ECOGEOMORPHOLOGY OF THE CHILKO AND CHILCOTIN RIVERS, BRITISH COLUMBIA, CANADA

Joshua M. Garber[1]
Jacob Montgomery[2]
Joy Cookingham[3]
Eva Bush[2]
Nicholas Corline[4]
Conor Hoff[2]
Jacob Selander[1]
Brett Winters[5]
Lauren Austin[1]
Denisse Jauregui[2]
Nathan Burley[6]

[1]Department of Geology, University of California, Davis
[2]Department of Wildlife, Fish, and Conservation Biology, University of California, Davis
[3]Department of Land, Air, and Water Resources, University of California, Davis
[4]Environmental and Resource Sciences, Department of Land, Air, and Water Resources, University of California, Davis
[5]Department of Environmental Toxicology, University of California, Davis
[6]Civil and Environmental Engineering, University of California, Davis

INTRODUCTION

During the Spring Quarter of 2011, the UC Davis Ecogeomorphology class (GEL 136) studied the Chilko-Chilcotin watershed of British Columbia (see papers on this website). In late August and early September of 2011, the class visited the watershed to conduct a reconnaissance field study of the ecology and geomorphology of the Chilko and Chilcotin Rivers. This report is a summary of the key findings of this field study.

The Chilko and Chilcotin Rivers are tributary to the Fraser River, which is the largest watershed of the Coast Mountains and Interior Plateau of British Columbia. The Fraser and its tributaries form an important biological corridor for a variety of aquatic and terrestrial organisms, including the largest sockeye run of any river in North America (Northcote and Larkin, 1989). The hydrology of the Chilko-Chilcotin River system is dominated by two large glacial lakes: Chilko Lake and Taseko Lake. Below these lakes, the rivers alternate between entrenched, bedrock channels and wandering, gravel-bed channels (e.g. Church and Rice, 2009) with mid-channel islands and forested floodplains.

Given the rivers' importance for salmonids, other aquatic fauna, and a variety of terrestrial species, we undertook a reconnaissance study of numerous islands and confluences along the Chilko and Chilcotin Rivers with the aim of (1) characterizing the physical and geomophological dynamics of this wandering gravel-bed river reach and (2) identifying the sources and location of riverine and riparian biological productivity. Based on our earlier work (reported on this website) we focused our analysis on the alluvial river segments and confluences.

Within the wandering, gravel-bed segments we identified two major types of islands: *constructive*, mid-channel islands that form by the accumulation of woody debris and sediment along a gravel bar, followed by vegetative colonization, and *destructive*, marginal islands that have been isolated from a mature floodplain by the development and incision of cutoff channels. The classification of these islands is based on the processes that dominate their formation. Biologically, constructive islands are characterized by successionally younger and more variable vegetation communities and higher physical complexity of aquatic habitats, including backwaters, eddies, and riffles. In contrast, destructive islands are characterized by more mature vegetation communities and less complex aquatic habitats with higher-velocity flows. As such, we found differences in fish, invertebrate, avian, and mammalian diversity, abundances, and habitat use on each type of island.

We recognize that distinctions between the two types of islands are often blurred, but differences in their geomorphology and associated biological productivity argue for our first-order clarification.

Most previous work on the Chilko-Chilcotin system has focused on the importance of the large headwater lakes as a source of biological productivity (especially salmonid productivity). While these are important, our work suggests that the physical complexity created by island formation (and degradation) within the alluvial segments of the Chilko-Chilcotin Rivers plays an underappreciated role in supporting aquatic and riparian diversity and productivity within the watershed.

METHODS

Geomorphic sketch maps were developed for each island using a laser range finder to approximate distances and a Brunton compass to take bearings. Successional classes of vegetation were overlaid on geomorphic maps. Plant species were noted as present or absent at various stages of succession on islands and river confluences. Surveys of the biotic life surrounding the island were indicated on island sketch maps (reference geomorphology appendix). Sketches of the islands were used to determine spatial patterns between the geomorphology of the island and the biotic life.

Fish surveys were conducted in a variety of habitats surrounding both destructive and constructive islands in order to compare differences in species composition and abundance. Fish observations were made using seines and hook-and-line sampling. A 30-foot seine was used to sample backwater and overflow channel habitats. A 10-foot seine was used to sample riffles, pools, and other areas unsuitable for the 30-foot seine. The 10-foot seine also had a smaller mesh size than the 30-foot seine and hence samples smaller fish more accurately. Hook-and-line sampling was used in overflow channels and in areas with large debris where any seining would have been ineffective. Hook-and-line data was assembled into a catch-per-unit-effort (CPUE) index, which shows the effectiveness of the multiple anglers and various methods used.

Macroinvertebrates were surveyed using a three kick composite sample at each sample site. A D-net was placed down stream of the sample area (approximately 930 cm^2), where substrate and plant material was disturbed for 1 minute with foot or hand to remove macroinvertebrates. The sample was then placed into a tray where invertebrates were removed at a constant rate for 15 minutes. Invertebrates were sorted to family and placed in ice cube tray wells. Family designation was confirmed by use of pictorial keys from Aquatic Invertebrates of Alberta online Textbook (http://sunsite.ualberta.ca/Projects/Aquatic_Invertebrates/index.php). Invertebrates were then counted, recorded, and released back into the stream. Whenever possible riffle habitat at the top of the island was sampled as this habitat often has the highest abundance of aquatic macroinvertebrates. When riffles were absent or inaccessible edge habitat along the island was sampled.

Evidence of wildlife was observed as the rafts approached the island and before other surveys were conducted in order to ensure evidence was not destroyed by other surveying activities. Survey of wildlife included visible identification of present species on the island, and through indirect evidence of wildlife activity such as prints, scat, or evidence of feeding activity.

Water Quality parameters were measured in the mainstem of the river and in the backwaters of all islands. Samples were also taken of water from incoming tributaries (Big Creek and Chilcotin) and at the confluence of the two rivers meeting. A multimeter was used in the field to measure dissolved oxygen, electric conductivity, and temperature. Water samples were taken back to the lab to measure turbidity, pH, and total nitrogen and phosphorus. Samples were stored in a cooler prior to laboratory analysis.

OBSERVATIONS/DATA

CONSTRUCTIVE ISLANDS

Physical and Vegetative Characteristics of Constructive Islands (*Type I*): (see Figure 1 and 2). These islands are formed in the main river channel through the accumulation of mid-stream sediment, large woody debris (LWD), and growth of early successional vegetation. Their formation eventually results in the shrinking of channel width and potential extension of the floodplain. Constructive islands have three stages of early successional vegetation: young vegetation reaching less than a meter in height, mid-sized vegetation growing 1 to 3 m in height, and mature vegetation with plant species reaching their maximum height (>3 m).

Stage I: Island Formation. A number of factors must be present in order for island formation to occur. The sediment input or supply to the stream must be greater than the stream's transport capacity; gradient must be low enough to allow for sediment deposition in low-velocity zones within the channel; and there must be sufficient addition of LWD to the system to promote the further development of low-velocity depositional areas. These factors are mediated by the flow regime of the river: high precipitation and corresponding flood events are required to recruit both sediment and LWD, followed by a reduction in flow that facilitates their deposition. The physical response of the river is to develop shallow separation bars that are dominated by medium pebble to small cobble-sized sediment that is imbricated in a general downstream direction. These gravel bars are then responsible for accumulating longitudinally-oriented LWD with roots that point upstream, which in turn traps additional LWD (of varying orientations) and further diverts the channel around the separation bar.

As the gravel bar continues to grow, lateral and longitudinal "levees," or gently-humped overbank deposits, allow finer-grained sediment (as small as fine sand) to wash over the edges and deposit on top of the island. At the same time, coarser sediment continues to be deposited on the lateral and downstream edges of the island, resulting in downstream growth and the development of minor topographic variation (which eventually peaks above the water level).

Vegetation begins to colonize exposed fine sediments and LWD jams shortly after their formation, playing an important role in the further development and stabilization of constructive river islands. The plant species that colonize newly established constructive islands are known as pioneer species; they have unique life history traits that allow them to succeed in an environment with limited or no soil development, limited nutrient availability, and high occurrence of hydrological disturbances. (See Cookingham, this website, for further details.)

The species that colonize any given island(s) vary depending on substrate. Stika Alder (*Alnus sinuata).* and Pacific Willow (*Salix lucida)* are found throughout the island; however, LWD jams were exclusively colonized by only *Salix spp.* and

Alnus spp., with Black Cottonwood (*Populus trichocarpa*) increasing in abundance directly behind LWD jams. These species are able to take root in small amounts of fine sediments trapped within and behind the debris jam or take root directly on the decomposing woody debris. Small cobbles are also colonized by American milk vetch (*Astragalus americanus*), a symbiotic nitrogen fixing plant. Finer sediments are colonized by grasses, sedges, and wildflowers (e.g., daisy, asters, and rose hips).

Vegetation plays an important role in the continued construction and stability of river islands through increasing organic matter accumulation and nutrient pools. Organic matter increases either through litter production or root turnover. Roots act to trap sediments, stabilize cobbles, and protect the island from increased erosion during higher-water flows. These early plants also create flow separation and further sediment deposition, encouraging additional willow to colonize in a downstream direction. Pioneer species that are symbiotic nitrogen fixing plants play an especially important role in the early stages of succession. *Alnus spp.* and *Astragalus spp.* are two of the symbiotic nitrogen-fixing plants that are able to convert gaseous nitrogen in the atmosphere into bio-reactive forms of nitrogen (ammonium, NH_4). This increases the stock of nutrients in the island system allowing for increased plant growth and colonization by other species of plants. These feedbacks result in early successional species reaching the mid-size class of greater than 1m but less than 3m. Mid-successional stage includes greater species richness (Appendix Vegetation).

Stage II: Island Maturation and Connectivity. The increasing influence and build-up of LWD creates three important feedback systems that extend the island in both upstream and downstream directions. First, the development of hydraulics upstream of LWD agglomerations creates new separation bars and further accumulation of LWD. At the same time, the slowing of water around LWD piles creates downstream eddies that allow deposition of fine sand and mud in areas of lower current velocity. Finally, further accumulation of LWD also acts to increase the lateral size of the islands.

As these feedbacks develop, multiple islands begin to connect as they grow downstream, separated by diagonal, gravel-lined "overflow channels" that contain quieter, slower-moving water relative to the main channel. The relatively calm waters and growth of vegetation (specifically *Salix spp.* and *Alnus spp.*) along the channels results in the trapping of finer sediment, which decreases channel width. Eventually, these channels become cut off by LWD accumulation at the upstream end and thus smaller islands converge to form a larger island. Even after final cut-off, overflow channels are likely exploited during high-flow events and thus may contribute to the long-term stability of larger islands.

On parts of the island that have higher topographic relief, finer sediments and organic material accumulate leading to the vertical growth of the island. Soil pits on constructive islands show the development of sandy soils with well-mixed organic matter accumulation. These higher topographic sections of the island have mature, early successional species that have reached their maximum height. *Salix* reaches 10 m in height while *Alnus spp.* reach 6m in height. In the mature stages of early succession, *Populus trichocarpa* seedlings increase in abundance and size (>3m). Understory species are listed in Appendix Vegetation. These older parts of the island are often marked by LWD piles that are stranded above the water surface (usually no more than a few feet).

Finally, continued gravel accumulation and lateral growth of these islands allows clear delineation of a main channel and single narrower side channel; constructive islands of this stage were rarely observed to equally divide the river channel. Vegetation reaches a late successional stage with canopy being dominated by mature *Populus trichocarpa* and conifers.

Stage III: Extension of Island and Connection with Floodplain. At this point in island development, many generations of overflow channels have been abandoned and can easily be identified on the island surface, and the mature island may represent the agglomeration of a significant number of smaller islands. It may be stressed again, however, that the development of a single island may precipitate the development of other islands upstream or downstream by changes in the hydrology of the river channel. Thus, multiple connected islands may in fact be genetically related (in a physical rather than biological sense).

Continued soil development and vertical accumulation of organic material result in the development of late successional plant communities on highest parts of the island, while early and mid-successional vegetation continue to colonize the either newer, or more frequently disturbed areas of the island that are closest to the water surface. Late successional plant communities begin to shift from plant community composition being dominated by pioneer species such as *Salix spp.*, *Alnus spp.*, and *Populus trichocarpa*, and begin to transition to the establishment of conifers. There are longitudinal differences in the type of conifers that establish. Greater moisture content in the upper reaches of the Chilko River favors Lodgepole Pine (*Pinus contorta*), White Spruce (*Picea glauca*), Grand Fir (*Abies grandis*), and Interior Douglas Fir (*Pseudotsuga menziesii var. glauca*). In the drier, lower reaches of the CCR, *Pseudotsuga spp.* is the dominant conifer.

Though some islands will inevitably remain stable for long periods of time, lateral accretion and continued island growth into the side channel may eventually create an unsustainably narrow channel. At this point, LWD from either the adjoining floodplain or from upstream blocks this channel, and the island connects with the floodplain. Further development of the island as a distinct unit ceases, and the island eventually becomes indistinguishable from the floodplain.

Insect Use of Constructive Islands. Aquatic macroinvertebrates were sampled from side channel habitats along several constructive islands. Standard aquatic invertebrate metrics were calculated and included: percent Ephemeroptera, Plecoptera, and Trichoptera (EPT), Taxa Richness (number of families observed), Simpsons Index of Diversity, and percent Functional Feeding Group (FFG). Results are reported in Table 1 and Figures 4-6.

Fish Use of Constructive Islands. Habitat use by fishes on the constructive islands was fairly consistent throughout the CCR system. In general there were four types of habitats associated with the constructive, mid-channel islands: overflow channel, backwater, riffle and eddy. Water velocities were slower in the backwater habitats, faster in the riffle and eddy habitats, and fastest in the overflow channel. Depth was shallowest in the riffles, deeper in backwater and eddy habitats, and deepest in the overflow channel. Figure 2 shows general locations of fishes in these aquatic habitats around constructive islands.

Overflow channels adjacent to the eddy habitats contained the largest fish we observed near the islands [mature rainbow trout (*Oncorhynchus mykiss)* and bull trout (*Salvelinus confluentus*)]. These fishes are very strong swimmers and have no problem maintaining their position in the current; they are likely strategically positioned to feed on small fishes that stray from the safety of the backwaters, riffles, and eddies.

Backwater habitats contained the highest abundance of the smallest salmonids we observed [juvenile *O. mykiss*, sockeye salmon (*O. nerka*), and small mountain whitefish (*Prosopium williamsoni*)]. These areas have very little water movement and generally muddy/sandy substrate and frequently contained woody debris and some macrophyte vegetation. These elements of structure provide further cover for the fishes and more places for aquatic insects and zooplankton to congregate. It is likely that the juvenile *P. williamsoni* and rainbow use these habitats as rearing grounds, resting areas from higher-velocity environments, and as shelter from larger fish. *O. nerka* use these habitats as resting areas during their downstream migration and likely feed there too before moving on downstream.

Eddies contained the strongest swimmers of the juvenile salmonids [chinook (*O. tshawytscha)* and larger *P. williamsoni*]. These fish were larger, on average, and likely took advantage of their swimming ability to feed on drift at the borders of eddies and to escape the larger predatory fishes in the overflow channels. Riffles contained abundant longnose dace (*Rhinichthys cataractae)* and a variety of salmonids (*O. mykiss* and *O. tshawytscha*) depending on the depth of the water. The salmonids maintained their positions in the deepest parts of riffles and in areas where there were remnants of vegetation (many of the riffles cut right through the middle of these islands). *R. cataractae* were abundant in all the shallow riffle habitats, likely taking shelter from the fastest water under rocks and feeding on drift.

Terrestrial Mammal and Avian Use of Constructive Islands.

Stage I: The open area on this type of island lends itself to use by a variety of mammal and avian species. The fine sediment deposited on the backwater channel behind LWD gives shorebirds easy access to foraging as the water slows down, making both juvenile fish and aquatic invertebrates easier to find. These slower-flowing channels are used by Spotted Sandpiper (*Actitis macularia*), Great Blue Heron (*Ardea herodias*) and Common Merganser (*Mergus merganser*). The river channel side of Site #5 was used as a nesting site for an unknown species of duck, the nests of which were made from the American Milk Vetch (*Astragalus americanus*) which occupies much of the island's interior. Bald eagles were seen using the edges of both sides of the islands.

Based on observed tracks, the channel sides of the islands were used by black bear (*Ursus americanus*), deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), river otter (*Lontra canadensis*) and beaver (*Castor canadensis*). At Site #4, tracks from black bear, elk and both adult and juvenile deer were found crossing the channel on approximately the same path. The slower-velocity backwater channel is clearly the natural crossing from the floodplain to the island. Additionally, the backwater channel provides excellent foraging grounds for nocturnal and crepuscular mammals such as river otters.

Stage II. Increased riparian vegetation on this type island lends itself to increased use by smaller riparian bird species as a nesting habitat. Two small empty nests were found in the upstream vegetation on Site #6. Deer beds were discovered in the same area, with nearby tracks from an adult and juvenile deer; the tracks were adjacent to each other, and thus presumably from a doe and her fawn. The only predator tracks found on this island were from the red fox (*Vulpes vulpes).* These tracks were observed around the overflow channel separating the island's upper and lower sections. This island was also the only one with moose tracks present.

Stage III. Signs of heavy beaver use (bordering on overuse) were present on the most mature constructional island. Several large trees had been cut down and blocked part of the backwater channel, but some had also been felled into the main channel and had their branches sheared off for foraging. Additionally, bear tracks were found along the backwater channel. River otter were also seen at the upstream tip close to the beaver tracks and LWD pile, perhaps suggesting a shared beaver-otter den. Red fox and coyote tracks were likewise found at the upstream tip. Finally, the open inland section of the island was heavily used by goose, which was noted based on abundant scat.

DESTRUCTIVE ISLANDS

Physical and Vegetative Characteristics of Destructive Islands (*Type II*) (see figure 3): These islands are restricted to the upper part of the Chilko River between Chilko Lake and Lava Canyon. They are formed by the isolation and eventual destruction of a well-established floodplain, and are responsible for the widening of the main channel of the Chilko River. They can be clearly distinguished from constructive islands by the development of cut banks on all edges, late successional plant communities across the entire island (with the exception of island edges), and a mature soil profile that includes an anoxic, organic-rich peat layer.

Stage I: Isolation and Formation of Island from the Floodplain. Unlike in the case of Type I (constructive) islands, we did not observe the initial formation of Type II islands, but we speculate that these islands are created in high flow events, given their near congruence with the adjoining floodplain. We present a few options for their formation:

- Prior channels or depressions, perhaps inherited from Type I island formation (i.e., overflow "paleo-channels"), are exploited by single or multiple high flow events and are eroded to create a small side channel (or "cutoff channel") between the island and the adjoining floodplain. We observed a number of small indentations into the floodplain that could represent the beginning stages of this process.
- Coarse cobbles or boulders smash into the floodplain during high flow events and excavate a small section of the floodplain that is converted into a side channel.

- Groundwater flows may excavate organic material from the soil that is not being actively stabilized by root balls of larger trees (see below) and cause collapse pits. These pits are then excavated during high flows to create a side channel.

Once the island is formed, the accumulation of LWD on the upstream end of the island causes some accumulation of gravel and slows water in the cutoff channel relative to the main channel, which provides an important habitat.

Stage II: Destruction of Island. Erosion of cut banks on all sides results in the reduction of island size. Along the edges, mature conifer species are replaced by species that can tolerate exposure to fast-flowing water and frequently inundated soils. The extent of the late successional conifer species on the island continues to shrink with time, and conifers become increasingly isolated to the middle of the island. The observation of "collapse pits" on the downstream ends of these islands suggests the excavation of organic material by both rising hyporheic groundwater flow and high river flow events, and causes the downstream reclamation of the island by the main channel. As multiple high flow events proceed, the same process that creates the island causes its instability, and the river eventually reclaims it.

Insect Use of Destructive Islands. See Table 1 and Figures 4-6 for a summary of data.

Fish Use of Destructive Islands. We observed four species of fish on destructive islands: coho (*O. kisutch)*, *O. nerka*, *P. williamsoni*, and *R. cataractae*. Only *O. kisutch* and *P. williamsoni* were found at site 1. *O. kisutch* were most abundant (84%) and larger (61mm) than *P. williamsoni* (56mm) at site 1. All of these fish were caught in the one major backwater at the downstream end of the island. The seine was ineffective for catching fish among the shoals of the island at site 2. The banks of the island at site 2 were steep, the adjacent water velocity was fast, and where the water was slow there was abundant woody debris. We were able to sample fish from the riverbank directly across from the island in site 2 which had very similar conditions to the banks of the island. We assume that fish found at this site are equally likely to be found in the shoals along the banks of the island at site 2. *O. nerka* were must abundant at site 2 (50%), followed by *P. williamsoni* (36%), *R. cataractae* (9%), and finally *O. kisutch* (5%). *O. kisutch* were the largest (53mm), followed by *P. williamsoni* (47mm), *O. nerka* (41mm), and *R. cataractae* (37.5mm). All of these fish were caught among grassy shoals.

Terrestrial Mammal and Avian Use of Destructive Islands.

Stage I: At this point in the development of destructive islands, its limited separation from the floodplain is not significant enough to impede the continued use of the area by terrestrial organisms. At the earliest separation from the floodplain, flows may be too high for smaller terrestrial wildlife to cross the cutoff channel, but as flows recede, the short separation distance would probably not limit terrestrial use of the island. Based on the observed use of channels on the constructive islands, we speculate that the cutoff channel would be used as a drinking and foraging area both by mammals and avian species, especially during lower flows.

Stage II: This island stage showed limited terrestrial use. Riparian birds were present on both sides of the channel; however, this is not unexpected as their crossing does not require significant energy expenditure or hazard.

Rodent burrows were present in the center of the island, especially at the base of mature deciduous and coniferous trees. Neat piles of salmonid bones, identified by their jaws and teeth, were seen at peripheral edges of the islands. Each pile contained the bones from up to five salmonids. Some piles were on the edge of the island facing the main channel; these piles were next to burrows in soft soil along the river bank, under the roots of mature cottonwood trees, and were presumably made by the northern river otter (*Lontra canadensis*).

We observed moose scat along the overflow channel side of the island. Along the same edge, bones from a larger ungulate were found. These may have resulted from a death on the island or have been carried from upstream and eventually deposited in the LWD pile at the upper tip of the island.

WATER QUALITY

The physical properties of the water are vital to organisms throughout the Chilko-Chilcotin River system. While pH, turbidity, water temperature and available nutrients (nitrogen and phosphorus) are vital to the invertebrates and the resident and anadromous fish, there did not seem to be any significant differences in water surrounding either the constructive or destructive islands. While water temperature increased slightly (typically less than 1° C) in the slower moving backwater and overflow channels, it is unlikely that the temperature difference explicitly caused any terrestrial or aquatic ecological variations. When water temperature remains below 13° C, as it did throughout the river system, it is not likely to be a significant factor influencing salmonid habitat preference.

Dissolved oxygen, which is mostly determined by water temperature, organism activity (respiration), and aeration, did not vary significantly between the main channel and the backwater habitats of the islands. The trivial variance is probably due to the slightly increased temperature of the backwater. However, water from both locations showed near complete saturation at their respective temperatures. Both the backwater channel and main channel of each type of island had sufficient water temperature, dissolved oxygen and pH to support abundant aquatic insect and fish life.

pH remained relatively consistent throughout the Chilko-Chilcotin River system. The pH also remained constant in both the fast-moving main channel of the slower-moving waters of the river.

CONFLUENCES

In addition to the survey of various islands, we surveyed the two major confluences along this river system: the confluence of the Chilcotin and Chilko Rivers, and the confluence of the Chilcotin and Fraser Rivers. The data and observations that were made at these locations are not part of the same geomorphic story as the islands, and therefore we have chosen not to discuss them in this paper. However, the data from these confluences are available in Appendix Confluence if further information is desired.

DISCUSSION

Constructional vs. Destructional Islands, Causes of Their Formation, and Island Stability. As noted above, Type I (constructional) islands were noted along the entire stretch of the Chilko and Chilcotin Rivers, while the Type II (destructional) islands were only noted in a small area from Chilko Lake to Lava Canyon. We interpret the cause of these differences as a function of changes in the factors that affect their formation. We posit that constructional islands are most affected by changes in streampower, through alternations in gradient, sediment supply, and channel width, thus representing *long-term* changes in the capacity of the river to transport sediment and LWD. On the other hand, the location of destructional islands strongly suggests the strong influence of seasonal high-flow pulses from Chilko Lake, which are predictable from year to year. Therefore, we expect destructional island formation to result from *short-term* river variability. Since these short-term high-flow pulses are mediated and accommodated by floodplains, they only appear in the upstream end of the river that is most affected by these floods.

However, the stability and time-scale of both types of islands is unclear. Most islands were shown on maps based on aerial photos dating back to 1977, so both islands types are clearly stable for more than thirty years; this is supported by a recent study along a downstream stretch of the Fraser River that suggested a 100-year stability for gravel bars (Church and Rice, 2009). However, unreported destructional and constructional islands were spotted, and some constructional islands shown on the maps were not seen, suggesting that the most important process for both types of island formation relates to high-flow pulses rather than long-term adjustments to streampower. Beyond this, any discussion of island stability time-scales would be purely speculative.

Recruitment of LWD, Longitudinal Variations, and Implications for Island Formation. The Chilko-Chilcotin system is unique from other rivers that also form river islands due to its large influx of LWD from the terrestrial landscape. LWD acts to increase the size of river islands, aid in the establishment of vegetation, and potentially increase the islands' long-term stability.

Importantly, there are notable longitudinal variations in the LWD inputs and mechanisms by which coarse woody debris (CWD) on hillslopes is transported to the river. In the upper reaches of the Chilko River, the terrestrial landscape is composed of Lodgepole Pine (*Pinus contorta*), White Spruce (*Picea glauca*), Grand Fir (*Abies grandis*), Ponderosa Pine (*Pinus ponderosa*), and Interior Douglas Fir (*Pseudotsuga menziesii var. glauca*). The forests are predominantly composed of single-species, even-aged stands of *Pinus contorta* due to the frequent fire history in the region. The natural regime of the mountain pine beetle (MPB) and fire, combined with steep slopes directly adjacent to the river, have all potentially led to a historically high recruitment of LWD to this river system. In recent years (ten-year timescale), the epidemic levels of MPB outbreak combined with frequent intense fires have decimated large stretches of the forests adjacent to the Chilko River and has led to increased production of LWD. Heavy rainfalls after an intense fire contribute to soil erosion and provide another mechanism by which LWD are physically transported from the steep hillslopes into the river.

Downstream, the following conditions result in less LWD input from the terrestrial landscape:

- forest community composition shifting to Douglas fir, a species that resists damage from fire and experiences less frequent fire regimes
- increased orographic effect resulting in more sparse vegetation
- topographic changes and less dramatic slopes adjacent to the river except for basalt outcrops, which support limited amounts of vegetation if any.

LWD inputs downstream are a combination of debris input carried by heavy flows from upper reaches, and riparian species from bank erosion. The main floodplain species that accumulated in island LWD piles was large cottonwoods (up to one meter in diameter) that either entered the river either by bank erosion, old age, or beaver activity.

Insect Variation and Trends in Constructional and Destructional Islands. Our observations show insect trends and differences between constructive and destructive islands, and between constructive island stages. Of the calculated metrics, only the Ephemeroptera, Plecoptera, and Trichoptera (EPT) index did not yield any conclusive trends and was variable between all island types. However, one of the destructive islands sampled had the lowest EPT value of all islands sampled (see Table 1). This may result from increased erosion on destructive islands, leading to higher sediment loads than for constructive islands, decreasing the abundance of gill breathers.

Scrapers and shredders were not observed on all destructive islands or were only observed at low abundances (see Table 1). Scrapers may have not been present or had low abundance due to the steep margins (less edge habitat) and shading created by mature trees. Both steep margins and mature trees would decrease biofilm production, which is the main food source for scraping insects. However, the absence of shredders is counter-intuitive, as destructive islands often have mature foliage that provides coarse particulate organic matter (CPOM), the main food source for shredding invertebrates. The lack of shredders may be due to the high velocity of the side channels within the destructive islands; the high water velocity may not allow CPOM to be retained in the substrate.

For constructional islands, taxa richness, diversity, and functional feeding groups (FFG) showed trends with respect to island maturity. In general, more mature constructional islands had higher taxa richness and diversity (Figure 5 and 6). This may be due to increased habitat diversity in the later stages of island development: initially the substrate is dominated by cobbles, but substrates become more varied with age, incorporating patches of mud, sand, gravels, and cobbles. These changes in substrate may drive changes in FFG proportions, and the increase in habitat complexity creates more microhabitats that different aquatic invertebrates can utilize. Additionally, more edge habitat is created as the islands mature, which may also explain the increasing trend in richness and diversity with island maturity. Together, the processes that create a greater amount of available habitat on constructional islands could decrease the amount of competition between invertebrates for space and food resources.

Scraping invertebrates decrease in abundance with island age (Figure 4). Early stage islands have many cobbles and little shading, creating favorable conditions for periphyton growth. However, progressive changes in substrate and stream cover may decrease the production of periphyton and lead to the observed decrease in scraping invertebrate taxa.

Fish Habitat Complexity and the Relationship of Islands to Sockeye Salmon. The islands of the Chilko-Chilcotin River system are a major source of aquatic habitat complexity, contributing to the high levels of salmonid productivity present in the system. Islands break up the open water and large hydraulics of the main channel into microhabitats with slower-moving water with sufficient structure to give shelter to juvenile fishes. Similar microhabitats exist along the margins of the main channel, but we speculate that they are more concentrated and more abundant around the islands. Additionally, the islands are most available to out-migrating salmon during periods of decreasing flow. This tends to happen in the late summer or early fall, which corresponds to the timing of juvenile salmonid out-migrations.

The habitats created by the islands function as rearing grounds for resident juvenile fishes (*P. williamsoni*, *O. mykiss*, *R. cataractae*), out-migrant rest stops for juvenile anadromous salmonids (*O. tshawytscha*, *O. kisutch*, *O. nerka*), feeding lanes for piscivorous fishes (adult *S. confluentus* and *O. mykiss*), and probably many more functions as well. Larger size was correlated with downstream location of observation of three fish species (*P.williamsoni, O. nerka*, and *O. tshawytscha*, one a resident, the other two anadromous) that were ubiquitous throughout the entire CCR system (figure 7). Presumably these fish are larger because they are older and have already taken advantage of feeding and resting opportunities among the habitats associated with islands along their downstream migration. The fish fauna likely do not associate these habitats with islands, as they simply reside wherever. The fish fauna likely do not associate these habitats with islands, as they simply reside wherever their needs are met, but the islands provide necessary habitat complexity when compared with the mainstem river. The distribution of these juvenile refugees may also aid in their avoidance of predators.

The islands, in addition to Chilko Lake, are key resources that supply the unique *O. nerka* population of the CCR system. While the headwater lake is required for successful spawning and rearing, the islands provide breaks in the main flow of the channel which adult salmon take advantage of in their spawning migrations. The islands also provide shallow, sheltered habitat at which juvenile *O. nerka* rest and feed along their out-migration. These stops allow the juvenile *O. nerka* to grow larger before entering the ocean, presumably increasing their survival success. Without the islands, we speculate that the CCR system would be far less productive for *O. nerka*, other fishes, and all other organisms that rely on the CCR watershed as a resource.

Water Quality and Physical Properties of the River System. As noted above, there were no significant differences in water surrounding either the constructive or destructive islands. However, significant differences in water quality parameters existed in the Chilcotin and Fraser prior to meeting the Chilko and Chilcotin, respectively. The differences observed in water quality in the Chilcotin (higher total nitrogen and phosphorus, electrical conductivity, and lower turbidity) quickly disappeared once it joined the Chilko River.

The most important aspect of water quality in regards to juvenile salmonids is turbidity. While it is not possible to define a link between turbidity and juvenile salmon survivability with our data, more turbid waters may benefit the salmon by keeping them hidden from predators on their way out to sea. The juvenile salmonids found in turbid waters of the Chilko River after the Taseko confluence were significantly less colorful than the fish found in the clearer upper reaches of the Chilko River. However, more research is needed to determine if the difference in coloration is due to high turbidity or other factors. Surprisingly, the highly turbid waters of the Chilko-Chilcotin below the Taseko River continued to sustain relatively high diversity and abundance of gill breathing insects of Ephemoroptera and Plecoptera orders surrounding constructive islands (see Table 1).

In sum, water quality is a determining factor in the success of both aquatic insects and fishes of the Chilko-Chilcotin River system. However, it appears that the physical aspects of the water do not act specifically on the islands; instead, islands are able to slow the fast-flowing river enough to act as a sanctuary for aquatic organisms.

Terrestrial Wildlife Use of and Effect on the Islands. Ubiquitous beaver activity on surveyed islands suggests they play an important role in continuing island formation and the eventual connection of constructive islands to the floodplain. On two of the four islands surveyed, beavers had felled trees that partially blocked the backwater channel, resulting in an upstream LWD jam. This collected debris creates a possible location for a beaver lodge or river otter den; these two species will occasionally occupy the same lodge. In time, the debris pile will collect sediment and organic matter floating in the river, possibly giving rise to the bog-like areas between the floodplain and islands that were observed at some locations along the river.

Interestingly, the beaver-assisted process of extending islands to the floodplains may cause destruction of their own habitat, as less desirable tree species begin to colonize the newly-formed floodplain. Beavers are known to create habitats no longer suitable for their needs, at which point they relocate better foraging opportunities. The possibility of beaver-aided floodplain formation in the Chilko-Chilcotin River warrants further investigation as more research is conducted in this system.

The consistent use of the islands by deer is interesting given the risk and energetic cost associated with swimming across fast-moving water. This is especially puzzling considering that the deer is crossing this water while pregnant or with a young fawn. It is unlikely this activity is random given only one island surveyed was absent of deer tracks; that island had been taken over by beavers and very few saplings were present. One hypothesis is that the islands provide better foraging opportunities for the deer, since herbaceous plants and saplings are more abundant than in the mature forest along some sections of the river. The islands would also provide a separation from predators common on the floodplain; predator tracks on the islands were only found along the channels and edges, indicating they mainly use the islands to forage for fish.

In a broader sense, the two different types of islands present an interesting cost/benefit scenario for the mammals that take advantage of them. While constructive islands may offer better resources (such as young vegetation) and refuge from predators, there is a significantly higher cost associated with drowning mortality. On the other hand, destructive islands likely offer less attractive resources and predator refuge, but are significantly easier to access.

SUMMARY

Geomorphic and ecological reconnaissance work along mid-channel islands in wandering gravel-bed reaches of the Chilko and Chilcotin Rivers show evidence of two main processes of island formation, with associated variations in biological productivity and terrestrial and aquatic habitat complexity. (1) *Constructive* islands are formed by the interaction of sediment, LWD, and successional plant communities; these factors are responsible for lateral, longitudinal, and vertical island growth. They are strongly influenced by both long-term adjustments to streampower and short-term fluctuations in river flow. Early successional plant species, specifically symbiotic nitrogen fixing plants, produce a positive feedback that allow for increased colonization of newly exposed sections of the island, and continued growth of vegetation via increasing nutrient pools. (2) *Destructive* islands result from the isolation of a small section of mature floodplain, and are dominantly controlled by short-term flow considerations.

The Chilko-Chilcotin River system is unique in regards to the recruitment of LWD into the river system from the adjacent hillslopes. Recent increases in fire severity, outbreak of the mountain pine beetle, and increased precipitation events have allowed for additional mechanisms by which LWD is recruited into the river system. This is further combined with a river that is actively cutting through glacial material, producing steep slopes adjacent to the river that are easily eroded.

While destructive islands showed no definite pattern in invertebrate metrics, diversity, or functional feeding groups, maturing constructive islands progress towards a more diverse invertebrate community. This increase in diversity is most likely a product of increased habitat heterogeneity within the island complex.

Constructive and destructive islands showed similarities in the diversity of fish species, but significant differences in abundance (Figure 8). Constructive islands also had more aquatic habitat variability and complexity. These islands are an important habitat feature for both in-migrating adult sockeye and out-migrating juvenile sockeye. Major differences in fish fauna were observed in night versus day observations, and at the confluence of the Chilcotin and Fraser Rivers.

Terrestrial mammal and avian use of these islands showed a preference for constructive islands by both predators and prey. Mammal activity was also observed to have an important impact on the physical dynamics of island evolution.

Overall, our observations and data clearly elucidate the importance of river islands and the riparian corridor on the biological diversity, complexity, and productivity of the Chilko-Chilcotin River system.

FURTHER RESEARCH

Our reconnaissance field survey has highlighted the need for future research in order to understand the evolution of river islands and their implications on biota in the Chilko-Chilcotin River system. Future work should focus on addressing the temporal and spatial dynamics and mechanisms by which these islands are formed and destroyed. We suggest yearly observations or surveys with corresponding high-resolution flow data for a defined period of time (perhaps a five-year timescale). This could also be achieved through analysis of a time series of aerial photos examining the structural changes in islands over time. Synthetic island creation or destruction experiments could further elucidate the dominant geomorphic processes of island evolution.

In order to more accurately capture the implications of island formation on biota, future work should use more advanced equipment for fish surveys (e.g., an electrofisher) and both night and day time seining in greater locations. These methods would allow more thorough sampling of our sites. Additional qualitative surveying of invertebrate communities would also be useful.

Our preliminary water quality measurements indicated the Chilko-Chilcotin river system is a nitrogen-limited system. This highlights the potential importance of marine derived nutrients (MDN) in the form of spawning fish carcasses, and the input of nitrogen by symbiotic nitrogen-fixing riparian vegetation. We suggest future research should investigate the potential nitrogen contribution of these two different mechanisms and their interactions. We would expect the upstream section of the river to have a greater MDN input, which could potential inhibit the activity of symbiotic N-fixers (such as *Alnus*) or be acting synergistically to increase nitrogen supplies. Manipulation experiments could be conducted to examine these interactions.

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REFERENCES

Clifford, Hugh F. Aquatic Invertebrates of Alberta. The University of Alberta Press: Edmonton, AB. 1991.

Halfpenny, James C. Ph.D. and Telander, Todd. Scats & Tracks of North America. Falcon Guides, Morris Book Publishing: Guilford, CT. 2008

Lloyd, Dennis, Parish, Roberta, and Coupé, Ray. Plants of Southern Interior British Columbia. B.C Ministry of Forests, Lone Pine Publishing: Vancouver, BC.1996.

McPhail, J.D. and Carveth, R. Field Key to the Freshwater Fishes of British Columbia. University of British Columbia: Vancouver, B.C. 1994.

Northcote,T.G. and Larkin,P.A. The Fraser River: A major salmonine production system. In Proceedings of the International Large River Symposium (LARS). Edited by D.P.Dodge. 1989

Reid, Fiona A. Mammals of North America. Peterson Field Guides, Houghton Mifflin Company: New York,NY. 2006.

Sibley, David Allen. The Sibley Field Guide to Birds of Western North America. Alfred A. Knopf, Inc.: New York, NY. 2003.

Stebbins, Robert C. Western Reptiles and Amphibians. Peterson Field Guides, Houghton Mifflin Company: New York, NY 2003.

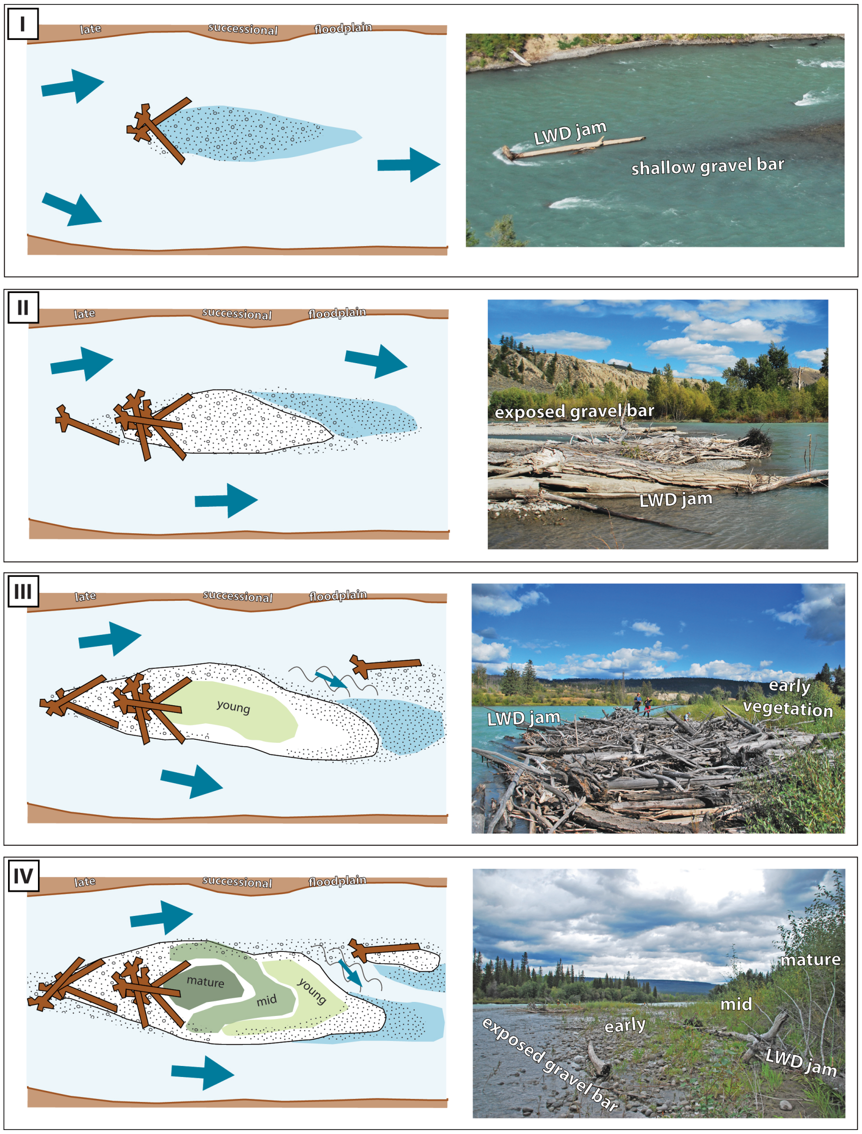

Figure 1. Schematic map-view cartoons and annotated photographs showing the 4-stage evolution of a constructional island. Symbology and coloration is the same as in the previous figure. **(I)** Large woody debris (LWD) input to the system via high flow events or biological activity becomes lodged on shallowly submerged, mid-stream gravel bars, creating a localized zone of lower current velocity and allowing for deposition of material downstream of the LWD jam. **(II)** Further upstream accumulation of LWD leads to downstream growth of the island through enlarging the low velocity/ depositional zone. Decrease in river flow can expose the top of the gravel bar and cause upstream accumulation of additional LWD. **(III)** Young, early-successional vegetation development stabilizes the surface of the island. Lateral, upstream and downstream growth of the island continues via the accretion of LWD and gravel bars. **(IV)** The now stable island surface is flanked by gravels and early to mid-early successional vegetation, while the center of the island hosts mature-early successional vegetation. Vertical growth of the island occurs via soil development and the accumulation of organic material. Low velocity areas of the channel continue to accumulate coarse and fine material along the margins and downstream end of the island.

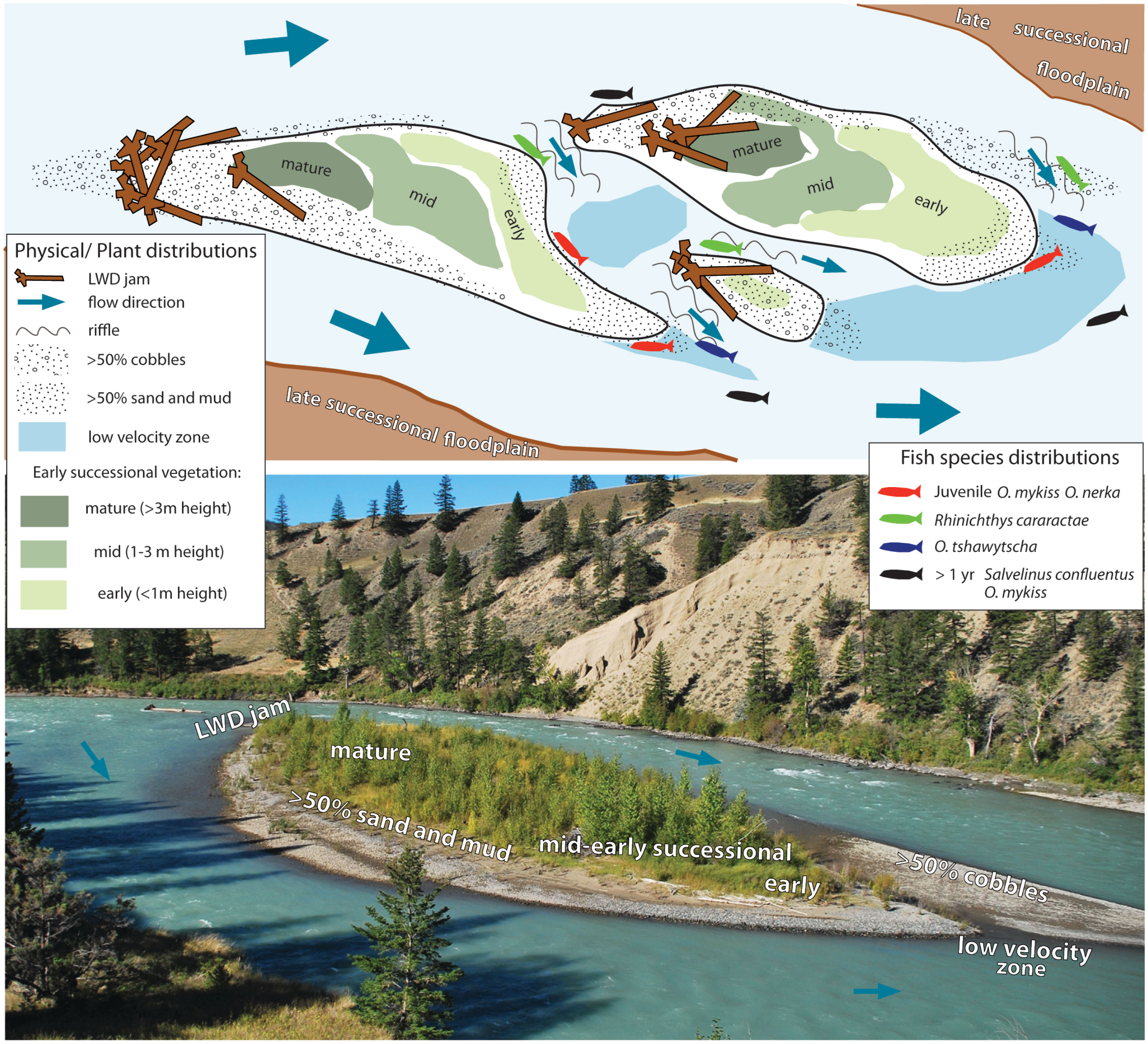

Figure 2. **(Top)** Schematic cartoon of a generic constructional island from the Chilcotin River, containing all the major physical and biological elements noted and surveyed. Upstream ends of the islands are dominated by debris jams and coarse sediment, sediment size and presence of debris decreases downstream. Islands are often split by smaller channels with riffles and low velocity zones. Vegetation is youngest around the island perimeter with early successional vegetation, and increases in age and maturity towards the center or oldest parts of the islands. Vegetation is grouped as follows: Early successional is divided into three groups; *early* (vegetation <1m height), *mid* (vegetation 1-3 m height), and *mature* (vegetation >3m or the greatest extent to which the pioneer species can reach). Late successional represents a transition from pioneer species (willows and alders) to mature cottonwoods (40 m tall) and conifer species. **(Bottom)** Annotated photo of an island upstream of the Chilcotin- Big Creek confluence noting the major physical island elements.

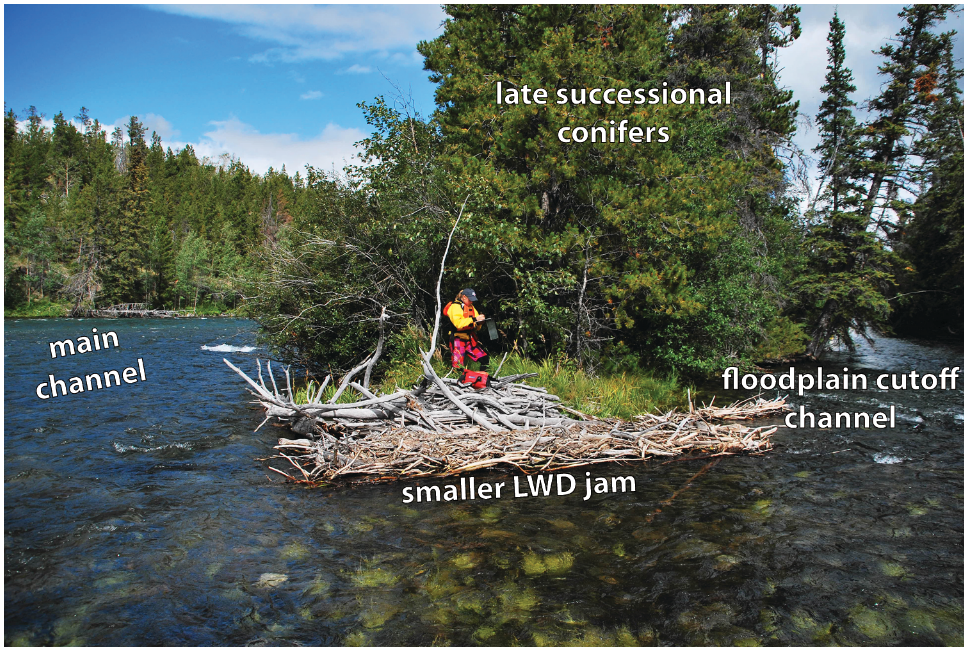

Figure 3. Annotated photo of the upstream end of a destructional island. Since these islands form by isolation of portions of the floodplain by episodic high flow events, the LWD jam at the head of the island is considerably smaller than a constructional island. Vegetation consists of mature late-successional conifers and dense undergrowth. The island is surrounded by fast-moving water, and has a surface elevation similar to that of the adjacent floodplain.

Table 1: Aquatic Insect Metrics per Island Type or Stage.

Island Type	Stage,Site	EPT %	Simpsons Diversity	Taxa Richness	%CG	%CF	%SCR	%SHR	%PRD
Destructive									
	0,1	42.87	0.7	7	51.61	19.35	-	-	29.03
	0,2	66.67	0.853	9	65.68	-	6.63	15.6	6.25
Constructive									
	1,4	60	0.698	5	75	-	21.43	-	3.57
	2/3, 5	57.14	0.698	7	72.72	-	18.18	-	9
	3,6	71.42	0.8	7	60	2.85	17.14	-	20
	3/4,7	62.5	0.749	8	80	10	6.67	-	3.33

EPT = Ephemeroptera, Plecoptera, and Trichoptera ; CG= collector-gatherers; CF = collector-feeders; SCR = scrapers; SHR= shredders; PRD= predators

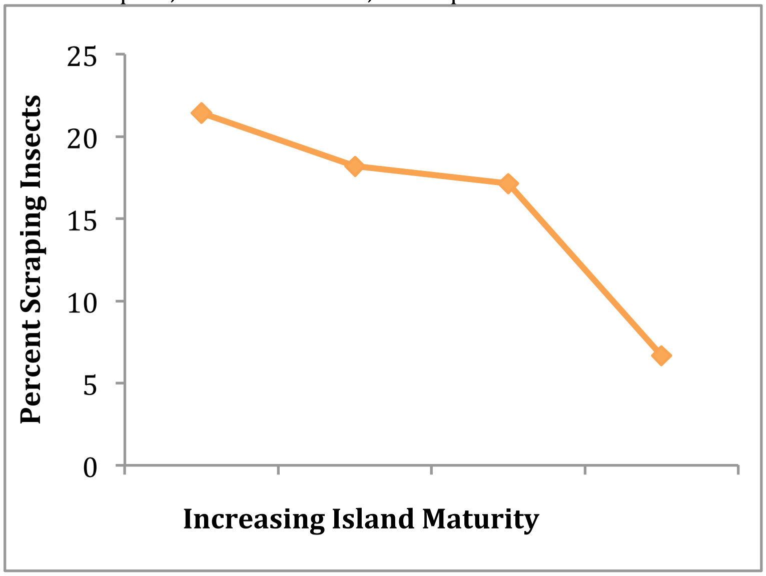

Figure 4: **Change In Scraping Invertebrate Proportions with Constructive Island Age**

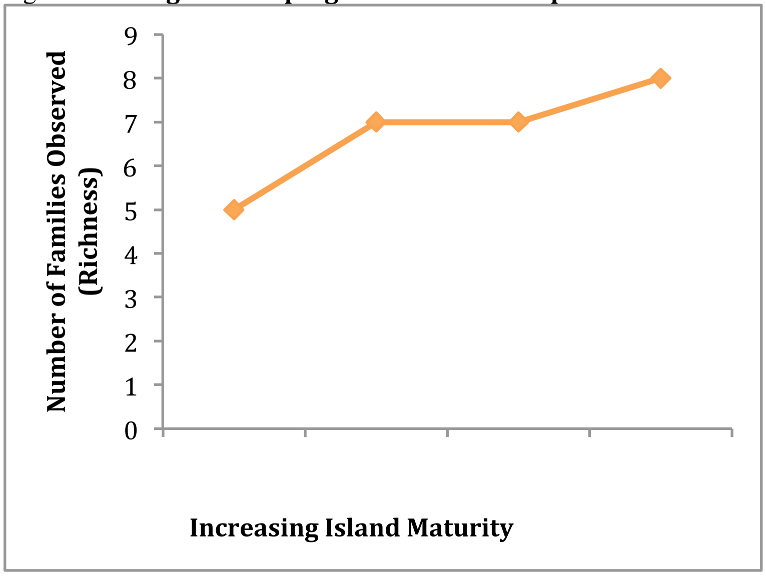

Figure 5: Invertebrate Taxa Richness for Constructive Islands

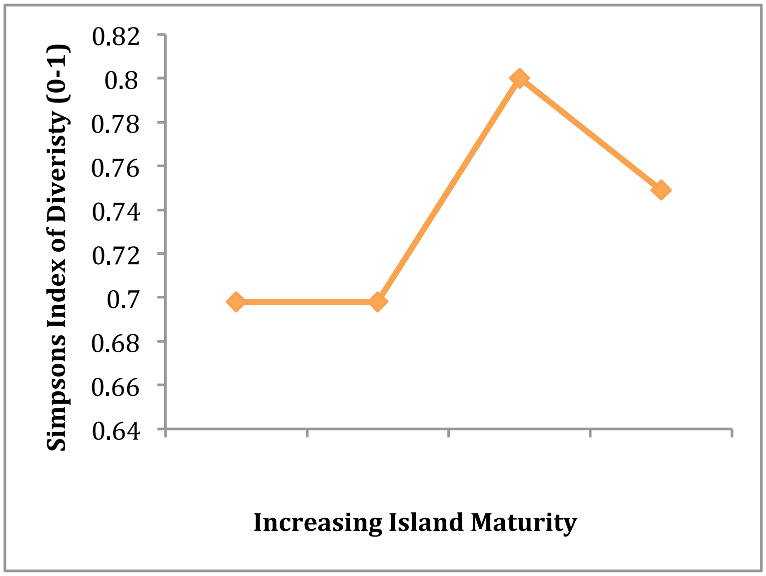

Figure 6: **Simpsons Index of Diversity for Constructive Islands**

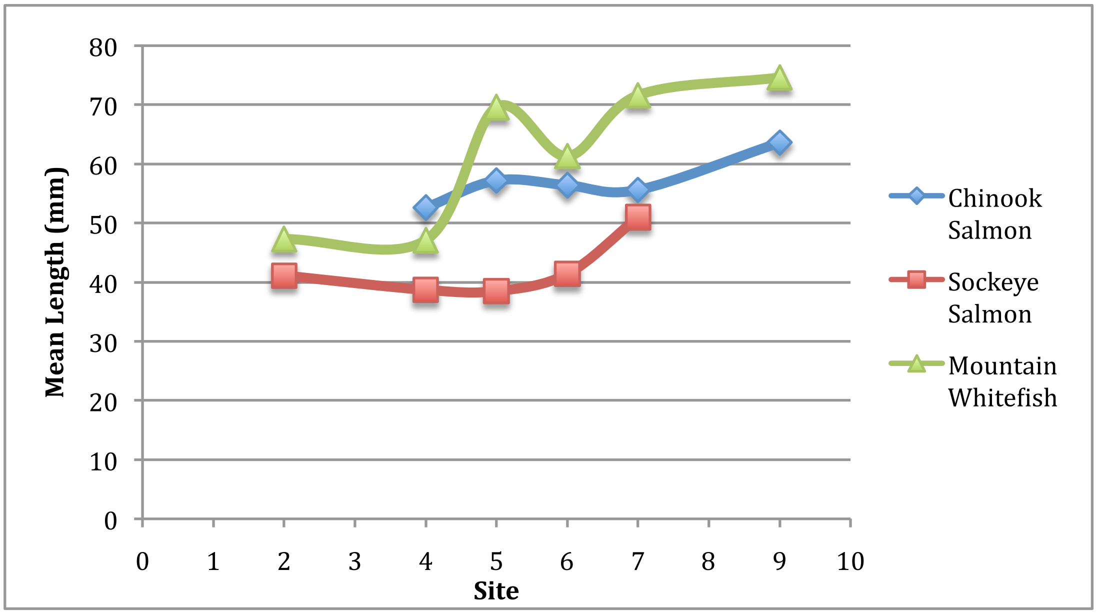

Figure 7: Longitudinal profile of mean fish lengths for three fish species

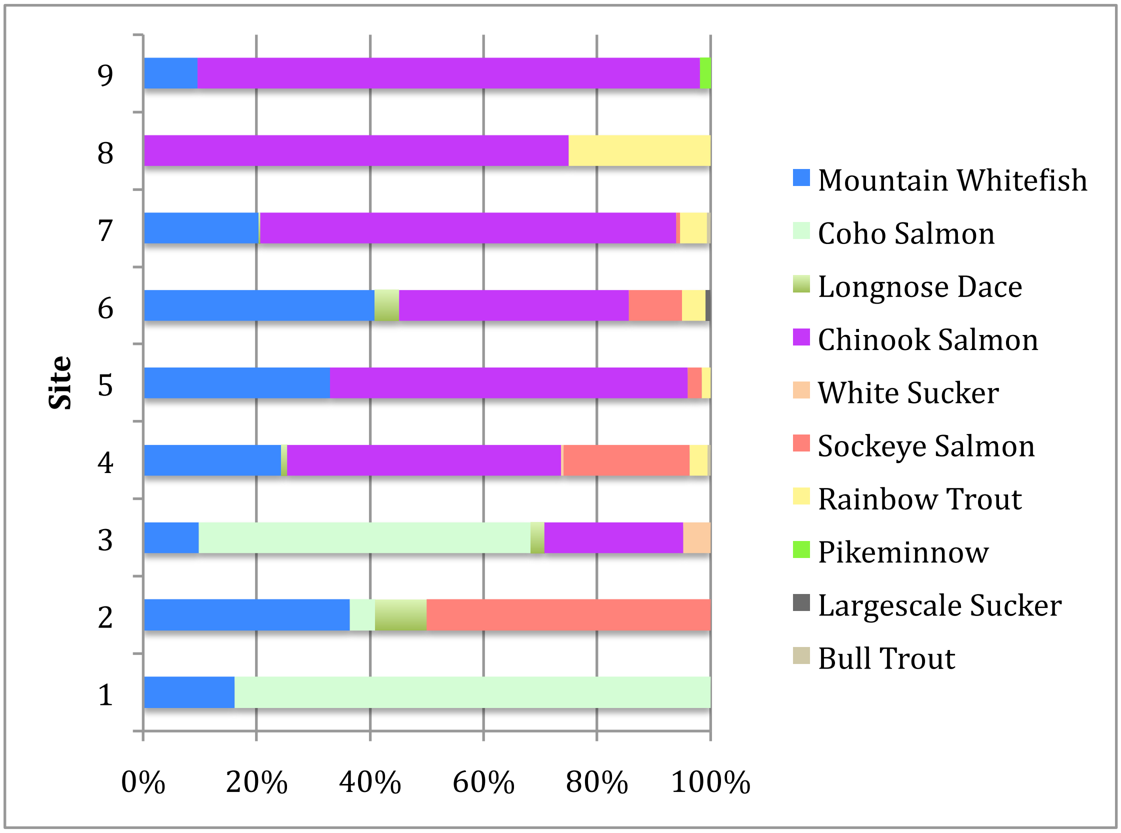

Figure 8: Summary of fish observation data for all sample sites showing percentage abundance within each site. Constructive Island sites = 4, 5, 6, 7; Destructive Island sites: 1,2; Big Creek = 8; Fraser Confluence=9. Chilko-Chilcotin Confluence =3