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AMONG STREAM CHANNEL TYPES OF THE COPPER
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# BENTHIC INVERTEBRATE COMMUNITY MEASURES AMONG STREAM CHANNEL TYPES OF THE COPPER RIVER DELTA, SOUTHCENTRAL ALASKA.

By

Todd C. White

A THESIS

Submitted to
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ABSTRACT

BENTHIC INVERTEBRATE COMMUNITY MEASURES AMONG STREAM CHANNEL TYPES OF THE COPPER RIVER DELTA, SOUTHCENTRAL ALASKA.

By

Todd C. White

The Copper River Delta of Southcentral Alaska is the largest contiguous wetland on the North American Pacific coast, and supports economically important commercial and recreational fisheries for all five species of pacific salmon. Some biological factors influencing salmon populations in the Copper River Delta have been previously investigated, but little effort has been made to establish baseline information on freshwater aquatic communities in the region. In an effort to provide area managers with aquatic community measures for future comparisons, benthic invertebrate community structure was contrasted among twelve streams representing six stream channel types common to the area and important to salmonid development. In general, invertebrate density, taxa richness, and diversity were greatest in channel types designated as high potential for salmonids. Taxonomic and functional feeding group measures show that macroinvertebrate communities of Copper River Delta streams sampled are representative of early (<50 years) stages of colonization after the major earthquake disturbance of 1964. Continued long term monitoring of invertebrate populations is required to track changes in food resources important to economically important fish species.

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# CHAPTER 1

# BENTHIC INVERTEBRATE COMMUNITY MEASURES AMONG STREAM CHANNEL TYPES OF THE COPPER RIVER DELTA, SOUTHCENTRAL ALASKA

## INTRODUCTION

### *History and Management of the Copper River Delta*

The Copper River Delta, Alaska is the largest contiguous coastal wetland on the Pacific coast of North America (Thilenius 1990). Fed by one of the world's largest river systems, the Delta extends 75 miles along the Gulf of Alaska southeast of Anchorage, and encompasses 700,000 acres of constantly changing river channels, marshland, tidal flats, and sloughs (Christensen 2000). The Delta is located in one of the most seismically active regions of the world (Thomas et al 1991), experiencing major earthquakes every 600-1000 years; the most recent event occurring in 1964. The 1964 earthquake measured 8.6 on the Richter scale, and lifted the Delta an average of 6.7 feet above previous levels (Hansen and Eckel 1971). The associated upheaval resulted in the establishment of 1.5 kilometers of new marshland on previously un-vegetated tidal flats. The rapid transformation of the formerly open marshland zone into shrubland was dominated initially by willow (*Salix* spp.), and more recently alder (*Alnus* spp.) (Thilenius 1995). The dynamic tectonic environment of the Delta results in alternate expansion of dry-land vegetation types which are eventually drowned and buried by sediment transport from upriver. Thus, Delta plant and animal communities constantly undergo regular and perpetual cycles of renewal and succession (Christensen 2000).

The Copper River Delta is located entirely within the Chugach National Forest under the management of the Forest Service, U.S. Department of Agriculture (USDA). The Delta is unique among USDA Forest Service systems in that it is the only such system mandated (Alaska National Interest Land Conservation Act 1980) with a priority to manage and conduct research to support the conservation of fish, wildlife, and their associated habitat. The Delta currently supports the most productive commercial fishery in Southcentral Alaska with annual spawning migrations of five species of Pacific salmon, thus sustaining a lucrative commercial fishing industry, human subsistence use, and a diverse native wildlife fauna (Christensen 2000). Current USDA Forest Service management assessments (Kruger 1995) in the Delta region have identified a critical need for baseline data on ecosystem processes and conditions in order to monitor and document physical and biological changes over time. In addition, understanding the natural processes that influence the Delta's salmon populations has been designated as a research area of high priority because of the ecological and economic importance of the region's fisheries (Kruger 1995).

*Summary of Copper River Delta Research Studies*

To date, only preliminary studies concerning the importance of freshwater habitats have been conducted within the Copper River Delta. The majority of the research questions posed have concentrated on the effects of tectonic uplift on plant communities (Thilenius 1995), the role of marine-derived nutrients in salmon ecology (Hicks et al 2005; Lang et al 2005), and the genetic relationships of some salmonid populations (Saiget et al 2007; Williams et al 2007). Only two studies concerning freshwater aquatic macroinvertebrates have been published since the earthquake of

1964, and none prior to, illustrating the need for additional research and baseline data in this area.

Thilenius (1995) investigated the effects of the 1964 uplift event on plant communities within the Copper River Delta. Pre-uplift aerial photographs were compared to vegetation sampling and aerial photography conducted in 1974 and 1979. Results showed that vegetation within uplifted areas of the Delta were undergoing a rapid successional sequence from grass/sedge-dominated communities to communities dominated by woody shrubs (alder/willow). The sequence of succession observed during the study period was typical to the Delta region above the uplift affected area.

Hicks et al (2005) studied the occurrence of marine-derived nutrients in Delta freshwater-riparian food webs. Seasonal sampling of stable isotopes showed that juvenile coho salmon, threespine sticklebacks, and aquatic macroinvertebrates in Delta beaver ponds were enriched with marine nitrogen and carbon, and that artificial enrichment with salmon carcasses increased the marine-derived N and C values of juvenile coho salmon. Aquatic vascular plants were found to be enriched with marine N only, and riparian vegetation showed no marine-derived enrichment.

Lang et al (2005) investigated the influence of fall-spawning adult coho salmon on the growth and production of juvenile coho salmon in Delta beaver ponds. They compared beaver ponds with natural spawning, ponds without spawning, and ponds without spawning but artificially enriched with salmon eggs and carcasses. Results were variable in the study, with increased growth in some pond-spawning adults and improved conditions of juvenile salmon. Enrichment of ponds without natural spawning significantly increased the growth and condition of juvenile coho salmon, but the results provided little evidence that the observed short-term growth benefits led to greater overwinter survival/outmigration.

Spawning and movement of coastal cutthroat trout on the Delta was investigated by Saiget et al (2007). Movements of coastal cutthroat trout were monitored for two years using radio telemetry and tag-recapture. Similar sized, morphologically indistinct individuals displayed anadromous and/or potamodromous migrations seemingly at random. Timing of spawning stream entry and post-spawning movements were highly variable among individual trout and spawning was found to be concentrated within the upper reaches of streams.

Natural hybridization of rainbow and coastal cutthroat trout was investigated by Williams et al (2007). Mitochondrial DNA molecular genetic methods were used to identify the presence of rainbow/cutthroat (cuttbow) hybrids at eleven sites on the Delta. Hybridization of cutthroat and rainbow trout populations across study sites varied from 0% to 58% of fish sampled. No significant correlation was found between stream channel process groups and number of hybrid fish sampled. Backcrossed hybrid individuals were found indicating that at least some cuttbow hybrids on the Delta were reproductively viable.

The intertidal benthic resources of silt-clay substrates at outflows of two Delta rivers were studied by Powers et al. (2002). The benthic community was characterized by low species diversity, and was dominated by tellinid bivalves, polychaete worms, and corophid amphipods. Temporal and spatial changes in benthic community abundances and densities were found to correspond to differences in tidal inundation and sediment temperature.

Powers et al. (2006) also studied the distribution of the invasive bivalve *Mya arenaria* on intertidal flats of the Copper River Delta. Abundance of *M. arenaria* was found to be greatest ($4000/m^2$) in areas of higher salinity and water clarity. Density and growth of *M. arenaria* in tidal flats of the Delta were observed to be similar to values reported for the White Sea (Russia), an area located at a similar latitude.

Mason (1991) conducted a 2 week interdisciplinary survey of aquatic habitats on the Copper River Delta including geomorphology, limnology, and wetland plant ecology. In this study, samples were qualitative and concentrated among wetlands that experience periodic flooding. Mason (1991) found that abundance and diversity of phytoplankton, macrophytes, macroinvertebrates, and fish in interbasin habitats (beaver ponds) was higher than in main channel (glacial) habitats . Marsh (tidal) habitats were characterized by dominance of euryhaline crustacea while pond - (non-tidal) habitats were dominated by Cladocera and Chironomidae. Wetland ponds also were shown to have the highest diversity of macroinvertebrates of all habitats sampled.

*Macroinvertebrate community*

Macroinvertebrate communities play an important role within food webs of many aquatic ecosystems by providing a link between organic matter inputs, primary producers, and higher trophic levels (i.e. fish) (Allan and Castillo 2007). Aquatic macroinvertebrates influence nutrient cycles, decomposition rates, and translocation of materials within stream habitats (Hauer and Resh 2006), and also serve as indicators of stream integrity and water quality (Wallace & Webster 1996). The feeding habits of benthic macroinvertebrates convert both autochthonous (in-stream) primary production by macrophytes and periphyton, and allochthonous (terrestrial) inputs of organic matter into insect biomass directly available to fish in aquatic habitats (Cummins and Klug 1979). In the Pacific Northwest, macroinvertebrates serve not only as a direct form of nutrition for many fish species, but also facilitate indirect transport of marine derived nutrients to higher trophic levels of coastal food webs (Hicks et al. 2005). Inputs of macroinvertebrates into the rearing habitats of juvenile fish species can be of particular importance, especially in the case of juvenile salmonid fishes that undergo a migration event before attaining adulthood. Fisheries research has shown that juvenile salmonids that attain the greatest size prior to migration have the highest probability of returning as reproductive adults (Smith and Griffin 1994; Bilton et al. 1982), making the quantity and quality of prey items consumed during rearing of considerable importance.

The objectives of this study were to characterize and contrast benthic macroinvertebrate communities across stream channel types common to Alaska temperate streams of the Copper River Delta. Baseline data generated from this study will be used by fisheries managers of the USDA Forest Service to make future management decisions concerning commercial and recreational fishing as well as land use on the Copper River Delta.

## MATERIALS AND METHODS

### *Study Area*

The study was conducted within 12 streams of the Copper River Delta, Southcentral Alaska (Figure 1). Weather patterns of the Delta are similar to those seen in Southeast Alaska, with approximately 380 inches of rain per year with greatest discharges most common in the fall months. Low water periods typically occur in late spring and mid- summer (Meyer et al. 2001). The Delta is separated into east and west ranges by the mainstream and braided channels of the Copper River (Figure 1). The area is hydrologically complex, and characterized by networks of beaver ponds interconnected by stream channels (Hicks et al 2005). Twelve study sites representing six US Forest Service designated channel types were selected using aerial photographs, US Forest Service GIS data, channel morphology, presence/absence of salmonid rearing habitat, and access. Physical characteristics of each channel type are summarized in Table 1. Benthic macroinvertebrate sampling was conducted on a monthly basis during the period of June–August, 2005 and 2006.

*Sampling Sites by Channel Type Description:* (from Paustian et al. 1992)

<u>Estuarine Channel Type: Silt Substrate Estuarine Channel or Slough (ES1)</u>

Silt Substrate Estuarine streams are associated with shallow embayments along coastal forelands and large glacial river deltas. The ES1 channels are characterized by stream gradient 0-0.5%, incision depth 0-4 m (13 ft), bankfull width < 20m (66 ft), and dominant substrate of silt/clay and sand. Riparian vegetation is dominated by non-forested grass and sedge communities with some alder/willow. Silt Substrate Estuarine streams are depositional channels with low energy due to nearly flat gradients. Water flow and depth is strongly influenced by tidal stage. Suspended glacial silt load is generally high. Little, if any, spawning occurs in ES1 streams due to fine sediments dominating the substrates. Available rearing area is high with pools showing good depth for overwintering, but habitat is generally underutilized due to suspended sediment load. One study area was classified as ES1: Alaganik River in the Alaganik river system.

Estuarine Channel Type: Large Estuarine Channel (ES4)

Large Estuarine Channels on the Delta are associated with moderate to large drainage basins of inland bays and inlets. The ES4 channels are characterized by stream gradient ≤ 2%, incision depth of < 5 m (16.5 ft), bankfull width > 10 m (33 ft), substrate dominated by gravel and cobble. Riparian vegetation is dominated by grass and sedge communities. Large estuarine streams are depositional channels subject to tidal influences. Low stream energy, gravel and sand bars, and large woody debris typify ES4 channel types on the Delta. High quality gravel substrate is frequented by pink and chum salmon in high densities during spawning. Rearing habitat is minimal with salmon fry only temporarily remaining in the system before moving seaward. One study site was classified as ES4 channel type: Hartney Creek in the Hartney Range system.

Floodplain Channel Type: Narrow Low Gradient Flood Plain Channel (FP)

Floodplain streams on the Delta are characterized by stream gradient ≤ 2%, incision depth ≤ 2m (6.5 ft), bankfull width < 10m (33 ft), and dominant substrate of sand to small rubble. Riparian vegetation is dominated by Sitka spruce, western hemlock, and alder communities. The FP3 streams function as temporary sediment deposition systems dominated by deposits of sand and fine gravel with frequent large woody debris accumulations. Available spawning habitat for coho salmon is high. If located next to accessible lakes, FP3 channels provide excellent spawning habitat for sockeye salmon. Good average depth, woody debris occurrence, and beaver dams provide good overwintering and rearing habitat for juvenile salmonids. Two study sites were classified as FP3 streams: the Little Martin River in the Martin River system of the East Delta, and BlackHole Creek of the Alaganik system on the West Delta.

Glacial Ouput Channel Type: Moderate Width Glacial Channel (GO)

Moderate width glacial output channel types occur in the mid to upper valley position in glacial watersheds. The GO4 streams are characterized by stream gradient of 2-6%, incision depth ≤ 4m (13 ft), variable bankfull width, mean = 31 m (103 ft), and dominant substrate of coarse gravel to small boulder. Riparian vegetation is dominated by non-forested alder and willow shrub communities. Glacial output streams are moderate energy streams that transport large sediment loads. Available salmonid spawning and rearing habitat is low due to high glacial silt suspended load and regular flushing events. One study site was classified as a GO4 stream: Power Creek in the Upper Eyak system.

Glacial Output Channel Type: Large Braided Glacial Outwash Channel (GO3)

GO3 channels occur in broad, glacial valley bottoms or outwash plains in very large glacial drainage basins. GO3 streams are characterized by gradient < 3%, incision depth ≤ 2 m (6.5 ft), variable bankfull width from 60-300m (200 – 1000 ft), with a dominant substrate of coarse gravel to large cobble. The riparian vegetation is dominated by nonforested Sitka alder and willow shrub communities. GO3 channels function as sediment deposition systems with extremely large sediment loads. GO3 channels typically provide salmonids with migration routes to spawning areas in clear water tributaries. Spawning habitat is limited by fine sediments, and coho salmon rear in low numbers in these channels. One study site was classified as a GO3 stream: Ibeck creek in the Lower Eyak River system.

Moderate Gradient Contained Channel Type: Narrow Shallow Contained Channel (MC1)

Moderate gradient contained channel types occur in middle to upper valley positions of glacially scoured lowland landforms. MC1 channels are characterized by stream gradient of 1-6%, incision depth of < 4 m (13 ft), bankfull width < 10m (33 ft), and dominant substrate of cobble and bedrock. Riparian vegetation is dominated by mixed conifers. The MC1 streams function as sediment transport systems with moderate energy, and instream storage of fine sediments is minor. Salmonid spawning habitat is limited, but coho salmon and Dolly Varden char use pools for summer rearing. Two study sites were chosen from this area and classified as Narrow Shallow Contained Channel (MC1): Upper Pipeline Creek in the Alaganik River system and 1971 Pond in the 18 Mile system, both of the West Delta.

Palustrine Channel Type: Narrow Placid Flow Channel (PA1)

Narrow placid flow channels on the Delta are characterized by stream gradient less than 2%, incision depth of less than or equal to 2m (6.5 ft), bankfull width less than 10m (33ft), and dominant substrate of organic silt to fine gravel. Riparian vegetation communities are dominated by non-forested sedge, sphagnum bog, and

Sitka alder. Sediment retention is very high in PA1 channels so fish spawning potential is low. Deep, pooled water and cover from overhanging streambank vegetation provide good rearing habitat for coho salmon and Dolly Varden. Two study sites were classified as narrow placid flow channels: the Middle Branch of the 18 Mile system, and Salmon Creek of the Alaganik system.

Palustrine Channel Type: Beaver Ponds (PA5)

Beaver pond habitats on the Delta are characterized by a stream gradient of 0-1%, incision depths less than or equal to 2 m (6.5 ft), bankfull width normally greater than 10m (33 ft), and dominant substrate of sand and organic silt. Riparian vegetation is dominated by nonforested communities of sedge and sphagnum bog with some Sitka alder (*Alnus sinuate*) and willow (*Salix* spp). PA5 channels function as sediment sinks and buffer flows from extreme runoff events. Salmonid spawning potential is low due to prevalence of fine sediments. PA5 channels provide the necessary depth and woody debris cover for overwintering and growth making them good rearing habitat for juvenile coho salmon and Dolly Varden char. Two of the sampling sites in this PA5 channel were beaver ponds: Pipeline #4 in the Alaganik River system, and a second pond in an adjacent system known as Goose Meadows.

*Benthic Macroinvertebrates*

To estimate abundance and composition of macroinvertebrate communities, quantitative samples were collected with a $0.1m^2$ Hess sampler (Merritt et al. 2008). During each sampling period, I collected three replicate samples from each stream reach. Hess samples were taken at random within the first riffle area encountered upstream of access point $\geq 10m^2$ in area and $\leq 0.3$ m depth. The sampler was placed in a shallow, fast-flowing section of stream, and the enclosed substrate was agitated for ~1 minute allowing the disturbed macroinvertebrates to be washed into the collection bag at the end of the sampler. Samples were passed through a 250-micron sieve and transferred into a 250 ml Whirl-Pak©, preserved in 70% ethanol, and returned to the lab for sorting & identification under a dissecting scope. All invertebrates were picked from each sample, counted, and identified to the lowest possible taxonomic level, mostly generic (except Chironomidae) using Merritt et al. (2008). Chironomidae were identified to subfamily.

Invertebrate density, (mean total number of organisms per square meter), was estimated from abundance and surface area calculations for the Hess sampler, and converted to number per $m^2$. Richness was measured as total number of taxa present, and diversity was measured using the Shannon-Weiner diversity index (- Hauer and Resh 2006). Macroinvertebrates were designated a functional feeding group status (shredders, filtering-collectors, gathering-collectors, scrapers, and predators) according to Merritt et al. (2008). The following metrics were calculated in order to classify stream channels taxonomically: mean percent EPT taxa (no. of Ephemeropetera, Plecoptera, and Trichoptera / total # of organisms) , mean percent Diptera (# of Diptera / total # of organisms), and mean percent non-insect taxa, (# of non-insect taxa / total # of organisms).

*Analysis*

The main objective of this study was to assess differences in the overall macroinvertebrate community among streams and stream channel types. As a result, variation among months was not a focus of this paper and all monthly samples were combined to calculate overall average macroinvertebrate values for each year (n=12 samples per stream per year). Two-way ANOVAs (JMP 8.0, 2008) were generated contrasting community measures among sampling sites, between sampling years, and site by year interactions ($\alpha = 0.05$). In addition, multiple comparison tests using Tukeys Honest Significant Difference (HSD) Tests were made among streams ($\alpha = 0.05$). All data were tested for normality and (log + 1) transformed where necessary to meet statistical test assumptions. We found no significant differences due to year and no significant interaction effects in all our analyses; thus to simplify and summarize differences due to only stream type, samples from both years were combined (n=18), averaged and listed in all data tables and figures.

## RESULTS

### *Macroinvertebrate Richness and Diversity Among Stream Channel Types*

Over 29,000 macroinvertebrates representing 52 distinct taxa were collected from streams of the Copper River Delta (Table 2). A total of 20 taxa were collected from the insect orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera (Table 2). In addition, 5 subfamilies of Chironomidae were identified (Table 2). The chironomid subfamily Orthocladiinae comprised the largest percentage of chironomid abundance across the 12 streams, followed by the Diamesinae and the Tanytarsinae (Table 4). Twelve additional insect taxa and fifteen non-insect taxa were also collected from Copper River Delta streams during 2005 & 2006 (Table 2).

Results showed a significant difference in taxa richness among streams ($F = 67.108$, $df = 11$, $p = < .0001$), however no difference among years ($F = 0.725$, $df = 1$, $p = 0.396$), or an interaction effect ($F = 1.283$, $df = 11$, $p = 0.236$). Mean richness (total number of taxa collected) was lowest (2-6 taxa) in estuarine (ES) and glacial output (GO) stream channels. Richness was significantly lower (Tukey HSD, $p<0.05$) than higher ranked stream channels with the exception of Salmon Creek (PA1) that was not significantly different from Hartney Creek (ES) (Figure 2). Mean richness was intermediate (7-12 taxa) in moderate gradient contained (MC), placid flow (PA1), and floodplain (FP) channel types. Within this group, all sites were significantly greater (Tukey HSD,$p<0.05$) than lower ranked sites with the exception of Salmon Creek (PA1) which was not significantly greater than Hartney Creek (ES) (Figure 2). Mean richness was greatest (13-17 taxa) in beaver pond channel types (PA5). Mean richness at both PA5 sites, Goose Meadows and Pipeline # 4, was significantly greater than the low-ranked channel types, but neither were significantly greater than all intermediate channel types (Figure 2).

I found a significant difference in diversity among streams ($F = 44.943$, $df = 11$, $p = <.0001$); however, no difference among years ($F = 1.164$, $df = 1$, $p = 0.2821$) and no interaction effect ($F = 0.576$, $df = 11$, $p = 0.8470$). Mean Shannon-Weiner diversity was lowest (0.79 – 1.18) in all estuarine, glacial output, and one PA1 channel, Salmon Creek (Figure 3). These sites were significantly lower than higher ranked sites with the exception of Hartney Creek (ES) and Ibeck Creek (GO) which were not significantly different from Blackhole Creek (FP). Diversity was intermediate (1.37-1.93) in all placid flow, floodplain, and in one moderate gradient contained channel, Pipeline Up. These sites were all significantly greater than (Tukey HSD, $p<0.05$) lower ranked sites with the exception of Blackhole Creek (FP) (Figure 3). Shannon-Weiner diversity was greatest (>2.0) in beaver pond channel types (PA5). Both Goose Meadows (PA5) and Pipeline # 4 (PA5) were significantly greater ($p<0.05$) than the lowest ranked sites, but neither were significantly greater than all intermediate ranked sites (Figure 3).

Mean percent EPT (Table 3) was low (≤ 5%) in all beaver pond channels (PA5), and estuarine channels (ES), intermediate (5 – 10%) in one placid flow channel (PA1) (Salmon Creek), one glacial output channel (GO) (Power Creek), and one floodplain channel (FP) (Blackhole Creek). Mean percent EPT was high (> 10%) in all moderate gradient channels (MC), one placid flow channel (PA1) (18 Middle), one glacial output channel (GO) (Ibeck Creek), and one floodplain channel (FP) (Little Martin) (Table 3).

Mean percent Diptera (Table 3) was high (> 60%) in all placid flow channels (PA1), moderate gradient channels (MC), glacial output channels (GO), floodplain channels (FP), and one estuarine channel (ES) (Alaganik). Mean percent Diptera was intermediate for both beaver pond channels (PA5) and low for one estuarine channel (ES) (Hartney Creek) (5%) (Table 3).

Mean percent non-insect taxa, (Table 3) was high in both beaver pond channels (PA5), and one estuarine channel (ES) Hartney Creek, intermediate in all floodplain - (FP), moderate gradient channels (MC), one estuarine channel (ES) Alaganik, and one placid flow channel (PA1) 18 Middle. Mean percent non-insect taxa was low in both glacial output channels (GO), and one placid flow channel (PA1) Salmon Creek

*Macroinvertebrate Densities Among Stream Channel Types*

A statistically significant difference in macroinvertebrate density among streams ($F = 27.783$, $df = 11$, $p = <.0001$) was identified; however, no difference among years ($F = 0.139$, $df = 1$, $p = 0.7094$) and no interaction effect ($F = 0.411$, $df = 11$, $p = 0.9497$) was observed. Mean densities of macroinvertebrates were lowest (100 – 999 individuals/$m^{-2}$) among all glacial output streams, one estuarine stream, Alaganik Slough (ES), and one moderate gradient contained stream, Pipeline Up (MC) (Figure 4). Within this group the mean density of Ibeck Creek (GO) was significantly lower (Tukey HSD, $p<0.05$) than the other sites. Mean densities were intermediate (1000-1999 individuals/$m^{-2}$) in all PA1, beaver pond (PA5), one floodplain site, Blackhole Creek (FP), and one moderate gradient contained site, 1971 Pond (MC). Multiple comparison tests indicated that intermediate ranked streams were significantly greater. than lower ranked sites with the exception of 1971 Pond (MC)

(Figure 4). Mean density was greatest (>2000 individuals/$m^{-2}$) in one estuarine site, Hartney Creek (ES), and one floodplain site, Little Martin (FP). Mean density of both of these sites was significantly greater (Tukey HSD, $p<0.05$) than all low ranked streams, but only Hartney Creek (ES) was significantly greater than all intermediate ranked streams (Figure 4).

*Functional Feeding Group Proportions Among Stream Channel Types*

Functional feeding groups and their proportions varied both across and within stream channel types (Figure 5; Table 5). Estuarine channel types (ES) were characterized by relatively few taxa in large numbers. Alaganik Slough (AG) was dominated by collector-gatherers (86%) (Figure 5) of the chironomid subfamily Orthocladiinae (Table 5), with some scrapers (12%) (Chironomidae: Diamesinae), and few collector-filterers (1%), shredders (<1%), and predators (<1%). Hartney Creek (HC) was characterized by a high percentage of shredders (61%) (euryhaline Amphipoda and Isopoda), collector-gatherers (38%) (Oligochaete worms), few scrapers (1%), and the absence of collector-filterers and predators (Figure 5). The functional communities of floodplain channel types, Blackhole Creek (BH) and Little Martin (LM), were composed of similar macroinvertebrate assemblages and included collector-gatherers (BH = 57%; LM=44%) (Chironomidae: Orthocladiinae, - *Baetis* mayflies and oligochaete worms), scrapers (BH = 23%; LM = 26%) (Chironomidae: Diamesinae, planorbid snails and *Cinygmula* mayflies), collector-filterers (BH = 5%; LM = 16%) *(Simulium* black flies and Chironomidae: Tanytarsinae), predators (~ 10% both sites) (Chironomidae: Tanypodinae, Ceratopogonidae and *Haploperla* and *Isoperla* stoneflies), and shredders (~ 5% both sites) (*Zapada* stoneflies and

*Ecclisomyia* caddisflies) (Figure 5; Table 5)). The glacial output channel types, Ibeck Creek (IC) and Power Creek (PC), were dominated by collector-gatherers (IC = 47%; PC = 74%) (Chironomidae: Orthocladiinae), followed by scrapers (IC = 39%; PC = 21%) (Chironomidae: Diamesinae), predators (IC = 12%; PC = 3%) (*Haploperla* and *Isoperla* stoneflies), and few filterers (~ 2%), and shredders (~ 1%) (Figure 5; Table 5). Moderate gradient contained sites, 1971 Pond (19P) and Pipeline Up (PU), were characterized by similar proportions of shredders (7%) (*Lepidostoma*, *Onocosmoecus*, *Psychoglypha* caddisflies, and *Zapada* stoneflies), scrapers (15 % – 17 %) (Chironomidae: Diamesinae and Planorbid snails), and predators (10 % - 13 %) (Chironomidae: Tanypodinae and Ceratopogonid biting midges). Moderate gradient sites differed in the percentages of collector-gatherers (19P = 57%; PU = 31%) (Chironomidae: Chironominae, Orthocladiinae, and *Paraleptophlebia* mayflies) and collector-filterers (19P = 8%; PU = 35%) (Simulium blackflies, Chironomidae: Tanytarsinae, and sphaeriid fingernail clams) (Figure 5; Table 5). Placid flow channel types, 18 Middle (18M) and Salmon Creek (SC), differed in percentages of collector-gatherers (18M = 51%; SC = 34%) (Chironomidae: Orthocladiinae and *Baetis* mayflies), scrapers (18M = 12%; SC = 60%) (Chironomidae: Diamesinae), and collector-filterers (18M = 26%; SC = 1%) (*Simulium* blackflies and Chironomidae: Tanytarsinae). Placid flow channel types showed similar percentages of predators (4% at both sites) (Chironomidae: Tanypodinae, - *Haploperla* and *Isoperla* stoneflies), and shredders (18M = 7%; SC = 1%) (*Zapada* stoneflies and *Ecclisomyia* and *Onocosmoecus* caddisflies) (Figure 5; Table 5). Beaver pond channel types (Figure 5; Table 5)), Goose Meadows (GM) and Pipeline #4 (P4), were very similar in taxonomic assemblages of all functional feeding groups including collector-gatherers (28%-30%) (Copepoda, Hydrachnida, and Chironomidae: Orthocladiinae), collector-filterers (46% - 47%) (Cladocera, Sphaeriidae, and Chironomidae: Tanytarsinae), shredders (12% -16%) (Ostracoda, Amphipoda, *Haliplus* beetles, and *Onocosmoecus* caddisflies), scrapers (5% - 8%) (Chironomidae: Diamesinae; planorbid and valvatid snails), and predators (4% at both sites) (Chironomidae: Tanypodinae; Ceratopogonidae; Dytiscidae; Aeshnidae)

## DISCUSSION

### *Macroinvertebrate communities of the Copper River Delta.*

The results of this study showed that taxonomic and functional differences in macroinvertebrate composition occurred among stream channel types of the Copper River Delta. Studies that compared streams of Glacier Bay, Southeast Alaska indicated that community development was mainly influenced by abiotic factors, especially water temperature and channel stability (Milner 1987; Sidle and Milner 1989). In general, invertebrate densities, richness, and diversity were lowest in Delta streams and channel types characterized by high gradient and stable substrate (glacial output channels), or low gradient and unstable substrate (estuarine channels). Invertebrate densities, richness, and diversity were highest in Delta streams and channel types characterized by low gradient and stable organic substrates (beaver pond and floodplain channels) (Figure 1). The Copper River Delta pulse study (Bryant 1991) qualitatively compared diversity of beaver ponds with main channel habitats with similar results. Estuarine and glacial output stream channel types were characterized by low densities, low taxa richness, low diversity, and few functional feeding groups of freshwater macroinvertebrates. Estuarine stream channel types (ES), Alaganik Slough and Hartney Creek, were characterized by the dominance of relatively few taxa in large numbers. Habitat diversity at Alaganik Slough was dominated by unstable sand/silt restricting the invertebrate community to collector-gatherers of the chironomid subfamily Orthocladiinae. Hartney Creek was immediately adjacent to the estuary at Hartney Bay, and underwent tidal inundation daily. Exposure to saltwater allowed the colonization of the substrate by euryhaline amphipod and isopod shredders, and effectively eliminated freshwater macroinvertebrates from the stream channel. Glacial output stream channels (GO), Ibeck Creek and Power Creek, were characterized by high glacial suspended sediment loads and contained the lowest densities, richness, and diversity of all stream sites examined. Both of these stream channel types were dominated by chironomid collector-gatherers (Orthocladiinae) and scrapers (Diamesinae). Moderate gradient contained stream channel types (MC), Pipeline Up and 1971 Pond, were characterized by low invertebrate density, high taxa richness, high invertebrate diversity, and presence of all five functional feeding groups. Accumulations of organic debris provided habitat for *Paraleptophlebia* (Leptophlebiidae) mayfly gatherers and caddisfly, *Lepidostoma* (Lepidostomatidae), shredders which were not found at other stream channel types (Table 5). Placid flow stream channels (PA1), Middle 18 and Salmon Creek, were characterized by similar densities and taxa richness, but differing diversities of functional feeding groups. The Middle 18 stream habitat consisted of gravel riffles with an associated fauna consisting of Orthocladiinae (Chironomidae) and *Baetis* collector-gatherers, *Simulium* collector-filterers, chironomid (Diamesinae) scrapers, limnephilid caddisfly shredders (*Ecclisomyia* and *Onocosmoecus*), and predatory chironomid midges (Tanypodinae). The dominant habitat of Salmon creek also consisted of gravel riffles, but this site was dominated by chironomid scrapers (Diamesinae) and collector-gatherers (Orthocladiinae). Salmon Creek was located in close proximity to the mouth of McKinley Lake which could have acted as a source of chironomid influx into the surrounding aquatic habitat. Milner et al 2000, found that percent Chironomidae was significantly greater downstream of lakes in stream habitats in Glacier Bay, Southeast

Alaska. Floodplain stream channels (FP), Blackhole Creek and Little Martin River, were characterized by high invertebrate densities, taxa richness, diversity, and the presence of all five functional feeding groups. Habitat at both floodplain stream sites was similar and dominated by gravel riffles. The fauna of both floodplain streams was similar with the exception of the scraper and shredder communities which differed in taxa (Table 5). Beaver pond stream channel types (PA5), Goose Meadows and Pipeline #4, were characterized by high invertebrate densities, taxa richness, diversity, and the presence of all five functional feeding groups. Habitat at both beaver pond sites was similar and dominated by organic silt and sand substrates. The fauna of both beaver pond sites was similar and was dominated by fauna more indicative of lentic habitats (Table 5). In addition, beaver ponds were found to contain invertebrate taxa not normally found in other stream channel types including predatory diving beetles (Dytiscidae), immature dragonflies (Aeshnidae), hydroptilid caddisflies (*Oxyethira*), and the dipteran *Pericoma* (Psychodidae). This may have been due to a more lentic environment conducive to colonization by the above taxa.

*The Copper River Delta and other regions of Alaska.*

Invertebrate densities and diversity in Copper River Delta streams were found to be lower than those reported for other streams and rivers in Alaska (Milner et al. 2000, Hernandez et al. 2005). With one exception, Copper River Delta streams were found to have mean density values less than 2500 $m^{-2}$; whereas, macroinvertebrate densities for gravel riffle habitats ranged from 3750 to 5700 $m^{-2}$ for streams of Glacier Bay, Alaska (Milner et al 2000), and from 3000 to 6500 $m^{-2}$ for streams on Prince of

Wales Island, Alaska (Hernandez et al 2005). The exception, the estuarine stream channel, Hartney Creek, was immediately adjacent to Hartney Bay estuary, and received daily tidal inundation which allowed euryhaline amphipods and isopods to colonize the channel, thus artificially increasing the total invertebrate density for the site. Macroinvertebrate diversity also was lower in Copper River Delta streams (52 taxa) as compared to Glacier Bay streams where 128 taxa were recorded (Milner et al. 2000).

Invertebrate communities of stream channels of the Copper River Delta were dominated by taxa indicative of new or disturbed systems in Alaska. Mackay (1992) suggested that the first macroinvertebrate colonizers of new or disturbed systems would typically be Baetidae and Leptophlebiidae (Ephemeroptera), Simuliidae, Orthocladiinae (Chironomidae), and Hydropsychidae (Trichoptera). Taxonomically, most streams of the Copper River Delta are characterized by dominance of the chironomid subfamilies Orthocladiinae and/or Diamesinae. Milner et al (2000), during a colonization and development study of aquatic habitats representing a time span of 200 years in Glacier Bay, Alaska, found that Orthocladiinae and Diamesinae were the dominant groups of Chironomidae in young (≤ 50 years) streams with lakes and non-lake systems respectively. The genus *Baetis* (Baetidae) dominated the ephemeropteran taxa collected from most Copper River Delta stream channels with the exception of moderate gradient channels which were dominated by *Paraleptophlebia* (Leptophlebiidae). The genus *Cinygmula* (Heptageniidae) was collected from only one stream, the floodplain channel Blackhole Creek, and the genus *Epeorus* (Heptageniidae) was collected from only one stream, the glacial output channel Power Creek. The common genera of several southeast Alaskan streams (i.e.,*Drunella* (Ephemerellidae), *Rhithrogena* (Heptageniidae), *Ameletus* (Ameletidae (Lessard and Merritt 2006, Lessard et al. 2009), were not collected from Copper River Delta streams. Milner et al (2000) found that among the Ephemeroptera genera found in Glacier Bay streams, only *Baetis* was collected from streams less than 50 years old; *Cinygmula* was added to the fauna in streams between 50 and 100 years; *Drunella*, *Epeorus*, and *Rhithrogena* between 100 and 150 years; and *Ameletus* was found in the oldest post-glacial streams examined (150 - 200 years).

## CONCLUSION

The results of this study suggested that macroinvertebrate communities vary in density, taxonomic diversity, and functional feeding group diversity among stream channel types of the Copper River Delta, southcentral Alaska. Main channel habitats were found to be characterized by high densities of a few invertebrate taxa representing selective functional groups. Densities were reduced, but taxonomic and functional feeding group diversity was greater in interbasin channel types. Macroinvertebrate taxa found in streams of the Copper River Delta are also indicative of those found after recent disturbance (< 50 years).

The Copper River Delta is a system driven by recent geologic disturbance. Understanding how disturbance affects aquatic macroinvertebrate communities will allow managers to make informed decisions regarding resource use. There is a need for long term monitoring of macroinvertebrate communities on the Copper River Delta in order to understand the effects of time and succession upon this important aquatic ecosystem.

Table 1. Physical stream characteristics of study sites within the Copper River Delta, Alaska, (modified from Paustian 1991).

| Stream | Channel Type | Gradient (%) | Bankfull Width (m) | Substrate Type | Salmonid Potential |
|---|---|---|---|---|---|
| Alaganik | ES | 0.5 | 8 | silt/sand | Low |
| Hartney | ES | 1 | 23 | gravel/cobble | Low |
| BlackHole Creek | FP | 1 | 6 | sand/gravel | High |
| Little Martin | FP | 1 | 6 | sand/gravel | High |
| Power Creek | GO | 4 | 31 | cobble/boulder | Low |
| Ibeck Creek | GO | 2 | 65 | gravel/cobble | Low |
| Upper Pipeline | MC | 3 | 6 | cobble/bedrock | Moderate |
| 1971 Pond | MC | 1 | 4.6 | organic silt/gravel | Moderate |
| Salmon Creek | PA1 | 1 | 6 | sand/gravel | Moderate |
| Middle 18 | PA1 | 1 | 4.6 | organic silt/gravel | Moderate |
| Pipeline #4 | PA5 | 1 | > 10 m | organic silt/sand | High |
| Goose Meadows | PA5 | 1 | > 10 m | organic silt/sand | High |

Table 2. Macroinvertebrate taxa collected from 12 streams during June-August 2005 and 2006 within the Copper River Delta, Southcentral Alaska. * Chironomidae identified to Subfamily.

| Class | Order | Family | Genus | Alaganik | Hartney Creek | Power Creek | Ibeck Creek | Upper Pipeline | Blackhole Creek | Little Martin | Salmon Creek | Middle 18 Mile | 1971 Pond | Pipeline #4 | Goose Meadows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Malacostraca | | | | | | | | | | | | | | | |
| | Amphipoda | | | | | | | | | | | | | | |
| | | Corophiidae | | | X | | | | | | | | | | |
| | | Gammaridae | | | X | | | | | | | | | X | |
| | Isopoda | | | | | | | | | | | | | | |
| | | Asellidae | | | X | | | | | | | | | | |
| Branchiopoda | | | | | | | | | | | | | | | |
| | Cladocera | | | | | | | | | X | | X | X | X | X |
| Copepoda | | | | | | | | | | | | | | X | X |
| Ostracoda | | | | | X | | | X | X | X | X | X | X | X | X |
| Acari | | | | | | | | | | | | | | | |
| | Hydrachnida | | | | | | | | | | | | | | |
| Annelida | | | | | | | | | | | | | | | |
| | Oligochaeta | | | X | X | X | X | X | X | X | X | X | X | X | X |
| | Hirudinea | | | | | | | | | | | | | X | X |
| Nematoda | | | | | | | | | | | | | | | |
| | Nematoda | | | | | | | | | | | | X | | |
| Platyhelminthes | | | | | | | | | | | | | | | |
| | Planaria | | | | | X | X | | X | | X | | X | X | X |

Table 2. (cont'd)

| Class | Order | Family | Genus | Alaganik | Hartney Creek | Power Creek | Ibeck Creek | Upper Pipeline | Blackhole Creek | Little Martin | Salmon Creek | Middle 18 Mile | 1971 Pond | Pipeline #4 | Goose Meadows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mollusca | | | | | | | | | | | | | | | |
| | Bivalvia | | | | | | | | | | | | | | |
| | | Sphaeriidae | | | | | | X | X | | | | | X | X |
| | Gastropoda | | | | | | | | | | | | | | |
| | | Lymnaeidae | | | | | | | | X | | | | X | X |
| | | Planorbidae | | | | | | X | | X | | | | X | X |
| | | Valvatidae | | | | | | X | | X | | | | X | X |
| Hexapoda | | | | | | | | | | | | | | | |
| | Collembola | | | | | | X | | X | | | X | | X | X |
| | Ephemeroptera | | | | | | | | | | | | | | |
| | | Baetidae | | | | | | | | | | | | | |
| | | | *Baetis* | X | X | X | X | | X | X | X | X | X | X | X |
| | | Leptophlebiidae | | | | | | | | | | | | | |
| | | | *Paraleptophlebia* | | | | X | X | X | X | | | X | | |
| | | Heptageniidae | | | | | | | | | | | | | |
| | | | *Cinygmula* | | | | | | X | | X | | | | |
| | | | *Epeorus* | | | X | | | | | | | | | |
| | Plecoptera | | | | | | | | | | | | | | |
| | | Chloroperlidae | | | | | | | | | | | | | |

Table 2. (cont'd)

| Class | Order | Family | Genus | Alaganik | Hartney Creek | Power Creek | Ibeck Creek | Upper Pipeline | Blackhole Creek | Little Martin | Salmon Creek | Middle 18 Mile | 1971 Pond | Pipeline #4 | Goose Meadows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Haploperla* | | | | X | X | X | X | X | X | X | | |
| | | Nemouridae | | | | | | | | | | | | | |
| | | | *Zapada* | | | | X | X | X | X | | | X | | X |
| | | Perlodidae | | | | | | | | | | | | | |
| | | | *Isoperla* | X | | X | X | | X | X | | | | | |
| | Trichoptera | | | | | | | | | | | | | | |
| | | Hydroptilidae | | | | | | | | | | | | | |
| | | | *Oxyethira* | | | | | | | | | | | X | X |
| | | Limnephilidae | | | | | | | | | | | | | |
| | | | *Ecclisomyia* | | | | | | X | | | X | | | |
| | | | *Onocosmoecus* | | | | | | | X | X | | X | | X |
| | | | *Psychoglypha* | | | | | | X | X | | | X | | X |
| | | Lepidostomatidae | | | | | | | | | | | | | |
| | | | *Lepidostoma* | | | | | X | X | | | | | | |
| | Lepidoptera | | | | | | | | | | | | | | |
| | | Pyralidae | | | | | | | | | | | | | |
| | Odonata | | | | | | | | | | | | | | |
| | | Aeshnidae | | | | | | | | | | X | X | X | X |
| | Hemiptera | | | | | | | | | | | | | | |

Table 2. (cont'd)

| *Class* | *Order* | *Family* | *Genus* | Alaganik | Hartney Creek | Power Creek | Ibeck Creek | Upper Pipeline | Blackhole Creek | Little Martin | Salmon Creek | Middle 18 Mile | 1971 Pond | Pipeline #4 | Goose Meadows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corixidae | | | | | | | | | | | X | X | X |
| | | Notonectidae | | | | | | | | | | | X | | X |
| | Coleoptera | | | | | | | | | | | | | | |
| | | Haliplidae | | | | | | | | | | | | | |
| | | | *Haliplus* | | | | | | | | | | | X | X |
| | | Dytiscidae | | | | | | | | | | | | | |
| | | | *Ametor* | | | | | | | | | | X | X | X |
| | Diptera | | | | | | | | | | | | | | |
| | | Chironomidae | | | | | | | | | | | | | |
| | | | Chironominae* | | | X | X | X | X | X | X | X | X | X | X |
| | | | Diamesinae* | | | X | X | X | X | X | X | X | X | X | X |
| | | | Orthocladiinae* | X | X | X | X | X | X | X | | X | | X | X |
| | | | Tanypodinae* | | | | | X | X | X | | X | X | X | X |
| | | | Tanytarsinae* | | | | X | X | X | X | | X | X | X | X |
| | | Ceratopogonidae | | | | | | | | | | | | | |
| | | | *Bezzia* | | | | | X | X | X | | X | X | | X |
| | | | *Ceratopogon* | | | | | X | X | X | | X | X | | X |
| | | Empididae | | | | | | | | | | | | | |
| | | | *Chelifera* | | | X | X | | | X | X | | | | |

Table 2. (cont'd)

| Class | Order | Family | Genus | Alaganik | Hartney Creek | Power Creek | Ibeck Creek | Upper Pipeline | Blackhole Creek | Little Martin | Salmon Creek | Middle 18 Mile | 1971 Pond | Pipeline #4 | Goose Meadows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Oreogeton* | | | | | | | | | | | | |
| | | Psychodidae | | | | | | | | | | | | | |
| | | | *Pericoma* | | | | | | | | | | | X | X |
| | | Simuliidae | | | | | | | | | | | | | |
| | | | *Simulium* | | | | X | X | X | X | | | X | | X |
| | | Sciomyzidae | | | | | | | | | | | | X | |
| | | Tipulidae | | | | | | | | | | | | | |
| | | | *Antocha* | | | | | | | | | | X | | |
| | | | *Dicranota* | | | | | | X | X | X | | | | X |
| **Total** | **19** | **27** | **27** | **4** | **7** | **9** | **14** | **17** | **23** | **23** | **11** | **15** | **23** | **25** | **31** |

Table 3. Selected macroinvertebrate indices for stream channel types within the Copper River Delta, Southcentral Alaska.

| Site | Channel Type | Mean Total Abundance (n=18) | Mean % EPT | Mean % Diptera | Mean % Non-Insect |
|---|---|---|---|---|---|
| Alaganik | ES | 62.4 | 3.2 | 73.3 | 23.5 |
| Hartney Crk | ES | 300.7 | 0.3 | 4.6 | 95.1 |
| BlackHole | FP | 152.7 | 7.5 | 80.2 | 12.2 |
| Lt. Martin | FP | 203.2 | 20.8 | 65.9 | 13.4 |
| Ibeck Crk | GO | 30.6 | 16.6 | 78.3 | 5.0 |
| Power Crk | GO | 68.9 | 8.7 | 87.4 | 3.9 |
| 1971 pond | MC | 101.6 | 14.1 | 66.3 | 19.6 |
| Pipe Up | MC | 73.8 | 11.9 | 74.1 | 13.9 |
| 18 Middle | PA1 | 153.5 | 10.4 | 72.3 | 17.2 |
| Salmon Crk | PA1 | 163.8 | 6.7 | 85.4 | 7.9 |
| Goose | PA5 | 173.2 | 3.4 | 38.4 | 55.2 |
| Pipe #4 | PA5 | 141.1 | 0.9 | 43.3 | 52.5 |

Table 4. Mean relative abundance of subfamilies of the Chironomidae among stream channel types of the Copper River Delta, Southcentral Alaska, 2005 & 2006.

| Site | Channel Type | % Chironominae | % Diamesinae | % Orthocladiinae | % Tanypodinae | % Tanytarsinae |
|---|---|---|---|---|---|---|
| Alaganik | ES | 1.8 | 16.9 | 77.2 | 0.2 | 3.9 |
| Hartney Crk | ES | 5.5 | 24.7 | 57.1 | 1.6 | 0.0 |
| BlackHole | FP | 0.2 | 28.4 | 58.6 | 6.7 | 6.1 |
| Lt. Martin | FP | 0.5 | 61.7 | 26.0 | 4.5 | 7.2 |
| Ibeck Crk | GO | 0.6 | 51.5 | 47.5 | 0.0 | 0.4 |
| Power Crk | GO | 0.3 | 22.7 | 75.4 | 0.0 | 1.6 |
| 1971 pond | MC | 31.9 | 29.0 | 13.2 | 20.6 | 5.3 |
| Pipe Up | MC | 2.5 | 23.2 | 18.4 | 8.1 | 47.8 |
| 18 Middle | PA1 | 11.3 | 27.2 | 42.6 | 6.8 | 12.0 |
| Salmon Crk | PA1 | 1.3 | 69.9 | 27.9 | 0.0 | 0.8 |
| Goose | PA5 | 0.0 | 8.9 | 18.2 | 2.9 | 70.0 |
| Pipe #4 | PA5 | 16.7 | 8.5 | 17.3 | 5.0 | 52.5 |

Table 5. Dominant invertebrate taxa by functional feeding group among Copper River Delta streams across channel type and year (2005-2006).

| Stream | Channel Type | Collector Gatherers | Collector Filterers | Scrapers | Shredders | Predators |
|---|---|---|---|---|---|---|
| Alaganik | ES | Orthocladiinae | * | Diamesinae | * | * |
| Hartney | ES | Oligochaeta | * | * | Amphipoda | * |
| Power Crk | GO | Orthocladiinae | * | Diamesinae | * | *Haploperla*<br>*Isoperla* |
| Ibeck Crk | GO | Orthocladiinae | * | Diamesinae | * | *Haploperla*<br>*Isoperla* |
| Pipeline Up | MC | Orthocladiinae<br>*Paraleptophlebia* | *Simulium* | Diamesinae<br>Planorbidae | *Lepidostoma*<br>*Zapada* | Tanypodinae<br>*Ceratopogon* |
| 1971 Pond | MC | Chironominae<br>*Paraleptophlebia* | Tanytarsinae | Diamesinae<br>Planorbidae | *Onocosmoecus*<br>*Psychoglypha* | Tanypodinae<br>*Ceratopogon* |
| BlackHole | FP | Orthocladiinae<br>*Baetis* | *Simulium*<br>Tanytarsinae | Diamesinae<br>*Cinygmula* | *Ecclisomyia* | Tanypodinae<br>*Ceratopogon* |
| Lt. Martin | FP | Orthocladiinae<br>*Baetis* | *Simulium*<br>Tanytarsinae | Diamesinae<br>Planorbidae | *Zapada* | *Haploperla*<br>*Isoperla* |
| Salmon Crk | PA1 | Orthocladiinae<br>*Baetis* | Tanytarsinae | Diamesinae | Zapada | *Haploperla*<br>*Isoperla* |
| Middle 18 | PA1 | Orthocladiinae<br>*Baetis* | *Simulium* | Diamesinae | *Ecclisomyia*<br>*Onocosmoecus* | Tanypodinae |
| Pipeline #4 | PA5 | Orthocladiinae<br>Copepoda | Cladocera<br>Sphaeriidae | Diamesinae<br>Planorbidae | Ostracoda<br>*Haliplus* | Tanypodinae<br>*Ceratopogon* |
| Goose | PA5 | Orthocladiinae<br>Copepoda | Cladocera<br>Sphaeriidae | Diamesinae<br>Planorbidae | Ostracoda<br>*Haliplus* | Tanypodinae<br>*Ceratopogon* |

* functional feeding group represents ≤ 1% of total mean abundance.

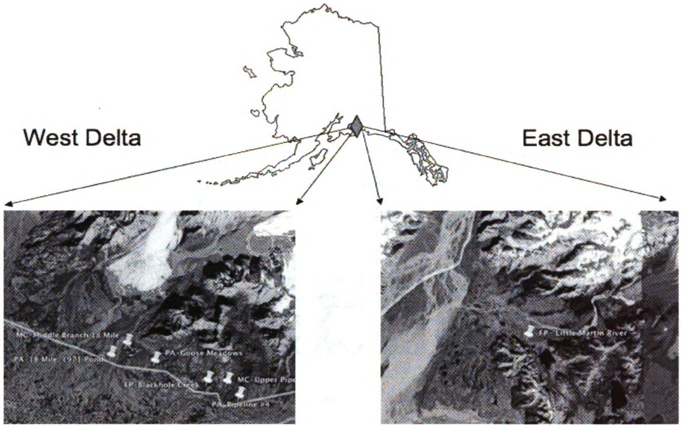


Figure 1. Copper River Delta, Chugach National Forest, Southcentral Alaska.

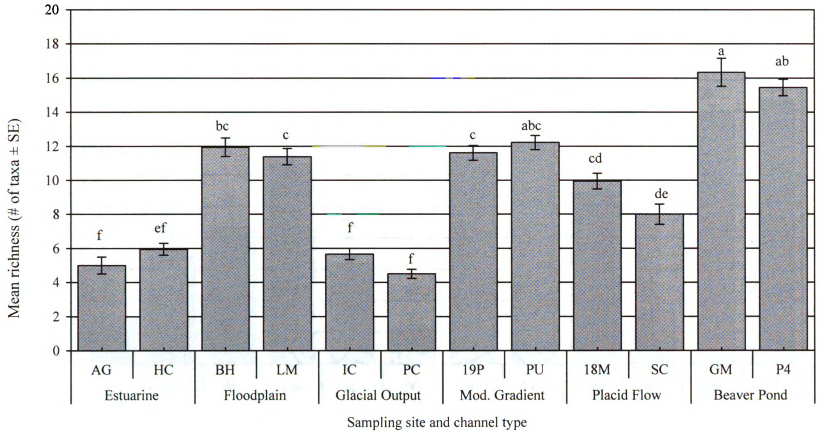


Figure 2. Mean richness of invertebrates among streams across channel type over entire study period (2005 and 2006). Means with different letters are significantly different (Tukey HSD, $p<0.05$).

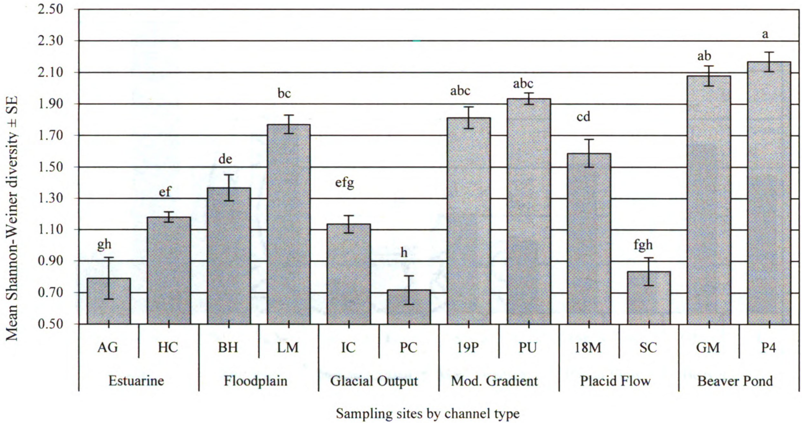


Figure 3. Mean Shannon-Weiner diversity of invertebrates among streams across channel type over the entire study period (2005 and 2006). Means with different letters are significantly different (Tukey HSD, $p<0.05$)

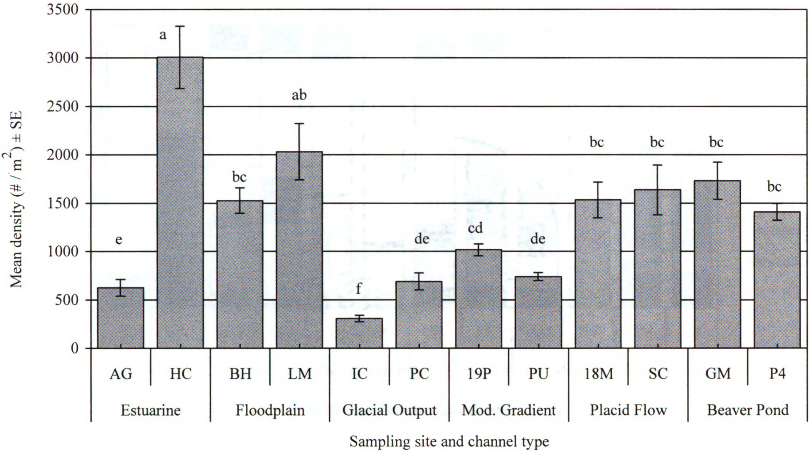


Figure 4. Mean densities of invertebrates among sampling sites across channel type over entire study area (2005 and 2006). Means with different letters are significantly different (Tukey HSD, $p<0.05$).

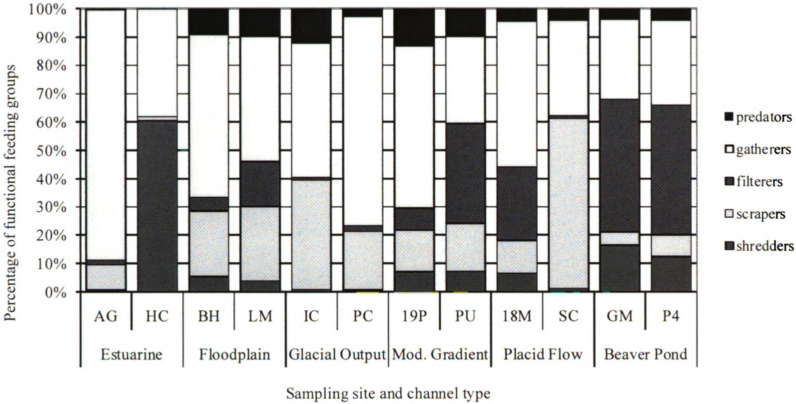


Figure 5. Percentage of functional feeding groups, based on abundance, present among streams across channel types over the entire study period (2005 and 2006).

APPENDIX

Appendix 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2009-07

Title of thesis or dissertation (or other research projects):

BENTHIC COMMUNITY MEASURES AMONG STREAM CHANNEL TYPES OF THE COPPER RIVER DELTA, SOUTHCENTRAL ALASKA.

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)

TODD C. WHITE

Date 15, XII 2009

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:
Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

## Appendix 1.1

Voucher Specimen Data

Page 1 of 3 Pages

| Species or other taxon | Label data for specimens collected or used and deposited | Number of: Eggs | Larvae | Nymphs | Pupae | Adults ♀ | Adults ♂ | Other | Museum where deposited |
|---|---|---|---|---|---|---|---|---|---|
| | USA, AK, Copper River Delta | | | | | | | | |
| AMPHIPODA | | | | | | | | | |
| Corophiidae | Hartney Creek 22, VII 2005 | | | 2 | | | | | |
| Gammaridae | Hartney Creek 22, VII 2005 | | | 3 | | | | | MSU |
| CLADOCERA | Goose Meadows 26, VII 2005 | | | 1 | | | | | MSU |
| COPEPODA | Goose Meadows 26, VII 2005 | | | 5 | | | | | MSU |
| HYDRACHNIDA | Goose Meadows 26, VII 2005 | | | 4 | | | | | MSU |
| HIRUDINEA | Goose Meadows 26, VII 2005 | | | 1 | | | | | MSU |
| ISOPODA | Hartney Creek 22, VII 2005 | | | 3 | | | | | MSU |
| OLIGOCHAETA | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |
| TRICLADIDA | Goose Meadows 26, VII 2005 | | | 4 | | | | | MSU |
| BIVALVIA | | | | | | | | | MSU |
| Sphaeriidae | Little Martin R. 25, VIII 2005 | | | 2 | | | | | MSU |
| GASTROPODA | | | | | | | | | MSU |
| Lymnaeidae | Little Martin R. 25, VIII 2005 | | | 2 | | | | | MSU |
| Planorbidae | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |
| Valvatidae | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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Voucher No. 2009-07

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date

## Appendix 1.1

Voucher Specimen Data

Page_2__of_3__Pages

| Species or other taxon | Label data for specimens collected or used and deposited | Number of: Eggs | Larvae | Nymphs | Pupae | Adults ♀ | Adults ♂ | Other | Museum where deposited |
|---|---|---|---|---|---|---|---|---|---|
| | USA, AK, Copper River Delta | | | | | | | | |
| COLLEMBOLA | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |
| EPHEMEROPTERA | | | | | | | | | MSU |
| Baetidae *Baetis spp.* | Goose Meadows 26, VII 2005 | | | 4 | | | | | MSU |
| Heptageniidae *Cinygmula spp.* | Blackhole Creek 2, VIII 2005 | | | 4 | | | | | MSU |
| Heptageniidae *Epeorus spp.* | Power Creek 22, VII 2005 | | | 2 | | | | | MSU |
| Leptophlebiidae *Paraleptophlebia spp.* | 1971 Pond 3, VIII 2005 | | | 4 | | | | | MSU |
| PLECOPTERA | | | | | | | | | MSU |
| Chloroperlidae *Haploperla spp.* | Ibeck Creek 4, VIII 2005 | | | 3 | | | | | MSU |
| Nemouridae *Zapada spp.* | Upper Pipeline 2, VIII 2005 | | | 3 | | | | | MSU |
| Perlodidae *Isoperla spp.* | Little Martin R. 25, VIII 2005 | | | 3 | | | | | MSU |
| TRICHOPTERA | | | | | | | | | MSU |
| Lepidostomatidae *Lepidostoma spp.* | Upper Pipeline 2, VIII 2005 | | | 1 | | | | | MSU |
| Limnephilidae *Ecclisomyia spp.* | 18 Mile Middle Br. 20, VII 2005 | | | 2 | | | | | MSU |
| Limnephilidae Onocosmoecus spp. | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |
| Limnephilidae Psychoglypha spp. | Goose Meadows 26, VII 2005 | | | 2 | | | | | MSU |
| | | | | | | | | | MSU |

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

TODD C. WHITE

Date 15, XII 2009

Voucher No. 2009-07

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Curator Date

# Appendix 1.1

Voucher Specimen Data

Page 3 of 3 Pages

| Species or other taxon | Label data for specimens collected or used and deposited | Number of: Eggs | Larvae | Nymphs | Pupae | Adults ♀ | Adults ♂ | Other | Museum where deposited |
|---|---|---|---|---|---|---|---|---|---|
| | USA, AK, Copper River Delta | | | | | | | | |
| ODONATA | | | | | | | | | MSU |
| Aeshnidae | Goose Meadows 26, VII 2005 | | | 1 | | | | | MSU |
| HEMIPTERA | | | | | | | | | MSU |
| Corixidae | Goose Meadows 26, VII 2005 | | | 1 | | | | | MSU |
| Notonectidae | Goose Meadows 26, VII 2005 | | | 1 | | | | | MSU |
| COLEOPTERA | | | | | | | | | MSU |
| Haliplidae *Haliplus spp.* | Goose Meadows 26, VII 2005 | | | | | 2 | | | MSU |
| Dytiscidae *Ametor spp.* | Goose Meadows 26, VII 2005 | | | | | 2 | | | MSU |
| DIPTERA | | | | | | | | | MSU |
| Chironomidae | Goose Meadows 26, VII 2005 | | 10 | | | | | | MSU |
| Ceratopogonidae *Bezzia spp.* | Little Martin R. 25, VIII 2005 | | 1 | | | | | | MSU |
| Ceratopogonidae *Ceratopogon spp.* | Little Martin R. 25, VIII 2005 | | 2 | | | | | | MSU |
| Empididae *Chelifera spp.* | Ibeck Creek 4, VIII 2005 | | 1 | | | | | | MSU |
| Psychodidae *Pericoma spp.* | Goose Meadows 26, VII 2005 | | 2 | | | | | | MSU |
| Simuliidae *Simulium spp.* | Blackhole Creek 2, VIII 2005 | | 2 | | | | | | MSU |
| Tipulidae *Dicranota spp.* | Little Martin R. 25, VIII 2005 | | 1 | | | | | | MSU |

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

TODD C. WHITE

Date 15, XII 2009

Voucher No. 2009-07

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Curator Date

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