Ref	d1	0.016	2	0.008
T(Aft) * Location	a5-c1	1.707	21	0.081
T(Aft) * Impact	a5-c1-b3+d1	1.028	7	0.147
T(Aft) * Ref	b3-d1	0.679	14	0.049
Residual	a6	6.355	156	0.041
Total	a7	13.603	196	

	df	**F**	**Fcrit**	**p**
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	1.191	1.75	0.29
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	3.605	2.075	0.001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	6.063	39.4	0.150
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	1.323	948	0.59
NO… change was not coincident with impact				

TAXON RICHNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	234.244	1	234.244	a1
Times(B)	1637.361	8	204.670	a2
Locations	26.372	3	8.791	a3
B * L	13.871	3	4.624	a4
T(B) * L	133.918	24	5.580	a5
Residual	481.823	157	3.069	a6
Total	2527.589	196		a7
B. Exclude Impact Site				
Bef/Aft - B	138.747	1	138.747	
Times(B)	1044.639	8	130.580	
Locations	15.640	2	7.820	b1
B * L	7.077	2	3.539	b2
T(B) * L	100.763	16	6.298	b3
Residual	375.056	105	3.572	
Total	1681.922	134		
C. All Locations Before Impact				
Times(B)	185.570	1	185.570	
Locations	12.841	3	4.280	
B * L	19.885	3	6.628	c1
Residual	223.056	34	6.560	
Total	441.352	41		
D. Reference Locations Before Impact				
Times(B)	132.302	1	132.302	
Locations	2.589	2	1.295	
B * L	19.881	2	9.941	d1
Residual	207.556	27	7.687	
Total	362.328	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	234.244	1	234.244
T(B)	a2	1637.361	8	204.670
Location	a3	26.372	3	8.791
Impact vs Ref	a3-b1	10.732	1	10.732
Among Refs	b1	15.640	2	7.820
B * Location	a4	13.871	3	4.624
B * Impact	a4-b2	6.794	1	6.794
B * Ref	b2	7.077	2	3.539
T(B) * L	a5	133.918	24	5.580
T(Bef) * Location	c1	19.885	3	6.628
T(Bef) * Impact	c1-d1	0.004	1	0.004
T(Bef) * Ref	d1	19.881	2	9.941
T(Aft) * Location	a5-c1	114.033	21	5.430
T(Aft) * Impact	a5-c1-b3+d1	33.151	7	4.736
T(Aft) * Ref	b3-d1	80.882	14	5.777
Residual	a6	481.823	156	3.089
Total	a7	2527.589	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	1.871	1.75	0.033
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	0.820	2.76	
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.533
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	1.350
Power (based on F-distribution)	0.23

NUMBER OF TAXA REPRESENTED BY EPHEMEROPTERA, PLECOPTERA, TRICOPTERA

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	174.386	1	174.386	a1
Times(B)	899.942	8	112.493	a2
Locations	22.739	3	7.580	a3
B * L	8.000	3	2.667	a4
T(B) * L	92.102	24	3.838	a5
Residual	298.449	157	1.901	a6
Total	1495.618	196		a7
B. Exclude Impact Site				
Bef/Aft - B	102.327	1	102.327	
Times(B)	585.328	8	73.166	
Locations	16.499	2	8.250	b1
B * L	2.174	2	1.087	b2
T(B) * L	67.694	16	4.231	b3
Residual	236.333	105	2.251	
Total	1010.355	134		
C. All Locations Before Impact				
Times(B)	58.368	1	58.368	
Locations	11.785	3	3.928	
B * L	12.485	3	4.162	c1
Residual	133.167	34	3.917	
Total	215.805	41		
D. Reference Locations Before Impact				
Times(B)	44.180	1	44.180	
Locations	4.346	2	2.173	
B * L	12.221	2	6.111	d1
Residual	121.833	27	4.512	
Total	182.580	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	174.386	1	174.386
T(B)	a2	899.942	8	112.493
Location	a3	22.739	3	7.580
Impact vs Ref	a3-b1	6.240	1	6.240
Among Refs	b1	16.499	2	8.250
B * Location	a4	8.000	3	2.667
B * Impact	a4-b2	5.826	1	5.826
B * Ref	b2	2.174	2	1.087
T(B) * L	a5	92.102	24	3.838
T(Bef) * Location	c1	12.485	3	4.162
T(Bef) * Impact	c1-d1	0.264	1	0.264
T(Bef) * Ref	d1	12.221	2	6.111
T(Aft) * Location	a5-c1	79.617	21	3.791
T(Aft) * Impact	a5-c1-b3+d1	24.144	7	3.449
T(Aft) * Ref	b3-d1	55.473	14	3.962
Residual	a6	298.449	156	1.913
Total	a7	1495.618	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	2.071	1.75	0.016
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	0.870	2.76	0.55
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.803
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	1.148
Power (based on F-distribution)	0.336

SIMPSON'S DIVERSITY

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.121	1	0.121	a1
Times(B)	3.353	8	0.419	a2
Locations	0.383	3	0.128	a3
B * L	0.209	3	0.070	a4
T(B) * L	1.170	24	0.049	a5
Residual	3.749	157	0.024	a6
Total	8.985	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.020	1	0.020	
Times(B)	2.725	8	0.341	
Locations	0.313	2	0.157	b1
B * L	0.137	2	0.069	b2
T(B) * L	0.793	16	0.050	b3
Residual	2.145	105	0.020	
Total	6.133	134		
C. All Locations Before Impact				
Times(B)	0.834	1	0.834	
Locations	0.209	3	0.070	
B * L	0.011	3	0.004	c1
Residual	0.660	34	0.019	
Total	1.714	41		
D. Reference Locations Before Impact				
Times(B)	0.621	1	0.621	
Locations	0.126	2	0.063	
B * L	0.009	2	0.005	d1
Residual	0.595	27	0.022	
Total	1.351	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.121	1	0.121
T(B)	a2	3.353	8	0.419
Location	a3	0.383	3	0.128
Impact vs Ref	a3-b1	0.070	1	0.070
Among Refs	b1	0.313	2	0.157
B * Location	a4	0.209	3	0.070
B * Impact	a4-b2	0.072	1	0.072
B * Ref	b2	0.137	2	0.069
T(B) * L	a5	1.170	24	0.049
T(Bef) * Location	c1	0.011	3	0.004
T(Bef) * Impact	c1-d1	0.002	1	0.002
T(Bef) * Ref	d1	0.009	2	0.005
T(Aft) * Location	a5-c1	1.159	21	0.055
T(Aft) * Impact	a5-c1-b3+d1	0.375	7	0.054
T(Aft) * Ref	b3-d1	0.784	14	0.056
Residual	a6	3.749	156	0.024
Total	a7	8.985	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	2.330	1.75	0.006
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	0.957	2.76	0.5
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	2.229
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	0.929
Power (based on F-distribution)	0.486

SIMPSON'S EVENNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.489	1	0.489	a1
Times(B)	14.441	8	1.805	a2
Locations	0.098	3	0.033	a3
B * L	0.059	3	0.020	a4
T(B) * L	0.770	24	0.032	a5
Residual	2.393	157	0.015	a6
Total	18.250	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.429	1	0.429	
Times(B)	9.509	8	1.189	
Locations	0.089	2	0.045	b1
B * L	0.054	2	0.027	b2
T(B) * L	0.274	16	0.017	b3
Residual	1.640	105	0.016	
Total	11.995	134		
C. All Locations Before Impact				
Times(B)	1.874	1	1.874	
Locations	0.077	3	0.026	
B * L	0.068	3	0.023	c1
Residual	0.406	34	0.012	
Total	2.425	41		
D. Reference Locations Before Impact				
Times(B)	1.276	1	1.276	
Locations	0.070	2	0.035	
B * L	0.060	2	0.030	d1
Residual	0.372	27	0.014	
Total	1.778	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.489	1	0.489
T(B)	a2	14.441	8	1.805
Location	a3	0.098	3	0.033
Impact vs Ref	a3-b1	0.009	1	0.009
Among Refs	b1	0.089	2	0.045
B * Location	a4	0.059	3	0.020
B * Impact	a4-b2	0.005	1	0.005
B * Ref	b2	0.054	2	0.027
T(B) * L	a5	0.770	24	0.032
T(Bef) * Location	c1	0.068	3	0.023
T(Bef) * Impact	c1-d1	0.008	1	0.008
T(Bef) * Ref	d1	0.060	2	0.030
T(Aft) * Location	a5-c1	0.702	21	0.033
T(Aft) * Impact	a5-c1-b3+d1	0.488	7	0.070
T(Aft) * Ref	b3-d1	0.214	14	0.015
Residual	a6	2.393	156	0.015
Total	a7	18.250	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	0.996	1.83	0.46
NO…				
2. Does scalping affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	4.545	2.14	0.008
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	0.510	39.4	0.82
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	8.714	948	0.26
NO… change was not coincident with impact				

Appendix J. Benthic ANOVA results – Bar Edge Unit

INVERTEBRATE DENSITY

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	2.647	1	2.647	a1
Times(B)	71.848	8	8.981	a2
Locations	0.693	3	0.231	a3
B * L	0.512	3	0.171	a4
T(B) * L	3.766	24	0.157	a5
Residual	4.756	115	0.041	a6
Total	84.222	154		a7
B. Exclude Impact Site				
Bef/Aft - B	1.962	1	1.962	
Times(B)	45.796	8	5.725	
Locations	0.603	2	0.302	b1
B * L	0.509	2	0.255	b2
T(B) * L	1.979	16	0.124	b3
Residual	2.447	66	0.037	
Total	53.296	95		
C. All Locations Before Impact				
Times(B)	9.738	1	9.738	
Locations	0.690	3	0.230	
B * L	1.252	3	0.417	c1
Residual	1.118	22	0.051	
Total	12.798	29		
D. Reference Locations Before Impact				
Times(B)	6.346	1	6.346	
Locations	0.671	2	0.336	
B * L	1.193	2	0.597	d1
Residual	0.819	15	0.055	
Total	9.029	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	2.647	1	2.647
T(B)	a2	71.848	8	8.981
Location	a3	0.693	3	0.231
Impact vs Ref	a3-b1	0.090	1	0.090
Among Refs	b1	0.603	2	0.302
B * Location	a4	0.512	3	0.171
B * Impact	a4-b2	0.003	1	0.003
B * Ref	b2	0.509	2	0.255
T(B) * L	a5	3.766	24	0.157
T(Bef) * Location	c1	1.252	3	0.417
T(Bef) * Impact	c1-d1	0.059	1	0.059
T(Bef) * Ref	d1	1.193	2	0.597
T(Aft) * Location	a5-c1	2.514	21	0.120
T(Aft) * Impact	a5-c1-b3+d1	1.728	7	0.247
T(Aft) * Ref	b3-d1	0.786	14	0.056
Residual	a6	4.756	113	0.042
Total	a7	84.222	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	1.334	1.75	0.20
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,113	5.865	2.075	<0.00001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	0.094	39.4	0.99
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	4.184	948	0.36
NO… change was not coincident with impact				

PROPORTION REPRESENTED BY EPHEMEROPTERA, PLECOPTERA, TRICOPTERA

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.997	1	0.997	a1
Times(B)	2.594	8	0.324	a2
Locations	0.826	3	0.275	a3
B * L	0.270	3	0.090	a4
T(B) * L	1.710	24	0.071	a5
Residual	3.760	115	0.033	a6
Total	10.157	154		a7
B. Exclude Impact Site				
Bef/Aft - B	0.381	1	0.381	
Times(B)	1.221	8	0.153	
Locations	0.297	2	0.149	b1
B * L	0.043	2	0.022	b2
T(B) * L	0.483	16	0.030	b3
Residual	1.221	66	0.019	
Total	3.646	95		
C. All Locations Before Impact				
Times(B)	0.701	1	0.701	
Locations	0.609	3	0.203	
B * L	0.146	3	0.049	c1
Residual	0.421	22	0.019	
Total	1.877	29		
D. Reference Locations Before Impact				
Times(B)	0.308	1	0.308	
Locations	0.181	2	0.091	
B * L	0.040	2	0.020	d1
Residual	0.325	15	0.022	
Total	0.854	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.997	1	0.997
T(B)	a2	2.594	8	0.324
Location	a3	0.826	3	0.275
Impact vs Ref	a3-b1	0.529	1	0.529
Among Refs	b1	0.297	2	0.149
B * Location	a4	0.270	3	0.090
B * Impact	a4-b2	0.227	1	0.227
B * Ref	b2	0.043	2	0.022
T(B) * L	a5	1.710	24	0.071
T(Bef) * Location	c1	0.146	3	0.049
T(Bef) * Impact	c1-d1	0.106	1	0.106
T(Bef) * Ref	d1	0.040	2	0.020
T(Aft) * Location	a5-c1	1.564	21	0.074
T(Aft) * Impact	a5-c1-b3+d1	1.121	7	0.160
T(Aft) * Ref	b3-d1	0.443	14	0.032
Residual	a6	3.760	113	0.033
Total	a7	10.157	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	0.951	1.75	0.510
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,113	4.813	2.075	<0.00001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	1.582	39.4	0.45
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	1.511	948	0.56
NO… change was not coincident with impact				

TAXON RICHNESS

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	120.293	1	120.293	a1
Times(B)	1336.507	8	167.063	a2
Locations	68.836	3	22.945	a3
B * L	32.078	3	10.693	a4
T(B) * L	126.535	24	5.272	a5
Residual	267.379	115	2.325	a6
Total	1951.628	154		a7
B. Exclude Impact Site				
Bef/Aft - B	50.135	1	50.135	
Times(B)	820.065	8	102.508	
Locations	46.310	2	23.155	b1
B * L	10.698	2	5.349	b2
T(B) * L	85.735	16	5.358	b3
Residual	168.000	66	2.545	
Total	1180.943	95		
C. All Locations Before Impact				
Times(B)	141.440	1	141.440	
Locations	55.699	3	18.566	
B * L	15.930	3	5.310	c1
Residual	110.833	22	5.038	
Total	323.902	29		
D. Reference Locations Before Impact				
Times(B)	92.182	1	92.182	
Locations	29.896	2	14.948	
B * L	15.263	2	7.632	d1
Residual	95.333	15	6.356	
Total	232.674	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	120.293	1	120.293
T(B)	a2	1336.507	8	167.063
Location	a3	68.836	3	22.945
Impact vs Ref	a3-b1	22.526	1	22.526
Among Refs	b1	46.310	2	23.155
B * Location	a4	32.078	3	10.693
B * Impact	a4-b2	21.380	1	21.380
B * Ref	b2	10.698	2	5.349
T(B) * L	a5	126.535	24	5.272
T(Bef) * Location	c1	15.930	3	5.310
T(Bef) * Impact	c1-d1	0.667	1	0.667
T(Bef) * Ref	d1	15.263	2	7.632
T(Aft) * Location	a5-c1	110.605	21	5.267
T(Aft) * Impact	a5-c1-b3+d1	40.133	7	5.733
T(Aft) * Ref	b3-d1	70.472	14	5.034
Residual	a6	267.379	113	2.366
Total	a7	1951.628	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	2.127	1.782	0.015
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	1.139	2.76	0.39
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	2.423
Degrees of Freedom	7,113
Falt = Fcrit / (1+n0) = 2.09 / (1+n0)	0.863
Power (based on F-distribution)	0.538

NUMBER OF TAXA REPRESENTED BY EPHEMEROPTERA, PLECOPTERA, TRICOPTERA

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	109.014	1	109.014	a1
Times(B)	771.526	8	96.441	a2
Locations	45.659	3	15.220	a3
B * L	18.461	3	6.154	a4
T(B) * L	81.805	24	3.409	a5
Residual	168.061	115	1.461	a6
Total	1194.526	154		a7
B. Exclude Impact Site				
Bef/Aft - B	50.653	1	50.653	
Times(B)	488.736	8	61.092	
Locations	33.915	2	16.958	b1
B * L	5.869	2	2.935	b2
T(B) * L	50.551	16	3.159	b3
Residual	114.667	66	1.737	
Total	744.391	95		
C. All Locations Before Impact				
Times(B)	50.298	1	50.298	
Locations	35.604	3	11.868	
B * L	11.628	3	3.876	c1
Residual	70.500	22	3.205	
Total	168.030	29		
D. Reference Locations Before Impact				
Times(B)	36.379	1	36.379	
Locations	21.429	2	10.715	
B * L	11.596	2	5.798	d1
Residual	59.167	15	3.944	
Total	128.571	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	109.014	1	109.014
T(B)	a2	771.526	8	96.441
Location	a3	45.659	3	15.220
Impact vs Ref	a3-b1	11.744	1	11.744
Among Refs	b1	33.915	2	16.958
B * Location	a4	18.461	3	6.154
B * Impact	a4-b2	12.592	1	12.592
B * Ref	b2	5.869	2	2.935
T(B) * L	a5	81.805	24	3.409
T(Bef) * Location	c1	11.628	3	3.876
T(Bef) * Impact	c1-d1	0.032	1	0.032
T(Bef) * Ref	d1	11.596	2	5.798
T(Aft) * Location	a5-c1	70.177	21	3.342
T(Aft) * Impact	a5-c1-b3+d1	31.222	7	4.460
T(Aft) * Ref	b3-d1	38.955	14	2.783
Residual	a6	168.061	113	1.487
Total	a7	1194.526	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	1.871	1.782	0.037
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	1.603	2.76	0.21
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	2.999
Degrees of Freedom	7,113
Falt = Fcrit / (1+n0) = 2.09 / (1+n0)	0.697
Power (based on F-distribution)	0.674

SIMPSON'S DIVERSITY

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.075	1	0.075	a1
Times(B)	2.863	8	0.358	a2
Locations	0.502	3	0.167	a3
B * L	0.137	3	0.046	a4
T(B) * L	1.198	24	0.050	a5
Residual	2.633	115	0.023	a6
Total	7.408	154		a7
B. Exclude Impact Site				
Bef/Aft - B	0.005	1	0.005	
Times(B)	2.318	8	0.290	
Locations	0.379	2	0.190	b1
B * L	0.020	2	0.010	b2
T(B) * L	0.747	16	0.047	b3
Residual	1.060	66	0.016	
Total	4.529	95		
C. All Locations Before Impact				
Times(B)	0.638	1	0.638	
Locations	0.318	3	0.106	
B * L	0.013	3	0.004	c1
Residual	0.427	22	0.019	
Total	1.396	29		
D. Reference Locations Before Impact				
Times(B)	0.436	1	0.436	
Locations	0.179	2	0.090	
B * L	0.012	2	0.006	d1
Residual	0.362	15	0.024	
Total	0.989	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.075	1	0.075
T(B)	a2	2.863	8	0.358
Location	a3	0.502	3	0.167
Impact vs Ref	a3-b1	0.123	1	0.123
Among Refs	b1	0.379	2	0.190
B * Location	a4	0.137	3	0.046
B * Impact	a4-b2	0.117	1	0.117
B * Ref	b2	0.020	2	0.010
T(B) * L	a5	1.198	24	0.050
T(Bef) * Location	c1	0.013	3	0.004
T(Bef) * Impact	c1-d1	0.001	1	0.001
T(Bef) * Ref	d1	0.012	2	0.006
T(Aft) * Location	a5-c1	1.185	21	0.056
T(Aft) * Impact	a5-c1-b3+d1	0.450	7	0.064
T(Aft) * Ref	b3-d1	0.735	14	0.053
Residual	a6	2.633	113	0.023
Total	a7	7.408	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	2.253	1.782	0.008
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	1.224	2.76	0.35
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	2.759
Degrees of Freedom	7,113
Falt = Fcrit / (1+n0) = 2.09 / (1+n0)	0.758
Power (based on F-distribution)	0.624

SIMPSON'S EVENNESS

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.248	1	0.248	a1
Times(B)	12.449	8	1.556	a2
Locations	0.112	3	0.037	a3
B * L	0.066	3	0.022	a4
T(B) * L	0.767	24	0.032	a5
Residual	1.314	115	0.011	a6
Total	14.956	154		a7
B. Exclude Impact Site				
Bef/Aft - B	0.178	1	0.178	
Times(B)	8.052	8	1.007	
Locations	0.106	2	0.053	b1
B * L	0.066	2	0.033	b2
T(B) * L	0.334	16	0.021	b3
Residual	0.586	66	0.009	
Total	9.322	95		
C. All Locations Before Impact				
Times(B)	1.533	1	1.533	
Locations	0.097	3	0.032	
B * L	0.066	3	0.022	c1
Residual	0.254	22	0.012	
Total	1.950	29		
D. Reference Locations Before Impact				
Times(B)	0.981	1	0.981	
Locations	0.095	2	0.048	
B * L	0.053	2	0.027	d1
Residual	0.220	15	0.015	
Total	1.349	20		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.248	1	0.248
T(B)	a2	12.449	8	1.556
Location	a3	0.112	3	0.037
Impact vs Ref	a3-b1	0.006	1	0.006
Among Refs	b1	0.106	2	0.053
B * Location	a4	0.066	3	0.022
B * Impact	a4-b2	0.000	1	0.000
B * Ref	b2	0.066	2	0.033
T(B) * L	a5	0.767	24	0.032
T(Bef) * Location	c1	0.066	3	0.022
T(Bef) * Impact	c1-d1	0.013	1	0.013
T(Bef) * Ref	d1	0.053	2	0.027
T(Aft) * Location	a5-c1	0.701	21	0.033
T(Aft) * Impact	a5-c1-b3+d1	0.420	7	0.060
T(Aft) * Ref	b3-d1	0.281	14	0.020
Residual	a6	1.314	113	0.012
Total	a7	14.956	154	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,113	1.726	1.75	0.06
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,113	5.160	2.075	<0.00001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	0.757	39.4	0.70
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	4.615	948	0.34
NO… change was not coincident with impact				

Appendix K. Benthic ANOVA results – Common Family Groups

BAETIDAE ABUNDANCE

Source Of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.489	1	0.489	a1
Times(B)	46.166	8	5.771	a2
Locations	2.090	3	0.697	a3
B * L	0.245	3	0.082	a4
T(B) * L	4.552	24	0.190	a5
Residual	13.144	157	0.084	a6
Total	66.686	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.195	1	0.195	
Times(B)	26.888	8	3.361	
Locations	0.126	2	0.063	b1
B * L	0.137	2	0.069	b2
T(B) * L	2.111	16	0.132	b3
Residual	8.631	105	0.082	
Total	38.088	134		
C. All Locations Before Impact				
Times(B)	6.889	1	6.889	
Locations	1.000	3	0.333	
B * L	1.218	3	0.406	c1
Residual	5.185	34	0.153	
Total	14.292	41		
D. Reference Locations Before Impact				
Times(B)	3.024	1	3.024	
Locations	0.063	2	0.032	
B * L	0.172	2	0.086	d1
Residual	4.905	27	0.182	
Total	8.164	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.489	1	0.489
T(B)	a2	46.166	8	5.771
Location	a3	2.090	3	0.697
Impact vs Ref	a3-b1	1.964	1	1.964
Among Refs	b1	0.126	2	0.063
B * Location	a4	0.245	3	0.082
B * Impact	a4-b2	0.108	1	0.108
B * Ref	b2	0.137	2	0.069
T(B) * L	a5	4.552	24	0.190
T(Bef) * Location	c1	1.218	3	0.406
T(Bef) * Impact	c1-d1	1.046	1	1.046
T(Bef) * Ref	d1	0.172	2	0.086
T(Aft) * Location	a5-c1	3.334	21	0.159
T(Aft) * Impact	a5-c1-b3+d1	1.395	7	0.199
T(Aft) * Ref	b3-d1	1.939	14	0.139
Residual	a6	13.144	156	0.084
Total	a7	66.686	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	1.644	1.75	0.073
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	2.365	2.075	0.03
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	1.610	39.4	0.45
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	0.191	948	0.94
NO… change was not coincident with impact				

HEPTAGENIIDAE ABUNDANCE

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	12.404	1	12.404	a1
Times(B)	31.283	8	3.910	a2
Locations	2.766	3	0.922	a3
B * L	1.363	3	0.454	a4
T(B) * L	8.154	24	0.340	a5
Residual	17.188	157	0.109	a6
Total	73.158	196		a7
B. Exclude Impact Site				
Bef/Aft - B	7.300	1	7.300	
Times(B)	16.524	8	2.066	
Locations	0.787	2	0.394	b1
B * L	1.068	2	0.534	b2
T(B) * L	5.191	16	0.324	b3
Residual	12.925	105	0.123	
Total	43.795	134		
C. All Locations Before Impact				
Times(B)	1.395	1	1.395	
Locations	1.249	3	0.416	
B * L	1.165	3	0.388	c1
Residual	8.081	34	0.238	
Total	11.89	41		
D. Reference Locations Before Impact				
Times(B)	1.208	1	1.208	
Locations	0.122	2	0.061	
B * L	1.051	2	0.526	d1
Residual	7.373	27	0.273	
Total	9.754	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	12.404	1	12.404
T(B)	a2	31.283	8	3.910
Location	a3	2.766	3	0.922
Impact vs Ref	a3-b1	1.979	1	1.979
Among Refs	b1	0.787	2	0.394
B * Location	a4	1.363	3	0.454
B * Impact	a4-b2	0.295	1	0.295
B * Ref	b2	1.068	2	0.534
T(B) * L	a5	8.154	24	0.340
T(Bef) * Location	c1	1.165	3	0.388
T(Bef) * Impact	c1-d1	0.114	1	0.114
T(Bef) * Ref	d1	1.051	2	0.526
T(Aft) * Location	a5-c1	6.989	21	0.333
T(Aft) * Impact	a5-c1-b3+d1	2.849	7	0.407
T(Aft) * Ref	b3-d1	4.140	14	0.296
Residual	a6	17.188	156	0.110
Total	a7	73.158	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	2.684	1.75	0.002
YES…				
2. Does scalping affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	1.376	2.76	0.29
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	3.694
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	0.560
Power (based on F-distribution)	0.787

EPHEMERELLIDAE ABUNDANCE

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	13.772	1	13.772	a1
Times(B)	21.961	8	2.745	a2
Locations	0.679	3	0.226	a3
B * L	0.465	3	0.155	a4
T(B) * L	11.102	24	0.463	a5
Residual	10.758	157	0.069	a6
Total	58.737	196		a7
B. Exclude Impact Site				
Bef/Aft - B	10.217	1	10.217	
Times(B)	14.655	8	1.832	
Locations	0.643	2	0.322	b1
B * L	0.464	2	0.232	b2
T(B) * L	9.826	16	0.614	b3
Residual	8.402	105	0.080	
Total	44.207	134		
C. All Locations Before Impact				
Times(B)	1.107	1	1.107	
Locations	0.030	3	0.010	
B * L	4.582	3	1.527	c1
Residual	4.110	34	0.121	
Total	9.829	41		
D. Reference Locations Before Impact				
Times(B)	0.109	1	0.109	
Locations	0.023	2	0.012	
B * L	3.949	2	1.975	d1
Residual	3.412	27	0.126	
Total	7.493	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	13.772	1	13.772
T(B)	a2	21.961	8	2.745
Location	a3	0.679	3	0.226
Impact vs Ref	a3-b1	0.036	1	0.036
Among Refs	b1	0.643	2	0.322
B * Location	a4	0.465	3	0.155
B * Impact	a4-b2	0.001	1	0.001
B * Ref	b2	0.464	2	0.232
T(B) * L	a5	11.102	24	0.463
T(Bef) * Location	c1	4.582	3	1.527
T(Bef) * Impact	c1-d1	0.633	1	0.633
T(Bef) * Ref	d1	3.949	2	1.975
T(Aft) * Location	a5-c1	6.520	21	0.310
T(Aft) * Impact	a5-c1-b3+d1	0.643	7	0.092
T(Aft) * Ref	b3-d1	5.877	14	0.420
Residual	a6	10.758	156	0.069
Total	a7	58.737	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	6.087	1.75	<0.0005
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	0.219	2.76	0.98
NO… no short-term impact detected				

Power Analysis

1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.332
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	1.554
Power (based on F-distribution)	0.153

CAPNIIDAE ABUNDANCE

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	5.220	1	5.220	a1
Times(B)	25.844	8	3.231	a2
Locations	0.214	3	0.071	a3
B * L	0.163	3	0.054	a4
T(B) * L	4.031	24	0.168	a5
Residual	12.618	157	0.080	a6
Total	48.090	196		a7
B. Exclude Impact Site				
Bef/Aft - B	3.745	1	3.745	
Times(B)	14.685	8	1.836	
Locations	0.029	2	0.015	b1
B * L	0.152	2	0.076	b2
T(B) * L	2.720	16	0.170	b3
Residual	9.955	105	0.095	
Total	31.286	134		
C. All Locations Before Impact				
Times(B)	3.504	1	3.504	
Locations	0.177	3	0.059	
B * L	1.583	3	0.528	c1
Residual	5.012	34	0.147	
Total	10.276	41		
D. Reference Locations Before Impact				
Times(B)	1.319	1	1.319	
Locations	0.088	2	0.044	
B * L	0.883	2	0.442	d1
Residual	4.396	27	0.163	
Total	6.686	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	5.220	1	5.220
T(B)	a2	25.844	8	3.231
Location	a3	0.214	3	0.071
Impact vs Ref	a3-b1	0.185	1	0.185
Among Refs	b1	0.029	2	0.015
B * Location	a4	0.163	3	0.054
B * Impact	a4-b2	0.011	1	0.011
B * Ref	b2	0.152	2	0.076
T(B) * L	a5	4.031	24	0.168
T(Bef) * Location	c1	1.583	3	0.528
T(Bef) * Impact	c1-d1	0.700	1	0.700
T(Bef) * Ref	d1	0.883	2	0.442
T(Aft) * Location	a5-c1	2.448	21	0.117
T(Aft) * Impact	a5-c1-b3+d1	0.611	7	0.087
T(Aft) * Ref	b3-d1	1.837	14	0.131
Residual	a6	12.618	156	0.081
Total	a7	48.090	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	1.622	1.75	0.08
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	1.079	2.075	0.43
NO… no short-term impact detected				
3. Do reference sites vary in difference from before to after impact?				
B * Ref / Residual	2,156	0.940	3.05	0.39
NO…				
4. Does impact affect differences from before to after?				
B * Imp / Residual	1,156	0.136	3.9	0.71
NO impact detected				

Power Analysis

1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.079
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	1.918
Power (based on F-distribution)	0.072

CHIRONOMIDAE ABUNDANCE

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	5.440	1	5.440	a1
Times(B)	122.079	8	15.260	a2
Locations	0.897	3	0.299	a3
B * L	1.021	3	0.340	a4
T(B) * L	5.965	24	0.249	a5
Residual	11.040	157	0.070	a6
Total	146.442	196		a7
B. Exclude Impact Site				
Bef/Aft - B	5.689	1	5.689	
Times(B)	77.639	8	9.705	
Locations	0.869	2	0.435	b1
B * L	0.474	2	0.237	b2
T(B) * L	2.884	16	0.180	b3
Residual	7.549	105	0.072	
Total	95.104	134		
C. All Locations Before Impact				
Times(B)	15.260	1	15.260	
Locations	0.955	3	0.318	
B * L	1.532	3	0.511	c1
Residual	1.711	34	0.050	
Total	19.458	41		
D. Reference Locations Before Impact				
Times(B)	9.043	1	9.043	
Locations	0.724	2	0.362	
B * L	1.138	2	0.569	d1
Residual	1.633	27	0.060	
Total	12.538	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	5.440	1	5.440
T(B)	a2	122.079	8	15.260
Location	a3	0.897	3	0.299
Impact vs Ref	a3-b1	0.028	1	0.028
Among Refs	b1	0.869	2	0.435
B * Location	a4	1.021	3	0.340
B * Impact	a4-b2	0.547	1	0.547
B * Ref	b2	0.474	2	0.237
T(B) * L	a5	5.965	24	0.249
T(Bef) * Location	c1	1.532	3	0.511
T(Bef) * Impact	c1-d1	0.394	1	0.394
T(Bef) * Ref	d1	1.138	2	0.569
T(Aft) * Location	a5-c1	4.433	21	0.211
T(Aft) * Impact	a5-c1-b3+d1	2.687	7	0.384
T(Aft) * Ref	b3-d1	1.746	14	0.125
Residual	a6	11.040	156	0.071
Total	a7	146.442	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	1.762	1.75	0.05
NO…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / Residual	7,156	5.424	2.075	<0.0001
YES… short-term impact detected				
3A. Was change observed at reference sites?				
T(Aft) * Ref / T(Bef) * Ref	14,2	0.219	39.4	0.97
NO… change was associated with Impact site				
3B. Was timing of change coincident with impact?				
T(Aft) * Imp / T(Bef) * Imp	7,1	0.974	948	0.660
NO… change was not coincident with impact				

NEMATODA ABUNDANCE

Source of Variance	SS	df	MS	Term
A. All Data				
Bef/Aft - B	0.018	1	0.018	a1
Times(B)	20.527	8	2.566	a2
Locations	0.111	3	0.037	a3
B * L	0.065	3	0.022	a4
T(B) * L	2.187	24	0.091	a5
Residual	8.029	157	0.051	a6
Total	30.937	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.007	1	0.007	
Times(B)	14.821	8	1.853	
Locations	0.089	2	0.045	b1
B * L	0.064	2	0.032	b2
T(B) * L	1.678	16	0.105	b3
Residual	6.434	105	0.061	
Total	23.093	134		
C. All Locations Before Impact				
Times(B)	3.444	1	3.444	
Locations	0.017	3	0.006	
B * L	0.018	3	0.006	c1
Residual	4.663	34	0.137	
Total	8.142	41		
D. Reference Locations Before Impact				
Times(B)	2.493	1	2.493	
Locations	0.012	2	0.006	
B * L	0.011	2	0.006	d1
Residual	4.254	27	0.158	
Total	6.77	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	0.018	1	0.018
T(B)	a2	20.527	8	2.566
Location	a3	0.111	3	0.037
Impact vs Ref	a3-b1	0.022	1	0.022
Among Refs	b1	0.089	2	0.045
B * Location	a4	0.065	3	0.022
B * Impact	a4-b2	0.001	1	0.001
B * Ref	b2	0.064	2	0.032
T(B) * L	a5	2.187	24	0.091
T(Bef) * Location	c1	0.02	3	0.006
T(Bef) * Impact	c1-d1	0.01	1	0.007
T(Bef) * Ref	d1	0.01	2	0.006
T(Aft) * Location	a5-c1	2.169	21	0.103
T(Aft) * Impact	a5-c1-b3+d1	0.502	7	0.072
T(Aft) * Ref	b3-d1	1.667	14	0.119
Residual	a6	8.029	156	0.051
Total	a7	30.9	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	2.314	1.75	0.006
YES…				
2. Does scalping affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	0.602	2.76	0.74
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	1.393
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	1.486
Power (based on F-distribution)	0.176

OLIGOCHAETA ABUNDANCE

A. All Data				
Source of Variance	**SS**	**df**	**MS**	**Term**
Bef/Aft - B	1.658	1	1.658	a1
Times(B)	10.970	8	1.371	a2
Locations	0.490	3	0.163	a3
B * L	2.349	3	0.783	a4
T(B) * L	9.474	24	0.395	a5
Residual	16.621	157	0.106	a6
Total	41.562	196		a7
B. Exclude Impact Site				
Bef/Aft - B	0.861	1	0.861	
Times(B)	5.667	8	0.708	
Locations	0.324	2	0.162	b1
B * L	2.045	2	1.023	b2
T(B) * L	6.594	16	0.412	b3
Residual	12.109	105	0.115	
Total	27.600	134		
C. All Locations Before Impact				
Times(B)	0.305	1	0.305	
Locations	1.371	3	0.457	
B * L	1.481	3	0.494	c1
Residual	5.988	34	0.176	
Total	9.145	41		
D. Reference Locations Before Impact				
Times(B)	0.100	1	0.100	
Locations	1.014	2	0.507	
B * L	1.476	2	0.738	d1
Residual	5.140	27	0.190	
Total	7.730	32		

Source of Variation	Term	SS	df	MS
B (bef-aft)	a1	1.658	1	1.658
T(B)	a2	10.970	8	1.371
Location	a3	0.490	3	0.163
Impact vs Ref	a3-b1	0.166	1	0.166
Among Refs	b1	0.324	2	0.162
B * Location	a4	2.349	3	0.783
B * Impact	a4-b2	0.304	1	0.304
B * Ref	b2	2.045	2	1.023
T(B) * L	a5	9.474	24	0.395
T(Bef) * Location	c1	1.481	3	0.494
T(Bef) * Impact	c1-d1	0.005	1	0.005
T(Bef) * Ref	d1	1.476	2	0.738
T(Aft) * Location	a5-c1	7.993	21	0.381
T(Aft) * Impact	a5-c1-b3+d1	2.875	7	0.411
T(Aft) * Ref	b3-d1	5.118	14	0.366
Residual	a6	16.621	156	0.107
Total	a7	41.562	196	

	df	F	Fcrit	p
1. Do reference sites have variable short-term trends after impact?				
T(Aft) * Ref / Residual	14,156	3.431	1.75	<0.0005
YES…				
2. Does impact affect short-term temporal trend?				
T(Aft) * Imp / T(Aft) * Ref	7,14	1.123	2.76	0.40
NO… no short-term impact detected				

Power Analysis	
1+n0 = MS[T(Aft) * Impact] / MS[Residual]	3.855
Degrees of Freedom	7,156
Falt = Fcrit / (1+n0) = 2.07 / (1+n0)	0.537
Power (based on F-distribution)	0.805