Cheakamus River Water Use Plan

Monitoring Channel Morphology in Cheakamus River

Implementation Year 5

Reference: CMSMON-8

Cheakamus River Channel Morphology

Study Period: April 2008-April 2012

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Executive Summary

Following implementation of a new WUP flow regime in February 2006, the Cheakamus WUP Consultative Committee expressed concern regarding the potential effects on salmonid habitat quality and availability from physical changes. To address these concerns, baseline and post-WUP monitoring was recommended to examine the effects of more frequent, higher flows that would mobilize and distribute sediment introduced by large floods, debris flows and mass wasting. The monitoring program also examined seasonal minimum flow releases from Daisy Lake Dam and access to side channel habitats.

Cheakamus River extends 25 km from Daisy Lake Dam to the confluence of Squamish River. The channel can be broadly characterized by four distinct sections: Rubble Creek landslide deposits, a bedrock canyon, a broad alluvial section and the Cheakamus River fan. These sections were divided into 13 distinct reaches above the Cheakamus fan that reflect differences in slope, morphologic characteristics, sediment supply, and discharge.

Within each reach, a baseline morphologic map was prepared from 1:5,000 colour orthophoto mosaics collected during low water conditions in April, 2008. The river was re-flown at the same scale in March, 2012 and the mapping exercise was repeated to illustrate the types and magnitude of channel changes during the past four years.

The wetted low flow channel dominates the areal fraction of most reaches, and is representative of the available overwinter habitat for salmonids. This low water wetted channel area has remained constant (averaging 59% of the total channel area) since 2008 indicating no substantive changes to the channel characteristics since implementation of the WUP. Unvegetated bars are the second most common morphologic feature in most reaches, averaging 28% of total channel area in 2008 and 23% in 2012. Together, unvegetated bars combined with the low flow wetted channel represented roughly 90% or more of total reach area in 9 of 12 reaches in 2008. The dominance of bar and wetted channel areas declined to 7 of 12 reaches in 2012.

The loss of open bar surface area is not due to erosion or degradation, but to the establishment and growth of vegetation on previously exposed bar areas. The increase in the mean area of young vegetation on formerly bare bars was statistically significant. There was also an increase in the mean area of young and mature islands – although not significant – which supports the observed trend that the channel is becoming increasingly stable. Unperturbed, the expansion and maturation of vegetation is expected increase bank strength, increase channel depths and reduce channel complexity, resulting in a loss of natural side channel habitat. Large sediment inputs from Rubble Creek or other tributaries could reverse or modify the established trend and help mitigate the effect of sediment supply reductions from the construction of the Daisy Lake Reservoir.

The low flow wetted channel was further divided into three (3) hydraulic mesohabitat units: pools, riffles, and rapids. Riffle habitats were dominant in mainly unconfined reaches, and rapids dominant in steeper, confined channel sections. Between 2008 and 2012 the distribution of pools, riffles and rapids remained relatively stable along the study reach. The variability in the size of the mapped units also remained the same ($p < 0.05$). Overall the Cheakamus River maintained a consistent morphology and distribution of habitat and channel units from 2008 to 2012. During the same period relatively few sediment supplying events occurred in the watershed.

To better understand the linkages between the habitat and fish productivity the long-term study design should attempt to inventory overall mesohabitat proportions in key alluvial reaches of the Cheakamus River, as this was also undertaken by the Fisheries Technical Committee prior to the WUP. These reaches should be selected based on concurrent fish use, populations and habitat quality studies undertaken as monitors under the WUP to allow some comparative analyses prior to review of the WUP.

Additional work could be undertaken to inventory and monitor natural side channels on the alluvial reaches of the river, and document their change through time as it relates to flood history and geomorphic changes in the river. Side channels have a high utilization by salmonids in the Cheakamus River, and are key habitats for some life stages and species. However, since these are side channels are located a ways downstream of the Daisy Lake Reservoir, separating project effects from the influence of unsteady tributary sediment and debris inputs will be difficult.

Additional data should be collected on sediment quality as it relates to substrate use by rearing and spawning salmonids. Changes to the distribution and quality of spawning substrates within the Cheakamus River area especially critical to chum and pink salmon, and are influenced by tributary and lateral supply and mobilization due to high flows. Further mapping and sampling should be completed, correlated to documented spawning sites, to provide direct data on spawning substrate conditions and how it changes over time.

In summary, Based on 2008 and 2012 air photos the overall morphology of the Cheakamus River has been shown to be reasonably stable, but a more detailed set of data looking at substrate quality and quantity at key biologically important sites is missing. Such data should be collected to characterize both the general substrate conditions that will effect habitat use by parr and fry, as well as spawning substrate surveys that characterize the availability and quality of the substrate. Inputs from tributaries also need to be qualitatively monitored to assess the temporal trends in supply and explain the observed channel changes.

Table of Contents

List of Tables

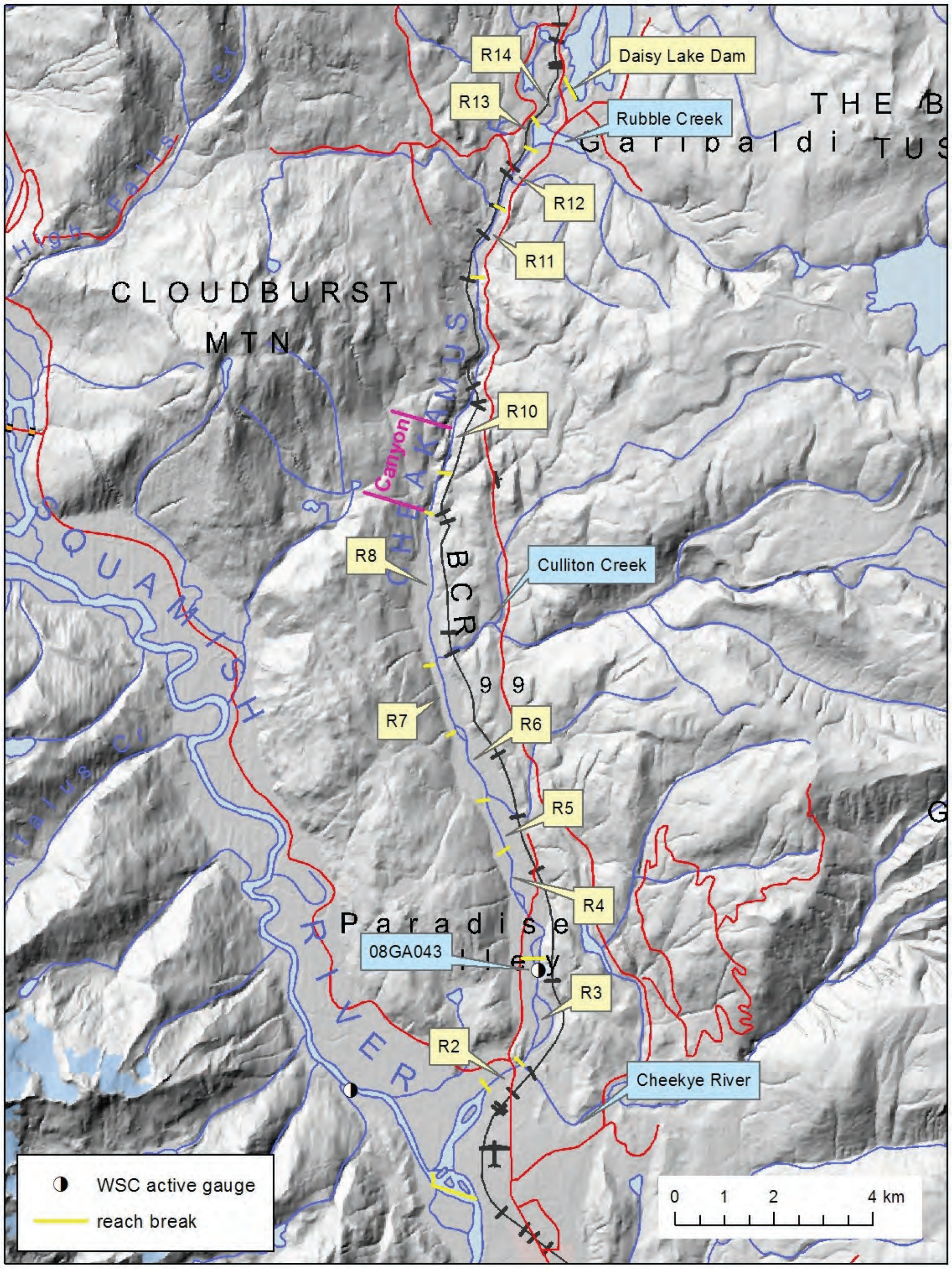
List of Figures

1 Introduction

1.1 Project Background

Cheakamus River flows southward from Daisy Lake reservoir to the confluence of Squamish River, roughly 25 km downstream (Figure 1-1). The river has been regulated since 1957 following completion of Daisy Lake Dam. The river drains a total watershed area of 1,070 km^2, including 300 km^2 below the dam.

Figure 1-1 Lower Cheakamus River Location and Reach Breaks



BC Hydro diverts flows from the reservoir - up to a maximum of 65 m^3/s - into an 11 km long tunnel leading to the 157 MW Cheakamus Powerhouse located in the Squamish River Valley, more than 20 km upstream of the Cheakamus confluence. The magnitude of power diversion flows fluctuates due to power generation and demand (i.e. peaking), with limited generation during periods of low inflow.

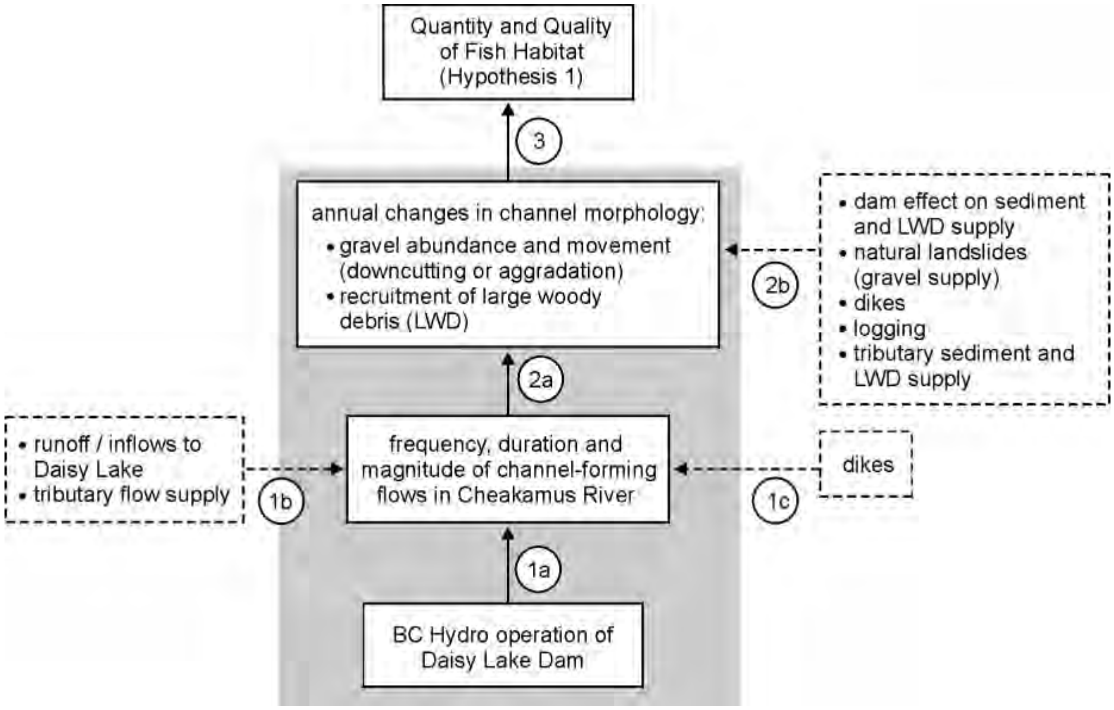
Daisy Lake reservoir has limited storage capacity (e.g., 55 Mm^3 or about 6 days of maximum generation) and is generally operated with a small buffer and is drafted prior to freshet. Once the reservoir is full and diversion capacity is reached, all inflows are spilled. As a result, the operation of the diversion and the reservoir have a limited effect on large magnitude, low frequency floods but may affect more frequent, morphologically-significant flows in the lower Cheakamus River. Following the impoundment of Daisy Lake in 1957 the sediment supply was reduced as the braided channel upstream of Rubble Creek no longer supplied sediment downstream. Prior to this time the sediment supply to the Cheakamus River was in flux, largely due to significant inputs from the tributaries and rock slide related dams that temporarily blocked the Cheakamus River before being overtopped and down-cut (e.g. Rubble Creek slide in 1855). NHC (2000) provides a detailed overview of the history of sediment supply and changes to the system. As part of the NHC (2000) scope of work, the Daisy Lake Reservoir was estimated to reduce the sediment supply by 2000-5000 m^3 per year.

During the development of the Cheakamus Water Use Plan (WUP; BC Hydro, 2005), the Cheakamus River Fisheries Technical Committee (FTC) created a set of impact hypotheses related to fish and fish habitat. These included whether dam operations altered channel morphology (*Hypothesis 2*), and affected the quality and quantity of available fish habitat and thereby limiting the carrying capacity for wild salmon. Figure 1-2 outlines the primary linkages and pathways of effects for the effects of flow on channel morphology.

Implementation of the WUP flow regime resulted in varying release flows from the dam with a seasonal base flow, a condition that was similar to the interim flow regime that preceded it and significantly different than the historical flow regime that resulted from operation of the facility before Water Use Planning (**Table 1-1**).

This report presents the results of the initial 5-year period of CMSMON 8, a period of relatively few disturbances and no significant sediment inputs from the tributaries.

Figure 1-2 Impact Hypothesis 2 - Effect of Flow on Channel Morphology (BC Hydro, 2000)



Link	Description
1a.	Dam operations affect the frequency, magnitude and duration of channel-forming flows in the Cheakamus River.
1b	Inflow to Daisy Lake and runoff to the Cheakamus River downstream of the dam also affect the frequency of channel-forming flows.
1c	Dikes affect what flow is a channel forming flow.
2a	The frequency of channel-forming flows affects the movement of gravel, channel morphology and input of large woody debris.
2b	Other factors (dam as barrier, natural landslides, dikes, logging, tributary sediment and large woody debris supply) also affect year-to-year changes in gravel and channel morphology.
3	Changes in channel morphology affect the quantity and quality of fish habitat [see H.1] by altering: access to side channel habitat, channel diversity, and the quality and distribution of spawning and rearing gravel.

Table 1-1 Overview of Flow Release Requirements Related to the Cheakamus Project

Flow Regime	Pre-WUP	Interim Flow Regime	Water Use Plan
Period	1957 to 1997 Flow targets added by BC Hydro in 1997	1999 to 2005	2005 to present
Instream Flow	None required	45% of average previous 7 days inflow	45% of average previous 7 days inflow
Minimum Flows	1.7 m^3/s	5 m^3/s	Jan 1 to Mar 31: 5 m^3/s Apr 1 to Oct 31: 7 $m^3/$ Nov 1 to Dec 31: 3 m^3/s
Target Flows	Mar 15 to Dec 31: 14 m^3/s Jan 1 to Mar 14: 10 m^3/s	Mar 15 to Dec 31: 14 m^3/s Jan 1 to Mar 14: 10 m^3/s	Nov 1 to Mar 31: 15 m^3/s Apr 1 to Jun 30: 20 m^3/s Jul 1 to Aug 15: 38 m^3/s Aug 16 to 31: 20 m^3/s[1] Sep 1 to Oct 31: 20 m^3/s
Point of Measurement	Gauge at Brackendale (WSC 08GA043)	Gauge at Brackendale (WSC 08GA043)	Gauge at Brackendale (WSC 08GA043)

The concerns and uncertainty identified by the original Cheakamus River channel morphology and sediment transport assessment (BC Hydro, 2000) were supported by the Consultative Committee and have been adopted in the current WUP (BC Hydro and Power Authority, 2007) which defines the scope of work for the CMSMON 8 Monitoring Channel Morphology in Cheakamus River. The 2013 Addendum to the Water Use Plan (BC Hydro and Power Authority, 2013) notes that CMSMON-8 should be extended for another 5 years.

The additional years of study are intended to understand if operations are effecting the morphology, or if other natural or anthropogenic factors are responsible. An improved understanding of morphology change is critical for the other Monitors as channel morphology and river processes ultimately form aquatic habitats, supporting anadromous and resident fish populations. As part of the CMSMON 8 program, the timing and amount of flow in the Cheakamus River are also monitored, and this information is critical to understanding the river flow regime, and the influence of project operations on flow in the Cheakamus and the contributions from the tributaries. Hydrology and flow data underpins all the monitoring programs on the Cheakamus River.

In Table 1-2 below, NHC has tentatively outlined what elements of the CMSMON 8 2013-2018 program other CMSMON projects depend on. This simply illustrates the importance of integrated planning and program delivery for all CMSMON projects.

[1] Provision to increase flows to 38 m^3/s for recreation.

Table 1-2 CMSMON-8 Project Dependencies

Cheakamus WUP Program	CMSMON-8 Component		
	Hydrology	River Morphology	Sediment
CMSMON-1a	X		
CMSMON-1b	X	X	X
CMSMON-2	X	X	X
CMSMON-3	X	X	X
CMSMON-4			
CMSMON-5	X	X	X
CMSMON-6	X		
CMSMON-7	X	X	X

Final results of this monitor should reduce uncertainty regarding the impacts of the Cheakamus Project under the current WUP operational scenario, and may therefore increase the potential for reaching consensus with respect to operational impacts in future WUP discussions. Other impacts to channel morphology may be occurring that are detrimental to the quality and quantity of fish habitat in the Cheakamus River. This monitor may also assist in identifying these causative factors, providing a rationale for future restoration or mitigation.

1.2 Study Objectives

The objective of the current monitor is to address the uncertainty expressed by the Fisheries Technical Committee and Consultative Committee under WUP operations. The channel morphology monitoring program is expected to address shortcomings in the knowledge of how the current flow regime impacts channel morphology and its consequences to the availability and quality of fish habitat. The program seeks to address the following management questions as outlined in the Terms of Reference (BCH, 2006):

1. Following implementation of the WUP, has there been a change in accessible substrate for salmonid spawning from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?
2. Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?, and
3. To what extent does the hydrology of major tributaries contribute to the general hydrology of lower Cheakamus River and how does it attenuate the effects of Daisy Lake Dam operations?

The management questions will be addressed by evaluating a set of impact hypotheses that test whether the morphology – hence aquatic habitat – has been significantly altered since implementation of the WUP.

In order to address the first question, the following impact hypothesis is to be tested:

H_{01}: Total area (ha) of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP.

The second management question is to be addressed by evaluating the following two impact hypotheses:

H_{02}: Total length (km) of connected side-channel habitat wetted at typical flows has not changed since implementation of the WUP, and

H_{03}: The diversity of side-channel habitat as measured by the number and ratio of pool, run and riffle habitats has not changed since implementation of the WUP.

The third management question is a data collection exercise and does not have an associated impact hypothesis. However, the summary results of the hydrology data collection may be used to support testing of morphologic and side-channel hypotheses. The hypotheses are to be tested within the context of a pre- and post-WUP comparison of channel surveys. Pre-WUP conditions are represented by the data collected during the first year of the monitor (2008).

This report summarized presents the first period of data collection for the post-WUP component of the monitor (2006 to 2012) and provides a summary of observed changes. It is expected that additional post-WUP monitoring will occur at 5 and 10 year intervals in the future and this monitoring will be required to fully address all impact hypotheses.

1.3 Scope of Work

Northwest Hydraulic Consultants Ltd. (NHC) was retained by BC Hydro to collect the necessary information required to address the management questions outlined in the WUP Terms of Reference (BC Hydro and Power Authority, 2007). In this report, data collected in Year 1 (2008) is compared and with data collected in Year 5 (2012) in order to address the specific impact hypotheses outlined in Section 1.2. The data collection procedures generally follow those described in the original response to the RFP.

The focus in Year 1 was to create baseline maps of channel morphologic elements to quantify potential changes to channel and off-channel morphology and habitat in the future. Baseline mapping of channel morphology for the Cheakamus River from the Daisy Lake Dam to Cheekye River was produced in GIS using 1:5,000 scale colour orthophotography and rectified air photos, all collected in April 2008, combined with field verification. New aerial photography was subsequently flown in March 2012 and is used to produce updated mapping for comparison with the baseline mapping. This report summarizes the changes that have occurred during the first 4 complete years of the monitor.

A second major component of this study is to quantify the discharge of major tributary streams to determine their incremental contribution to flow along Cheakamus River. A summary of the data collection procedures and results has been reported separately for this year of the monitor (NHC, 2014).

2 Methodology

2.1 Orthophotography

Aerial photography of the entire study reach from Daisy Lake Dam to the Squamish River confluence was acquired on April 22, 2008 at 1:5,000 scale during the leaf-free season prior to a spring flow release. The Cheakamus River was at low-flow conditions with a discharge of 18 m^3/s at the WSC gauge above the Cheekye River (WSC 08GA043; 17 m^3/s at pedestrian bridge and 13 m^3/s at FSR). Orthophoto mosaics of the aerial photography were commissioned by Triton Environmental Consultants Ltd. for CN with copies made available to NHC in late September, 2008.

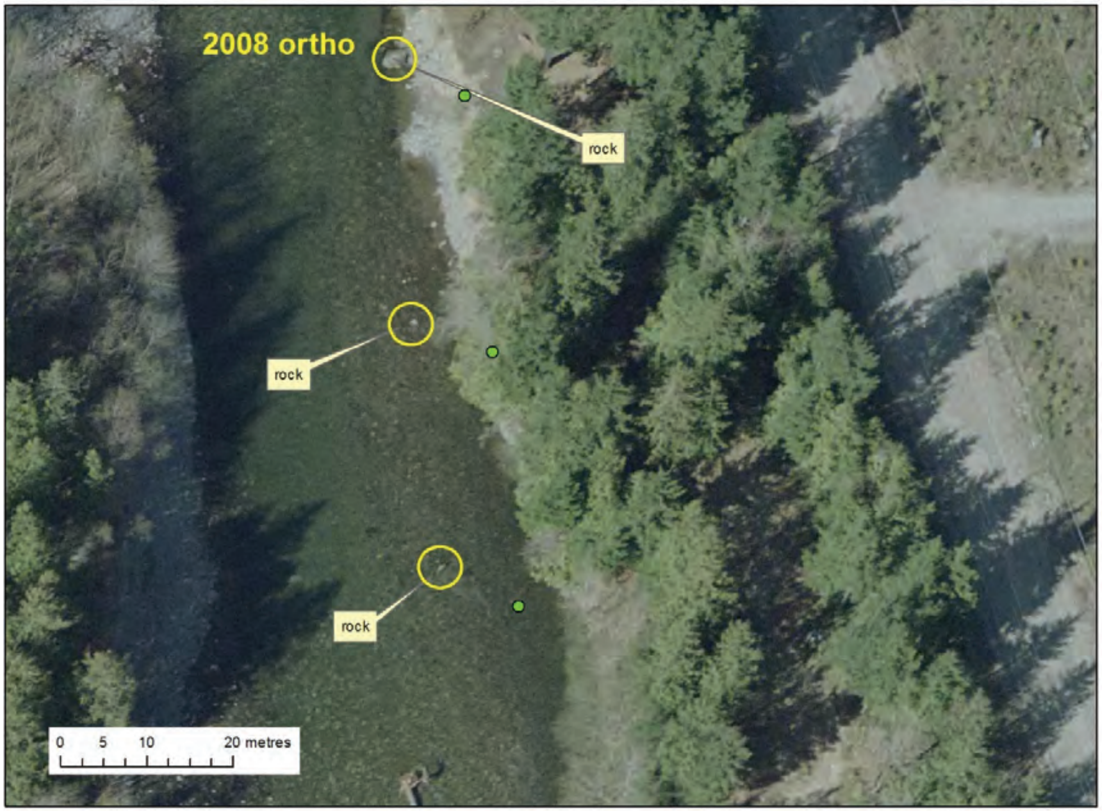
The commissioned orthophoto mosaics cover the majority of the study area with the exception of the upper 3.5 km of Cheakamus River to the Daisy Lake Dam. The orthophotos have a resolution of 15 cm (which roughly defines the smallest features that can be identified) and are oriented by a UTM projection (Zone 10 north) and the NAD83 datum.

An additional set of aerial images was acquired on March 25, 2012 covering the same spatial extent as the 2008 imagery, with similar environmental conditions. The Cheakamus River above the Cheekye River was flowing at 15.5 m^3/s on that date (12.5 m^3/s at pedestrian bridge and 12.8 m^3/s FSR bridge).

The images were collected using an UltracamX digital camera by Dudley Thompson Mapping Corporation at a resolution of 8 cm. Following subsequent discussions with BC Hydro representatives, it was decided that the 2012 imagery should also be converted to orthophotography to facilitate comparison with the earlier imagery. Dudley Thompson was contracted to complete aero-triangulation of the individual images by establishing control points on stereo models to create a digital elevation model. The digital images and aero-triangulation data were transferred to BC Hydro Photogrammetry Services for final orthophoto production.

Neither of the photo missions was flown with the specific intent to produce orthophotography, so no ground targets were located and surveyed prior to image acquisition. As a result, the DEMs created for orthophoto production are not as accurate as they would be with ground control. This causes minor displacement errors in some locations and limits analysis through direct superimposition of individual maps. The error varies spatially, and while there is near perfect agreement in alignment in limited locations, displacement errors can be several metres or greater (e.g. Figure 2-1).

Figure 2-1 Example of Orthophotography Displacement Differences



2.1.1 Air Photo Rectification

The 2008 orthophotography did not cover the uppermost 3.5 km of river channel immediately downstream of Daisy Lake Dam. Therefore, it was necessary to manually rectify contact prints for this length of channel. Contact prints of the photographs covering the missing area were scanned at 600 DPI, a sufficient resolution to ensure adequate detail was retained for defining the smallest geomorphic features of interest as well as providing a manageable file size.

Scaling and rectification (orientation) of the individual photographs was completed using the geo-referencing tools available in ArcGIS 9.3. Existing orthophoto mosaics from 2005 were used to provide control in the rectification process since they were also defined by the same projection and datum as the 2008 orthophotos. The transformation from photo to map coordinates was completed using a second-order polynomial function. The 2012 orthophotography extended over the entire study area and no manual georeferencing was required.

2.2 Geomorphic Mapping

Baseline mapping of channel morphology on the Cheakamus River was prepared during Year 1 of the monitor. Morphologic features were digitized directly from the orthophotos using tools in ArcMap GIS. The interpretation and mapping of channel features was aided by viewing the original air photos in stereo under a standard mirror stereoscope.

The primary morphologic features that were mapped include channel banks, bars, islands and side channels. The wetted channel defines the remaining area between channel banks not covered by bars or islands. Woody debris jams and bank protection structures were also digitized but are not a component of channel morphologic elements. These are generally distinct features that can be consistently interpreted and delineated on aerial photography.

Channel bars and islands were further grouped into young or mature age classes. Young bars represent active, mobilized deposits that are devoid of vegetation, while mature bars support sparse vegetation. Young islands support dense vegetation consisting of shrubs, grasses and smaller trees that mask most of the bar surface. Mature islands support stands of older, taller deciduous and conifer species.

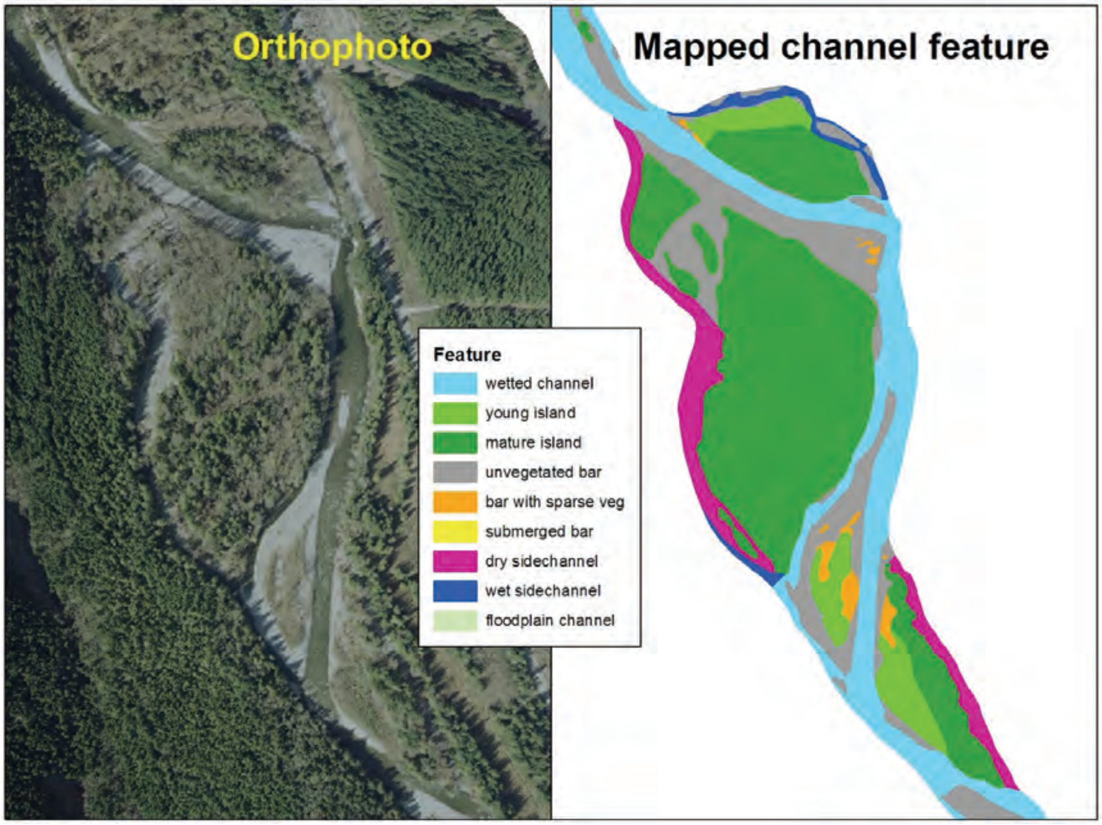
The Year 5 mapping was completed by interpreting and digitizing the identical suite of morphologic features listed above. The location of channel banks was copied from the Year 1 mapping and only modified where there were obvious deviations such as observable bank erosion. Given the narrowness of the channel, frequency of shadows and dense forest cover that often obscures the banks, completely re-digitizing the banks would have resulted in the spurious appearance of numerous locations of bank erosion and deposition when the two datasets were overlaid. All other features were interpreted and digitized 'blindly', meaning the previous mapping was not considered to prevent potential interpretive bias.

Once the initial mapping was complete, the 2012 lines were compared to the 2008 lines to check for consistency and identify major differences. Each set of lines was then re-checked against the corresponding orthophoto and modified if required. A number of minor changes were made to both sets of mapping where a feature was missed or the interpretation appeared incorrect.

For example, a small bar may have been missed in the 2008 or 2012 mapping, or the 2012 mapping may have identified a mature bar in an area that was classified as a young island in 2008 (which is not possible). In this case, the 2008 mapping would be adjusted to reclassify the feature as mature bar, while in 2012 the feature would either have remained a mature bar or was reclassified as a young island.

The final line work is converted to contiguous polygons in order to calculate areas, and geocoded to define the different morphologic features. An example of the original 2012 orthophoto and interpreted mapping is given in Figure 2-2.

Figure 2-2 2012 Interpretive Geomorphic Mapping



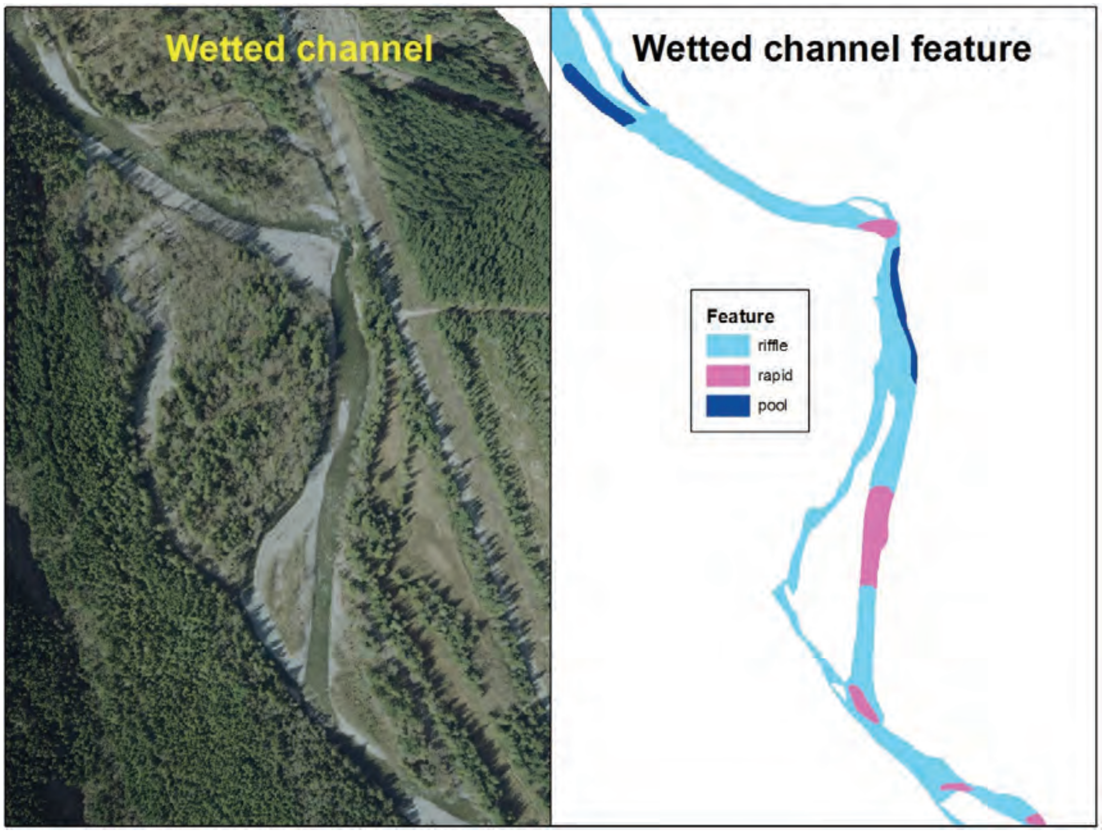
Side channels were also mapped in Year 1 and include both engineered off-channel (floodplain) habitat constructed along the study reach and natural, flow-through side channels. Natural side channels are defined along the outer margins of islands within the confines of outer channel banks. The islands split the flow at high discharge, and the side channel represents the smaller (secondary) channel. These areas represent important habitat units during different phases of salmonid life cycles and represent important areas of refuge at high flows.

These side channels are more susceptible to changes from Daisy Lake dam operations or other environmental / anthropogenic effects relative to engineered side channels. Natural side channels were further classified as wet or dry at the photographed discharge which is typical of low-flow levels for the river. Engineered side channels were not re-digitized in 2012, while natural side channels were mapped and classified as wet or dry as appropriate.

The low flow wetted channel was further divided into three basic morphologic units: riffle, pool and rapid/cascade. The units were defined following the conventions of Church (1992) who defines channel units for similar, intermediate-sized streams. These units were also chosen based on their distinct habitat characteristics and the ability to delineate these units on aerial photography with reasonable consistency. **Figure 2-3** illustrates typical examples of these morphologic units along the river.

Riffles are areas of relatively shallow, rapid flow with clasts remaining submerged at all but the lowest flow levels. This unit includes glides and runs used in biological classifications and are significant habitat units. Pools are defined as areas of deeper, slow flow with few or no boulders exposed at low flow and act primarily as holding and rearing habitats – depending on cover. Rapids are areas of higher gradient with emergent clasts at low flows and up to 50% of stream area can be in supercritical flow. Cascades are a higher gradient unit than rapids with tumbling, turbulent flow over large boulders with more than 50% of stream area in supercritical flow and have comparatively low habitat value.

Figure 2-3 Geomorphic / Hydraulic Mesohabitat Units



Upon completion of the preliminary mapping, site visits were conducted on March 10 and 27, 2009 using both road and boat access to ground truth the characterization and boundaries of delineated polygons. The sites could not be visited earlier in the year because of extensive snow cover on the bars. Flows on these dates were very comparable to the photographed flow at 22 and 23 m^3/s respectively at the WSC Brackendale gauge (WSC 08GA043).

The ground truthing focused on those features which were noted during map production to have a high uncertainty in either boundary position or morphologic classification. Boundaries and morphologic classifications were checked visually and deviations from the preliminary maps were recorded and used to modify the database. Sketch maps and ground photographs were used to aid in the ground trothing. **Appendix A** includes a selection of site photos illustrating the different morphological units that were identified.

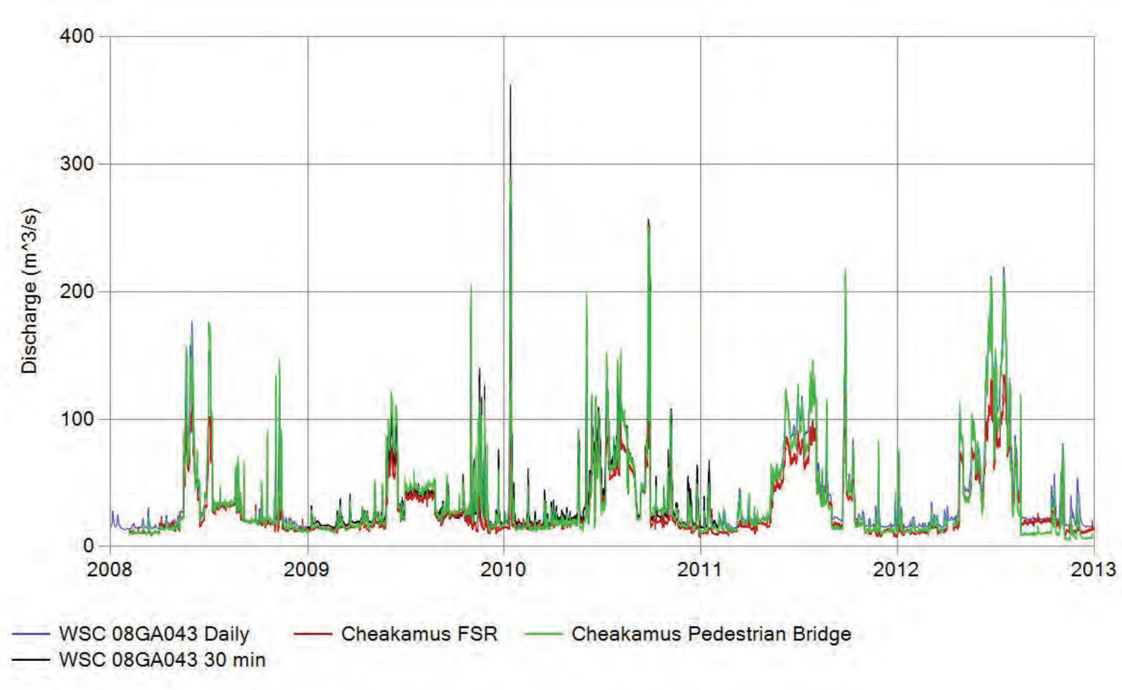
During the site visit the general substrate composition of exposed bar surfaces was also recorded during the site visits.

Once the preliminary maps were updated with the ground truthing data, topology was created using tools in ArcInfo GIS whereby linear boundaries between adjacent features are connected to create individual polygons for each morphologic feature class. This allows the area of the feature to be queried and summarized and creates a feature attribute table (database) that can be populated with quantitative or qualitative descriptors. Areas for each morphologic feature class and habitat classification unit were summarized by reach using the fourteen reach breaks previously defined in the Cheakamus River Water Use Plan (WUP).

3 Mainstem and Tributary Flows

Discharge records for the entire period of study are shown in Figure 3-1. All entries for the years 2008 and 2009 are mean daily discharges as provided by the Water Survey of Canada (WSC 08GA043, Cheakamus River near Brackendale). Water Survey Canada also provided flows for the period January 1, 2010 to January 31, 2011 but these values were recorded at 30 minute intervals. Short duration measurements reveal higher 'peak' flows than flows averaged over the course of an entire day.

Figure 3-1 Cheakamus River Flows 2008 to 2012



The morphology of the channel is strongly influenced by the magnitude and duration of very large flows that mobilize and transport bed material. NHC (2000) reports bankfull discharge in the reach between Culliton Creek and Cheekye River to be roughly 300 m^3/s while flows in the range of 320 to 680 m^3/s (daily average) were estimated to be required for general bed mobility near the Bailey Bridge, declining to 290 to 570 m^3/s roughly 2 km upstream. The difference between the two locations is due to channel slope, while the range of values provided at each location are due to size range of sediment in the channel bed.

In addition, NHC (2000) estimated that a discharge of 250 to 350 m^3/s at Brackendale would be required to overtop all bars, consistent with the estimate of bankfull discharge. It was further reported that even larger flows would likely be required to strip pioneering vegetation from bar surfaces. No estimate was made of the duration that flows would need to exceed this threshold to remove vegetation.

In NHC (2000), an empirical relation (Shield's entrainment function) was use to estimate the flow required for general transport given the median bed material size measured at different locations. There can be considerable variability in the median grain size distribution along and across the channel and sediment transport does not occur as an equilibrium response to flow hydraulics (Church, 1985). Shield's original data also exhibit scatter, so the relationship is better represented as a range (Buffington, 1999). This suggests that some finer fraction of the bed sediments may be mobilized at lower flows than the original estimates.

The flow rating curve developed by NHC (2014) at the Pedestrian Bridge (River km 14.4) reveals a shift once mainstem flows exceed approximately 150 m^3/s. This indicates that some bed material must be mobilized and transported at this lower threshold. It is not known if this lower limit can be more generally applied to all study reaches, but it provides an indication that smaller, more frequently occurring flows which are related to Daisy Lake operations likely transport and redistribute sediment input from larger floods. The mobilization and transport of sediments at these lower flows confirms the potential for morphological impacts at modest flows.

Over the period of study, the maximum recorded flow was 371 m^3/s on Jan 12, 2010. Flows remained very high (near 300 m^3/s) for nearly a full day and would almost certainly have resulted in detectable morphologic change in some sections of channel. Flows exceeded 250 m^3/s during two additional events and there were a total of eight (8) flow events in excess of 150 m^3/s that may have resulted in sediment transport.

The comparison of baseline and current mapping can be used to demonstrate where there has been active sediment transport. In planform mapping, this can be identified as bar, bank and island erosion or as bar deposition. The mapping interval is too brief to identify island or bank deposition which occurs over longer time scales as bars become vegetated and trap overbank fine sediments.

4 Year 5 Results

4.1 Geomorphic Features

Below the Daisy Lake Dam, lower Cheakamus River flows through four distinct sections before joining the Squamish River approximately 25 km downstream: the Rubble Creek landslide deposits, a bedrock canyon, a broad alluvial section, and the Cheakamus River fan (NHC, 2000). The last major landslide in Rubble Creek was in 1855-56 (Moore and Matthews, 1978) but the channel still actively transports sediment to the Cheakamus confluence.

The following reach designations was originally developed by the Department of Fisheries and Oceans who adapted it from earlier versions (NHC, 2000). Reach 1 (Cheakamus Fan) is outside of the study boundary and was not examined herein. A short canyon section (Figure 1) is also excluded as it is of limited value to fish (BC Hydro and Power Authority, 2007). The areal extent of each morphologic feature observed in the 2008 and 2012 imagery is summarized in **Table 4-1** and the data are shown in **Figure 4-1** and **Figure 4-2**. The baseline morphology mapping is found in **Appendix B**.

As a means of illustrating where the different channel morphologies are more prevalent, and if/how they differ between 2008 and 2012 the cumulative area associated with each geomorphic unit is plot as a function of channel chainage in **Figure 4-3**. The location of each polygon was assigned a chainage based on the centroid of the polygon. The chainage starts at the confluence with the Squamish River, while the cumulative area starts at the Daisy Lake Dam so that the cumulative area from the dam downstream can be assessed. On account of increasing watershed area, decreasing channel slope and grain size, in the absence of any other factors area would increase non-linearly in the downstream direction since channel width will increase downstream.

Between Reach 2 and 7 the Cheakamus River generally flows across a broad valley flat and has an irregular meandering pattern. Reach 2 is the start of the study area and is located immediately downstream of the Cheekye River confluence. The Cheekye River drains steep, unstable terrain and occasionally provides very large quantities of coarse sediment to the Cheakamus River.

Most recently, heavy rains carried an estimated 5,000 m^3 of sediment and debris to the Cheekye confluence, blocking the Cheakamus and resulting in morphologic change locally and upstream. Debris flows reaching Cheakamus River are also known to have occurred in the recent past (Clague et al., 2003). Reach 2 has a proportionally high occurrence of exposed bars over its short length (approx. 800 m) and is strongly influenced by the sediment delivery from the Cheekye River. The river at these downstream most sites is generally less stable; however, the overall distribution of habitat units is relatively constant (**Figure 4-3)**

Table 4-1 Geomorphic Mapping by Reach

2008 Data:

Reach	Wetted Channel	UnVeg Bar	Sparse Veg Bar	Young Island	Old Island	Dry Side Channel	Wet Side Channel
2	65.7%	31.2%	3.1%	0.0%	0.0%	0.0%	0.0%
3	61.3%	29.7%	2.3%	1.2%	5.2%	0.0%	0.3%
4	30.4%	28.2%	8.3%	6.8%	22.0%	0.1%	4.2%
5	65.1%	32.0%	2.8%	0.0%	0.0%	0.0%	0.0%
6	23.7%	18.9%	3.2%	5.5%	39.9%	7.0%	1.7%
7	66.1%	13.0%	4.0%	1.5%	9.6%	5.7%	0.0%
8	63.0%	32.0%	1.8%	0.0%	1.7%	1.6%	0.0%
10	62.2%	26.1%	2.5%	7.4%	0.0%	1.8%	0.0%
11	83.0%	17.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12	79.9%	20.1%	0.0%	0.0%	0.0%	0.0%	0.0%
13	60.2%	36.7%	0.4%	2.7%	0.0%	0.0%	0.0%
14	46.7%	46.7%	1.2%	3.3%	0.0%	0.0%	2.2%

2012 Data:

Reach	Wetted Channel	UnVeg Bar	Sparse Veg Bar	Young Island	Old Island	Dry Side Channel	Wet Side Channel
2	64.8%	24.5%	10.7%	0.0%	0.0%	0.0%	0.0%
3	65.6%	24.3%	3.4%	1.9%	4.8%	0.0%	0.0%
4	30.1%	21.7%	9.7%	11.2%	22.5%	0.1%	4.6%
5	58.5%	38.5%	3.1%	0.0%	0.0%	0.0%	0.0%
6	23.0%	11.5%	9.6%	7.2%	40.3%	5.9%	2.6%
7	69.1%	7.2%	5.9%	3.0%	9.3%	5.5%	0.0%
8	63.2%	31.4%	2.2%	0.9%	0.4%	1.9%	0.0%
10	60.3%	23.4%	4.6%	9.7%	0.0%	1.6%	0.5%
11	79.9%	20.1%	0.0%	0.0%	0.0%	0.0%	0.0%
12	80.4%	19.6%	0.0%	0.0%	0.0%	0.0%	0.0%
13	58.1%	19.9%	18.9%	3.1%	0.0%	0.0%	0.0%
14	50.1%	38.1%	7.3%	2.9%	0.0%	0.0%	1.7%

Figure 4-1 Cheakamus River Geomorphic Mapping 2008

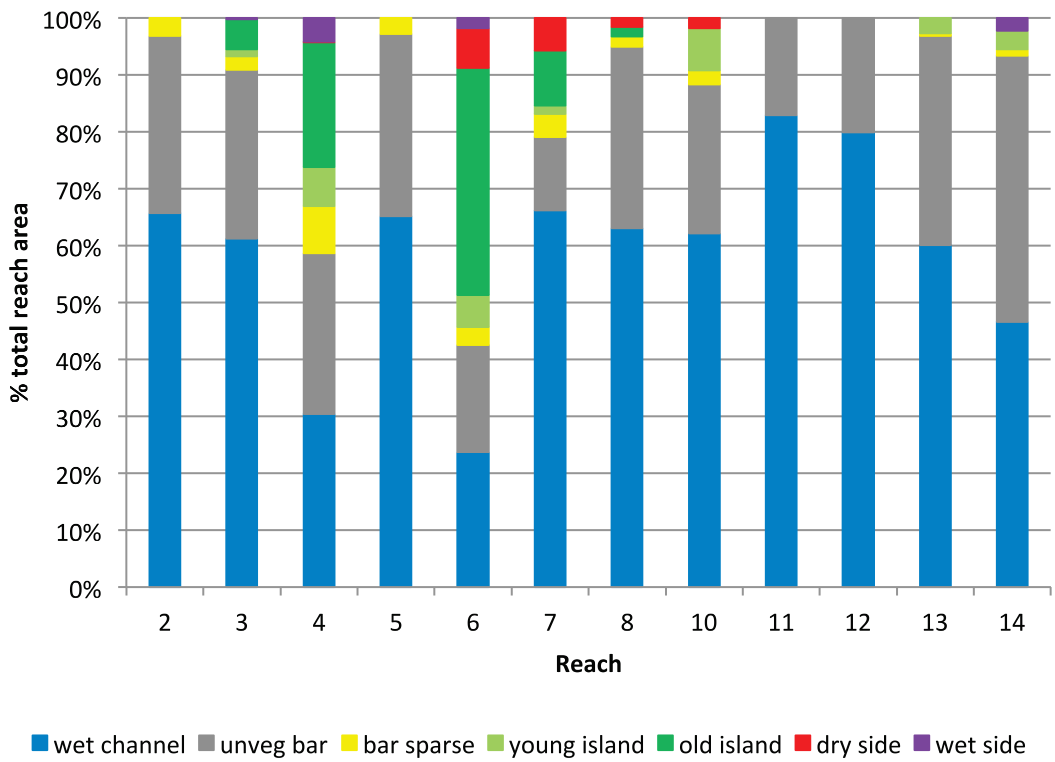


Figure 4-2 Cheakamus River Geomorphic Mapping 2012

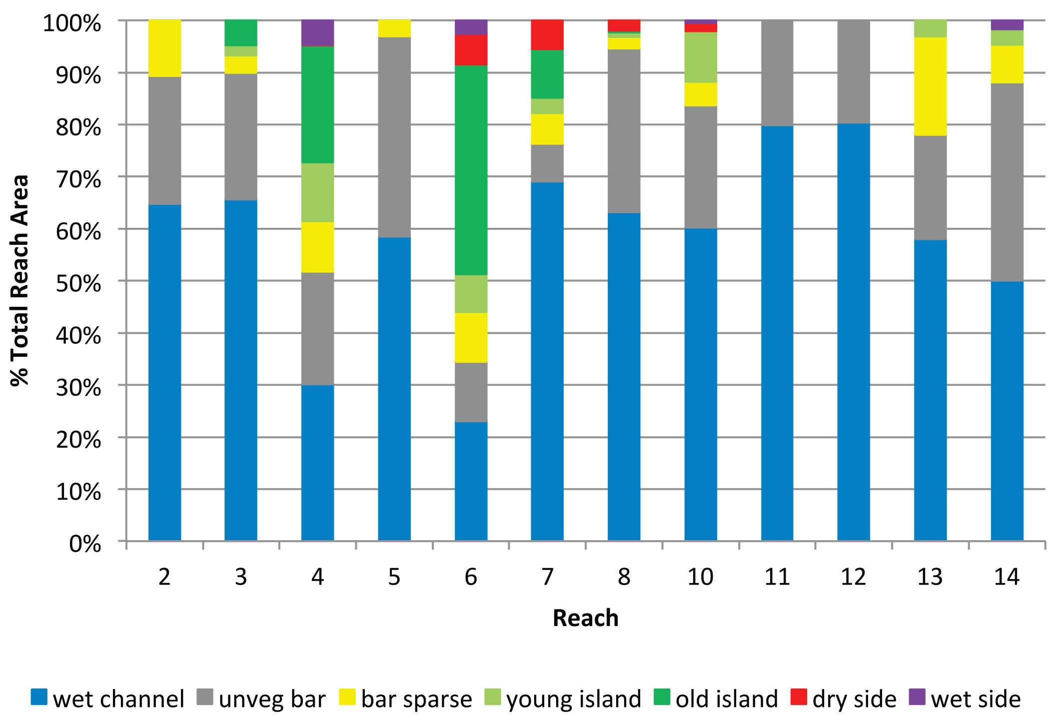
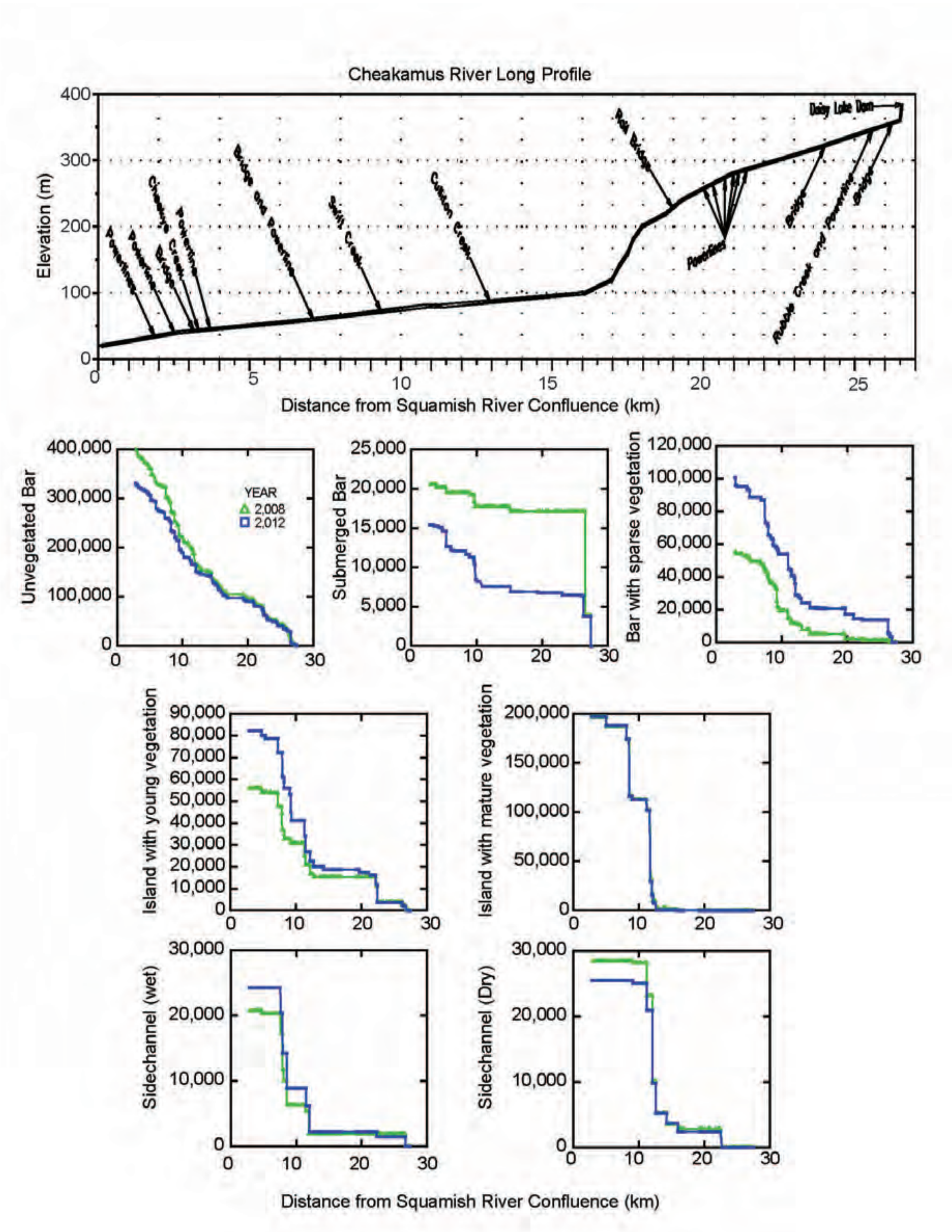
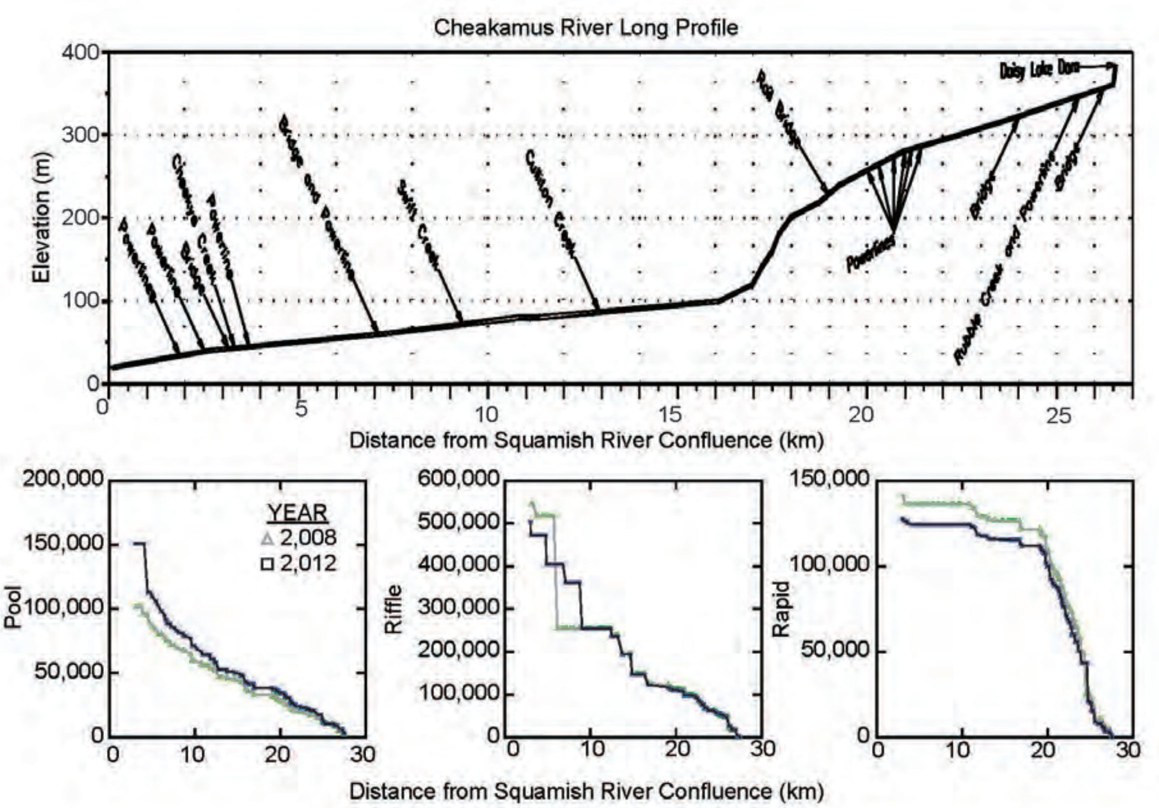


Figure 4-3 Cumulative Area Associated with Geomorphic Features Starting at Daisy Lake and Proceeding Downstream as a Function of Channel Chainage.



Above the Cheekye River the channel becomes more complex, with numerous side channels (see **Figure 4-4)** and locations where the channel splits around mature wooded islands. Woody debris are also common within Reaches 3, 4 and 6. Side channels are particularly prevalent within Reach 3 and 4 where many have been built or augmented for improved fish habitat. Reach 5 is a narrow, slightly sinuous transport zone with simple morphology. Reach 6 is characterized by a number of islands with mature or maturing vegetation. Many of these areas are currently connected to the channel banks at low flow.

Figure 4-4 Cumulative Area Associated with Habitat Units Starting at Daisy Lake and Proceeding Downstream as a Function of Channel Chainage.



The valley narrows upstream starting near the downstream end of Reach 7 and enters a relatively straight section with little deposition upstream to the Culliton Creek confluence. Culliton Creek is also susceptible to landslides but has not been studied (Clague et al., 2003) so the history of past, and risk of future landslides is unknown.

Above Culliton Creek the river becomes more confined, with Reach 8 regarded as a depositional reach downstream of the bedrock canyon (there are frequent exposed bar deposits). Reach 9 and the lower half of Reach 10 are characterized by a narrow channel flowing through a bedrock canyon and are excluded from the mapping since this section does not change over time. From the start of the bedrock canyon upstream to near Rubble Creek confluence (Reach 13 and 14) the river is flowing through re-worked Rubble Creek landslide deposits that confine the channel (NHC, 2000).

The proportion of total area covered by exposed bars increases upstream through these reaches to the source of the sediment at Rubble Creek. There is vegetation growth on higher elevation parts of the fan; the channel has incised through the mid 1800s landslide deposits and higher relict surfaces are no longer inundated. However, part of the fan near the mouth remains un-vegetated, as are all bars in downstream reaches 11 and 12, indicating sediments are still actively re-worked. Reach 14 includes part of Rubble Creek fan and extends upstream to the Daisy Lake Dam. This is a confined reach with small areas of exposed bar and a coarse lag deposit immediately downstream of the dam.

Dikes and other bank protection measures are common along the lower river outside of the canyon reaches, particularly within Reach 2, 3 and 4. Prior to diking, these reaches were wider with a wandering channel morphology consisting of numerous forested islands and extensive, nearly braided bar complexes (Clague et al., 2003; NHC, 2000). Following diking, the river was narrowed and rock bank protection has limited the ability of the channel to move laterally.

The wetted channel dominates the areal fraction of most reaches, averaging 59% of the total surface area between channel banks in both 2008 (Figure 4-1) and 2012 (Figure 4-2). The exception occurs in Reaches 4 and 6 where a very large island splits the flow. Un-vegetated gravel bars are the next most dominant feature, averaging 28% of the total surface area in 2008, but this declines to 23% in 2012.

The loss of un-vegetated gravel bar area is not due to erosion, but due to the gradual revegetation of these surfaces – the average area of old bar surface more than doubled from 2.5% in 2008 to 6.3% in 2012. There was also a modest increase in the areal extents of young islands. This is a clear signal that the channel is becoming increasingly stable and follows the trend first identified more than a decade ago (NHC, 2000).

4.2 Geomorphology Habitat Units by Reach

Areas for each morphologic unit (riffle, pool, or rapid/cascade) are summarized by reach in **Table 4-2** and illustrated in **Figure 4-5** and **Figure 4-6.** The baseline mapping of the units is found in **Appendix B**. Together, these units correspond to the areal (wetted) fraction listed in **Table 4-1**. Outside of the bedrock canyon reaches the majority of the lower Cheakamus River is characterized as riffle. The riffles tend to be very long, connected features with smaller pool units located at the channel margins.

As a means of illustrating where the different habitat units are more prevalent, and if/how they differ between 2008 and 2012 the cumulative area associated with each habitat unit is plot as a function of channel chainage in **Figure 4-3**. The location of each polygon was assigned a chainage based on the centroid of the polygon. The chainage starts at the confluence with the Squamish River, while the cumulative area starts at the Daisy Lake Dam so that the cumulative area from the dam downstream can be assessed.

On account of increasing watershed area, decreasing channel slope and grain size, in the absence of any other factors area would increase non-linearly in the downstream direction.

Table 4-2 Summary of Geomorphic Units by Reach

2008 Data:

Reach	Pool	Riffle	Rapid
2	2.4 %	83.0 %	14.6 %
3	20.9 %	79.1 %	0 %
4	11.4 %	88.6 %	0 %
5	14.8 %	85.1 %	0.1 %
6	9.1 %	78.7 %	12.2 %
7	11.2 %	85.5%	3.3 %
8	13.8 %	80.5%	5.7 %
10	13.6 %	36.6 %	49.8 %
11	8.5 %	39.7 %	51.8 %
12	8.0 %	33.3 %	58.6 %
13	3.8 %	92.3 %	3.9 %
14	22.7 %	53.8 %	23.5 %

2012 Data:

Reach	Pool	Riffle	Rapid
2	1.0 %	89.5 %	9.5 %
3	45.9 %	54.1 %	0 %
4	15.6 %	84.4 %	0 %
5	23.5 %	76.4 %	0.2 %
6	13.9 %	74.9 %	11.1 %
7	12.6 %	84.4 %	3.0 %
8	13.3 %	82.4 %	4.3 %
10	16.5 %	33.2 %	50.3 %
11	10.2 %	41.0 %	48.8 %
12	13.6 %	30.0 %	56.4 %
13	3.1 %	93.0 %	3.9 %
14	22.2 %	61.3 %	16.5 %

Figure 4-5 2008 Cheakamus River Geomorphic Units

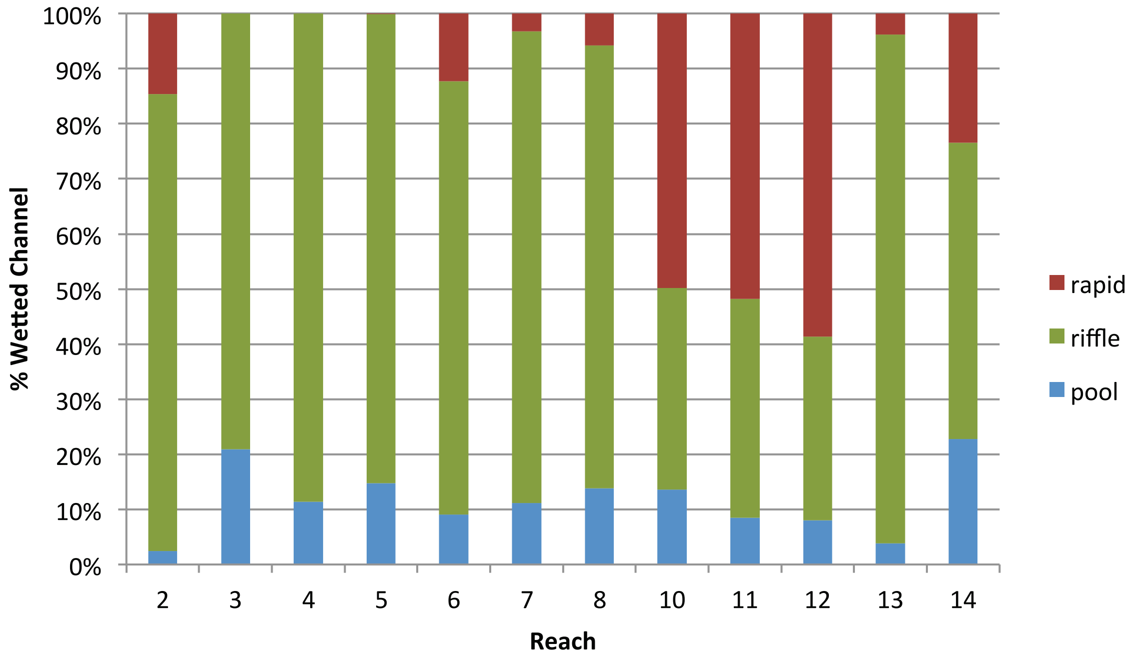
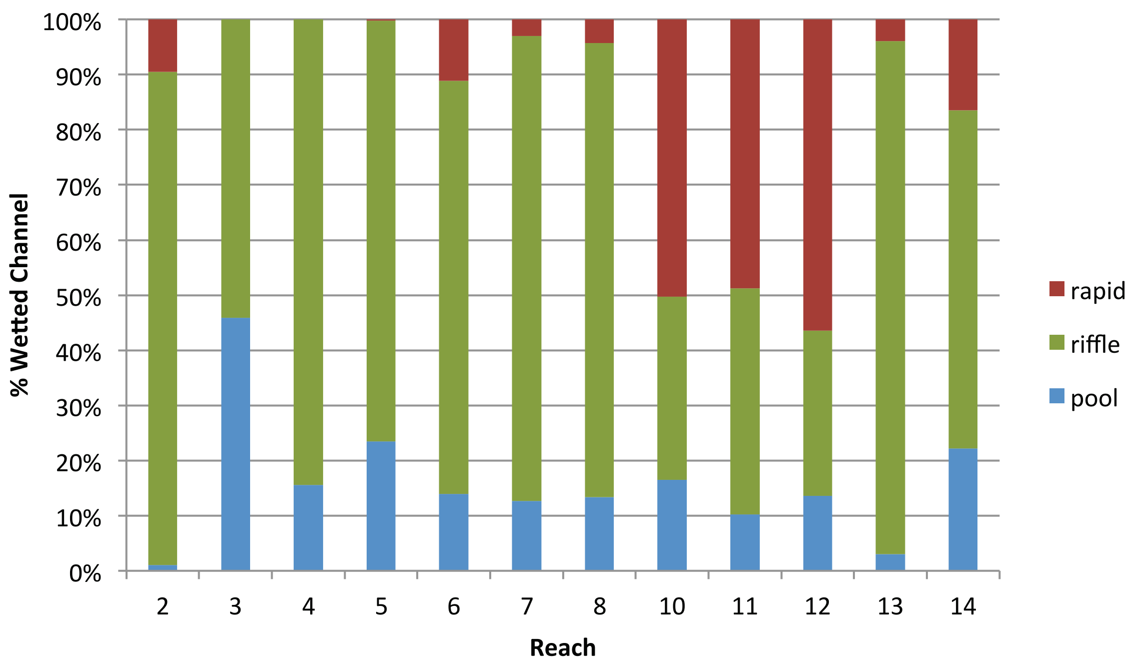


Figure 4-6 2012 Cheakamus River Geomorphic Units



In general, the area of rapids is very stable over time because there is modest sediment transport in the Cheakamus River – large inputs of sediment and flows capable of transporting this material downstream are necessary to effect significant morphologic change. There was a decrease in riffle area in Reach 2 which was caused by the Cheekye slide and remobilization of some of this material downstream.

Much of the upstream section of the river (Reaches 10 to 12) is characterized by long sections of rapids and cascades, particularly through the bedrock canyon where gradient is steepest. Downstream of these reaches, rapids are confined to small areas of channel and at the Cheekye River and Culliton Creek confluences. There are no rapids in Reaches 3 to 5 where gradient is lowest. Rapids and cascades are morphologically stable and would only be disturbed by exceptionally large flows. Correspondingly, the area of these features shows little change over time except in Reach 14 because of the lower water level. The lower flow in 2012 reduces the area of turbulent flow resulting in a reduction in rapid area (while increasing riffle area).

Pools are relatively limited throughout the lower river and tend to be located on the margins of the channel, rather than spanning the entire channel width. In 2008, Reach 3 had the largest total area of pools (2.47 ha) though Reach 14 had the greatest proportion of pool area due to the presence of plunge pools below the dam. Pools within the alluvial section (Reach 2 to 8) are generally confined to outside bends while upstream of Reach 8 pools are more likely to be plunge pools associated with rapid/cascade morphologies.

There was a large increase in pool area in Reach 3 (to 5.83 ha) which was caused by the Cheekye River debris flow that created a backwater effect, flooding upstream bar elements and riffle units. It is expected that pool area will become reduced over time if there is a sufficiently large flood capable of mobilizing the slide deposit downstream. There was also a modest increase in pool area in Reaches 4 and 5 which appears related to movement of bed material but also likely reflects some interpretive differences.

4.3 Interpretation and Significance of Observed Changes

To test whether any of the observed areal changes are significant, mean and variance values for different morphologic elements were compared. Given the large scale and high resolution of the orthophotos, it is possible to map different features at a wide range of spatial scales, so some features (i.e., bars) will be smaller than average, while others will be larger. If the complexity of the channel is changing, deviations from the mean (areal variance) must also change.

Sample size (N) and mean values are summarized in **Table 4-3**. For all of the statistical tests, the data were logarithmically transformed. Since many reaches have only a single polygon (water surface) or very few polygons (side channels, islands) it was not possible to test the significance of changes for individual reaches, so the entire river was considered collectively. A detailed presentation of the statistical results are provided in **Appendix C.**

Table 4-3 Summary Area Statistics for Morphological Features (whole river, N= sample size)

Feature	2008		2012	
	N	Mean	N	Mean
riffle	31	17,611.8	38	13,249.1
pool	61	1,670.8	65	2,321.9
rapid/cascade	51	2,767.1	57	2,239.7
young island	25	2,243.1	28	2,941.3
mature island	16	12,307.1	14	14,102.9
unvegetated bar	201	1,982.0	176	1,879.7
bar sparse veg	94	590.5	56	1,797.7
submerged bar	13	1,584.4	25	616.8
dry side channel	7	4,059.1	7	3,644.3
wet side channel	9	2,308.4	7	3,468.0

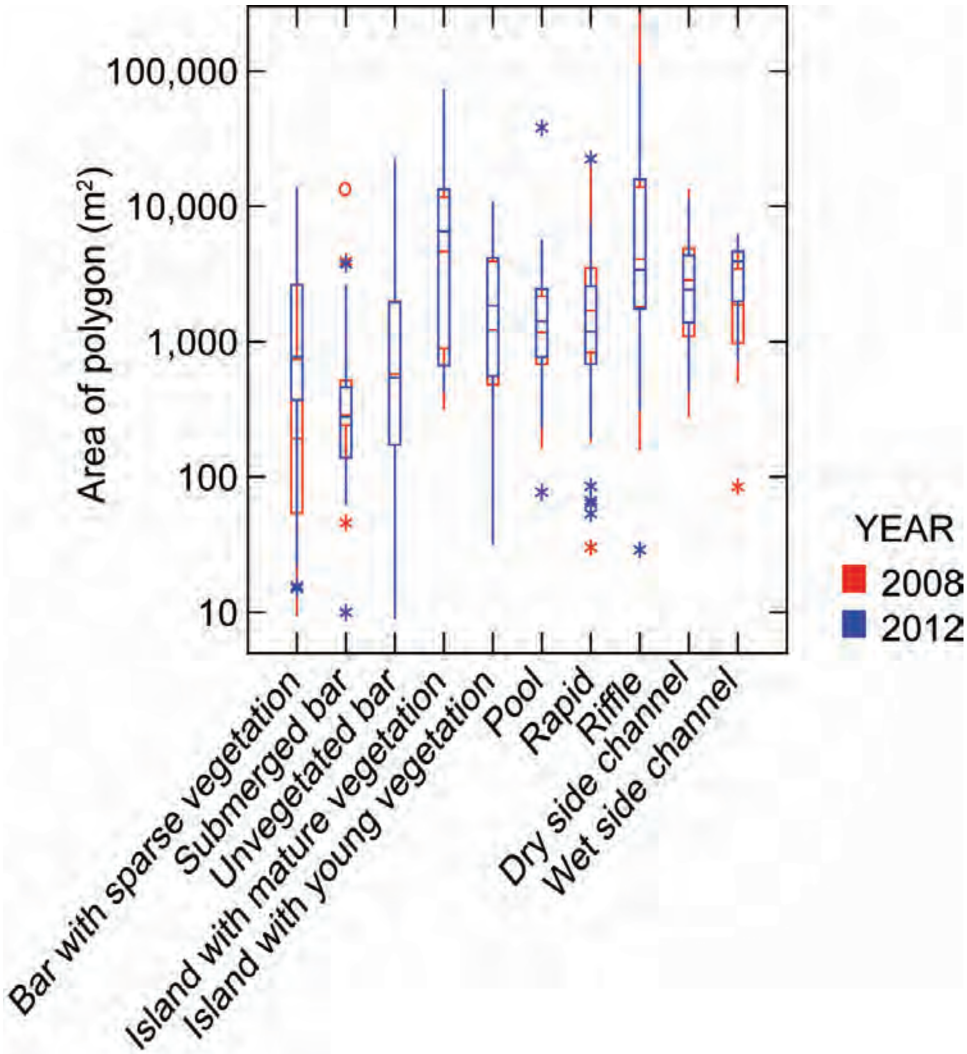
Overall the mean size and variance associated with the habitat and morphological units was similar in 2008 and 2013. Only the amount of bars covered with sparse vegetation increased significantly ($p<0.05$). The variance associated with areal extents of the polygons was not statistically different for any of the features. The mean and variance are graphically illustrated in **Figure 4-7.**

Between 2008 and 2012, the mean areas of pools, young islands, mature islands, bars with sparse vegetation and wet side channels all increased, but only the increase of bars with sparse vegetation was statistically significant. The areal increase of this feature was also associated with a large decrease in feature count from 94 to 56 mapped polygons, which is a signal of consolidation – that is, patches of sparse vegetation were becoming joined together, forming larger, but fewer patches.

Islands showed a similar trend, but the results were not significant as it takes much longer for islands to mature than for young vegetation to establish on bare bar surfaces. The increase in pool area and wetted side channels is likely transient as related to movement of bars; future monitoring will establish whether there is any actual trend.

An increase in deviation from the mean signals increased morphologic complexity, while a decrease indicates that the channel is becoming more homogenous. Statistically the variance associated with each of the units was unchanged.

Figure 4-7 Box plot illustrating area of each habitat and morphological unit in 2008 and 2012



5 Channel Sediments

At this time, the level and detail of monitoring cannot accept or reject impact hypothesis, H_{01}: *Total area of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP*.

The terms of reference provide only a rationale to monitor the areal extent of suitable substrate at a coarse scale. A river-scale bed sampling and mapping program was not included in the original monitor, and there have been no specific monitoring of changes to substrate calibre or quality, or distribution of spawning substrate in the reaches of the Cheakamus River has not been completed. In CMSMON 8, the coarse measure used was riffle habitat measured during the assessment period. Since 2008 this has not changed.

However, this coarse metric is not an accurate assessment tool for H_{01}. First, the assessment flows are relatively low in comparison to spawning flows for most of the salmonid species therefore the potential spawning areas are not accurately assessed. Second, the methodology does not account for the potential changes in the suitability of substrates (i.e., substrate quality as represented by gradation, embeddedness, percentage of fines, etc.). Third, the orthophoto methodology cannot accurately map the distribution of spawning substrates without significant field verification and sediment sampling to cross reference locations and channel sediment sizes.

To improve the data integrity and understanding of the Cheakamus River geomorphology, channel sediments and determine an outcome for H_{01}, additional work is suggested:

1. A more detailed examination of sediment supply changes, and understanding the linkages and effects of reduction in sediment supply.
2. Assessment of the substrate grain size and distributions at critical habitat and index sites.

Grain size sampling should be completed during the next phase of program. In November, 2000 three surface pebble counts were collected in Reach 4 and Reach 6 (see Figure 2A; NHC, 2000) and a subsurface sample in reach 6 was also collected. The sediment sampling program should begin by visiting these sites and re-sampling the substrate and comparing the results. The details of the sampling program will need to be developed with the other CMS WUP Monitors to ensure the sediment sampling information is meeting their needs and collected at sites where the information is most useful.

6 Year 5 Summary

The Year 1 (2008) baseline mapping found that the wetted low flow channel dominates the areal fraction of most reaches. The low flow channel was further divided into pools, riffles and rapids / cascades that represent distinct habitat types and qualities. Riffles were found to be dominant in mainly unconfined reaches, while rapids were dominant in steeper, confined lengths of channel. By Year 5 (2012) there was no change in the total area of the wetted channel. There was a modest increase in the number of mapped riffles, pools and rapids and the average area of pools increased, while the average area of riffles and rapids declined. None of these changes were statistically significant.

The mapped differences may simply represent a response to sediment influx and transport through the system, and transient conditions in the river channel. For example, a 2011 landslide and debris flow introduced an estimated 5000 m^3 of sediments from the Cheekye River to the Cheakamus River confluence. This created a hydraulic constriction and backwater effect on Reach 3, which resulted in changes to the hydraulic habitats upstream and downstream[2].

A similar issue resulted from the slide and debris flow on Rubble Creek in 1855. The 1855 event resulted in the deposit of tens of thousands of cubic meters of sediment on the fan and confluence with the Cheakamus River. Subsequent transport and downcutting of the channel at this location has resulted in exposure of the buried floodplain forest. In both cases, sediment sampling – if timed properly – may have detected additional changes.

The monitoring cannot accept or reject H_{01}, *Total area of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP*. As detailed in Section 5, resolution of this impact hypothesis cannot be completed using the study design and methodology as presented in the TOR.

A suggested approach is provided that would help examine changes in channel shape, elevations and composition by analysis of long term key cross sections in alluvial reaches, and base mapping and spatial analysis of sediments in the river channel (ideally by habitat type). This work is likely important as changes in sediment quality and composition may be affecting the certain fish habitats, and the current mesohabitat mapping is not adequate to resolve H_{01}.

The most important noted change between 2008 and 2012 study was the decrease in the number of bars with sparse vegetation, and an increase in the average area of this feature. These changes indicate that vegetation is increasing on formerly bare bar surfaces and consolidating into larger patches that will eventually become riparian forest.

This is an indication that recently these bars are not being mobilized under the current regulated flow regime such that flood flows are insufficient to mobilize the bed, or that the channel is becoming increasingly stable due to changes in the bed material gradation and sediment supply. In the absence of large sediment inputs or large flood events, vegetation is expected to continue to expand and mature. The resulting increase in bank strength provided by riparian forest cover could lead to decreasing channel widths and increasing depths, simplification of channel morphology and loss of natural side channel habitat (Millar, 2000).

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[2] Remedial works were later undertaken in 2012 to remove a large portion of the deposit from the Cheakamus River.

Natural side channels were identified as the secondary channels where mature islands split the flow, and further divided into wet and dry during observed conditions. In general, dry side channels do not provide overwinter habitat, but are likely important areas for feeding and refugia during freshet and flood flows. There was a decrease in the number of wet side channels, but the average area and areal variance of this feature actually increased though not significantly. Side channel area is considered a better metric of habitat availability than side channel length, as presented in H_{02}.

There was no change in the number, average area or areal variance of dry side channels during the first four year interval of this monitor. The modest decrease in mean area of dry side channels is consistent with the general expansion of vegetation, but the change is not statistically significant, This metric may become significant if current riparian forest growth and encroachment continues.

Orthophoto mapping specified in the terms of reference does not provide the resolution and accuracy for measuring the number and ratio of pool, run and riffle habitats for natural side channels (H_{03}). The temporal nature of the habitat as related to flow and forest cover makes it difficult to classify the mesohabitat type, and ground-based surveying and mapping is suggested. Changes in the number and areal extent of these features is recommended at a representative flow determined on a reach-specific basis.

A significant challenge in the monitoring program is addressing the impacts of unsteady sediment inputs from tributaries. Large inputs of sediment from tributaries will change the morphology of the channel and generally counter act the potential effects of the construction of Daisy Lake. In contrast, naturally occurring periods of relatively low sediment supply, especially from Rubble Creek (which is located closest to the dam) will result in channel changes that can also be attributed to the construction of the dam and the resulting interruption of sediment supply.

Since the sediment supply regime in this system varies considerably at the decadal time scale (variations are likely similar to, or even more pronounced than observed in the Fitzsimmons Watershed; see Schiefer *et al.*, 2010), distinguishing the Daisy Lake Dam influence from the effects of a variable sediment supply, using relatively frequent observations (interdecadal) will be difficult.

7 References

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Appendix A Site Photos

Photo 1. Examples of morphologic elements used in channel mapping.

Sparse shrub in foreground with young island (immature trees) behind

Mature island (mature trees) with woody debris in foreground

Start of side channel going off to right; dry at low flow (approx. 23 m^3/s)

Newly re-constructed side channel at low flow (approx. 23 m^3/s)

Typical riprap bank protection with adjacent bar displaying sparse shrub

Edge of Rubble Creek alluvial fan showing water flowing over surface

Photo 2. Examples of morphologic units that define low flow wetted channel.

Rapid/Cascade

Riffle

Pool

Appendix B Baseline Geomorphic Mapping

Appendix C Detailed Statistical Output

▼Hypothesis Testing: Two-sample t-test

Results for CODE_TEXT$ = bar_unvegetated

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

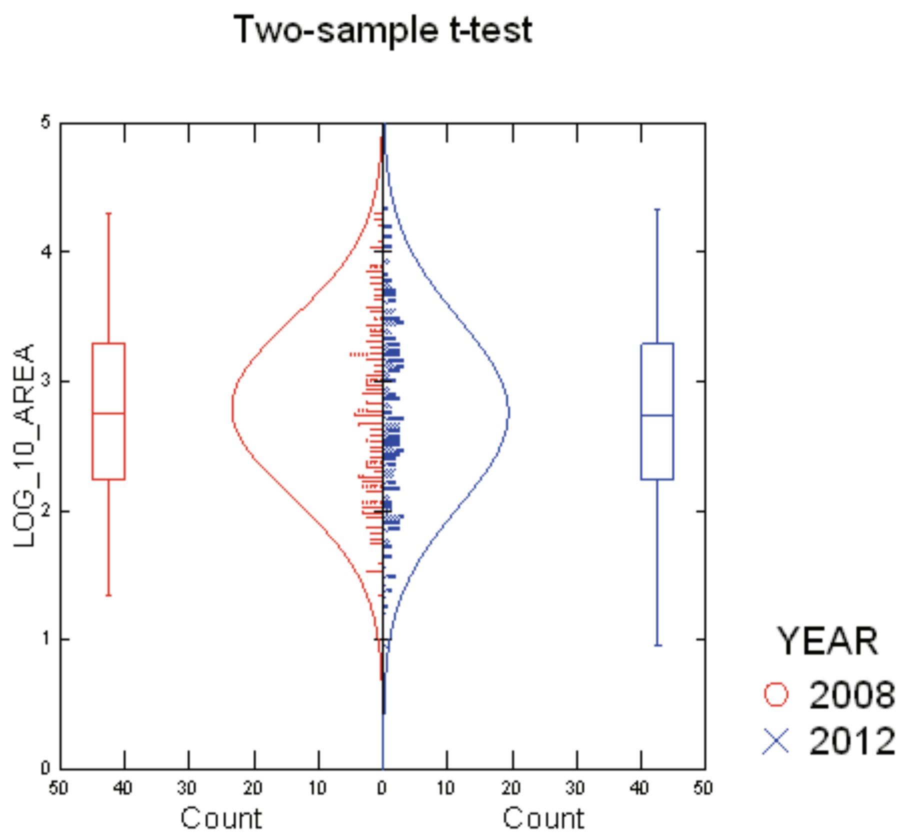
GROUP	N	Mean	Standard Deviation
2008	201	2.7960244	0.6839525
2012	176	2.7592002	0.7245200

Separate Variance

Difference in Means	:	0.0368242
95.00% Confidence Interval	:	-0.1064755 to 0.1801238
t	:	0.5053485
df	:	361.8691052
p-value	:	0.6136218

Pooled Variance

Difference in Means	:	0.0368242
95.00% Confidence Interval	:	-0.1059113 to 0.1795597
t	:	0.5072861
df	:	375.0000000
p-value	:	0.6122523



Results for CODE_TEXT$ = bar_submerged

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

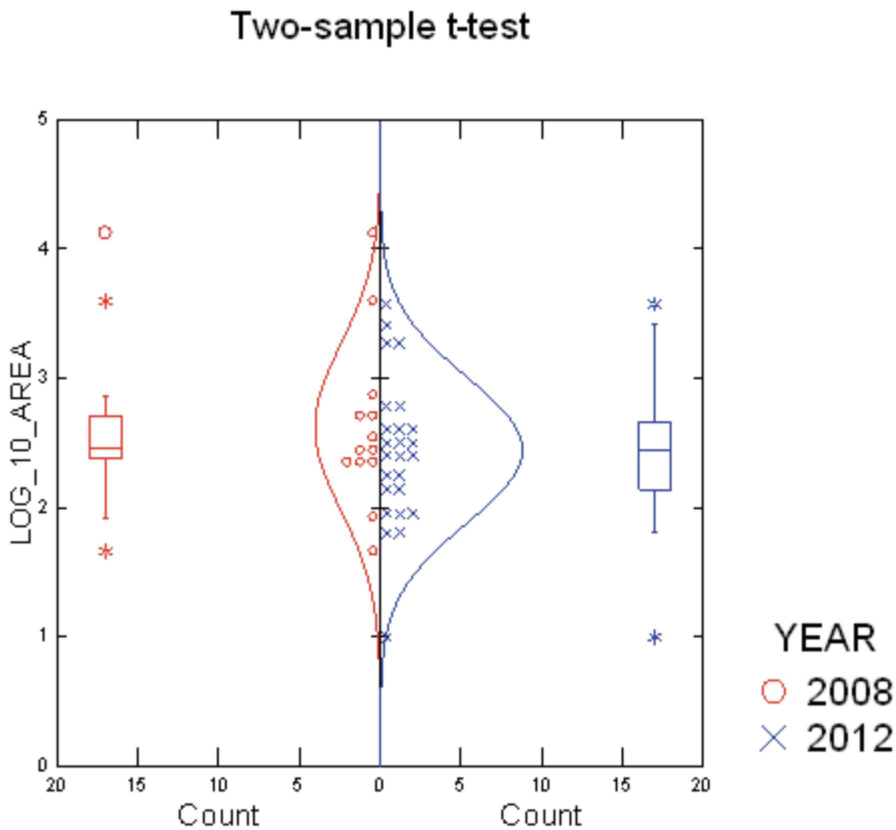
GROUP	N	Mean	Standard Deviation
2008	13	2.6240991	0.6421071
2012	25	2.4456719	0.5674716

Separate Variance

Difference in Means	:	0.1784272
95.00% Confidence Interval	:	-0.2596245 to 0.6164790
t	:	0.8449110
df	:	21.9190126
p-value	:	0.4072889

Pooled Variance

Difference in Means	:	0.1784272
95.00% Confidence Interval	:	-0.2330837 to 0.5899382
t	:	0.8793623
df	:	36.0000000
p-value	:	0.3850372



Results for CODE_TEXT$ = island_young

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
2008	25	3.0667481	0.5669154
2012	28	3.1501809	0.6626192

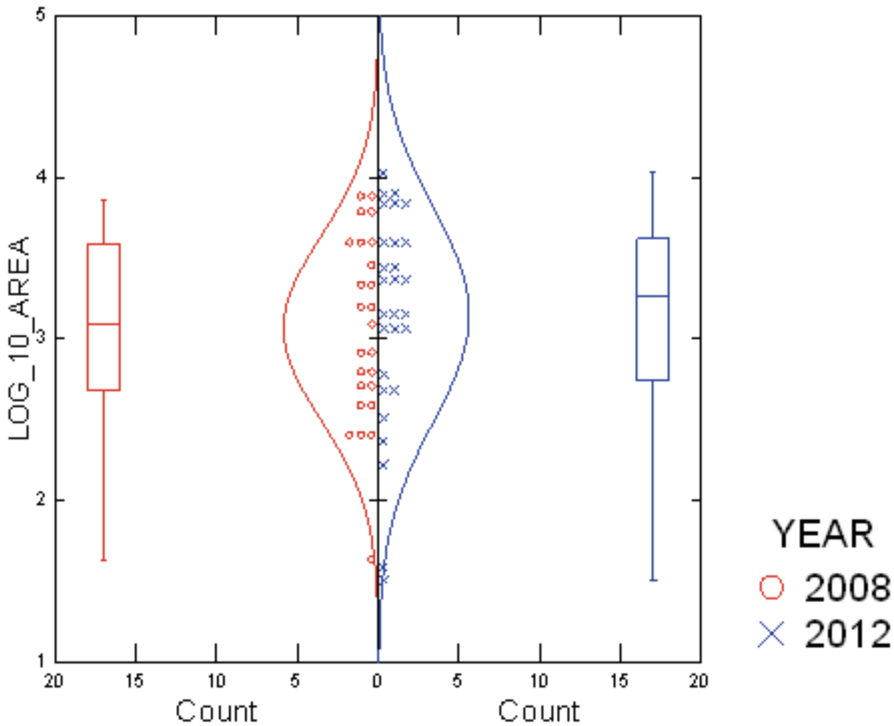
Separate Variance

Difference in Means : -0.0834328
95.00% Confidence Interval : -0.4225828 to 0.2557172
t : -0.4938964
df : 50.9175232
p-value : 0.6235033

Pooled Variance

Difference in Means : -0.0834328
95.00% Confidence Interval : -0.4256112 to 0.2587456
t : -0.4895059
df : 51.0000000
p-value : 0.6265825

Two-sample t-test



Results for CODE_TEXT$ = sidechannel_wet

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
2008	9	3.1607130	0.5608496
2012	7	3.4528785	0.3311477

Separate Variance

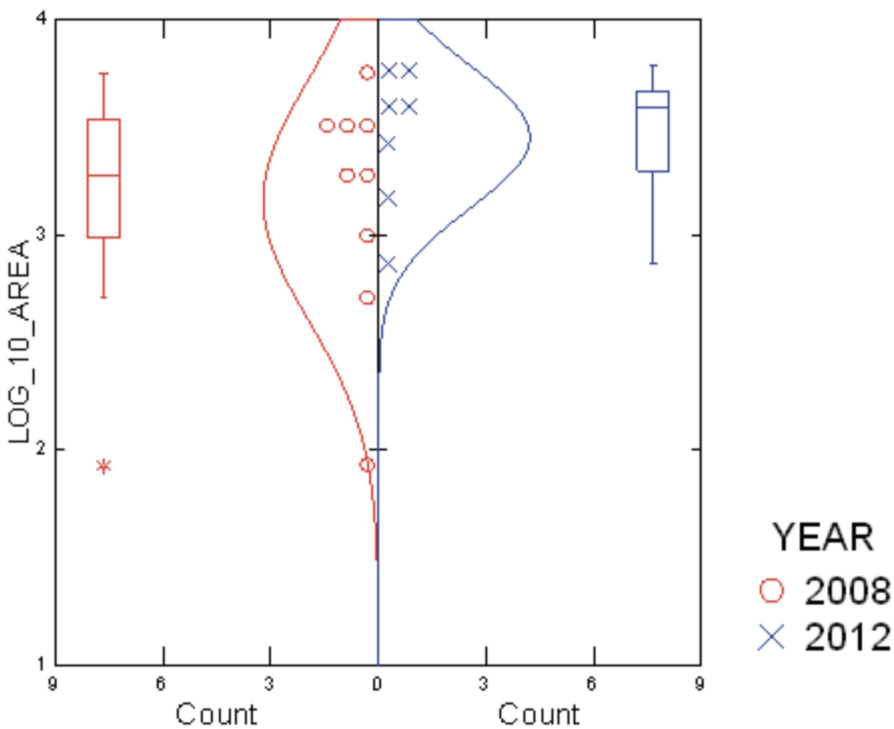
Difference in Means	:	-0.2921655
95.00% Confidence Interval	:	-0.7773327 to 0.1930017
t	:	-1.2986313
df	:	13.2338357
p-value	:	0.2162440

Pooled Variance

Difference in Means	:	-0.2921655
95.00% Confidence Interval	:	-0.8068471 to 0.2225161
t	:	-1.2175151
df	:	14.0000000

p-value : 0.2435325

Two-sample t-test



Results for CODE_TEXT$ = bar_sparse_veg

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
2008	94	2.2881845	0.6933122
2012	56	2.8482686	0.6985460

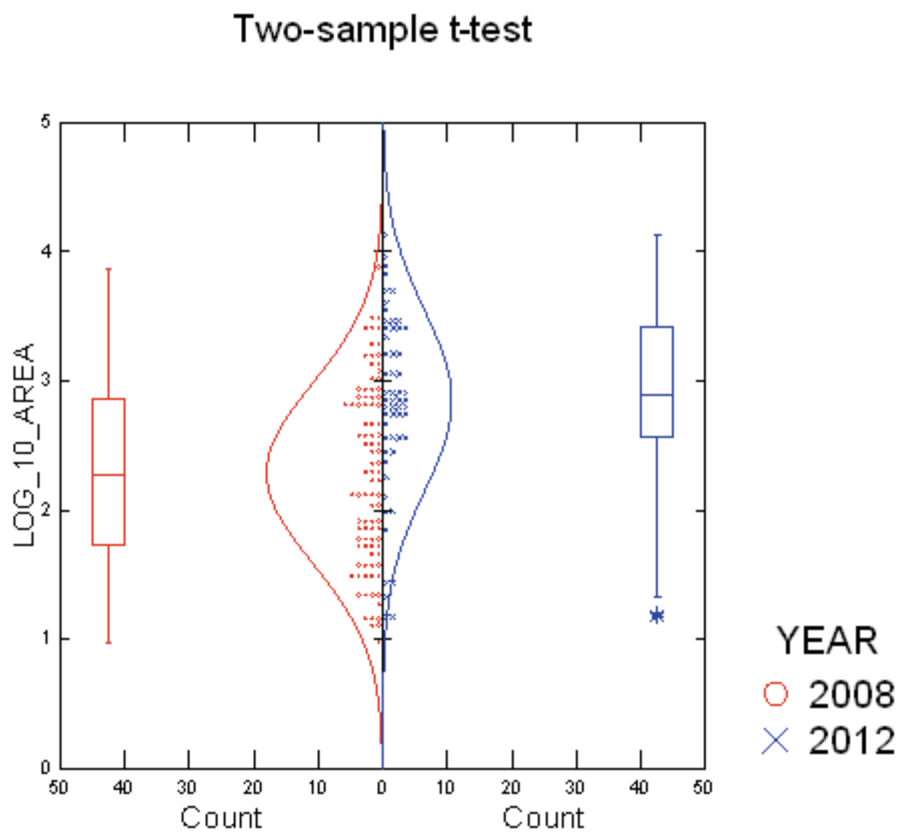
Separate Variance

Difference in Means : -0.5600841
95.00% Confidence Interval : -0.7930053 to -0.3271630
t : -4.7630397
df : 115.0604597
p-value : 0.0000056

Pooled Variance

Difference in Means : -0.5600841
95.00% Confidence Interval : -0.7920104 to -0.3281579
t : -4.7721845

df : 148.0000000
p-value : 0.0000043



Results for CODE_TEXT$ = sidechannel_dry

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
2008	7	3.3536954	0.5637516
2012	7	3.3744179	0.4583889

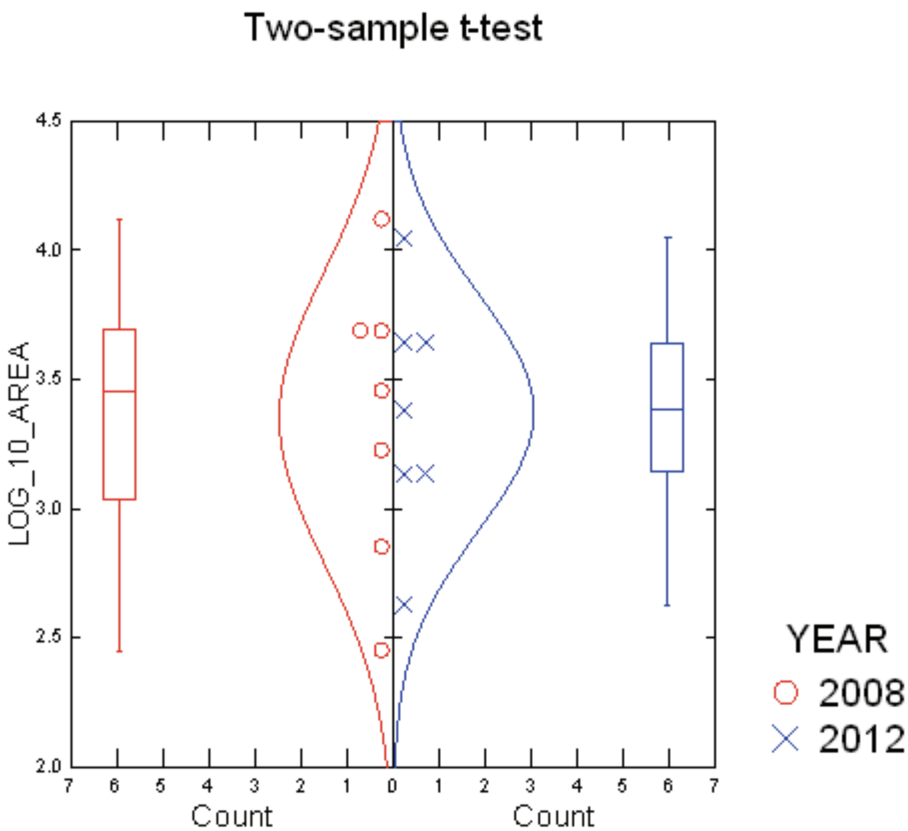
Separate Variance

Difference in Means : -0.0207226
95.00% Confidence Interval : -0.6218546 to 0.5804095
t : -0.0754574
df : 11.5205902
p-value : 0.9411453

Pooled Variance

Difference in Means : -0.0207226
95.00% Confidence Interval : -0.6190813 to 0.5776362

t : -0.0754574
df : 12.0000000
p-value : 0.9410942



Results for CODE_TEXT$ = island_mature

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
2008	16	3.5873093	0.7102068
2012	14	3.6368519	0.7533290

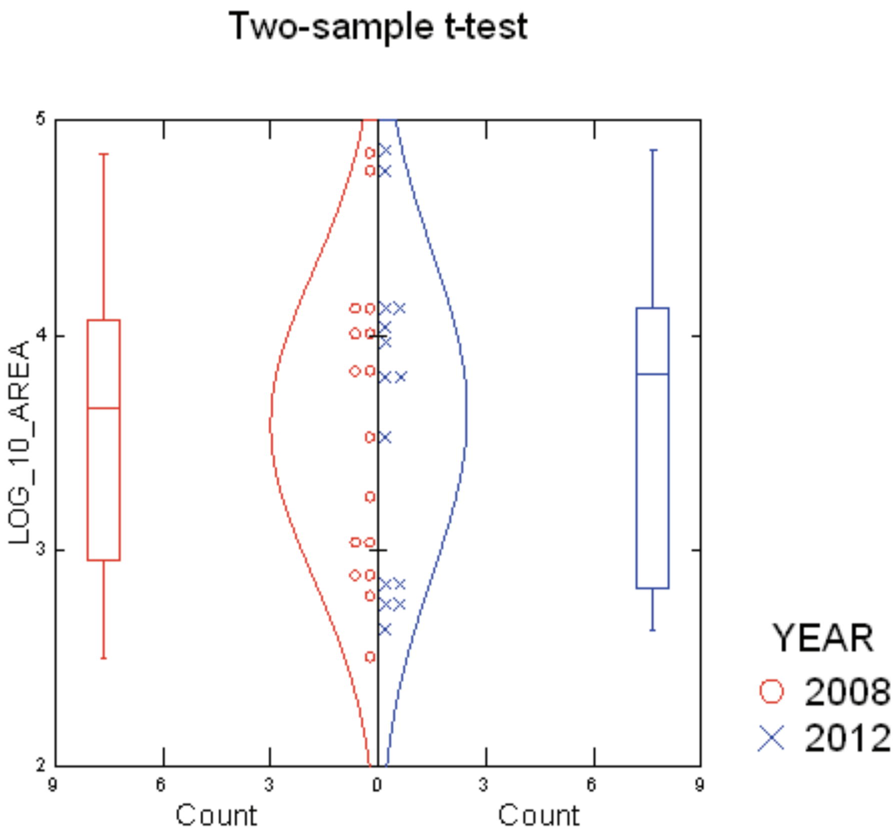
Separate Variance

Difference in Means : -0.0495426
95.00% Confidence Interval : -0.6003823 to 0.5012970
t : -0.1845568
df : 26.9540958
p-value : 0.8549582

Pooled Variance

Difference in Means : -0.0495426

95.00% Confidence Interval : -0.5971882 to 0.4981029
t : -0.1853088
df : 28.0000000
p-value : 0.8543227



Results for CODE_TEXT$ = pool

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

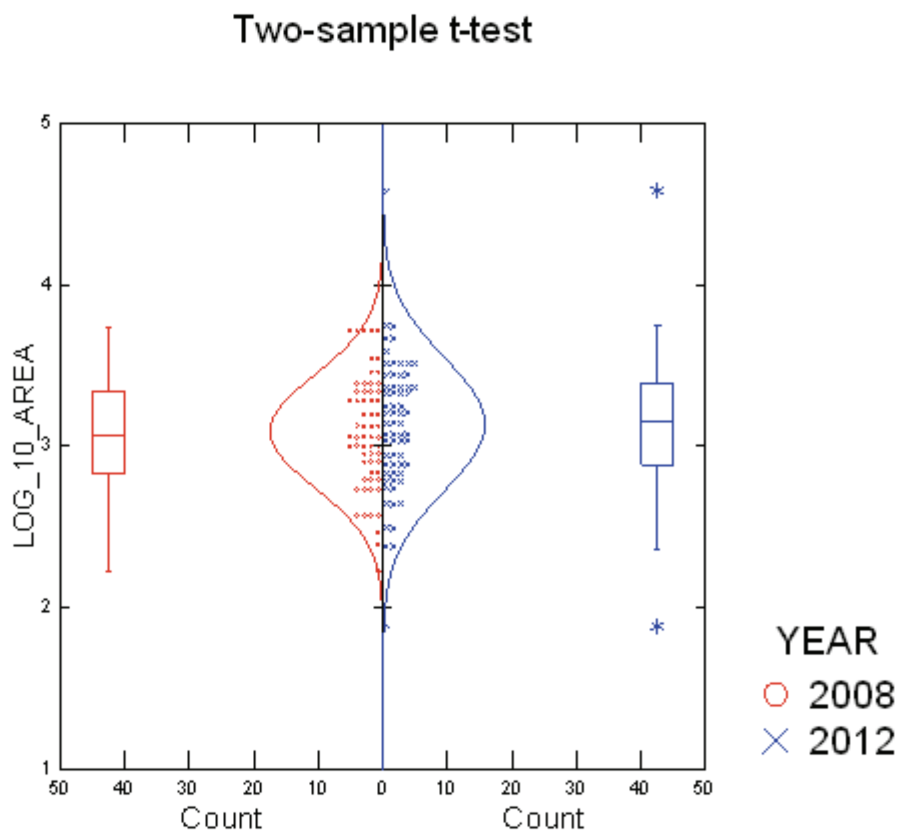
GROUP	N	Mean	Standard Deviation
2008	61	3.0933179	0.3481102
2012	65	3.1371786	0.4102851

Separate Variance

Difference in Means : -0.0438607
95.00% Confidence Interval : -0.1777691 to 0.0900478
t : -0.6483609
df : 122.7820088
p-value : 0.5179622

Pooled Variance

Difference in Means : -0.0438607
95.00% Confidence Interval : -0.1784557 to 0.0907344
t : -0.6449905
df : 124.0000000
p-value : 0.5201249



Results for CODE_TEXT$ = rapid

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

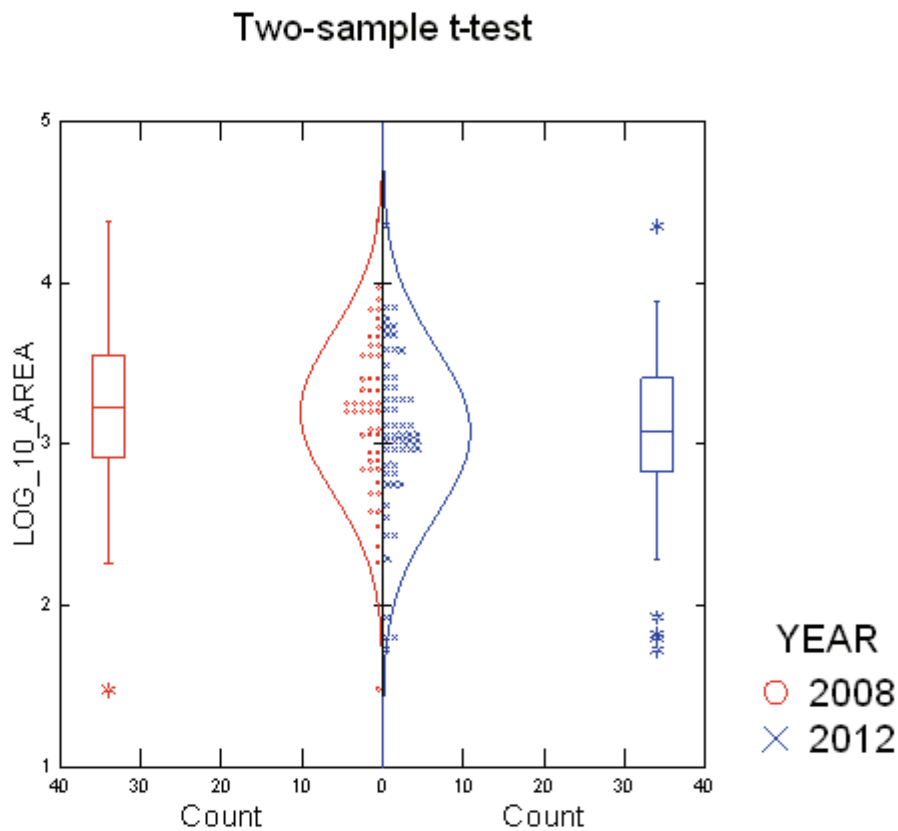
GROUP	N	Mean	Standard Deviation
2008	51	3.1959352	0.4996012
2012	57	3.0768807	0.5252544

Separate Variance

Difference in Means : 0.1190545
95.00% Confidence Interval : -0.0765629 to 0.3146720
t : 1.2066805
df : 105.5909109
p-value : 0.2302515

Pooled Variance

Difference in Means : 0.1190545
95.00% Confidence Interval : -0.0771037 to 0.3152128
t : 1.2032998
df : 106.0000000
p-value : 0.2315408



Results for CODE_TEXT$ = riffle

Two-sample t-test on LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

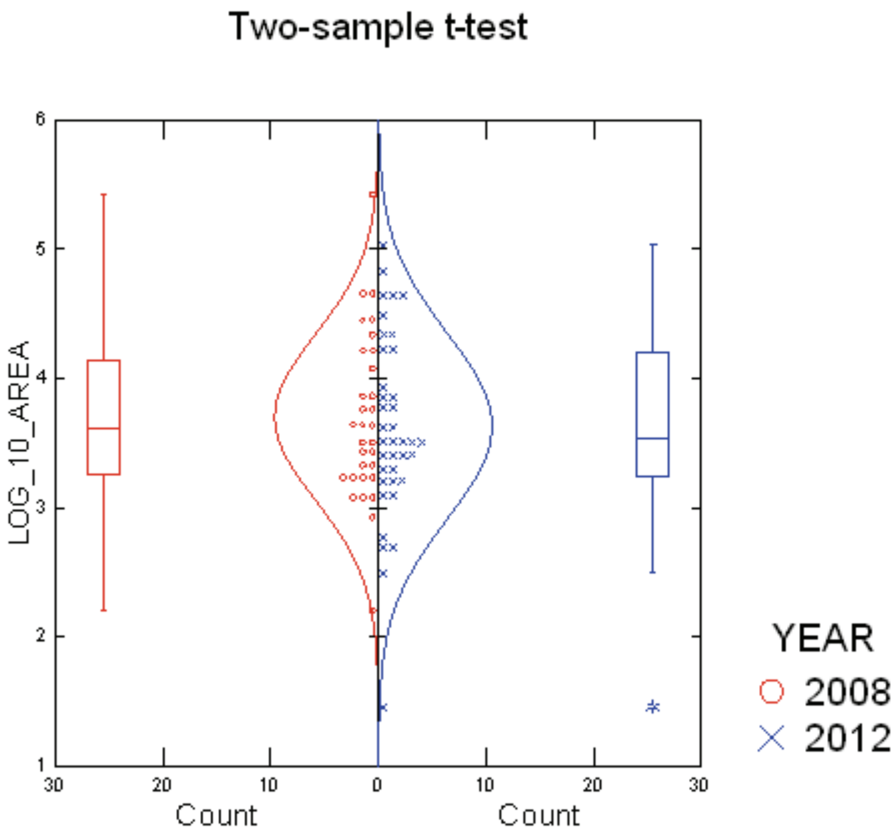
GROUP	N	Mean	Standard Deviation
2008	31	3.7016088	0.6427183
2012	38	3.6330646	0.7180991

Separate Variance

Difference in Means : 0.0685442
95.00% Confidence Interval : -0.2588538 to 0.3959421
t : 0.4179557
df : 66.3894143
p-value : 0.6773283

Pooled Variance

Difference in Means	:	0.0685442
95.00% Confidence Interval	:	-0.2625418 to 0.3996301
t	:	0.4132301
df	:	67.0000000
p-value	:	0.6807576



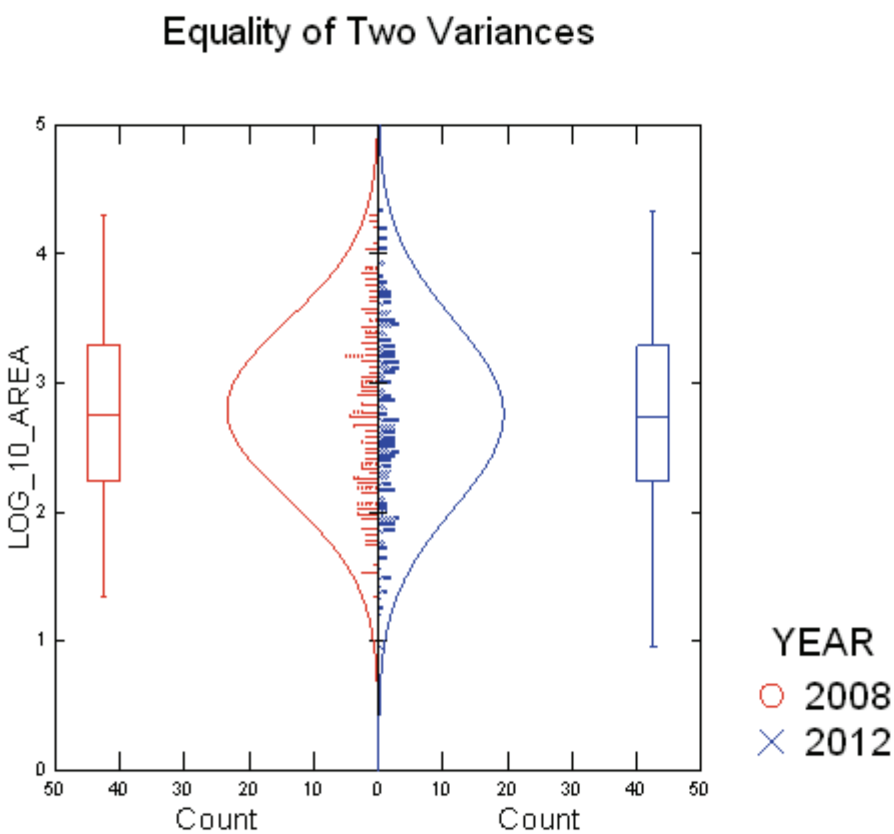
▼Hypothesis Testing: Equality of Two Variances

Results for CODE_TEXT$ = bar_unvegetated

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	201	2.7960244	0.4677910
2012	176	2.7592002	0.5249292

95.00% Confidence Interval : 0.6673569 to 1.1866692
F-ratio : 0.8911507
df : 200, 175
p-value : 0.4293841



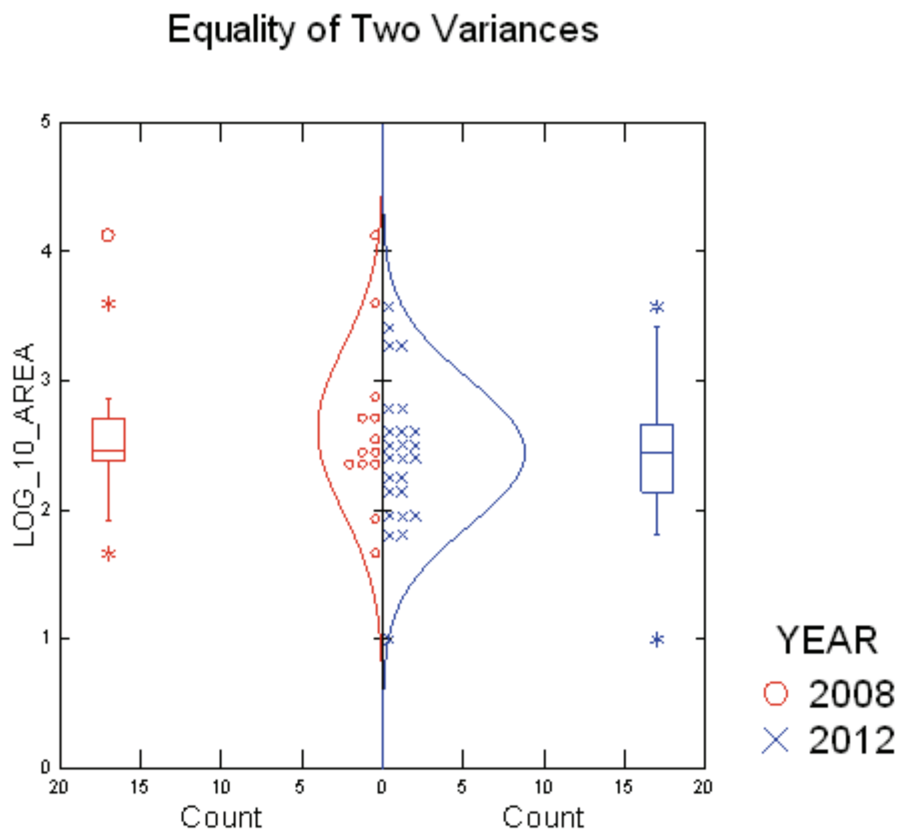
Results for CODE_TEXT$ = bar_submerged

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	13	2.6240991	0.4123015

GROUP	N	Mean	Variance
2012	25	2.4456719	0.3220241

95.00% Confidence Interval : 0.5038446 to 3.8649881
F-ratio : 1.2803437
df : 12, 24
p-value : 0.5828236

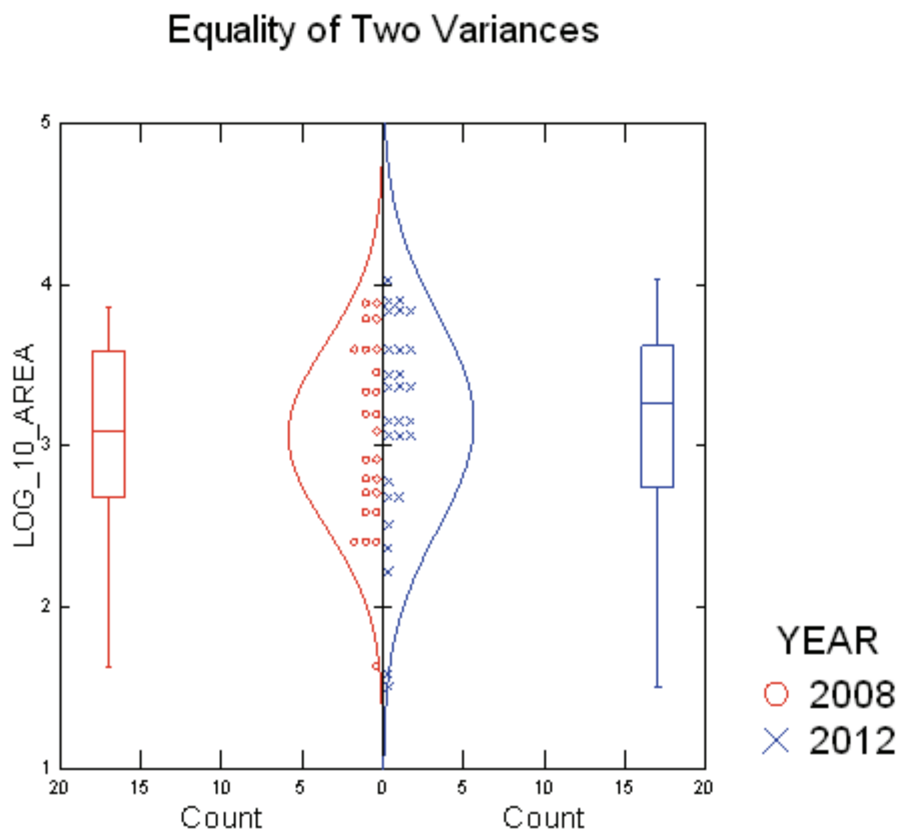


Results for CODE_TEXT$ = island_young

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	25	3.0667481	0.3213930
2012	28	3.1501809	0.4390642

95.00% Confidence Interval : 0.3335448 to 1.6368022
F-ratio : 0.7319955
df : 24, 27
p-value : 0.4431117

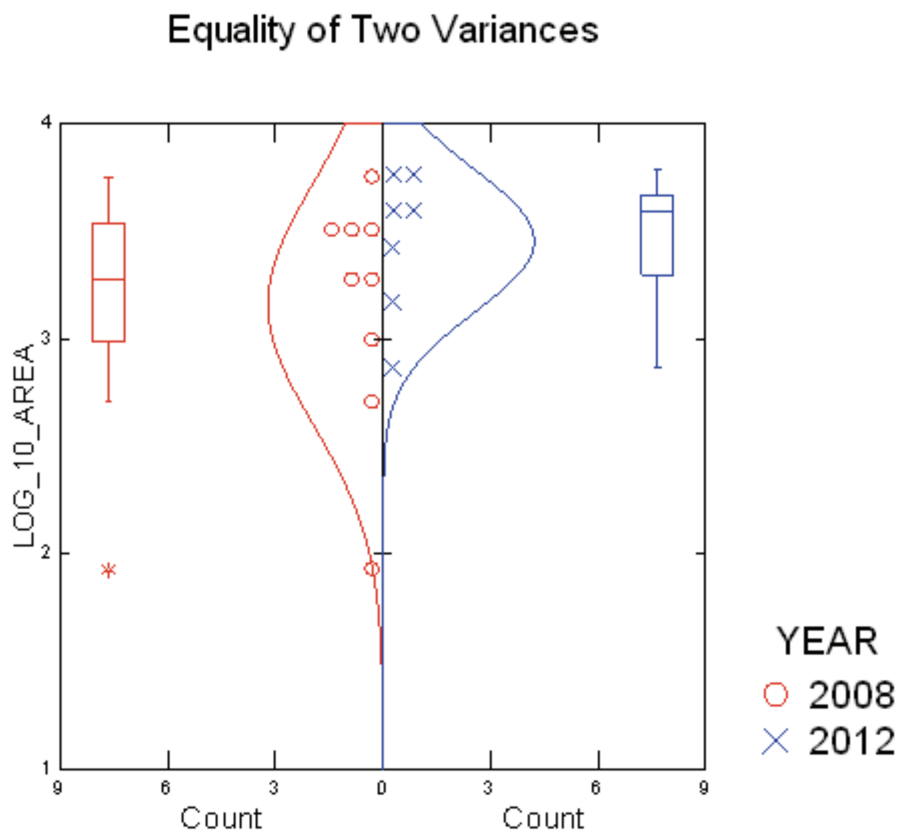


Results for CODE_TEXT$ = sidechannel_wet

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	9	3.1607130	0.3145523
2012	7	3.4528785	0.1096588

95.00% Confidence Interval	:	0.5122601 to 13.3432171
F-ratio	:	2.8684629
df	:	8, 6
p-value	:	0.2160310

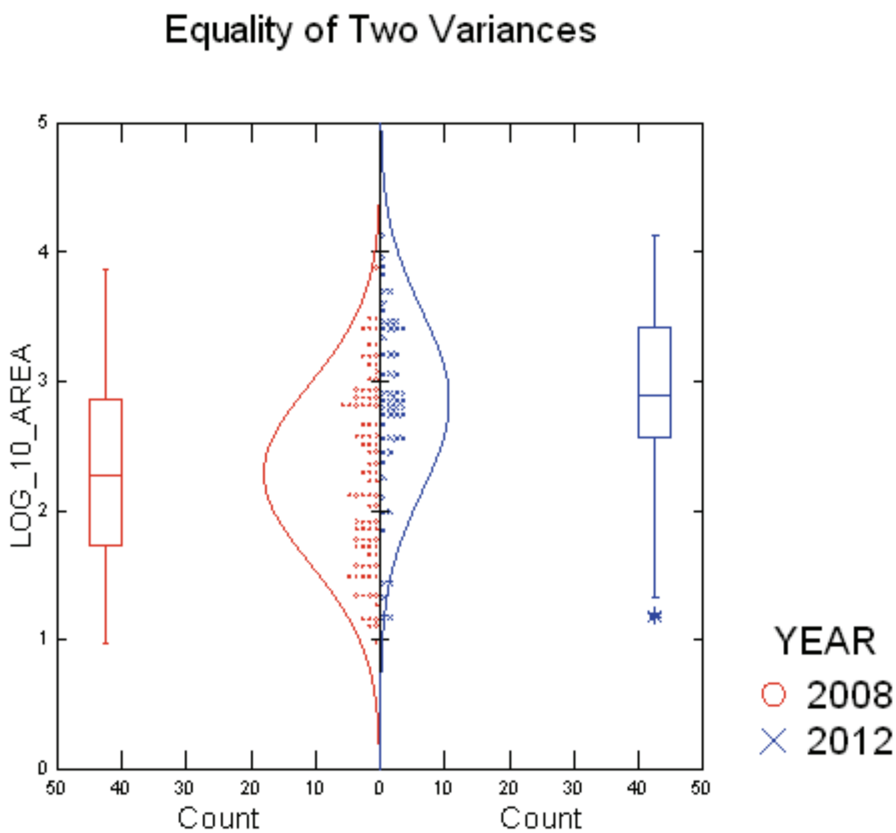


Results for CODE_TEXT$ = bar_sparse_veg

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	94	2.2881845	0.4806817
2012	56	2.8482686	0.4879665

95.00% Confidence Interval : 0.6033246 to 1.5618569
F-ratio : 0.9850711
df : 93, 55
p-value : 0.9338672

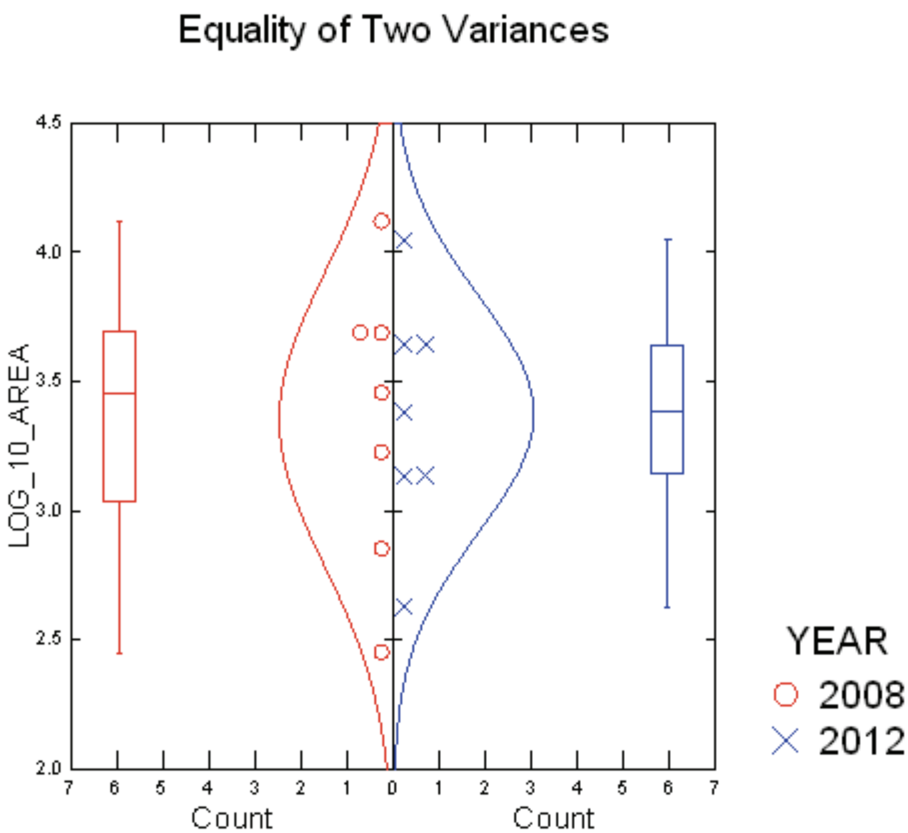


Results for CODE_TEXT$ = sidechannel_dry

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	7	3.3536954	0.3178158
2012	7	3.3744179	0.2101203

95.00% Confidence Interval : 0.2598978 to 8.8026267
F-ratio : 1.5125420
df : 6, 6
p-value : 0.6279910



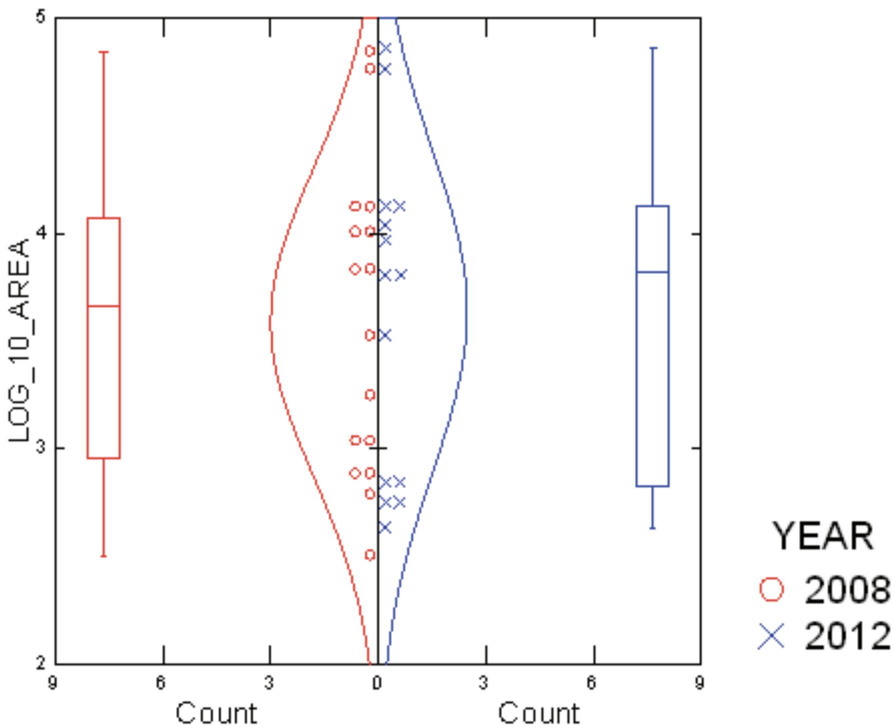
Results for CODE_TEXT$ = island_mature

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	16	3.5873093	0.5043938
2012	14	3.6368519	0.5675046

95.00% Confidence Interval : 0.2911483 to 2.5996328
F-ratio : 0.8887923
df : 15, 13
p-value : 0.8187004

Equality of Two Variances

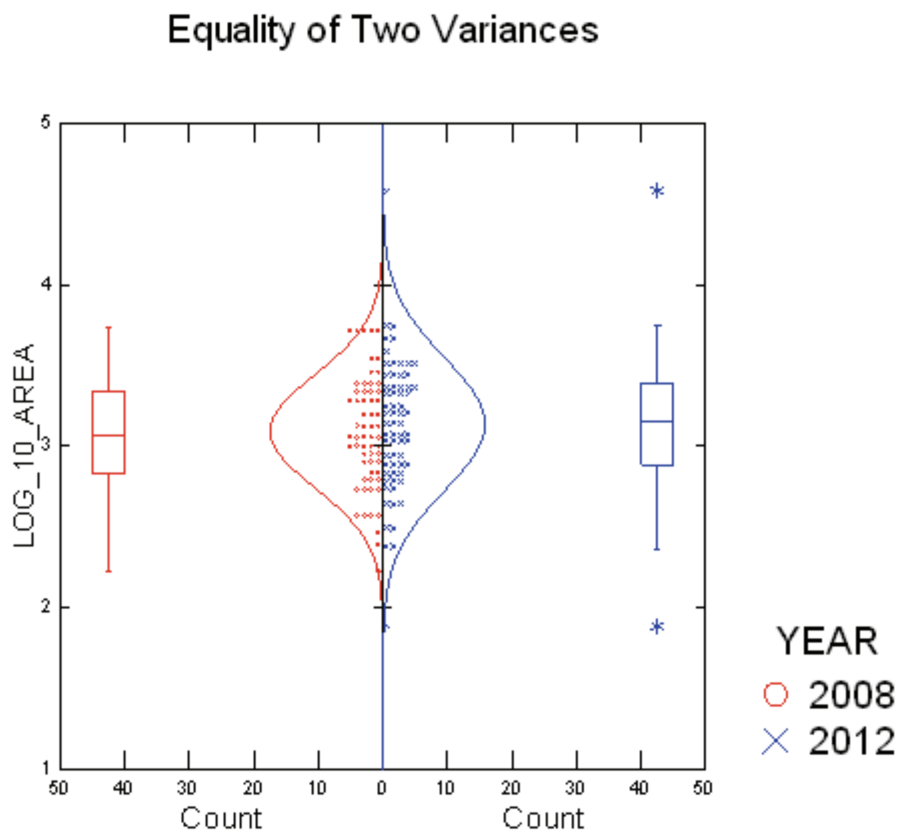


Results for CODE_TEXT$ = pool

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	61	3.0933179	0.1211807
2012	65	3.1371786	0.1683339

95.00% Confidence Interval : 0.4363487 to 1.1925593
F-ratio : 0.7198831
df : 60, 64
p-value : 0.2004656

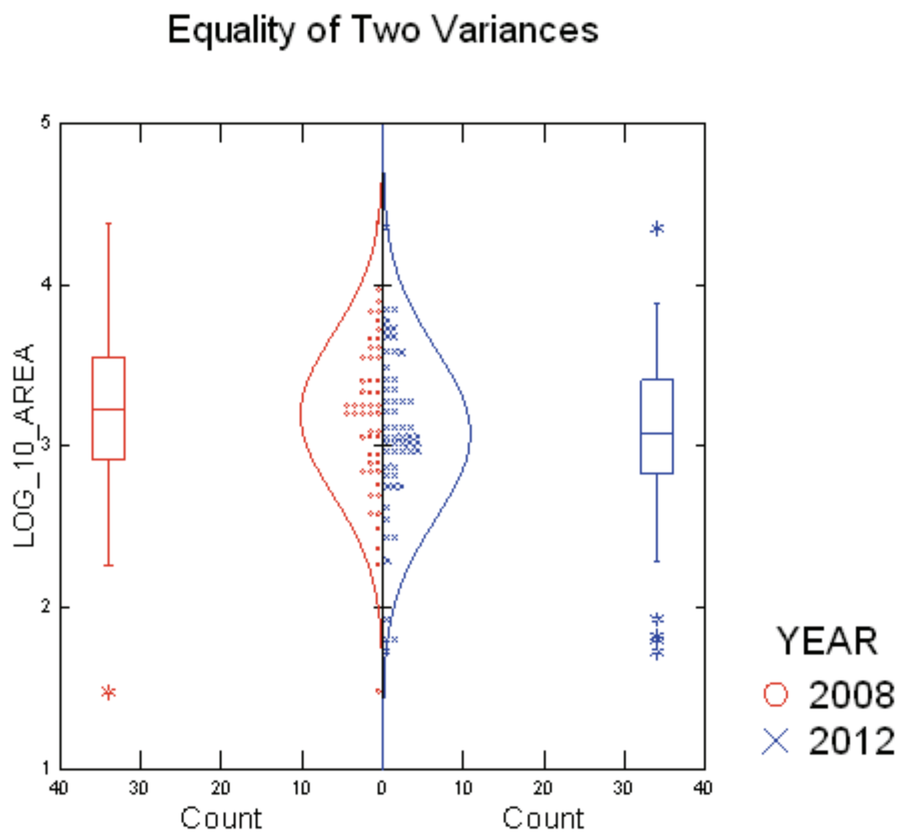


Results for CODE_TEXT$ = rapid

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	51	3.1959352	0.2496013
2012	57	3.0768807	0.2758922

95.00% Confidence Interval : 0.5267235 to 1.5671984
F-ratio : 0.9047061
df : 50, 56
p-value : 0.7213820

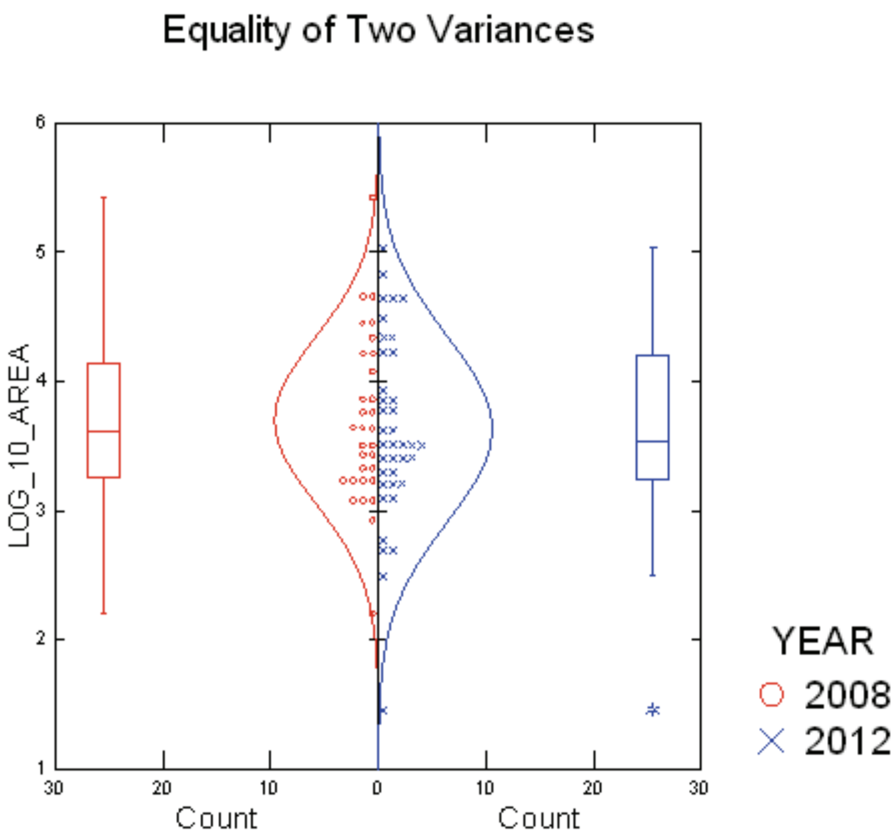


Results for CODE_TEXT$ = riffle

Two-sample Variance Test of LOG_10_AREA Grouped by YEAR vs Alternative = 'not equal'

GROUP	N	Mean	Variance
2008	31	3.7016088	0.4130868
2012	38	3.6330646	0.5156662

95.00% Confidence Interval	:	0.4057192 to 1.6221916
F-ratio	:	0.8010739
df	:	30, 37
p-value	:	0.5363145



> REM -- End of commands from the TOHV2 dialog
> REM -- Following commands were produced by the TOHT2 dialog:
> REM TESTING
*> TTEST LOG_10_AREA * YEAR*