Rufus Woods Lake – Columbia River
Reservoir Morphometrics, Initial Food Web and Rainbow Trout Fishery Studies

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Executive Summary

This study was conducted to provide a baseline and preliminary understanding of the food web and physical habitat of Rufus Woods Lake (RWL), a run-of-the-river hydropower reservoir located downstream of Grand Coulee Dam, so that the rainbow trout fishery can be more efficiently managed or enhanced. A laudable goal for RWL is to create a sustainable fishery. However, a myriad of information is needed to fully understand a complex and rapidly changing reservoir such as Rufus Woods Lake.

Commercial net pens are used in RWL within Colville Confederated Tribal jurisdiction to rear and in some cases intentionally release sterile rainbow trout (RBT). Determination of possible net pen effects was not the primary goal of this study, although positioning of sampling locations was performed throughout the reservoir with consideration to net pen location. Generally conditions for rearing RBT in net pens are good in RWL. However, high river flow years and operating practices of Grand Coulee Dam have resulted in supersaturated dissolved gas, gas bubble disease of aquatic organisms and severe mortality of the pen fish used for enhancing the fishery and for commercial fish farm production. As most of the fish caught in the RWL fishery are from net pen origin, the net pens are considered an important tool for managing the RBT fishery.

Presently, relatively large size RBT released by the CCT into RWL are purchased from net pen growers operating in the reservoir. RBT are released at different intervals throughout the year for fishing by CCT members and non-treaty anglers. The fish are very heavy relative to length, and little was known about their diet after release, longevity in the reservoir, the supporting food web and the distribution of different types of habitat in the system. Our study incorporates information from companion studies conducted by the CCT Fish and Wildlife Department that involved collection of fish stomachs for analyses of contents by our team. CCT also conducted an acoustic tagging study with a separate contractor that is being completed at the time of this report production. We surveyed the reservoir extensively to create a digital bathymetric map so that the morphometrics of the reservoir could be documented in relation to habitat features, focusing on the biologically-active littoral (nearshore) zone. Food web studies included benthic sampling using suction dredging, cobble basket deployments, periphyton (attached benthic algae) studies using tile samplers and cobble scrapes were conducted at a number of locations and times throughout RWL beginning in August 2010 and extending through the summer of 2011.

To place our results within the context of changing interannual conditions, we reviewed basic water quality conditions in the Grand Coulee Dam tailrace from the past decade and contrasted those results to conditions in 2010 and 2011 during this study. Several experienced observers of RWL had noted that in 2010 and 2011, macrophytes (rooted plants) were covered with epiphytic growth and many had a slime-like coating.

Morphology of RWL

The bathymetric map and subsequent geographic information study (GIS) study indicated that the reservoir can indeed be considered as having three regions as first proposed by Dr. Quentin Stober in 1977: 1) a relatively shallow, narrow and very fast flowing tailrace that is retained with a large amount of revetment on the right bank (looking downstream); 2) a generally wider and moderate depth fast flowing mid river section from Seaton's Grove many miles downstream to an area where river width increases with depth forming; and 3) a shorter Chief Joseph Pool area with greater depths and apparent reduced water flow velocities (Erickson et al. 1977). RWL is unique among mid and lower Columbia River reservoirs due to its very narrow, relatively deep morphology that limits the amount of backwater fisheries and wildlife riparian habitat.

The digital map was analyzed to construct tables of littoral habitat and other features that indicated:

- RWL is 11% shallow littoral by surface area and 2% by volume
- Upper reservoir is 23% littoral by surface area and 6% by volume
- Middle reservoir is 11% littoral by surface area and 2% by volume
- Lower reservoir is 7% littoral by surface area and 1% by volume
- Upper reservoir has highest, lower reservoir the lowest percent of shallow littoral-zone habitat
- Mixtures of fines, gravel and cobble are most dominant habitat class
- Hard bottom habitat is dominant in upper reservoir
- Macrophytes and filamentous algae are most common in lower reservoir, least common in upper reservoir
- Medium littoral zone slopes are most common in RWL; steep slopes are least common
- Steep and medium backshore slopes are most common; low slopes are less common
- The habitat types can eventually be related to food web production contribution, but that was not attempted in this preliminary project

Water Quality

We provide water quality data analysis to illustrate that water entering RWL in the two study years of 2010 and particularly 2011 exhibited increased concentrations of total phosphorus and dissolved inorganic phosphorus (orthophosphate) after a multi-decade period of declines to the 2000-2009 period that qualified the reservoir as nutrient poor (oligotrophic). Several other water quality variables showed major departures from the norm especially in 2011 including: elevated ammonia-nitrogen, water column chlorophyll *a* (an indicator of phytoplankton standing stock), fecal coliform, turbidity. Concurrent reduced dissolved oxygen concentrations were measured.

The specific causes of the water quality change entering the reservoir appears to be related to higher than normal, midsummer river discharge in 2010 and much higher-than-normal river discharge in most of 2011. High flows in regulated rivers may result in shoreline flooding and erosion and resuspension of bed load (river bottom) which mobilizes nutrients and fecal coliforms from riparian and tributary runoff. High flows in 2011, combined with the use of spill through "diffuser ports" in the face of the dam instead of spillway (over the top) discharge and the loss of turbine generation through poorly-timed maintenance work, all resulted in excessively high total dissolved gasses in RWL for weeks. Wild fish (including ESA-listed fish downstream) and invertebrates were adversely affected by this unfortunate event and millions of dollars of fish loss occurred at the net pens in RWL. Such events have happened previously, but the cumulative effects on the food web for our study are not fully known and no mitigation has been attempted for waters within Rufus Woods Lake.

Macrophytes, Periphyton and Blue Green Algae

Given the above, our study occurred at the most inopportune time if we were interested in documenting "normal conditions", but we were able to seize the opportunity to understand the system in its perturbed state by increasing our emphasis on algal communities that appeared to be altered and worked cooperatively with other users and managers of RWL.

We found noxious forms of filamentous periphyton and benthic diatoms on macrophytes throughout the lake where macrophytes occurred, often varying highly in density over scales of a few meters distance that was related to difference in exposure to water currents. Areas of high flows had macrophytes that were mostly free of periphyton, but macrophytes in calm areas were much more commonly covered with periphyton including dominance by the noxious species *Spirogyra* sp. and *Cladophora* sp. The former has been a problem in upstream reaches and tributaries of the Columbia River and the latter was a major problem in the pre-1990 era when thousands of kilograms per day of phosphorus were being discharged into Lake Roosevelt from a fertilizer plant in Canada. At that time, *Cladophora* sp. formed large floating mats in Lake Roosevelt that led to the call for phosphorus discharge abatement.

An additional problem occurred in 2011 with the appearance of floating mats of algae in RWL that tested positive for anatoxin-*a*, a biotoxin associated with blue green (cyanobacteria) algae. The reservoir was posted by the US Army Corps of Engineers to warn user groups. Sampling by USACE and consultants for Pacific Seafoods showed the presence of small densities of *Oscillatoria* sp., a potentially toxic blue green organism. Professor Wayne Carmichael was hired by Pacific Seafoods to advise and conduct taxonomic analysis of samples along with a consultant hired by the USACE. A 1999-2000 study downstream of downstream Rocky Reach Reservoir indicated blue green algae had peak biovolume occurrences in February, June, and August and were principally represented by *Oscillatoria* spp. and *Aphanizomenon flos-aquae*. These species were found in subsamples in RWL in 2011 mostly within floating mats accumulating just above Chief Joseph Dam along the boomstick used to catch debris (although the latter species is often misidentified). While conducting bathymetric surveys, we navigated the entire shoreline area in depth of < 5 m on both banks to make observations about the presence or absence of filamentous periphyton growth on macrophytes. We observed and sampled floating mats from upstream in RWL near Buckley Bar for algal species composition and abundance and found variable concentrations throughout the lake, suggesting the possibility of an upstream source. However, limited observations in Banks Lake and lower areas of Lake Roosevelt did not detect any of the floating mats, thus the actual source distribution of the mats remains undetermined. These algal events, along with the shift in water quality observed, augur strongly for the need to monitor Rufus Woods Lake more closely in the future and to seek to understand the source of the degraded conditions. No evidence collected to date indicates that the RWL net pens caused or exacerbated the 2011 periphyton conditions discussed herein, but as noted above, the determination of net pen effects was not a primary goal of this study.

Food Web Conditions for Rainbow Trout

Studies of primary and secondary productivity and standing stock were conducted in RWL during August 2010 through September 2011. These included: 1) cobble scrapes and artificial substrate sampling of periphyton to document periphyton assemblage structure, colonization, and primary productivity of periphyton and 2) benthic suction dredge sampling within the littoral zone and placement and recovery of cobble baskets to document benthic assemblage structure, estimate invertebrate colonization, and benthic secondary production standing crop both spatially and temporally within RWL.

Periphyton Growth Substrate Tile

Periphyton, (a complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces), include a wide array of possible autotrophic (photosynthetic) taxa, heterotrophic (non-photosynthetic that use organic carbon instead of fixing it) taxa or mixtures of the two. They are extremely useful indicators of trophic level and ecological status in freshwater aquatic systems when assessed for taxonomic composition and community structure, biomass (i.e., chlorophyll *a* and ash free dry mass concentration per unit area substrate) and autotrophic index (in this case chlorophyll *a* concentration divided by ash free dry weight of sample).

We collected and analyzed periphyton samples collected in August 2010, September 2010, October 2010, and July 2011 from several locations throughout RWL. Statistical analyses included non-metric multidimensional scaling (NMS) ordination to explore and document spatial and temporal periphyton assemblage structure. NMS allowed us to visualize relationships in the periphyton assemblages and then formally test several of these inferred relationships including location, depth, and seasonal differences using ANOVA and other standard statistical procedures. We then analyzed and compared chlorophyll *a*, ash free dry mass (AFDM), an autotrophic index (AI), and soft bodied algae relationships in RWL and with other select river systems.

We found seventy six algal taxa in RWL that formed assemblages which varied by relative abundances and composition. These assemblages varied by location, season, and to a lesser extent depth, soft bodied algae vs. diatoms, and early colonizing taxa vs. later successional taxa. Several soft-bodied algae dominated the algal assemblages including at least two noxious filamentous green algal taxa, *Cladophora* sp. and *Spirogyra* sp., as well as a potentially toxic cyanobacterial species, *Oscillatoria* sp. In addition, one cobble scrape from the middle reaches of RWL contained 2 cells of *Didymosphenia gemenata,* a nuisance species that has reached epidemic proportions in several large tail water tributaries of the Columbia River upstream of RWL. Periphyton chlorophyll *a* concentrations in October 2010 data varied by site and depth with a mean of 12.8 mg/m^2 (median = 7.9 mg/m^2). AFDM was not observed to statistically vary by location, season, or depth and had a mean of about 11g/m^2 (SE = 0.5g/m^2). The autotrophic index varied by location with a mean of 0.16 (SE = 0.02), indicating that autotrophic conditions predominated in many locations in RWL in October 2010. Chlorophyll *a* and AFDM values in our study were within the range of values found in other temperate, western North American riverine systems.

Suction Dredge Sampling

We collected benthic samples using suction dredge and SCUBA from quadrats at various benthic habitats and depths (1 to 8 m) in October 2010 and April and July 2011 from five locations in RWL. The resulting data were analyzed with NMS ordination to determine spatial and temporal relationships of benthic assemblages. We then conducted several additional statistical analyses including summary statistics and other graphical representations of the most important data. We estimated energy densities and caloric values of the benthic assemblages and explored basic ecology of the assemblages in relation to RBT diets and with other fisheries.

Benthic assemblages varied with season and location. Location differences were primarily due to the different habitats sampled between the upstream (primarily cobble) and downstream (primarily fine sediments and macrophytes) sites. The overall mean benthic invertebrate density was 2,385/m^2 (SE = 390; Min = 48.7; Median = 1,542; Max = 10,415). We consider these densities to be within the normal range for many trout fisheries but tending towards the low end. About 33 families of benthic invertebrates were collected from a wide array of life histories and ecologies, which translates to the availability of RBT diet items throughout the year. Sculpins, an important trout food item, were observed in all the upstream (upper and mid reservoir) sites but not in any of the downstream sites (lower reservoir). Estimated sculpin density ranged from about 1-10/m^2 in the upstream sites. Benthic dry weights were highly variable due to occasional large crayfish, caddisflies, or snails in the samples. The mean dry weight of the October 2010 samples (without crayfish) was 4.29 grams/m^2 (1SE = 0.43, Q1 = 0.15, Median = 1.66, and Q3 = 7.26). Estimated dry weight samples with crayfish was 34 g/m^2. Crayfish were often extremely abundant in RWL, especially in the mid to upper river sections.

An extremely important finding in the suction dredge sampling was that we did not collect any native signal crayfish, *Pacifastacus leniusculus*; however, 431 invasive Cambaridae crayfish were collected. These non-native crayfish are highly invasive and when established may have far reaching effects on biodiversity, community structure, energy transfer, food webs, effects on fisheries, and severe effects on the structure and functioning of RWL. Cambaridae crayfish are known predators of snails, an important RBT food item in RWL. Crayfish and snail abundance were significantly negatively correlated with each other.

Functional feeding group analysis relates the types of feeding strategies of organisms in relation to their food resources. Functional feeding groups in suction dredge samples were dominated by gatherers (70-90% of the total). The most common gatherers were midges, worms, and, scuds (amphipods). Scrapers were the next most abundant feeding group and most of these were snails. Oligochaetes (worms), crustaceans, midges, and snails were typically the most dominant taxa in the benthos. Suction dredge samples were only collected in the littoral zone and may not entirely reflect benthic assemblages that occur at greater depths. The absence or low densities of mayflies, stoneflies, and caddisflies in our samples suggest that RWL is somewhat compromised in its biological integrity due to reservoir flow regulation that does not match the requirements of these species.

The seasonal and location differences in benthic macroinvertebrate assemblages can directly affect trout diets and their distribution in RWL. In order to survive and grow, trout must learn to recognize, track, and successfully forage for these benthic assemblages as they vary by location and season.

Cobble Baskets

We placed twenty metal barbecue baskets stocked with conditioned cobbles at 3, 9 and 15 meters depth and seven locations in RWL starting on August 28 and 31, 2010. Invertebrates were collected from cobbles, counted, and identified on six collection dates. We conducted several summary statistics and created graphs with the data. We also conducted ANOVAs to examine the effects of depth, month, and location differences in total abundances of invertebrates.

Over 100,000 organisms were identified from the baskets. Dominant taxa included hydra, flatworms, scuds (amphipods), snails and segmented worms. Three of the 86 baskets had thousands of organisms each, ranging from 5,600 to 92,000 individuals, but were dominated by just a few taxa. The remaining baskets had an average of 128 organisms each, mostly flatworms and hydra. Relative abundance of taxa in the cobble baskets was similar to that found in suction dredge sampling. However, important components of the benthic community such as crayfish were not represented in the cobble baskets in most cases. These baskets were also subject to vandalism and loss, and sometimes were compromised by being trapped in macrophyte beds. Properly constructed, placed and sampled cobble baskets remain a potentially powerful tool for further studies in RWL.

Trout Stomach Samples

CCT biologists and technicians collected a total of 409 fish stomach samples during their creel surveys from April 2010 to August 2011 and from a gillnet study conducted on June 7, 2011 and July 7, 2011. Organisms in stomachs were identified to lowest practical taxon along with documentation of remnants of fish pellets and other contents. We calculated several summary statistics and graphically analyzed the stomach content data, again focusing primarily on RBT stomach contents.

At the time of this report, we had access to 2010 RWL creel census length and weight RBT data with a total of 179 fish. A large proportion (61%) of the total was less than 1.6 kg, the mean size of releases in 2010 and 2.9% of these fish were adipose clipped, indicating Lake Roosevelt enhancement project origin. Most of the acoustically tagged net pen RBT that were later recovered lost weight (about 5% loss) but this was for an average period of only 17 days and a small sample size. These data do not necessarily explain the origin of all the smaller fish, but simply because a smaller (i.e., < ~ 1 kg) fish is not fin clipped does not mean it is a RWL net pen fish, as the RWL net pen fish periodically and unintentionally escape. Given that most acoustically tagged fish were tracked and present for a short time (a few days to several months) and the mean residence time of acoustic tagged fish recovered was only a few weeks, as well as the fact that the mean weight loss of the acoustically tagged fish recovered averaged 5%, we believe that some of these smaller fish may have been RWL or Lake Roosevelt net pen escaped *f*ish. However, we cannot discount the possibility of natural production of RBT in RWL because there may be suitable gravels for spawning and in the past Lake Roosevelt hatchery fish were often diploid (not sterile). CCT managers have thought there is little natural RBT production in RWL, but no dedicated study of the issue has occurred. One of us (JR) has documented other wild Chinook salmon spawning in the mainstem below Wells Dam where gravels were highly suitable for salmonid spawning.

Diets of the 409 fish from 2010 and 2011 we examined varied significantly among fish within and between time periods. At least 96 separate prey taxa (mostly identified and grouped by family level) were found in the stomach samples ranging from a total of 56,273 individual organisms in RBT stomachs; 5,428 organisms in walleye stomachs and 175 organisms in northern pike minnow stomachs. Twenty five percent of the RBT stomachs (N = 73) were empty but there was significant variation of mean percent empty among sampling periods. Of the remaining 75%, most had < 4 different kinds of prey taxa in their stomachs. The mean number of taxa occurrence in RBT stomachs varied between months with the overall mean = 2.6 taxa. Aquatic based food items made up more of the RBT diet than did terrestrial food items but terrestrial food items were almost always present in stomachs except in Jan/Feb 2011 and March 2011 samples. There was also an obvious seasonal shift in diets. The vast majority of individual organisms in RBT stomachs were very small pelagic crustaceans (e.g. daphnia, copepods, ostracods, etc.) followed by diptera (midges and flies), snails, and terrestrial arthropods (insects and spiders).

There are tradeoffs (costs) between food energy content, the amount of time and effort needed to capture and handle food items and their digestibility. Crayfish and fish were less abundant food items in RBT stomachs than other taxa but obviously are much larger than almost all of the other food items. From 14 to 17% of the RBT stomachs examined contained crayfish (9%) or fish (5-8%). However, most of the crayfish and fish occurred in only a few trout stomachs. This could indicate that few RBT had acquired the skill or ability to feed on this often abundant food source in RWL, particularly in light of the fact that most of the RBT were large fish (> 30 to 40 cm). Snails were abundant in RWL and provided a substantial portion of RBT diets throughout the study even though they have indigestible calcareous shells which do not provide food energy. Most of the other taxa consumed by RBT in this study were more or less similarly digestible for RBT depending on if they were soft bodied as larvae or adults (more digestible, e.g. mayflies, dragonflies, worms, etc.); hard bodied larvae or adults (less digestible, e.g. scuds, beetles, etc.); their availability as adults when emerged (low to moderate capture rates, e.g. dragonflies, mayflies, caddisflies, etc.) or if they were cryptic or in habitats mostly unavailable to RBT (low capture rates, e.g. worms beneath the reservoir bottom surface). Many of this sessile or semi-sessile prey require less energy to capture than do crayfish and fish. The proportion of such prey in RBT diets should more or less be related to their relative abundances, availability, capture rates, and handling times, all of which were supported by the stomach sample data. Water column surface feeding by RBT on terrestrial invertebrates occurred throughout the study, even in early winter.

Walleye and RBT diets were similar except that proportionally, walleye had substantially more pelagic crustaceans than did RBT. However, 36% of the walleye stomachs contained fish as compared with 5 to 8% of the RBT stomachs. Creel census walleye were approximately 40 to 52 cm length, an important consideration when choosing a revised RBT planting size. Most of the food items found in RBT and walleye diets were also found in northern pike minnow but at different percentages. It appears that all three species' (RBT, walleye, and northern pike minnow) diets overlap to some extent and all three species are indirect competitors. It also appears that the invasive crayfish may also compete with RBT for snails (and other benthic prey), which may have strong fisheries management implications as such crayfish sometimes can become extremely abundant.

Recommendations

Our study was the first of its kind in RWL and this study should be considered as a baseline study for future research. This study included: habitat mapping, physical, chemical, and biological (algae and invertebrates) assessments of water quality, estimations of periphyton and invertebrate standing crops, and prey item availability and diets of several fish species with a focus on the RBT fishery. There is also wealth of information contained in the raw data analysis files that we have provided to CCT that can be used to address further management questions. We recommend continuation of these studies in RWL, particularly in light of the fact that the two years when we conducted the research were abnormal high flow years with associated and disturbing anomalies of water quality and algal communities in RWL.

We reemphasize that water quality is critical for maintaining and managing fisheries in RWL. The usefulness of algae (periphyton) and invertebrate population assessments in river water quality biomonitoring programs is well established and has many advantages compared to the use of chemical water quality measures. However, no biomonitoring of RWL water quality has ever been conducted on a regular basis except for stable isotope monitoring of invertebrates near fish farms. Our data provides this baseline information and can be used in the future along with nutrient, chlorophyll and water transparency to track the health of this water body. We do not envision the need for any one agency or organization to address the extensive list below, but hope that cooperation among stakeholders will occur.

Habitat Surveys

Our habitat surveys were based on ~0.5 km (1/3 mile) increments of the littoral zone of RWL. We readily acknowledge that in some locations this is an insufficiently short increment. It is, however, simple to perform such surveys and add to the existing EASy GIS computer system. This is a task that Tribal staff can do at any time during the algal growing season from about April through October. Other habitat areas of RWL remain to be explored, especially conditions in the deep areas of Chief Joseph Dam pool that were not a topic of this survey. The digital bathymetric map provides a good representation of the lake bottom and overall morphometrics of RWL. However, the accuracy can be improved without further field work by manual interpolation of waypoint depth data along the shoreline in selected areas.

Periphyton

We suggest that periphyton sampling should be a high priority and continued by using quantitative and qualitative means to determine overall species composition, i.e., beneficial versus noxious species. Qualitative periphyton methods that are simple to perform include annual photographic recording of macrophyte infestation with periphyton at exact locations with replicates nearby. This method is already required near Pacific Aquaculture fish farms by CCT permit requirements and when done on a regular basis with set protocols can provide useful reservoir health information. Quantitative methods may include: 1) cobble scrapes from cobbles collected below the water surface fluctuation zone and 2) using tiles placed in cobble baskets at several depths and at permanent site locations. Each of these two methods produces different but complimentary results.

Invasive and Noxious Species

Invasive algal and invertebrate species pose a large threat to the RWL fisheries. We highly recommend that nuisance and noxious alga be monitored closely, particularly the diatom *Didymosphenia gemenata* (“didymo”) because of its presence in RWL in 2011 in the middle reach. *Spirogyra* and *Cladophora* filamentous algae are also priorities given what occurred in 2010 and 2011. Monitoring of these algae can be done concurrently with cobble scrapes and tile samples.

We also highly recommend monitoring the native and invasive crayfish populations in RWL. This well established invasive crayfish may very well severely alter the biological communities in RWL and have important effects on its fisheries. Replicated crayfish traps placed in several different habitats and locations would be an excellent cost efficient method for monitoring population dynamics and relative abundances of the native and invasive crayfish but with the understanding that there are limitations of crayfish trapping methods. Relative population estimates of crayfish and spatial distribution can easily be determined by Tribal staff through a test fishery using carefully placed and monitored traps that are operated with specific protocols. The food habits of these crayfish could potentially be determined by stable isotope analysis, as there is a growing database of such information from other studies in RWL. However, crayfish are omnivores and often shift dietary preference by season and with age, and stable isotope analysis is difficult to interpret for organism with multiple and shifting food sources.

We collected several dozen suction dredge samples in September and October 2011 from the same sites reported herein. These samples were collected to measure annual variability and potentially examine the effects of gas bubble disease on the macroinvertebrate assemblages. The samples were not part of our contract requirements and have not been analyzed but should be and future collections should be made in consecutive years in the same locations to measure annual variability and the response of macroinvertebrates in RWL to gas bubble disease.

Invertebrates

Invertebrate sampling using cobble baskets should also be continued for measuring community assemblage changes over time. Suction dredge sampling should also be continued but because of its expense, should be limited to one or two sampling dates within a year and at only three to four locations. Suction dredge sampling allows for better estimation of benthic invertebrate standing crop than does the use of cobble baskets. Again, cobble baskets and suction dredge sampling provide different but complimentary information that we consider necessary for managing RWL fisheries. The locations where we collected data and the methods we used may provide a foundation for continued routine monitoring with additional sites, relocation of sites, and modifications of the methods performed as necessary

Wild non-salmonid Fish Populations

Estimating abundances of “baitfish” other than sculpins is a research priority as little work has been done in RWL on this topic for decades. Baitfish are a potentially important food items for larger RBT, but the general lack of occurrence in most fish stomachs is an enigma and their availability and spatial/temporal habits relative to RBT feeding habits should be estimated. The existing situation is, however, an advantage if it is determined that emigration rates downstream out of RWL are high because wild salmonid juveniles including ESA listed stocks must be protected. Several capture and monitoring methods are available including gill netting, beach seining and baitfish traps. At a minimum, estimating the relative abundance of the available baitfish taxa should be conducted in several habitats and at several locations. In addition, because sculpins are a preferred food item of RBT in many trout fisheries, a better understanding of sculpin distribution and habits is recommended. Visual observations from snorkeling, underwater cameras or watercraft could be useful methods.

RWL has a large population of carp. This species is an “ecosystem engineer” that can alter river ecosystems for the worse. Carp uproot macrophytes, increase turbidity, eat benthic food items and game fish eggs. We suggest initiating a carp removal /reduction plan in RWL that should not be difficult to conduct. Carp are group spawners and many of their spawning locations are known. For example an intermittent tributary to RLW on the left bank near China Bar (and River mile 576) is a prime spawning location for carp. This backwater area could easily be netted off when carp are spawning and the fish removed. This would eliminate millions of potentially destructive carp fry from the system. Other spawning locations can also be located and netted.

Rainbow Trout

As noted above, RBT length and weight relationships suggest that some of the RBT captured in RWL were not from intentionally released RWL net pen stock. This could be due to downstream recruitment from Lake Roosevelt fish, unknown escapes from RWL net pens or possibly RBT that were reproducing in RWL. There have been no studies attempting to determine if there is a self-sustaining population of 'wild' RBT in RWL. This is an important unknown. We recommend initiating research to determine if RBT spawning habitat exists below the depth zone that we have measured and estimated visually in the current study and to more closely monitor angler captured RBT for signs of gonad development, particularly during spawning season as well as location of catch by interview. A self-sustaining population of RBT or one that is minimally augmented with hatchery fish would be much less expensive than a 'put and take' fishery. We focused much of our biological research on the mid and lower sections of RWL, and it must be stated that working in the upper region is technically difficult due to high flow rates, but it can be done if timed properly and coordinated with Grand Coulee Dam operations.

As a result of this study, we recommend that the RBT planting program be altered to produce smaller fish that are less heavy by rearing them in separate pens. The releases could be incremental but spread over more time to the extent possible. It is apparent that the overly heavy fish presently planted are popular with anglers, but the cost effectiveness of planting them seems doubtful. Estimating the true cost/benefit ratio will remain difficult until a better assessment of survival and fishery contribution of the intentionally released RBT is available. We believe the very large fish are at a behavioral disadvantage to smaller fish in having been trained in the hatchery and net pen to eat only fish food pellets for a much longer period. Less rearing time in artificial production facilities and consideration of different stocks of RBT to plant should be examined as means to improve fishery contribution. From the available stomach and food web and acoustic tagging results discussed herein, we conclude that intentionally-released RBT are often caught very quickly or disappear downstream and are not accounted for at any of the acoustic monitoring stations. When water temperatures warm above optimum, we believe these out of proportion fish may have difficulty simply maintaining their body mass and basal metabolism and those that are not skilled at wild feeding may rapidly succumb.

We recommend that additional creel census sampling be conducted, particularly during late summer, because the percentage of empty RBT stomachs varied significantly within and between years. Year 2011 was such an atypical river discharge and water quality period that the results may not be representative of normal years and the 2011 length and weight data was not yet available for our consideration. Collection and archiving of RBT and walleye scale samples should be initiated, to determine fish age and help determine fish origin. To this end, a single database of intentional and accidental fish releases from net pens from RWL and Lake Roosevelt is needed to help determine fishery contribution rates and efficiency of differing planting strategies. In addition to creel census work, variable mesh gill net sampling could be conducted over short-term periods and constantly monitored by Tribal staff, to provide a different source of fish morphometrics and stomach content data. Such information may show within lake spatial variation not presently available in the creel census data as boat anglers are highly mobile.

Judging from the limited information available of walleye size in RWL, avoidance of smaller RBT at release may be achieved by releasing RBT larger than 500 grams that would be about 37 cm fork length, using existing length and weight relationships discussed herein. It would be desirable to have more complete information on the walleye size frequency before commencing this program. A revised net pen release program should be based on separate contract rearing arrangements from the normal, overly heavy fish production system. This could be accomplished through the use of separate pens at one of the commercial fish farm sites. At release of RBT from the pens, estimates of mean size and weight as well as variance data should be gathered to help facilitate probability analysis of fish origin and as a quality assurance measure of the size frequency of the purchased fish.

Future Coordination

In the past the RBT net pen industry in Rufus Woods Lake has assisted the CCT in collecting background water quality data that was either not collected by state or federal agencies or not of high enough quality, i.e., nutrient data with very sensitive detection limits. The Washington Department of Ecology has contributed greatly by maintaining the Grand Coulee Dam tailrace water quality sampling station that constitutes the longest record of water quality in the river and in recent decades has improved greatly in detection-limit quality. The U.S. Bureau of Reclamation maintains a remote sensing water quality station downstream of Grand Coulee Dam for selected parameter that is a potentially valuable real time and historical database but needs improved quality assurance measures. The U.S. Army Corps of Engineers is the agency charged with operating and maintaining the reservoir and has conducted riparian habitat enhancement work and other management functions and has an interest in all activities within the system.

We recommend that all stakeholders coordinate and renew their efforts to share sampling and analyses of water quality, habitat and fisheries data to further the wise resource use and public benefit of Rufus Woods Lake given the recent problem in Rufus Woods Lake in 2011. The operation of Grand Coulee Dam must take into account the damage that occurs to the aquatic food web in Rufus Woods Lake in high river discharge years if any progress is to be made in maintaining a healthy fishery for Treaty and non-treaty users groups. Such coordination could include an annual meeting to discuss ongoing and future work and networking to maximize efficient use of public funds and benefits.

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Acknowledgements

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Cover page photo by Dr. David Richards, taken at Buckley Bar, looking downstream on a perfect weather day in August 2010.

Project Goals

The goal of this project was to collect limited primary and secondary productivity data in Rufus Woods Lake and compare the observations to dietary preferences of net pen origin steelhead trout, 'wild' trout, and other game and non-game fish taxa. A three dimensional GIS was utilized to build a bathymetric map of the reservoir, focusing on the extent of littoral zones that are the most productive aquatic zones of the lake. By knowing the extent of different types of habitat, a crude estimate of the productivity of the lake for supporting trout and other fisheries could be estimated and compared to other Western North American rivers. Ultimately, these data and methods could lead to a carrying capacity estimate, if the rate of growth, entrainment and emigration of released fish were known. A companion project was conducted by a separate contractor in this regard, but data could only be qualitatively considered as that project was completed at the same time as our study. In addition, data collected and analyzed in this study can be used to guide alternative fisheries management strategies.

General Description of the Reservoir

Rufus Woods Lake (hereafter abbreviated "RWL") is located in north central Washington State in the mainstem Columbia River beginning at River mile 545.1 (river km 877.3) and presently extends 51.5 miles (82.9 km) to Grand Coulee Dam at River mile 596.6 (river km 960.1) (Figure 1).

RWL is not a truly a "lake", but a very fast flushing reservoir known as a run-of-the-river reservoir, that resembles some other downstream reservoirs in the Columbia River, but is unique in its narrowness, lack of shoreline complexity and backwaters compared to downstream reservoirs. Indeed, when navigating on the river in spring runoff period, it feels more like a fast flowing river in the upper and middle reaches than like a reservoir that most people are familiar with in the Pacific Northwest. However, the pools above Chief Joseph Dam can be tranquil and lacking in apparent current at times in late summer or early fall. Unlike the other reservoirs, it is very narrow throughout most of its domain, relatively deep with a limited littoral zone. RWL is relatively young, first created in 1955 through the construction of Chief Joseph Dam as a 44 miles (71 km) reservoir. Later the dam was raised to inundate the entire distance of 51.5 miles (82.9 km) to Grand Coulee Dam. Prior to creation of the upper Columbia River dams, the section of the river inundated by Chief Joseph Dam was regarded as treacherous by natives, settlers, surveyors, and scientists that were familiar with it. In particular, the four mile section of the Nespelem Canyon, Box Canyon, etc. had many formidable rapids often with large house sized boulders that claimed the lives of many individuals (Layman 2002).

Dr. Quentin Stober and his students provided the only formal study of the reservoir and surrounds, which was done prior to the raising of Chief Joseph Dam (Erickson et al. 1977). Although these authors provided estimates of RWL morphometrics predicted to occur after impoundment, no methods were provided to explain their estimates, so subsequent quality assurance is not possible. The assessment of fisheries resources in RWL in 1997 by Stober were rather dismal, in part because the reservoir was relatively new, with turbid water from bank sloughing, excessive algal production including *Cladophora* sp. from Lake Roosevelt and a benthic community that was transitioning from a more free flowing river community to a reservoir community. Unfortunately, no attention was focused on benthic primary or secondary productivity in Stober's 1977 study or in any other prior study except some occasional efforts by fish farm consultants. Water quality and aquatic communities in RWL has also greatly changed since 1977, as discussed herein.

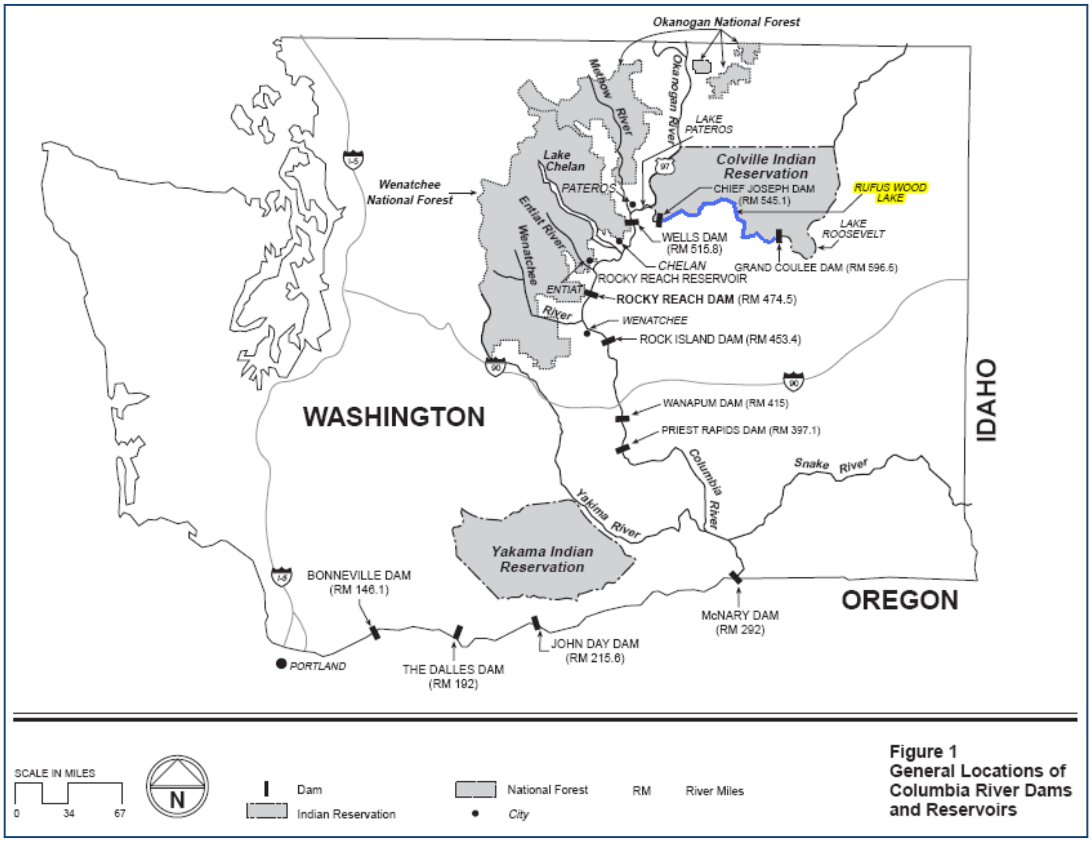
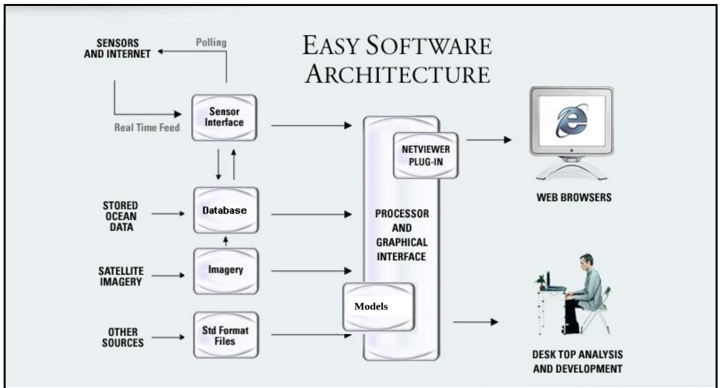


Figure 1. Vicinity map of Rufus Wood Lake (RWL), a reservoir of the mid-Columbia River bounded by Grand Coulee Dam upstream and Chief Joseph Dam downstream.

Methods

EASy Aquatic Geographic Information System

EASy (Environmental Assessment System) runs on Windows desktops and servers. It provides a 4 dimensional home (latitude, longitude, depth or altitude, and time) for the diverse types of data collected by aquatic scientists. Figure 2 shows the general capabilities of the software. The right hand side of the diagram illustrates that the software can be run as a desktop application or can be run remotely over the Internet using common browsers. The desktop mode of operations offers a greater range of capabilities and is used to create custom applications such as the one proposed here. When the application is placed on a server and the Netviewer plug-in activated the project can be viewed, analyzed, and queried interactively by the web client. The Netviewer is considered to be the most powerful, web-mapping software available. Most importantly, clients can choose data from the projects database and imagery file onto their own computer. Project information can be viewed in either of two modes: browsed independently of time or presented sequentially in time (step-wise or streamed) for selected duration and time intervals.



Components of the geographical information system. The figure also shows the 2 modes of operation, the "Netviewer" for serving information interactively over the Internet and the desktop for project development.

Figure 2. EASy GIS components.

The left hand side of the diagram illustrates that the software provides interfaces to import and visualization and processing tools to integrate the full suite of data types and formats for environmental information. As shown these data types include entries found in relational databases, raster and vector imagery, vector formats as well as multimedia and links to the Internet. Specifically, moving from bottom to top, interfaces are provided to import vector files of coastlines, shorelines, bathymetry, and stations in formats such as ESRI shapefiles and DXF. Interfaces also are provided to automatically import and geo-reference over 40 types of oceanographic imagery including those used for ocean color imagery. This interface also handles other raster formats commonly used by electron maps and photographs. EASy provides a Virtual Database Wizard for importing SQL command databases such as Access, SQL Server, and Oracle as well as Excel spreadsheets and ASCII files. Since the software contains a flexible contouring algorithm, information gridded data found in the database can be visualized not only as stations but also as contours and raster images. This facilitates data integration and analysis. At the top of the figure, one notes the capability of linking to the Internet or real-time data streams. It has full multimedia capability. Since all data that are found within a project are stored in their native format, these data can be easily exported to other commercial mapping software such as ARC View and MapServer.

As shown in the central "processing" component, the software offers tools for programming custom models and algorithms. Since the software is COM compatible, it can be easily linked to other compatible software. For example, EASy is linked to Excel so that selected data can be easily moved from the project into spreadsheets for graphical and statistical analysis. It is also linked to Visual Basic. The software contains an interface for adding custom computer code that has been compiled as a dynamic link library. Code written in FORTRAN, Visual Basic, and C can thus be added to the processing capability for a given project. EASy's API allows the programmer to take full advantage of the visualization and analysis tools that have been already developed for the software.

EASy software is described in greater detail and examples of projects developed with it are found at http://www.runeasy.com.

Bathymetry General

Bathymetric mapping was conducted beginning on August 1 to 5, 2010 (cross channel transects and many longitudinal transects); August 29, 2010 (Grand Coulee Dam tailrace); September 1, 2010 (Chief Joseph forebay); and July 27-29, 2011(additional longitudinal transects and an entire nearshore transect of the entire reservoir). Data sets from 2010 and 2011 were both collected during time periods of little water surface elevation variation.

A Garmin GPSMAP 188C (WAAS enabled) GPS/Sounder was used for all bathymetry measurements and was previously QAQC checked for depth accuracy with a surveyors tape in a calm location to about 10m depth. The unit's GPS self-reporting accuracy was checked and recorded regularly during surveying. Location accuracy was generally <3 meters at all times, and results were adjusted to account for submerged depth of the transom-mounted transducer.

A total of 7,347 shoreline GPS waypoints (0m depth) and 19,410 bathymetric waypoints were utilized for this study. Shoreline waypoints were generated using Google Earth with imagery dating to 06/30/2006 (more recent versions were affected by weather). A GPS point was collected whenever there was a minor turn or inflection of the shoreline.

All depth data were manually inspected for outliers in the software programs Garmin MapSource, Microsoft Excel and EASy GIS (bathymetry mode) and a few overly deep observations were discarded from the Chief Joseph Dam forebay.

Bathymetric waypoints were recorded during multiple longitudinal (up- and downstream) transects, cross-reservoir transects and nearshore navigation cruises along the shorelines of Rufus Woods Lake. Location and depth were recorded at each point. Longitudinal transects ran up and down lengths of the reservoir at different distances from shore. For instance, one transect was taken in the middle of the reservoir, two were taken approximately halfway between middle and shore, etc. GPS depth waypoints were recorded every ~15 m (~50 ft.) except in the Grand Coulee Dam tailrace and Chief Joseph Dam forebay, where the density was much higher.

Cross-reservoir transects were spaced at approximately 0.5 km apart, with approximately 150 transects taken in total. Each cross-reservoir transect contained anywhere from approximately 25-80 points, depending on the width of the reservoir at each transect location. Points within each transect were spaced ~3 m (10 ft.) apart.

Nearshore bathymetry GPS waypoints were recorded every ~15 m (~50 ft.), and more often whenever there were significant curves or variability in the shoreline. 'Nearshore' is defined as having a depth of < 5.5 m (18 ft.); however, this varied at times due to extreme shallows or areas with high depth variability.

Observed depth data were adjusted to correct for daily variation of Rufus Woods Lake water surface elevation through use of Chief Joseph Dam forebay elevation data and measurement of the water level relative to the ordinary high water mark observed on rock wall surfaces at different locations while surveying. Hourly high water marks at Chief Joseph Dam forebay were averaged to a daily value and then compared to an average RWL mean high water (MHW) mark of 290.5 m (953 ft.). All bathymetry measurements taken on each day were then adjusted by the difference between the daily average and the overall average (i.e., if the daily average was 0.1 m less than the overall average MHW mark, then each bathymetry point from that day was increased by 0.1 m).

Bathymetric Map Preparation

Bathymetry data were downloaded, organized and quality control inspected using Garmin MapSource and Microsoft Excel software; a few waypoints with missing depth data were removed. Bathymetry data from 2010 and 2011 were combined into a larger comprehensive Excel file which was used to generate an accurate bathymetric map in the Rufus Woods Lake EASy model. The Excel file was organized into shoreline then depth data and read into a routine used to process depth data within the software package EASy (Environmental Assessment System), a 3-dimensional GIS software package produced by Science System Applications http://runeasy.com/. The software was adapted and improved during this project to address the unusual needs of a 51 mile long but very narrow reservoir such as Rufus Woods Lake.

EASy created the reservoir images within the software system such that it only interpolates pixel values that are over water. As a result, created bathymetry files contain a zero pixel value for all land pixels. The image creation algorithm searches for pairs of pixels that can be used for linear interpolation of missing values. For each empty pixel the algorithm searches for bounding pixels in four directions (N-S, E-W, NE-SW, and NW-SE). If one or more pair of bounding pixels are found then the algorithm linearly interpolates between the located bounding pixels. The search is limited by a pixel 'range' value. That is, the search looks for pixels that are closer to the empty pixel than the currently specified 'range'. The initial 'range' value is specified by the user. After attempting to fill all empty pixels the algorithm increments the 'range' by one pixel and iterates the process until all empty pixels are filled (or until the user specified maximum number of iterations is reached). The result is that the created image depends on the initial 'range' value. If the initial 'range' value is too small then the initial iteration will create small 'clumps' that will eventually grow to connect with other clumps. If the initial 'range' value is too large then the initial iteration will tend to interpolate specified depth pixels vertically, horizontally, and diagonally. This eliminates most of the 'clumping' but creates excessive vertical, horizontal, and diagonal patterns.

Because the RWL reservoir is very narrow relative to its depth, the contouring subprogram in EASy required modifications to increase accuracy of interpolation among way points. We tested the system in a sensitivity analysis on the created RWL bathymetry specifying 'range' values of 4, 8, 16, 32, 64, and 96. Range 32 was selected for this project partly because the results for smaller values seemed to vary while results for larger values did not seem to change. The range values can be easily changed by the user and the bathymetry file processed to use again with different settings or input values.

Habitat Subsampling

Summer 2011 fieldwork also included a detailed habitat study. We recorded a variety of habitat observations at specified GPS points (~130 points on each shore of RWL, stretching between Seaton's Grove upstream and Chief Joseph Dam downstream). The far upstream area between Seaton's Grove and Grand Coulee Dam was not extensively covered because previous observation suggested uniform habitat type in this area. GPS points used for habitat studies were the ends of previously recorded cross-reservoir transects observed in August 2010 and are spaced regularly throughout RWL at ~0.5 km intervals. The same Garmin GPSMAP 188C GPS unit used during bathymetry measurements was used here to determine the precise locations of each habitat point. Google Earth shoreline points were added in shallow, inaccessible areas when necessary. Observed shoreline points were compared to Google Earth estimated points and found to be highly accurate for use in this 2010-2011 application.

At each point, the underwater shoreline habitat (defined as the area from the shoreline to approximately 3 m (10 ft.) depth, which included the visible range) was visually observed and estimates of percent substrate cover were recorded. Substrate categories included Fines, Sand, Gravel, Cobble, Large Cobble and Hard Bottom. Fines and Sand were later merged into one category because of the difficulty of determining the difference between fines and sand using visual observation only.

Presence/absence of macrophytes, filamentous algae and submerged trees were recorded at each habitat point.

Visual observations of the steepness of the nearshore littoral shallows, as well as the backshore slope, were also recorded. Steepness was defined into three categories: Low slope, Medium slope, and Steep slope.

Time of each observation as well as general comments were also recorded.

Habitat Data Post-fieldwork processing

Habitat data were transcribed from hand-written field notes into Microsoft Excel, and then analyzed and organized using Garmin MapSource, Microsoft Excel and Google Earth. Each habitat point was classified into one of 9 different types, listed as follows:

F = Fines (no macrophytes)

C = Cobble only (may have some gravel)

FGC = Fines/gravel/cobble (no macrophytes) (may not have much/any gravel)

H = Hard bottom (rock or clay, no macrophytes)

FM = Fines/macrophytes (assumes fines in the macrophytes deep zone)

FGM = Fines/gravel/macrophytes

CM = Cobble/macrophytes (mostly small to large cobble in shallower water and macrophytes established deeper, below the zone of water surface elevation)

FGCM = Cobble/fines/gravel/macrophytes (may not have much/any gravel)

FHM = Fines/hard bottom mix with macrophytes (may not have much/any fines)

Data analysis, statistics and figures were generated with Microsoft Excel either as standalone software or integrated into the EASy GIS and modeling software. Google Earth was used to determine length between shoreline and nearshore bathymetry GPS points for each habitat location. Using length and depth, littoral slope was calculated at ~15 m (~50 ft.) distance from shore. The generated slope values were then classified into low, medium and steep classifications to compare with the visual observations made in the field. For calculation purposes, values of less than 0.25 were classified as “low”; slopes between 0.25 and 0.75 were “medium”, and slopes with values greater than 0.75 were “steep”. Calculated slopes were compared to visual observations as a quality control check; for the most part, calculations and visual observations matched up well.

Within the EASy bathymetry model, we used a specifically built-in function to calculate areas and volumes of different sections of the reservoir. The model enables us to select any rectangular area and receive an output of the maximum depth, total area (in km^2) and volume (in km^3) of the selected region, as well as cross-sectional and 3D depth profiles. Furthermore, the option of inputting desired minimum and maximum depths allows us to calculate area and volume for only a specified vertical portion of the region.

To further investigate differences between different areas of the reservoir, three distinct sections were chosen and analyzed: 1) the upriver portion, defined as Grand Coulee Dam to Seaton's Grove; 2) the downriver section, from Chief Joseph Dam and pool up to where the reservoir becomes much narrower and faster-flowing; and 3) the extensive middle section area dividing the upriver and downriver sections.

A range of statistical data were collected for each of the three reservoir sections, as well as for Rufus Woods Lake as a whole. Areas and volumes were recorded at littoral depths (0-18 ft.), 18-50 ft., 50-100 ft., and 100+ ft., as well as a 3 to 18 foot macrophyte zone that excluded the nearshore 0 – 3 ft. range where macrophytes do not grow due to spring through fall water surface elevation fluctuations.[1]

Periphyton Methods

Cobble and macrophyte scrapes

Three cobble scrapes were compiled into one sample at each of eleven sites in RWL in August and September 2010 (Figure 3, Table 1). One sample of macrophytes (S10e) was also collected and periphyton was scraped off of and analyzed at the EcoAnalysts, Inc. lab (Table 1). Diatom and soft-count periphyton taxonomic identification to the genus and species level and relative abundance of taxa using a standard 300 cell count per sample were made by EcoAnalysts, Inc. taxonomists. See Table 1 for sample number classification, date collected, latitude, longitude, method used and depth at which collected.

Tiles

We placed unglazed tiles (area = 100.3 cm^2) in rock filled cobble baskets at seven locations in RWL (Table 1) on August 28 (upper section) and August 31, 2010 (lower section). We put 2 tiles in each cobble basket and positioned the baskets at three different depths per site: 3.0, 9.1, and 15.2 m using a depth finder. Baskets were secured to the shoreline with nylon ropes for locating after an incubation period. Periphyton was allowed to condition and colonize tiles for 35 days upstream and 38 days downstream. Tiles were then retrieved and placed on ice and transported to EcoAnalysts Inc. and University of Idaho Analytical Sciences Laboratory, Moscow, ID. Periphyton was scraped off of tiles and analyzed for: chlorophyll *a*, chlorophyll *a+ b*, ash free dry mass (AFDM), and detailed taxonomic and metric analyses. Priority was given to chlorophyll *a* analysis (chlorophyll *a* + *b* were not analyzed in this study) and for several samples there was not enough periphyton for all three analyses. See Figure 3 for locations of sample sites and Table 1 for sample number classification, date collected, latitude, longitude, and depth at which collected.

[1] Units presented as feet and not meters, because we purposely set up the EASy depth data in feet and all of our RWL morphometry tables are in feet.

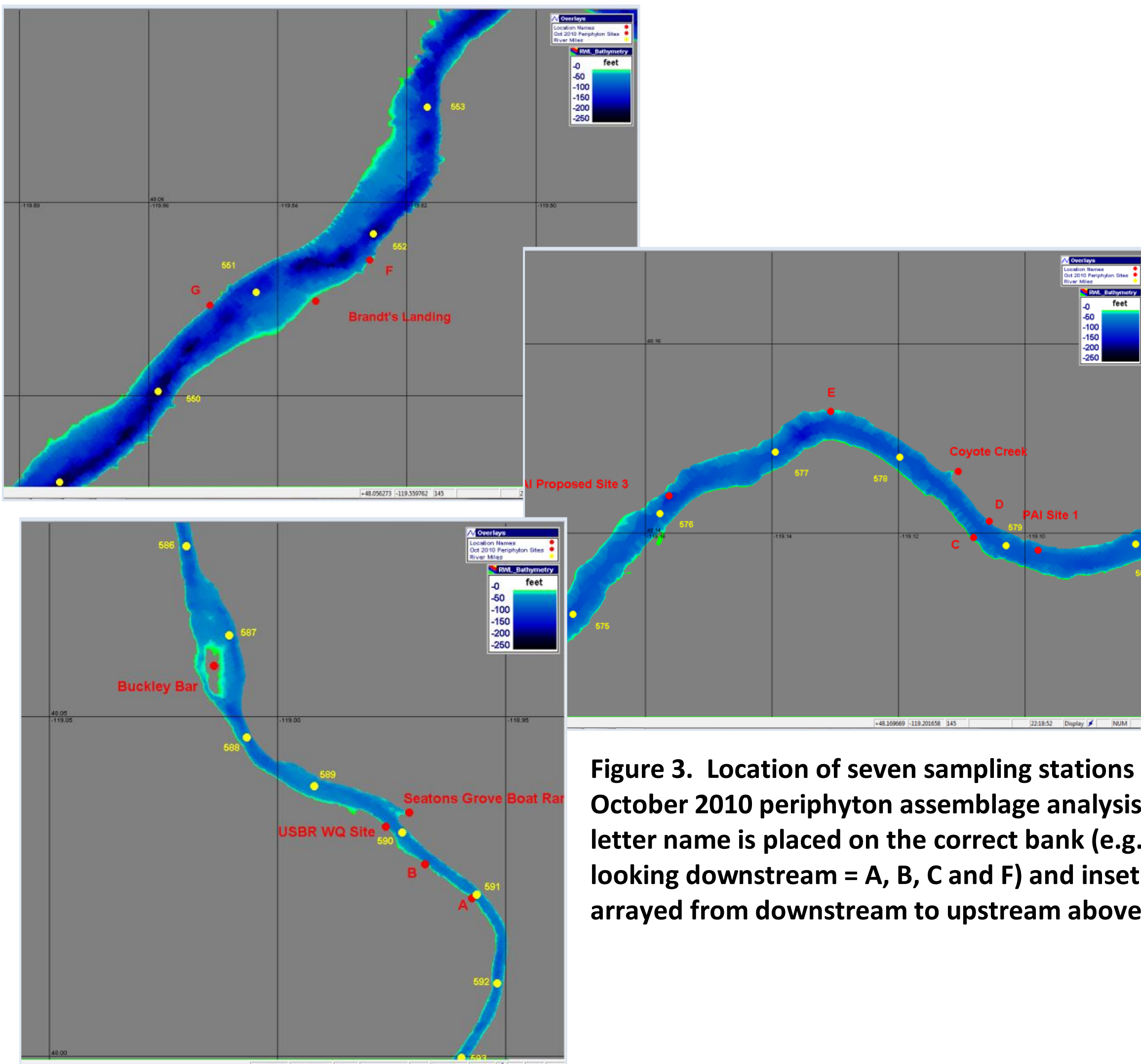


Figure 3. Location of seven sampling stations used for October 2010 periphyton assemblage analysis. Station letter name is placed on the correct bank (e.g., left bank looking downstream = A, B, C and F) and inset figures arrayed from downstream to upstream above.

Table 1. Periphyton sample number, date collected, latitude, longitude, collection method used and depth at which collected. Date for tiles was the date they were retrieved and were allowed to colonize with periphyton for approximately 1 month. Note: in the October 2010 tile periphyton analysis results we used different sample codes.

Sample	Date	Lat (N)	Long (W)	Method	Depth (m)
A10a	8/1/2010	48 00.185	118 57.295	Cobble scrape	< 1.0
A10b	8/1/2010	48 00.318	118 57.170	Cobble scrape	< 1.0
A10c	8/2/2010	48 00.422	118 57.097	Cobble scrape	< 1.0
A10d	8/2/2010	48 00.485	118 57.072	Cobble scrape	< 1.0
A10e	8/3/2010	48 01.286	118 57.117	Cobble scrape	< 1.0
A10f	8/3/2010	48 01.136	118 56.996	Cobble scrape	< 1.0
A10g	8/4/2010	48 09.171	119 7.842	Cobble scrape	< 1.0
S10a	9/1/2010	48 08.371	119 06.485	Cobble scrape	< 1.0
S10b	9/1/2010	48 03.242	119 31.542	Cobble scrape	< 1.0
S10c	9/1/2010	48 01.286	118 57.117	Cobble scrape	< 1.0
S10d	9/1/2010	48 04.008	119 25.809	Cobble scrape	< 1.0
S10e	9/1/2010	48 04.337	119 31.254	Macrophyte scrape[1]	< 1.0
O10a	10/5/2010	48 01.395	118 57.436	Tiles	3.0
O10b	10/5/2010	48 01.395	118 57.436	Tiles	3.0
O10c	10/5/2010	48 01.395	118 57.436	Tiles	9.1
O10d	10/5/2010	48 01.395	118 57.436	Tiles	9.1
O10e	10/5/2010	48 01.395	118 57.436	Tiles	15.2
O10f	10/5/2010	48 01.694	118 58.052	Tiles	3.0
O10g	10/5/2010	48 01.694	118 58.052	Tiles	3.0
O10h	10/6/2010	48 01.694	118 58.052	Tiles	9.1
O10i	10/6/2010	48 01.694	118 58.052	Tiles	9.1
O10j	10/6/2010	48 08.371	119 06.485	Tiles	3.0
O10k	10/6/2010	48 08.371	119 06.485	Tiles	3.0
O10l	10/6/2010	48 08.371	119 06.485	Tiles	15.2
O10m	10/6/2010	48 08.473	119 06.336	Tiles	3.0
O10n	10/6/2010	48 08.473	119 06.336	Tiles	15.2
O10o	10/6/2010	48 08.473	119 06.336	Tiles	15.2
O10p	10/6/2010	48 03.242	119 31.542	Tiles	9.1
O10q	10/6/2010	48 02.960	119 33.024	Tiles	3.0
O10r	10/6/2010	48 02.960	119 33.024	Tiles	3.0
O10s	10/6/2010	48 02.960	119 33.024	Tiles	9.1
J11a	7/27/2011	48 03.023	119 32.032	Tiles	4.6
J11b	7/27/2011	48 03.023	119 32.032	Tiles	4.6
J11c	7/27/2011	48 03.102	119 31.759	Tiles	3.0
J11d	7/27/2011	48 03.075	119 31.884	Tiles	6.1
J11e	7/27/2011	48 03.102	119 31.759	Tiles	6.1

[1]Sample S10e periphyton was scraped off of algae in lab.

Statistical Analyses

We conducted two general separate analyses: 1) for all samples (cobble scrapes and tiles) and 2) for the more robust tile samples retrieved in October 2010. We explored the all sample data using ordination and then used ordination, descriptive, and hypothesis testing analysis for the tile samples retrieved in October 2010**.**

All sample statistical analysis

Ordination was used to explore multivariate relationships of the periphyton assemblages in RWL using all of the samples (cobble scrapes and tiles). For exploratory, visual analyses; ordination techniques are often superior for explaining relationships of assemblages and communities than hypothesis testing approaches (McCune and Grace 2002). In general, ordination is the ordering of objects along axes according to their similarities. The main objective of ordination is data reduction and expressing many-dimensional relationships into a small number of easily interpretable dimensions (axes on a plot). The strongest correlation structure in the data is extracted (using correlation in the broad sense) and is then used to position objects in ordination space. Objects that are close in the ordination space are generally more similar than objects distant in the ordination space (McCune and Mefford 2011).

Several types of ordination exist; non-metric multidimensional scaling (NMS) was used for this data. NMS has been shown to be robust for ordination of species composition (e.g., Kenkel and Orloci 1986, Ludwig and Reynolds 1988) and is often more useful than other ordination techniques because, among other things, it avoids the assumption of linear relationships among variables. NMS is also the most widely accepted ordination technique used in community ecology (Peck 2010).

Although uncommon or rare taxa are important in their own right; they have disproportionate influence on NMS results and contribute little to the functioning of benthic assemblages, therefore we removed samples that had taxa which occurred in less than 3 samples. We then conducted several dozen NMS scenarios using different distance measures and numbers of axes and compared these with randomized data Monte Carlo simulations using raw data, log +1 transformed data, and square root transformed data. All the transformations performed similarly, therefore for the final analysis we used the untransformed raw data. We then conducted a post hoc analysis of coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space. This provided estimates of the amount of variability in the data explained by each of the ordination axes. We used the computer program PC-ORD (McCune and Mefford 2011) for the NMS ordination.

October 2010 tile data

We also conducted NMS ordination on the 2010 tile data separately (excluding cobble scrapes) to further explore spatial and temporal multivariate relationships in the periphyton assemblages in RWL. This was done in part to reduce sample method bias and seasonal affects.

We then computed descriptive statistics and graphically depicted chlorophyll *a*, AFDM, and an Autotrophic Index (AI %) for the October 2010 data. The AI % is the ratio of chlorophyll a to AFDM measured as a percentage and is commonly used as a measure of autotrophic or heterotrophic autochthonous production. We based this on the following discussion by Flotemersch et al. (2006):

> *" … AFDM is an estimate of total organic material accumulated on the substratum. This organic material includes all living organisms (e.g., algae, fungi, bacteria, and macroinvertebrates) as well as non-living detritus. Dry mass values are used in conjunction with chlorophyll a as a means of determining the trophic status of rivers through the use of the autotrophic index (AI). The formula used to calculate AI is:*

AI = Dry mass (mg/m^2)/Chlorophyll a (mg/m^2).

High AI values (i.e., >200) indicate that the assemblage is dominated by heterotrophic organisms and can indicate poor water quality (Weber 1973, Weitzel 1979, Matthews et al. 1980). This index should be used with discretion because non-living organic detritus can artificially inflate the AFDM value. One option is to modify the AI to include AFDM and invert:

AI = Chlorophyll a (mg/m^2)/AFDM (mg/m^2)

In this form, the index is positively related to the autotrophic proportion of the assemblage instead of the heterotrophic proportion. Also, since chlorophyll a / AFDM values normally are about 0.1%, the modified index would have better statistical properties than the original index".

We then conducted General Linear Model ANOVAs examining seasonal or depth affects. Sites D and E appeared to have been affected by shading from macrophyte beds; therefore to further examine location and depth affects, we conducted a GLM ANOVA on chlorophyll *a* only at sites A, B, C, F, and G. Because we had limited number of replicates and several tiles did not have enough periphyton growth for all the types of analyses, we also conducted a power analysis to determine the level of power in our ANOVAs. We then estimated daily growth rates of chlorophyll *a* and AFDM and examined spatial patterns of the soft bodied algae.

Cobble Baskets Methods

Cobble basket samplers can be more efficient for evaluating macroinvertebrate assemblages than suction dredge sampling or other methods used in large run of the river reservoirs. Baskets are easily deployed and retrievable and do not require certified SUBA divers, as does suction dredging.

Twenty cylindrical cobble baskets (dia. = 18. 4 cm, length = 30.5cm) were placed at seven locations in RWL starting on August 28 and 31, 2010. Baskets were stocked with fist sized preconditioned cobbles or smaller that were scrubbed free of invertebrates and then placed at approximately three depths: 3.0, 9.1, and 15.2 m using a depth finder. Baskets were secured to the shoreline with nylon ropes. These were the same baskets that housed tiles for our periphyton/primary productivity study. Baskets were then retrieved at several intervals: October 2010, January, February, March, May, June, and July 2011. Several of the cobble baskets were lost or vandalized and were replaced if possible. On retrieval dates, invertebrates were scrubbed off of the cobbles into separate jars containing 95% EtOH. Invertebrates were then identified to lowest practical taxon, typically to the family, genus, or species level by taxonomists at EcoAnalysts, Inc. using a standard 300 organism count. Table 2 contains the site locations and other cobble basket information.

Table 2. Cobble basket site locations, retrieval dates, and sample depths.

Site	Latitude	Longitude	Retrieval dates	Depths (m)
A1[1]	48 01.624	118 57.940	Oct	3.0, 9.1,15.2
A	48 01.395	118 57.436	Oct Jan Feb Mar May	3.0, 9.1,15.2 3.0 3.0 3.0, 9.1,15.2 9.1
B	48 01.694	118 58.052	Oct Jan	3.0, 9.1,15.2 3.0, 9.1,15.2

Site	Latitude	Longitude	Retrieval dates	Depths (m)
			Feb Mar May June	3.0, 9.1,15.2 3.0, 9.1,15.2 3.0, 9.1,15.2 3.0, 9.1,15.2
C	48 08.371	119 06.485	Oct Jan Feb Mar May June	3.0, 9.1,15.2 9.1 3.0, 9.1 3.0, 9.1,15.2 3.0 3.0, 9.1
D	48 08.473	119 06.336	Oct Jan Feb Mar May June	3.0, 9.1,15.2 3.0, 9.1,15.2 9.1 9.1 3.0 3.0, 9.1
E	48 09.171	119 07.842	Oct Mar Jul	3.0, 9.1,15.2 9.1,9.1, 15.2,15.2
F	48 03.242	119 31.542	Oct Jan Feb Mar May June Jul	3.0, 9.1,15.2 3.0, 3.0, 3.0 3.0, 9.1 3.0, 9.1 3.0, 9.1 3.0, 9.1 3.0, 9.1
G	48 02.960	119 33.024	Feb Mar May June Jul	3.0, 9.1,15.2 3.0,9.1,15.2 3.0, 15.2 3.0, 15.2 3.0, 15.2

[1]Discontinued site due to strong currents

Statistical analysis

We conducted several summary statistics and created graphs on the data. We also conducted a General Linear Model ANOVA examining the effects of depth, month, and location differences in total abundances of invertebrates.

Suction Dredge Sampling Methods

Field collection

We suction dredge sampled benthic macroinvertebrates from five locations (Figures 4 and 5) in RWL using a portable suction dredger and SCUBA on October 5 and 6, 2010, April 25, 2011, and July 28 and 29, 2011. Samples were randomly chosen and then vacuumed from within a 0.37 m^2 quadrat to a sediment depth of about 5mm. Sample depths ranged from approximately 1.0 to 8.2 m and were collected from various mixtures of substrates (Table 3). Replicate samples were taken from each site and depth indicated in Table 3.

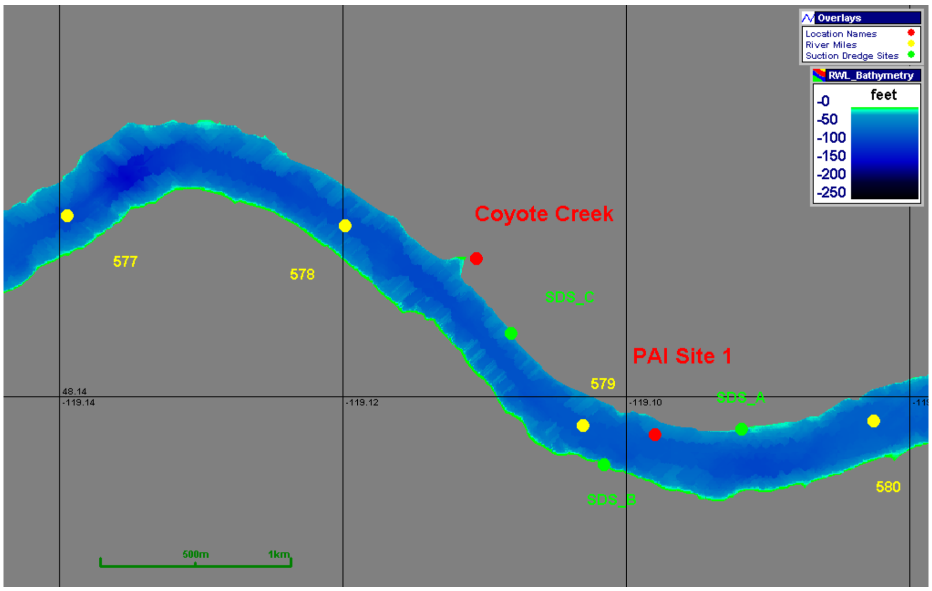


Figure 4. Suction Dredge Site locations A-C in Rufus Woods Lake, shown as green points and labeled SDS.

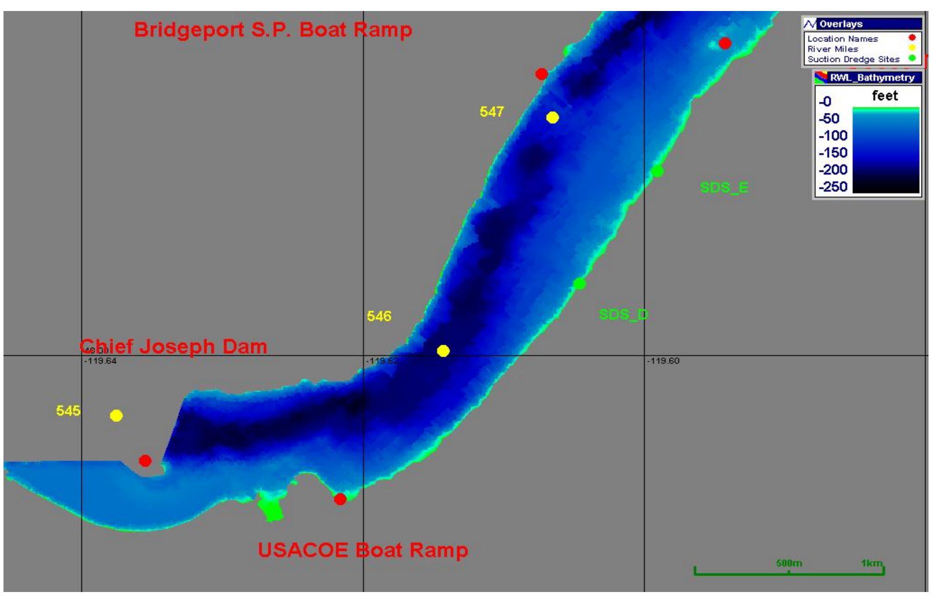


Figure 5. Suction Dredge Site locations D and E in Rufus Woods Lake, shown as green points and labeled SDS.

Table 3. Suction dredge sites, latitude, longitude, sample date, sampling depths, substrate type, and slope.

Site	Latitude (N)	Longitude (W)	Month Year sampled	Sampling Depths (m)[1]	Substrate	Slope
A	48° 8.305'	119° 5.507'	October 2010	0.9, 1.5, 1.2, 3.1, 6.1, 1.5, 3.1, 6.1	Cobble and boulders slightly embedded with gravel/sand/fines	Shallow, low gradient
			April 2011	4.3, 5.2, 4.6, 6.1, 5.5		
			July 2011	4.6, 4.6, 4.6, 5.5, 4.6		
B	48° 8.205'	119° 6.091'	October 2010	3.1, 6.1, 7.9, 0.9	Mostly loose cobbles on top of gravel/sand	Moderate
			July 2011	4.6, 6.1, 6.1, 6.1, 3.0		
C	48° 8.577'	119° 6.484'	October 2010	4.6, 6.1, 7.5, 9.1	Loose cobble on top of gravel/sands	Moderate
D	48° 0.217'	119° 36.272'	July 2011	4.6, 6.1, 6.1, 3.0	Sand/fines and macrophytes	Shallow, low gradient
E	48° 0.558'	119° 35.942'	July 2011	3.0, 4.6, 4.0, 3.0	Sand/fines and macrophytes	Shallow, low gradient

[1/]Sampling depths are ordered by sample number and equal the number of samples taken at a specific date and location

Samples were collected and filtered through a 1 mm diameter mesh D-net and then elutriated at the site and preserved in 95% EtOH. Samples were then transported to EcoAnalysts, Inc. lab in Moscow, ID for analyses.

Our suction dredge samples did not include any fish taxa. This was because sculpins, the most abundant benthic dwelling fish in this area, easily avoided suction. Therefore, our diver visually observed and recorded sculpin abundance within the quadrat prior to suction dredge sampling.

Laboratory analysis

Macroinvertebrate samples were sorted using a standard 300 organism subsample method and identified to the lowest practical taxon, typically genus or family. Several dozen metrics were calculated including abundance estimates after adjustment for subsampling and to a $1m^2$ area.

Statistical Analysis

Ordination was used to explore multivariate relationships of the periphyton assemblages in RWL in October, 2010. Although uncommon or rare taxa are important in their own right; they have disproportionate influence on NMS results and contribute little to the functioning of benthic assemblages, therefore we removed samples that had taxa which occurred in less than 2 samples. Because of taxonomic discrepancies, we 'rolled up' taxa into the following groups: crayfish, mayflies, caddisflies, dragonflies, mites, worms, flies, beetles, bugs, non-crayfish crustaceans, snails, and 'others'. We then log generalized transformed the abundances so that taxa with extreme high occurrences such as midges (flies) or worms did not overly influence results. Next we conducted several dozen NMS scenarios using different distance measures and numbers of axes and compared these with randomized data Monte Carlo simulations. We then conducted a post hoc analysis of coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space. This provided estimates of the amount of variability in the data explained by each of the ordination axes. We used the computer program PC-ORD (McCune and Mefford 2011) for the NMS ordination.

We also calculated descriptive summary statistics and other graphical representations of the most important data. We estimated energy densities (joules/g) and caloric values of the benthic assemblages and explored basic ecology of the assemblages in relation to RBT diets.

Fish Stomach Collection and Analyses Methods

Colville Tribal biologists and technicians collected a total of 409 fish stomach samples during their creel surveys from April 2010 to August 2011 and from a gillnet study conducted on June 7, 2011 and July 7, 2011. Stomach samples collected during creel surveys were primarily from RBT (N = 297), walleye (N = 28), and northern pike minnow (N = 15). Tribal staff also recorded total lengths and whole fish weights in addition to other information including if fish were caught from shoreline or boats and the location of the boats exiting RWL. However, only the lengths and weight data were available for this study. We focused primarily on RBT diets with some limited diet analysis on walleye and northern pike minnow.

Tribal staff removed digestive tracts from fish from the esophagus to just below the stomach, cut open the stomach, and preserved digestive tract and contents in 95% EtOH Contents were then examined at EcoAnalysts, Inc. lab in Moscow, ID by North American Benthological Society certified invertebrate taxonomists.

We calculated several summary statistics and graphically analyzed the stomach content data, again focusing primarily on RBT stomach contents. We did not attempt to calculate energy densities or amount of calories consumed per time period that the fish ingested based on the contents of stomachs because of unknown factors including; probable unequal digestion rates of organisms, undetermined body lengths or head capsule widths of stomach content organisms, the unknown amount of time the contents were in stomach which resulted in differing degrees of digestion and ability to be identified.

Basic Water and Sediment Quality

Water quality is an important basic component in understanding aquatic ecology and is generally "good" in Rufus Woods Lake as measured at the Grand Coulee Bridge by the Washington Department of Ecology (Ecology) at a long-term monitoring station established in 1949. Ecology's on line website reports that "*Overall water quality at this station met or exceeded expectations and is of lowest concern (based on water-year 2010 summary)*." Unlike for natural lakes, there are no universal reservoir assessment indices or ranking schemes, but typically low water column chlorophyll, low total phosphorus and relatively high Secchi disk ratings would result in an oligotrophic (nutrient poor and modest or less biological abundance) ranking if we applied Carlson's (1977) trophic ratings to RWL. However, water quality is increasingly measured as 'biological integrity' [Clean Water Act (1972)] that is often defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981). Unfortunately no measures have been developed to evaluate the biological integrity of large unique rivers such as the Columbia River or for reservoirs in the Pacific Northwest.

Because of fast water flow, short retention times, and other factors such as the relatively great depth of some sections of this reservoir, data from the Ecology station below Grand Coulee Dam are representative of downstream conditions with the probable exception of a few backwater sloughs or bays and perhaps some isolated nearshore areas in the Chief Joseph Dam pool.

Although most of the water flowing through RWL stems from discharge through Grand Coulee Dam or Lake Roosevelt (LR), RWL is ecologically different than LR for several reasons primarily due to physical and reservoir operation differences. As a result of extensive drawdown of Lake Roosevelt surface elevation each spring, macrophyte populations are not as established in LR as they are in RWL. Water surface elevations in RWL are relatively stable (usually changes of a foot or two at most), particularly in the spring through fall period. Unlike Lake Roosevelt, there does not appear to be as great of seasonal stratification in subareas or excessively warm surface water temperatures that occur in the Spokane Arm of LR during summer.

Water quality and especially nutrient flux through the reservoir has changed dramatically over the years too, due to the cessation of discharge from the Cominco Ltd. fertilizer plant (and other facilities related to the metals smelter operation) in Trail, British Columbia. This change was initiated in 1974 and was fully completed in 1994 (although this apparently was phased in over several prior years (Teck Cominco 2004)). The following discussion is in part extracted and updated from the *Pacific Aquaculture Site 3 NEPA Environmental Assessment* (2011) that was compiled and analyzed by Rensel Associates Aquatic Sciences in spring of 2011. Water quality components, especially water temperature and dissolved oxygen are of particular interest for calibrating the fish growth modeling component of this study, discussed later in this report.

Lake Bottom sediment quality

Rensel (2010) conducted studies of sediment quality, total organic content (TOC) and stable isotope tracing of nutrients to aquatic invertebrates downstream of the Pacific Aquaculture net pens near Nespelem at ~ River Mile 579. At upstream reference areas in this fast flowing and coarse bottom area, sediment TOC and nitrogen averaged 0.26% and 0.04%, indicating relatively low levels of organic enrichment. Immediately downstream of PAI existing net pen Site #1, sediment TOC averaged 0.43% and sediment nitrogen averaged 0.07% with declines to ambient conditions over the next several hundred feet downstream in a narrow path associated with the prevalent flow direction from the cages. Although surficial (surface of the bottom) sediments are normally coarse in this area too, there was a ~ 2 cm layer of organic matter on the bottom immediately downstream of the net pens for several tens of meters. However, no indicators of sediment hypoxia or anaerobic conditions were observed (e.g., hydrogen sulfide smell, black sediments at the surface or a few cm deep, lack of invertebrates, methane gas production). Rather, there were numerous isopods, snails and other invertebrates in and upon these same affected sediments and results of our suction dredge benthic survey about ½ mile downstream of the Site #1 pens shows a diverse faunal community. Approximately 33 miles (55 km) downstream in the Chief Joseph Dam pool, TOC was much greater (2.5%) due to the naturally higher levels of silt and clay that are trapped through sedimentation in that area of generally slower water motion.

Water Column Physical Circulation

Recent 10 year (January 1, 2000 through 2009, Figure 6) average river discharge at Grand Coulee Dam was relatively low (97.7 KCFS) compared to previous historical data (1930-97). Total discharge (spill plus generation discharge) from Grand Coulee Dam has averaged 107.8 KCFS from 1930 to 1997. A linear equation fitted to the data shows no significant trend of increase or decrease, although considerable decadal or shorter term variation is prevalent. Mean annual discharge in 2010 was much lower, at 82.5 KCFS, despite an abnormally high peak in June 2010 (Figure 7). However, discharges in 2011 have been much higher than normal, and year-to-date (as of 24 September 2011) mean annual discharge is 148.1 KCFS and is shown in comparison to the two prior time periods in Figure 8. As a result of these flows, and operation and maintenance practices at Grand Coulee Dam, total dissolved gas levels regularly exceeded lethal levels for fish in surface waters, with concentrations often > 140%. The high flows apparently mobilized high flux of nutrients too, as discussed later in this section.

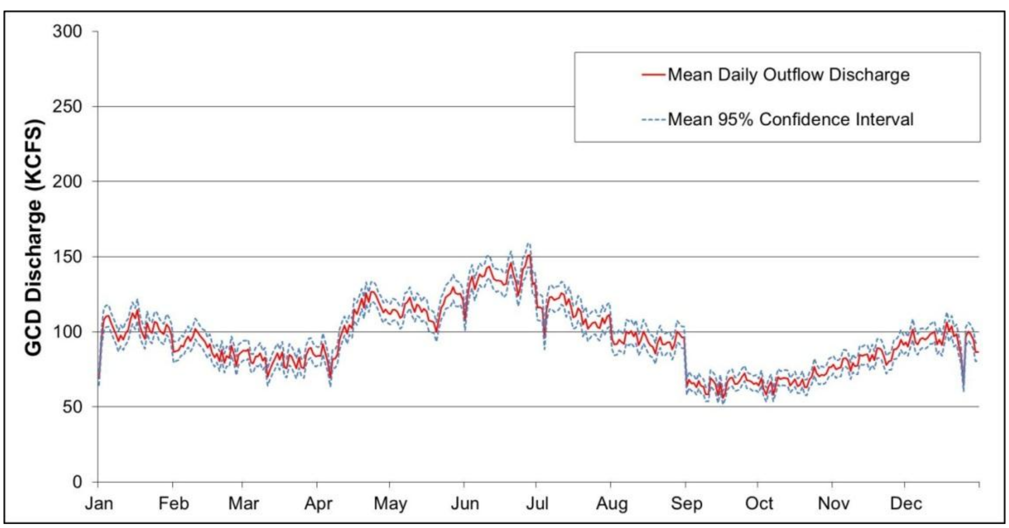


Figure 6. Ten-year mean daily discharge and 95% confidence intervals at Grand Coulee Dam for the period 2000-2009.

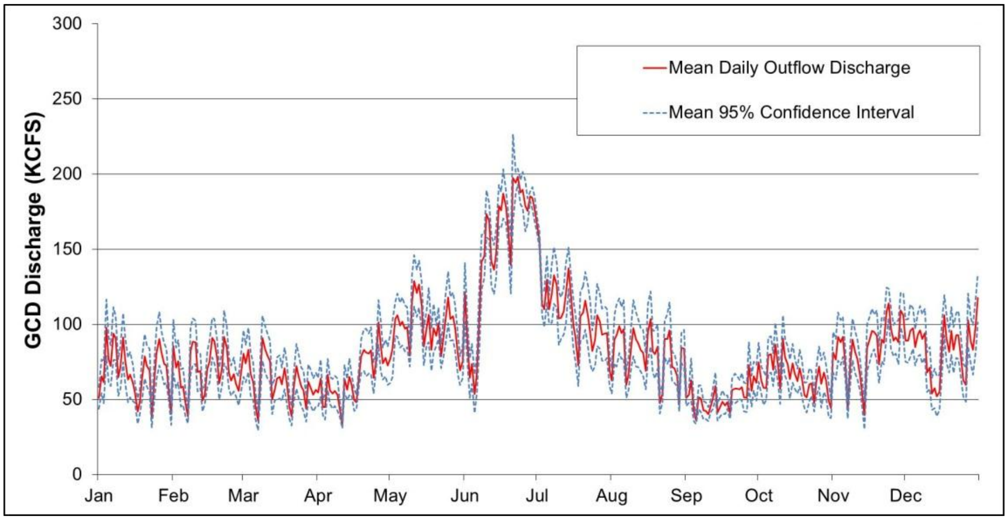


Figure 7. Mean 2010 daily discharge and 95% confidence interval Grand Coulee Dam.

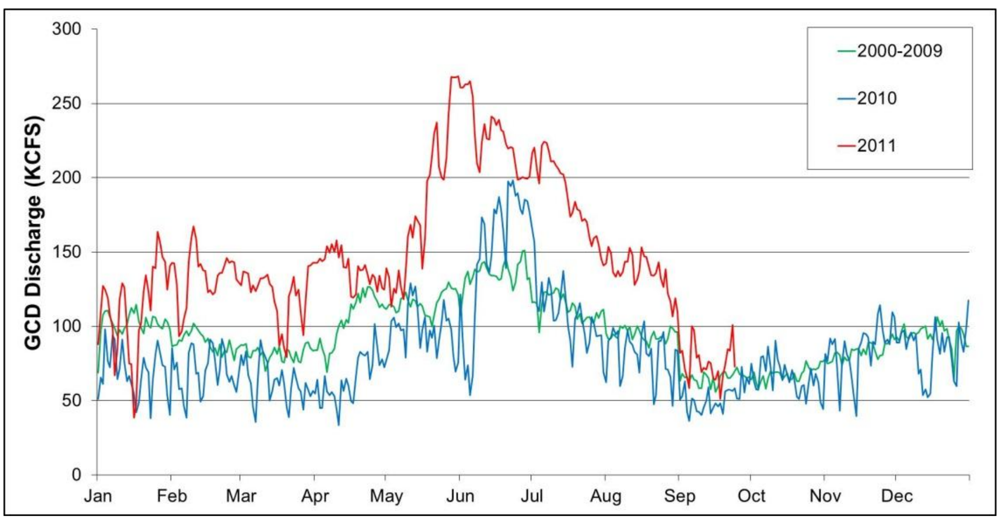


Figure 8. Mean daily discharge 2000-2009 (green), 2010 (blue) and 2011 through 24 September 2011 (red).

Water Temperature

Water temperature is a key component controlling the growth of fish, invertebrates and algae in any aquatic system and is used later in this report to estimate growth of released trout, along with other important factors. Figure 9 illustrates the seasonal range of daily water temperature in RWL at the U.S. Bureau of Reclamation Hydromet-AgriMet System monitoring station across from Seaton's Grove http://www.usbr.gov/pn-bin/arcread.pl?station=GCGW . Because of the fast flushing rates of RWL, vertical or horizontal temperature stratification is not predicted to occur, except in the few shallow, littoral zones of bays or backwaters and inside of dense macrophyte beds in summer. The plot illustrates that growth conditions for rainbow trout are suboptimal to rarely dangerously low in late winter, from early January through early April as there is a lag time in cooling of Lake Roosevelt compared to air temperature. In summer over the past 12 years, average daily water temperatures in mid-August through late September peak at the high end of the preferred physiological range, occasionally exceeding it but remaining well below the "avoid" levels of Bell (1976, the USACE sponsored review of bioenergetics of Pacific Northwest salmon, trout and other key species). This means that over half of the year these fish are less able to eat and grow optimally.

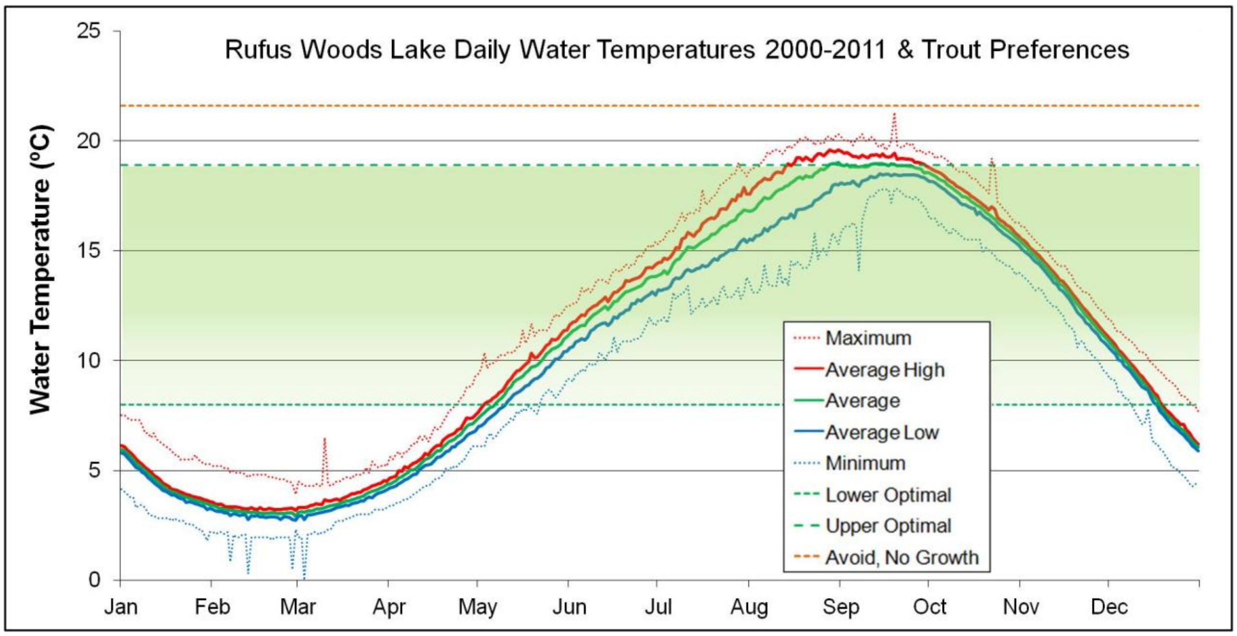


Figure 9. Daily water temperature statistics (derived from U.S. Bureau of Reclamation web site after quality assurance steps) plus range of optimal (green shaded) and "avoid high temperature" for Pacific Northwest rainbow trout stocks (from Bell 1976, modified for RWL with Shallenberger, unpublished fish farm data).

Because of the range of temperature, release timing of the fish in cold water periods may affect feeding rate, available energetics of the fish for activity and related factors. In 2010 about 70% of the intentionally-released cultured trout were planted in the coldest period of January through early April. It is reasonable to assume these fish were at a disadvantage compared to later timing as both the food web and the physiological capability for growth and locomotion are minimal in spring. The downside of waiting until the water warms is that river discharge increases in most years beginning in May.

However, an annual adaptation approach to flows and water temperature factors may improve the growth, survival and fisheries contribution of fish released into RWL, as discussed later in this report.

pH

Measurements of pH in Rufus Woods Lake exhibited very little variation over the 10-year period of record from 2000 through 2009. Average monthly pH values taken just downstream of Grand Coulee Dam between 2000 and 2009 ranged from a minimum of 7.96 to a maximum of 8.12. The 10-year average pH was 8.02, with very low deviation on both monthly and yearly bases. In 2011, however, there were several months of unusually low pH. Late spring pH readings at the Ecology station below Grand Coulee Dam ranged from ~7.5 to 7.7. These departures from the norm coincide with other major changes discussed herein including much greater than normal discharge.

Dissolved Oxygen

Dissolved oxygen concentrations remain relatively high in Rufus Woods Lake at all times. Ecology reports infrequent violations of water quality standards for freshwater of dissolved oxygen (8.0 mg/L), usually associated with elevated water temperatures above 18°C that reduce the saturation level of water for dissolved oxygen. When these events occur, they invariably happen in late summer, and dissolved oxygen concentrations remain just slightly less than the standard, but always greater than (>) 7.5 mg/L, and therefore not near chronic stress levels for the most sensitive species (typically salmonids, such as trout). Note, however, that dissolved oxygen concentrations were slightly diminished in spring and early summer of 2010 and spring of 2011 in comparison, with summer 2011 elevated significantly, due to gas supersaturation from spill (Figure 10). No dissolved oxygen data has been reported in the section of RWL upstream of Chief Joseph Dam but we suspect values are close to those measured at Grand Coulee Dam.

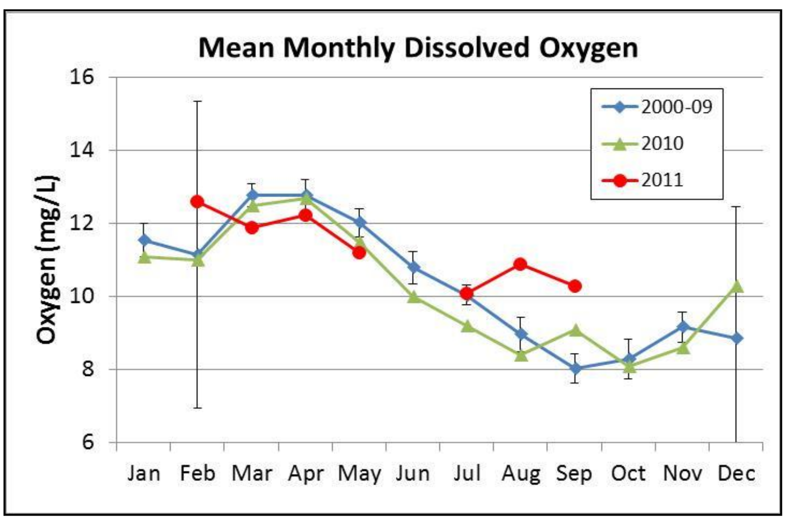


Figure 10. Mean monthly dissolved oxygen at Ecology Station 53A070 downstream of Grand Coulee Dam. In this figure, as in all following figures unless otherwise noted, error bars represent ±1 standard deviation.

Turbidity

Turbidity measurements in the Rufus Woods Lake water column are generally low, especially in fall and early winter. Rensel (1993) concluded that transparency in RWL was greater in the late 1980s and early 1990s than in prior measurement periods. The depth at which macrophytes grow has also increased dramatically over the years, as discussed below, due to increasing clarity of the water. This may have been related to reduced phosphorus loading into Lake Roosevelt following the change in discharge practices at the Cominco, Ltd. fertilizer plant in Trail, British Columbia.

A major exception to the prior trends was observed for turbidity in 2011 that increased greatly above historical levels in May 2011 (Figure 11); unfortunately, sampling was not conducted the following month of June. These data are consistent with other changes seen in 2011 discussed herein, including much greater than normal water discharge through the river.

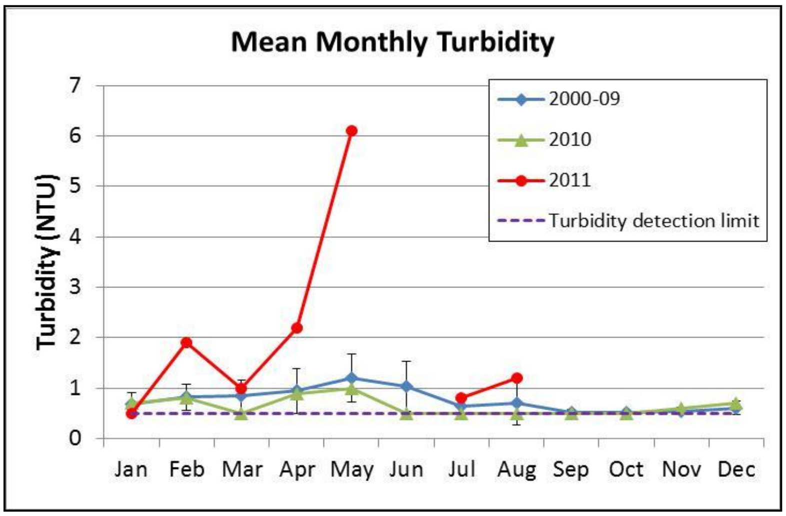


Figure 11. Mean monthly turbidity at Ecology Station 53A070 downstream of Grand Coulee Dam.

Fecal Coliform

Testing of fecal coliform bacteria is an often used water quality parameter that indicates the probability of vertebrate fecal contamination in some cases. Many years of monthly sampling have yielded detection limits readings of 1 cfu/100ml or occasionally just above 2 cfu/100ml concentrations. For example, Figure 12 shows the year 2000-2009 period with mean values at detection limit or just a small fraction above and very small error bars. However, in 2010 slightly elevated concentrations were detected in summer months and more extensively in 2011, fecal coliform concentrations were much larger than normal in May and August tests, but June was not sampled. It is difficult to draw firm conclusions from a single sample per month, but these data do indicate 2011 as an anomalous year in RWL water quality.

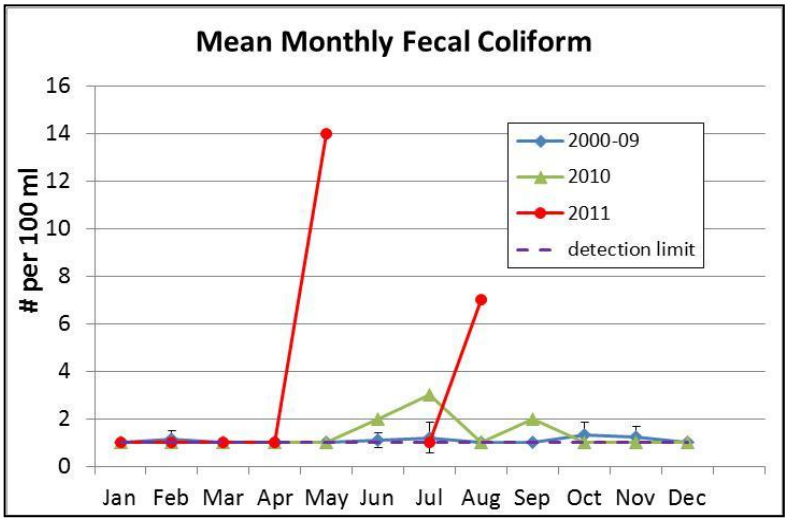


Figure 12. Mean monthly fecal coliform at Ecology Station 53A070 downstream of Grand Coulee Dam.

Conductivity

Conductivity is relatively low in Rufus Woods Lake and has been noted to decrease in mid-summer in prior years (Rensel 1993). Older studies suggested it has been positively correlated with river discharge and total suspended solids load in the past (see review by Rensel 1993). Annual peaks in late winter to early spring have preceded the late spring and early summer snowpack-melt-driven peak flows by several months (Figure 13), and in recent years there was a general inverse correlation between discharge and conductivity with the lowest late winter and early spring values seen in 2011.

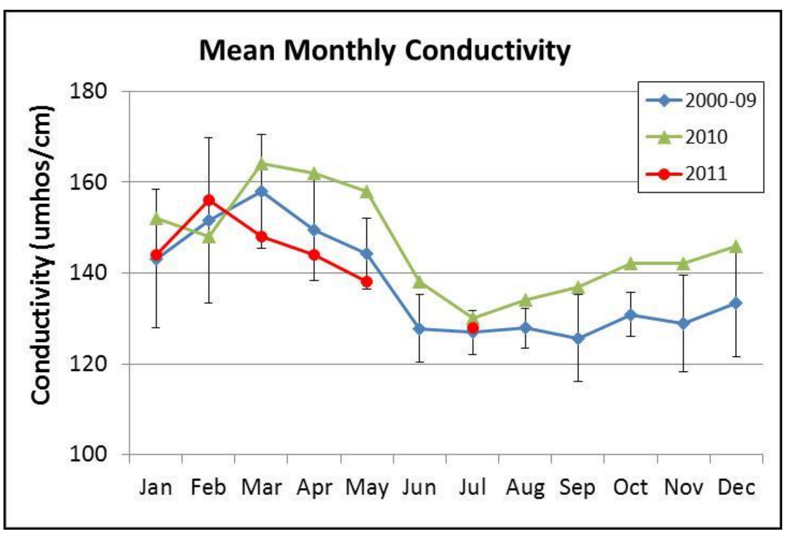


Figure 13. Mean monthly conductivity at Ecology Station 53A070 downstream of Grand Coulee Dam.

Dissolved Gas

Elston and Rensel (1996) report extensive losses of farmed trout and some wild fish in Rufus Woods Lake that were directly linked to gas bubble disease (GBD) from high levels of atmospheric supersaturated gases produced by Grand Coulee Dam. Subsequently, additional monitoring of dissolved gas levels has been conducted by Grand Coulee Dam operations and the problem has generally been reduced. Total dissolved gas (TDG) in the upper Columbia River and near Chief Joseph Dam can exceed Washington State maximum standards frequently. TDG in Rufus Woods Lake is influenced primarily by Grand Coulee Dam and Canadian dam operations upstream. TDG spikes reaching 140% have been observed in Rufus Woods Lake (USACE 2000). Many vertebrate and invertebrate species occupying the near surface layers of the reservoir are killed or injured by such concentration of dissolved gas, but a few meters below the surface the effects are greatly reduced. There has been no detailed study of the effects on the food web in RWL of the high gas levels. Richards (unpublished) is presently conducting a limited study to determine if benthic communities at several locations in RWL differed seasonally between October 2010 and 2011 possibly in relation to gas bubble disease. A dissolved gas mitigation device was constructed downstream on the downstream side of Chief Joseph Dam (i.e. a “fliplip”) and apparently is somewhat effective, but this does not help mitigate GBD problems in RWL. The problem may affect species that have larval or early stages that require shallow water for development, including many species of fish and some invertebrates, but adult forms of fish often will maintain deeper habitat use than where their young develop nearshore.

Macronutrients

Pelagic algal growth (i.e., phytoplankton) in RWL was considered in the 1980s to be nitrogen-limited or limited by other factors such as seasonally reduced light and water temperature (Rensel 1989, 1993), but currently, in 2011, the water column algae (phytoplankton) and any macrophytes or periphyton that take a significant amount of nutrient from the water column are probably phosphorus-limited during the mid-summer to late fall algal growing period. Until the mid-1990s, biological production in Rufus Woods Lake and the mid-Columbia River was considered to be nitrogen-limited or not limited by the nutrient content in the water but by other factors (i.e., seasonally low water temperature and reduced light intensity at depth). With the alternation of process procedures at the Cominco, Ltd. fertilizer plant that formerly discharged many thousands of kilograms per day of total phosphorus into the river at Trail, British Columbia, primary algal productivity became severely phosphorus-limited (Rensel 1989, 1996).

Phosphorus

The concentration of total phosphorus (TP) at the Washington Department of Ecology monitoring station immediately below Grand Coulee Dam (No. 53A070, Columbia River at Grand Coulee) was exceedingly high in the 1980s and early 1990s averaging approximately30 µg/L during the algal growing season. For example, from April through November, 1982 – 1988 the mean TP concentration was 30.2 µg/L with considerable month to month variability (standard deviation = 19.2, Rensel 1989). More recent data from years 2000 through 2009 analyzed for the *Pacific Aquaculture Site 3 NEPA Environmental Assessment* indicated that phosphorus concentrations (and flux) are much lower than in the past. Mean monthly TP averaged only 5.6 µg/L (SD = 2.3) in that time period, or 81.5% less than what it formerly was when the Cominco, Ltd. Fertilizer plant was operating upstream of Lake Roosevelt.

Figure 14 presents mean monthly total phosphorus for the 2000-2009 versus 2010 or 2011 periods. It can be seen that there was a substantial increase in total phosphorus load entering RWL in 2010, but especially in 2011, reaching a maximum of 29 µg/L in May, 2011. Unfortunately, no WDOE data were collected in June 2011 due to repaving of the bridge at Grand Coulee where sampling is always conducted. Nevertheless, from these data it is clear that 2010 and certainly 2011 were unusual nutrient flux years, not seen for several decades. Figure 15 illustrates some of the older data, mostly collected by Rensel Associates as consultants for Columbia River Fish Farms (a predecessor of Pacific Aquaculture in the same locations), and analyzed at the University of Washington Routine Chemistry Laboratory as commercial and state laboratories were unable to provide adequately low detection limits or accurate results in some cases. The biological effects of this are discussed below with regard to periphyton and blue green algae that were noted to be more prevalent in these same years in RWL.

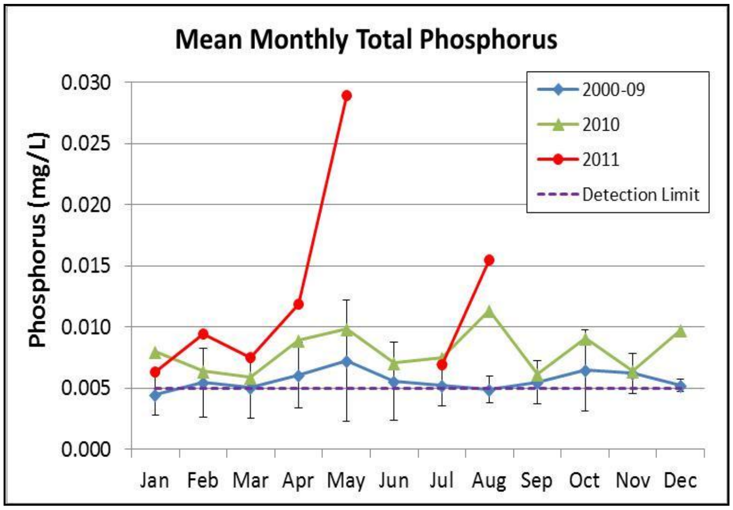


Figure 14. Mean monthly total phosphorus (mg/L) at RWL Ecology Station 53A070.

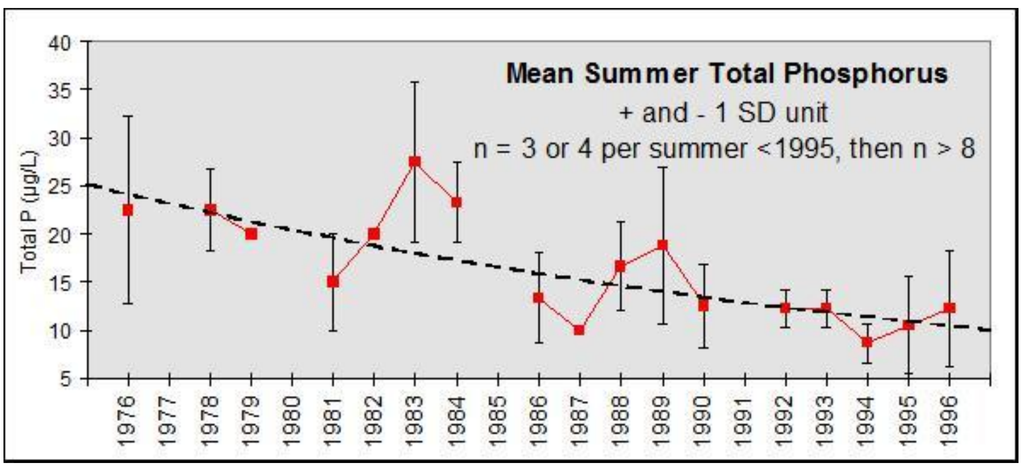


Figure 15. Historic total phosphorus trends at RWL Ecology Station 53A070 from Rensel (1996). Note units are µg/L (parts per billion). 1 µg/L = 0.001 mg/L.

Orthophosphate (the readily available to algae form of inorganic phosphorus) has also declined further since the early 1990s and prior years, and now is often at or below detection limits as it averages 3.8 µg/L (SD = 0.8) in the 2000-2009 period (Figure 16). This is also a highly conservative estimate because the average was calculated using the actual detection limit of 3.0 µg/L when many authors will use one-half of such a detection limit reading in their calculation. In 2010 and 2011 a different pattern emerged: monthly orthophosphate was generally the same or lower than the prior years except during April, May and August, when values far exceeded the 2000-2009 average and range. This suggests higher algal standing stock that would have been able to sequester the nutrient quickly resulting in higher TP and chlorophyll *a* values as discussed herein. The very high concentrations in August 2011 (8 µg/L) were far larger than previously seen, but periphyton stock reaction and the presence of blue-green algae flowing into the lake as discussed below indicate that the measurement was probably not an anomalous outlier.

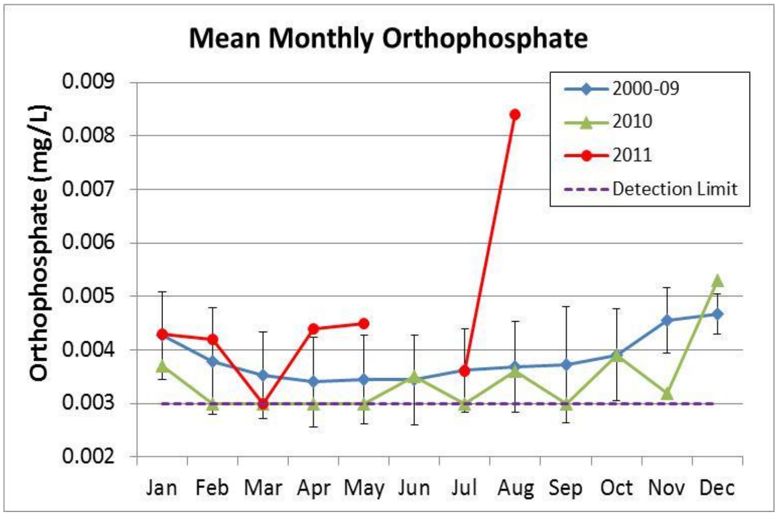


Figure 16. Mean monthly orthophosphate (mg/L) RWL Ecology Station 53A070.

Nitrogen

Ammonia nitrogen (also known as total ammonia nitrogen that includes both ammonium and ammonia) concentrations are at or below detection limits for most of the year in Rufus Woods Lake (Figure 17). In the period 2000-2009, ammonia nitrogen concentrations have not increased and likely decreased significantly over the years. Typical concentrations over the last decade are near or below detection limits in all months except June and July, about an order of magnitude less than what was observed in the 1970s (Rensel 1996). In 2010 and 2011, however, the curve broadened to include a peak in the May through July period, caused by roughly equivalent results from both 2010 and 2011.

Annual nitrate plus nitrate concentration averaged 109 µg/L in the period 2000 through 2009. Over the entire 1990s decade, mean annual nitrite plus nitrate averaged 117 µg/L with a relatively large standard deviation (103 µg/L). These and other reliable data indicate no significant change of nitrite plus nitrate concentration over the past 30 years but do indicate considerable variability. Likewise, mean monthly nitrate plus nitrate concentrations in 2010-2011 averaged 105 µg/L, suggesting that levels continue to remain stable.

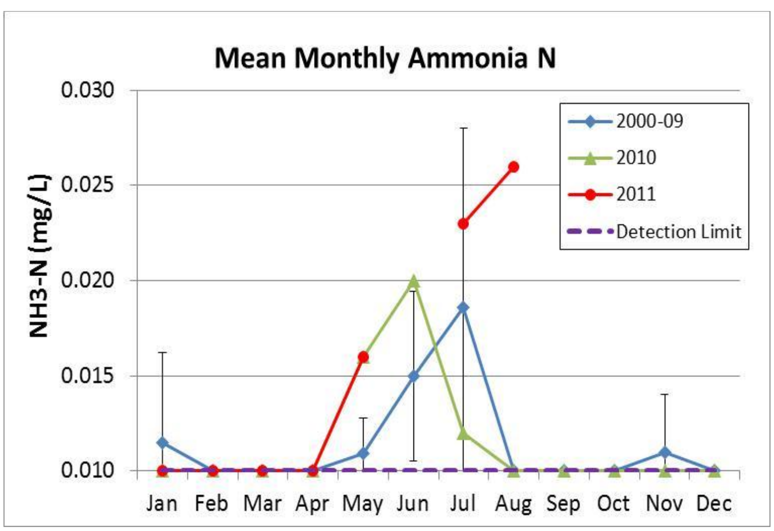


Figure 17. Mean monthly ammonia nitrogen (mg/L) at RWL Ecology Station 53A070.

Monthly total nitrogen concentrations (figure not shown here) have had a pattern similar to nitrite plus nitrate, which is reasonable as the latter compose much of the former, the remainder being organic forms of nitrogen, dissolved and particulate. There are no long-term records for total nitrogen concentrations in Rufus Woods Lake, but a comparison of years 1995 through 1999 indicate annual mean concentrations of 215 µg/L (SD =169.1). This prior result significantly exceeds the concentrations observed during the period 2000 through 2009 during which the annual average was 167.7 µg/L (SD = 54.2), and was slightly greater in 2010-2011 (SD = 48.0, 2011 data incomplete).

Nitrogen to Phosphorus Ratios

The ratio of N to P (nitrate+nitrite+ammonia to orthophosphate) in RWL waters during the period 2000 through 2009 (Figure 18) varied seasonally, not unlike the nitrogen results discussed above (compare to the shape of Figure 17). The system was strongly phosphorus-limited according to these data; i.e., N:P ratios were well above 7 in all cases (i.e., above 16:1 on an atomic weight basis). During the period 1976 through 1990, there was an annual average ratio of approximately 12 to 16 with data from the Ecology monitoring station in the algal growing season (i.e., April through October). In comparison, during the 2000 to 2009 interval mean growing season, the N:P ratio increased to 29.7 (SD = 18.8) showing increased P limitation that accompanies the nutrient impoverishment of the water column. Some analysts use total N to total P ratios, but in systems such as the Columbia River where much of the total N and P may be refractile, and not quickly cycled in the nutrient spiraling process, it is more reasonable to use the dissolved inorganic forms in such analyses. N:P ratios were significantly lower in 2011, but with the exception of July and August, remained indicative of phosphorus limitation and hence phosphorus shortage compared to nitrogen for algal production.

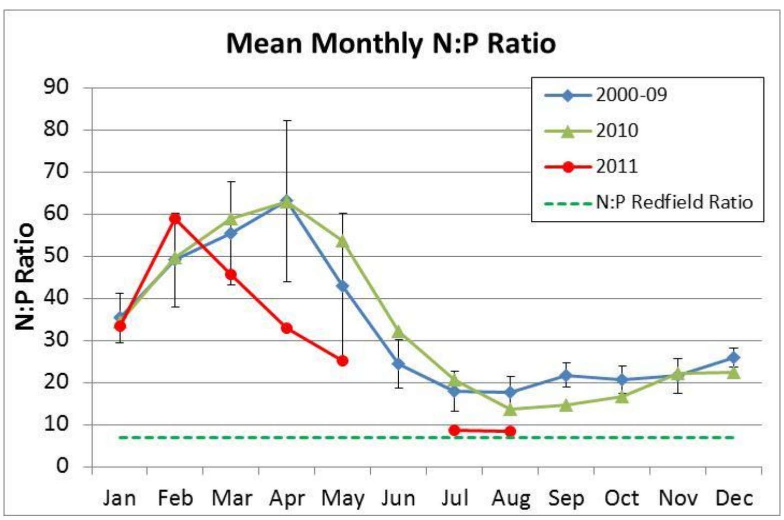


Figure 18. Mean monthly and standard deviation N to P ratio in grams weight units at Ecology Station 53A070 downstream of Grand Coulee Dam with the physiological balance point for algal nutrition of approximately 7 to 1 by weight (Redfield Ratio), shown as the dashed green line.

Chlorophyll *a*

Rensel (1996) reviewed the scant available data for RWL suggesting significant declines of chlorophyll *a* concentrations from the first measurements by Erickson et al. (1977, four evenly spaced locations in 1975) to mid-1990s data collected by fish farm consultants in Rufus Woods Lake that ranged from approximately 4 µg/L in May to < 1 µg/L in August through October (Figure 19). A concentration of 4 µg/L is, however, not an insignificant density of pelagic algae (phytoplankton) but there is significant variation within years that is driven by variability in the onset of the spring bloom in upstream Lake Roosevelt.

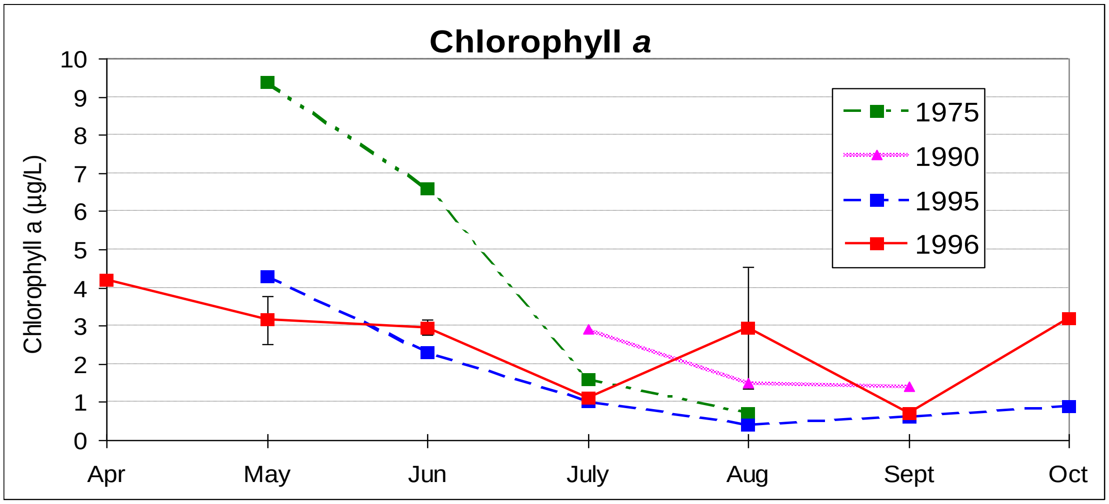


Figure 19. Historical chlorophyll *a* from Stober (1977) and Rensel (1996).

Figure 20 indicates that water column chlorophyll *a* was similar to the 1990s available data, but much less than that measured in 1975. The Department of Ecology discontinued chlorophyll data collection at one point prior to 2000, but we know from data one of us collected upstream of the net pens that during that decade concentrations were similar or less to what was seen in 2010 and 2011.

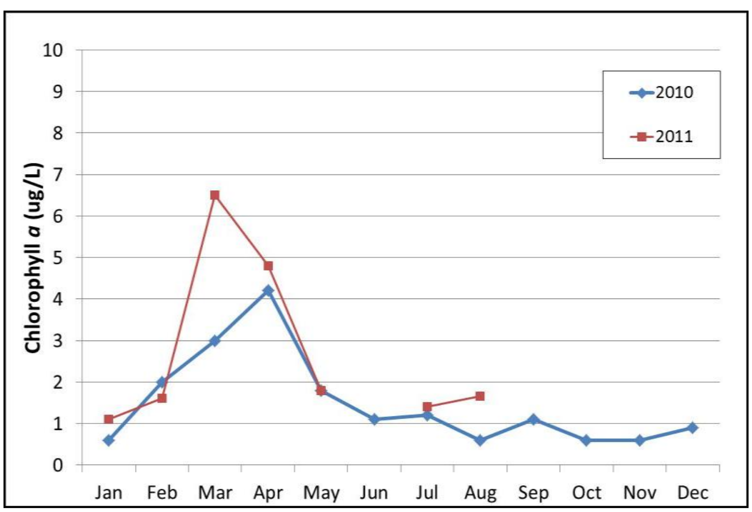


Figure 20. Monthly chlorophyll *a* pigment concentration for Ecology Station 53A070 downstream of Grand Coulee Dam: 2010 through 2011.

Algal Communities

Macrophytes have persisted along the shores of RWL since early after the reservoir's construction. Unlike Lake Roosevelt, which is drawn down extensively each year, water surface elevation is relatively stable in RWL, allowing for these rooted aquatic plants to exist nearshore. In 1991, Moore (1992) observed in the areas around Columbia River Fish Farm (near Nespelem, same as existing Pacific Aquaculture Site 1 today) that macrophytes grew only to about 2 meters depth. In recent years, we have routinely found them growing to ~6 m depth, which is an apparent function of decreasing turbidity and chlorophyll *a* concentrations associated with reduced phytoplankton abundance in Lake Roosevelt and the cessation of large discharges of phosphorus from the Cominco fertilizer plant complex in Trail B.C. that drained into Lake Roosevelt. There may be other reasons as well, such as increasing storage use upstream.

Surprisingly, the above trends seemed to reverse abruptly in 2010 and certainly in 2011. As discussed above, many measures of trophic state suddenly increased concurrent with the large flows in these two years. Even more surprisingly, the abrupt chemical and physical changes induced an amazing growth of problem algae in the system. For macrophytes, this meant infestation with noxious, undesirable periphyton including *Spirogyra* sp., a green filamentous alga that wraps around the growing leaves of the macrophytes and other suitable surfaces. Some *Cladophora* sp. was seen in many locations too; it is another filamentous green alga that was previously the principal noxious algae in Lake Roosevelt a few decades ago when the abundance led to unsightly and frequent floating algal mats on the surface. USACE staff located at Chief Joseph Dam who manage the reservoir and fish farming staff of Pacific Aquaculture Inc. who rear rainbow trout in the lake were both concerned and there was worry that the fish farming may have led to some of the changes observed. In 2010 fish farmers countered that they had numerous pictures of algal material on the upstream edge of their net pens, indicating that the problem was originating from upstream. No technical sampling or identification was attempted but the problem recurred and in some ways was worse in 2011.

In 2011, not only were *Spirogyra*, *Cladophora* and other periphyton abundant in some stands of macrophytes, but toxic blue green algal mats were discovered rafted up along the debris collecting boomstick assembly just upstream of Chief Joseph Dam. Technical analysis showed detectable and somewhat dangerous concentrations of anatoxin-*a*, and accordingly the reservoir was posted by USACE as having a toxic bloom. To our knowledge, this had not happened before, although Moore (1991, 1992, 1993) had previously found blue green algae in RWL water samples as had Rensel et al. (2000) downstream in Rocky Reach reservoir. But in the past no signs of floating mats of toxic algae had been seen, although floating algal mats are common in downstream Lake Pateros, which received blue green algae from the eutrophic Okanogan River System (Rensel 1998).

Several sets of samples of the floating mats were collected for toxin analysis and species identification. At first the sampling focused on the Chief Joseph Dam pool area, where the algal mats were seen along the boomstick, near the adjacent USACE boat launch, but also some distance upstream on the right bank including at Bridgeport State Park boat launch. While collecting other hydrographic data upstream near Buckley Bar on 28 July 2011, Rensel and Siegrist (unpublished data, photos, GPS entries and emails) noticed that a continual string of floating mats of algae was originating from shallows around Buckley Bar and floating downstream. River elevation was high and rising much higher that the ordinary high water mark at the time and it was apparent that the alga was either originating from this site or had previously been trapped at lower water and released as the water elevation increased. Buckley Bar (Figure 26, later in this report) is the only large island with extensive shallows in mid channel of RWL that would form an effective trap to floating algal mats.

Sampling of algal mats throughout the reservoir in mid to late summer 2011 by USACE staff and the authors of this report showed toxin throughout the reservoir. However, few algal mats were found except for the Chief Joseph Dam forebay (the boomstick and near the boat launches) and much fewer around Buckley Bar upstream. In the forebay, winds apparently shifted the location of the mat from the boomsticks to the boat launches and possibly other locations. Other portions of RWL were apparently mostly without floating mats including offshore waters. In mid-July 2011 we entered all embayments and backwaters along both banks of the entire reservoir (while depth sounding for the bathymetric map completion) to be able to state the above with some confidence. The principal species of blue green algae observed was *Oscillatoria* spp., and according to blue green expert Wayne Carmichael, the abundance of this species was quite low in the samples he observed from throughout the reservoir. Water samples near the stationary algal mats downstream yielded no toxin (Carmichael 2011). A USACE identification contractor identified the blue-green alga *Aphanizomenon flos-aquae* as present in some mat samples, but Professor Carmichael indicated that this would be extremely rare and that he had coauthored a paper indicating that misidentification of the species was common (Li et al. 2000). By October 2011, blue green algal toxins were apparently no longer present and observations of macrophytes remaining indicated little *Spirogyra sp. or Cladophora sp*. remained.

Water Quality Summary

The above analysis indicates that water flowing into Rufus Woods Lake was on track to be increasingly oligotrophic (nutrient poor) until 2010 and particularly 2011 when extremely high flows occurred. The abrupt change in 2010 and more so in 2011 of river water quality was striking, and along with this change there was a profound change in algal communities that is troublesome. Now that nuisance periphyton are established in the reservoir, it is unknown if they will persist into the following years, but may be a function of the high flows, peaks in phosphorus availability and other degraded water quality conditions observed especially in 2011. This is a situation that is important for numerous reasons, and we provide suggested monitoring and research suggestions for 2012 and subsequent years to insure that at least some baseline of monitoring and understanding occurs.

Bathymetry and Reservoir Morphometrics

Following the method previously outlined, here we present results of the bathymetric and reservoir morphometrics study of RWL. The EASy GIS system is digital and can be easily configured in many different ways, here we present just an overview of some of the main features starting with simple views of the reservoir that the user can zoom in and out on to suit their own purposes. Screen shots of the entire Rufus Woods Lake bathymetric map are shown in Figures 21 to 27 with place names and river miles overlays turned on.

Figure 21 offers an example of the features of the EASy bathymetric model. The detailed bathymetric map yields real-world information, such as the extreme depth of the lower Chief Joseph Pool, as well as the original sinusoidal path of the pre-RWL Columbia River, seen as the deepest (darkest blue) region. Relevant natural and anthropomorphic GIS locations, such as the USACE boat ramp and Goose Tub Island, are also shown, as well as river mile markers for the entire course of the river.

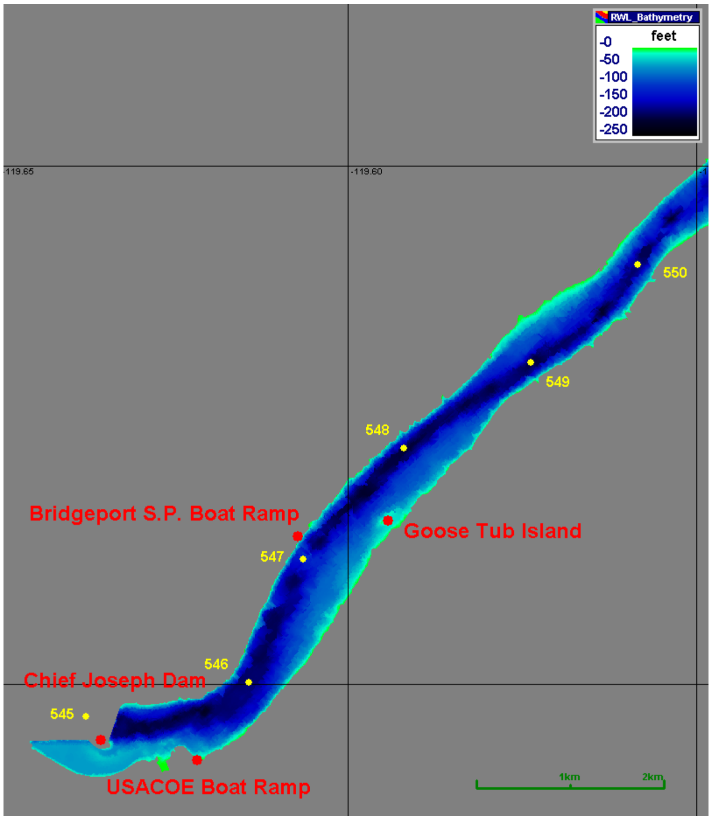


Figure 21. Chief Joseph Dam and lower Chief Joseph Pool, Columbia River miles 545-550.

Figures 22-24 show sections of Rufus Woods Lake from the upper Chief Joseph Pool downstream, to PAI Site 1 upstream. As we move upstream, the river becomes increasingly narrow and shallow; Figure 25 shows the extreme shallows of Buckley Bar and the Nespelem River mouth.

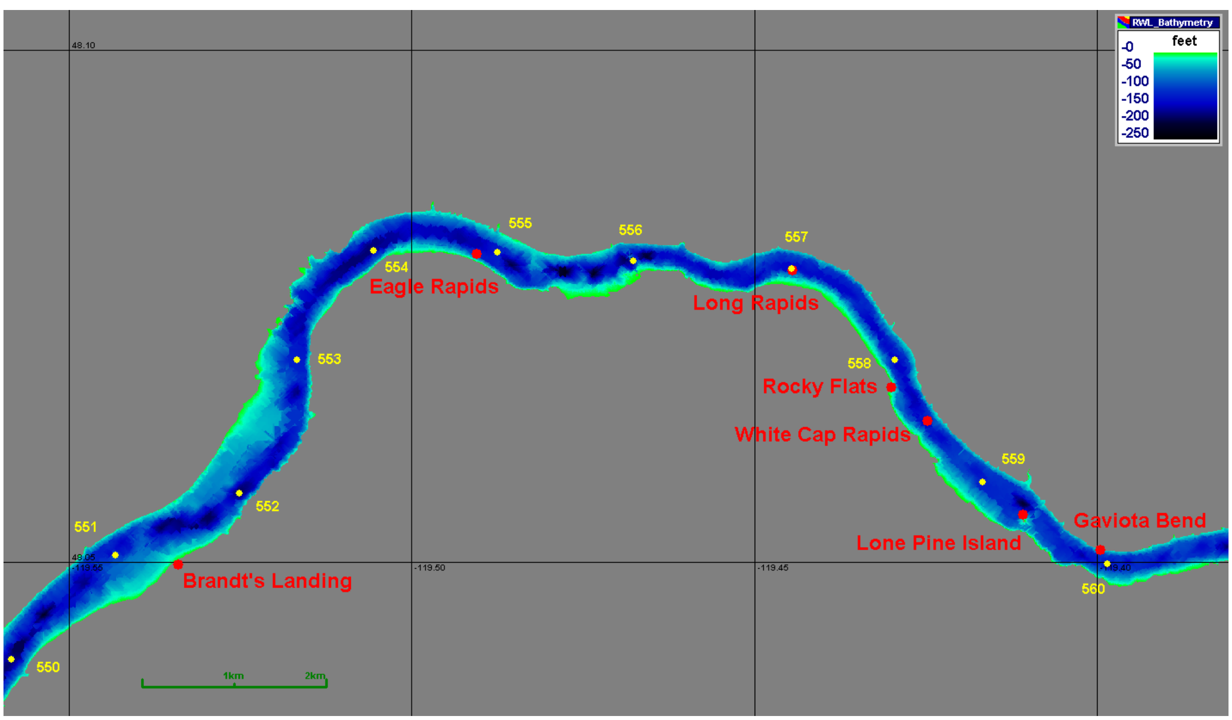


Figure 22. Upper Chief Joseph Pool to Gaviota Bend, Columbia River miles 550-560.

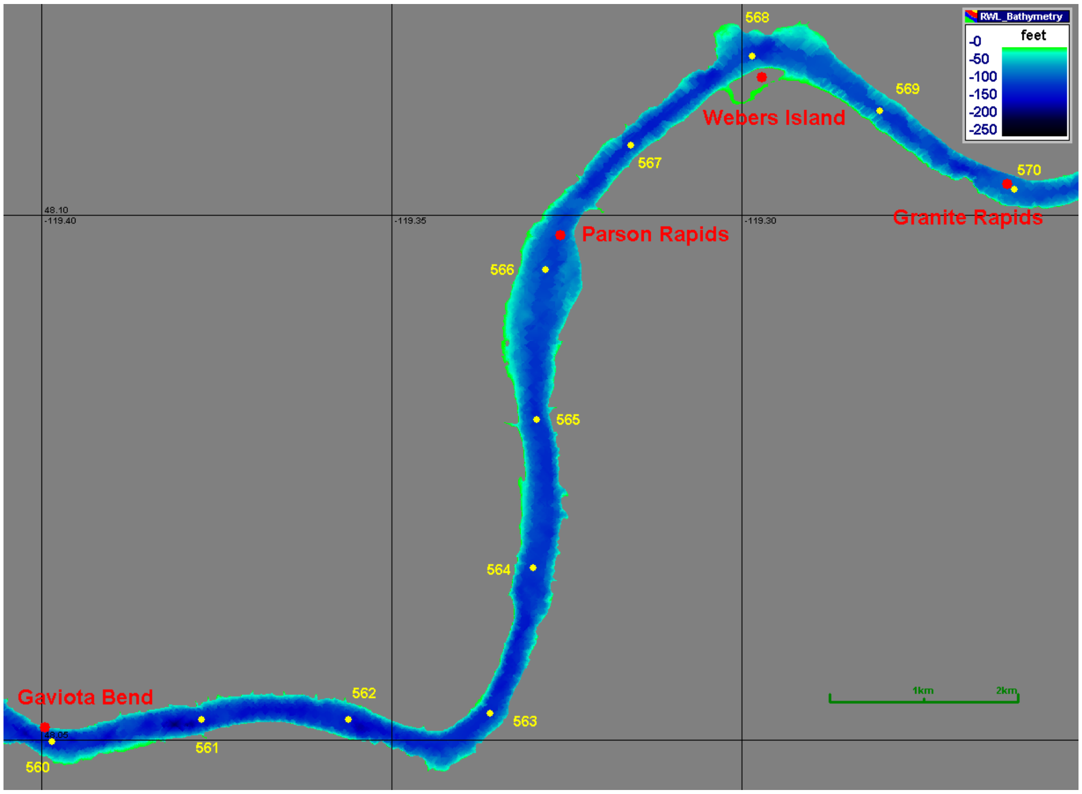


Figure 23. Gaviota Bend to Granite Rapids, Columbia River miles 560-570.

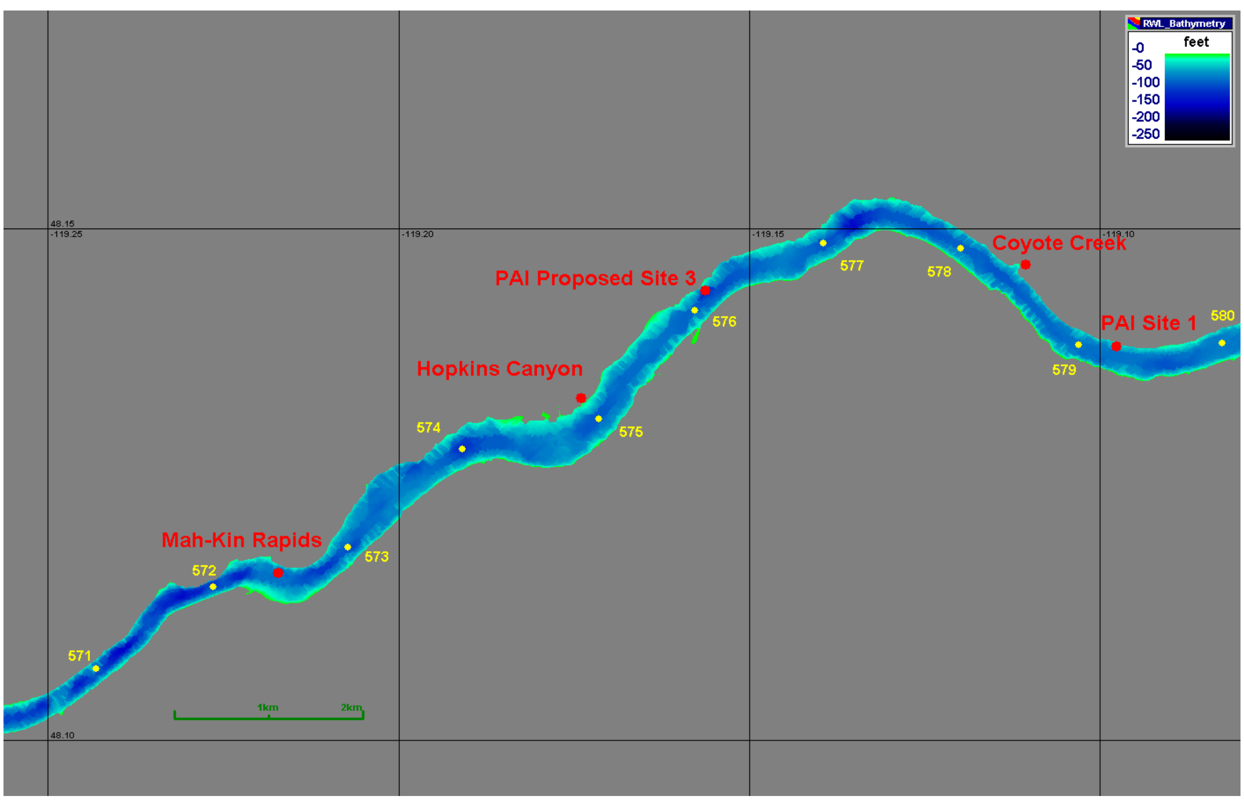


Figure 24. Mah-kin Rapids to PAI Site 1, Columbia River miles 571-580.

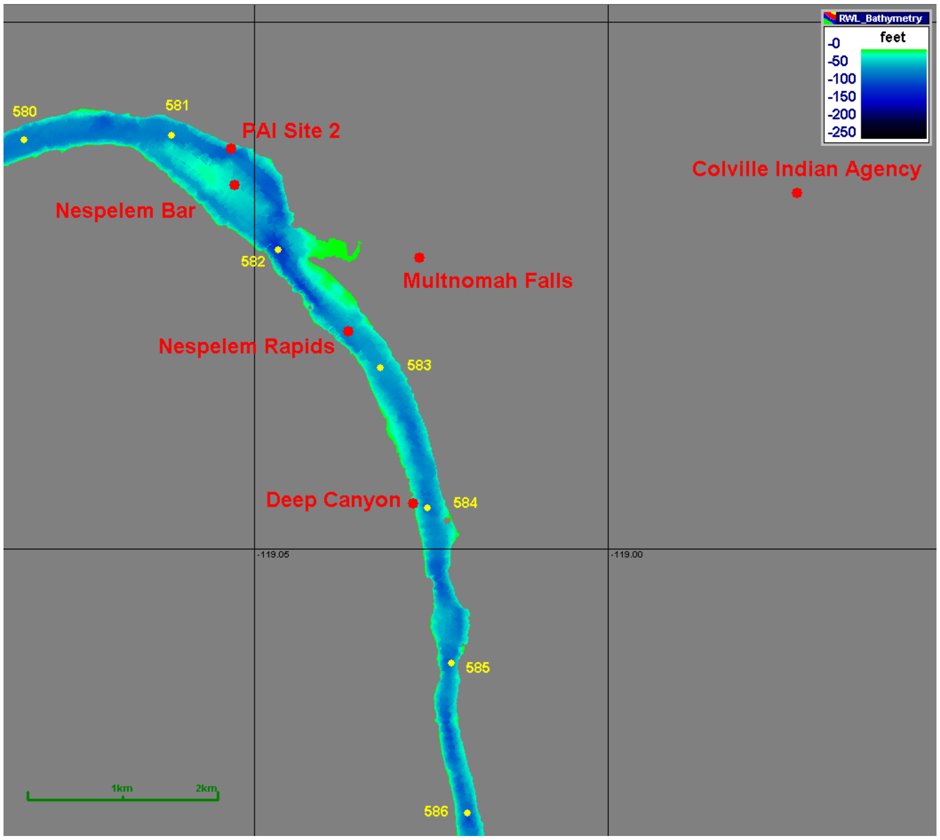


Figure 25. PAI Site 2 to downstream of Buckley Bar (not shown here), Columbia River miles 580-585.

Figures 26 and 27 show the upstream end of Rufus Woods Lake: Figure 26 contains Buckley Bar and Seatons Grove, while Figure 27 displays the last few river miles of Rufus Woods Lake, ending at Grand Coulee Dam tailrace.

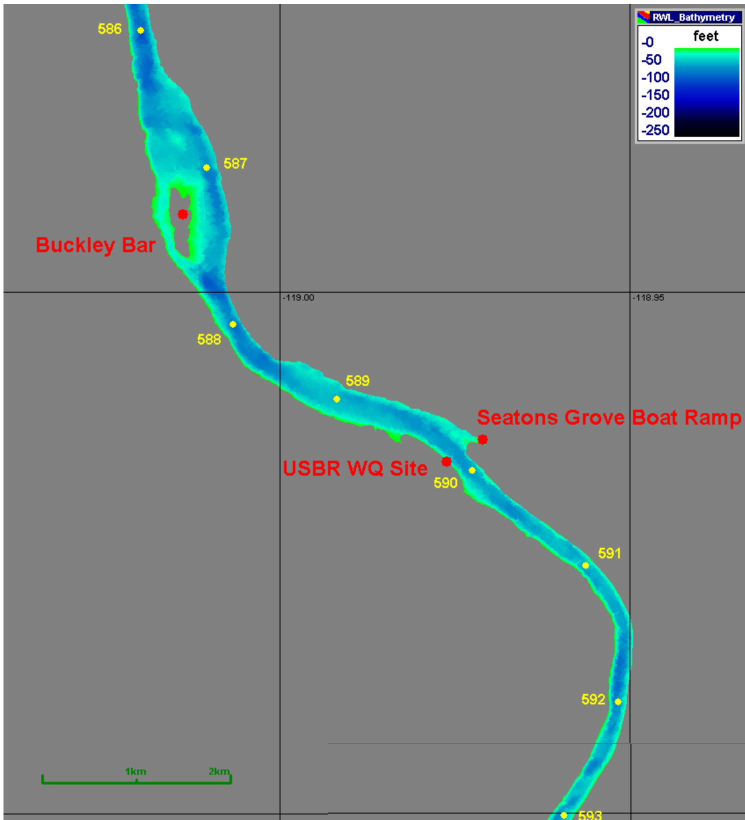


Figure 26. Buckley Bar to Elmer City, Columbia River miles 586-592.

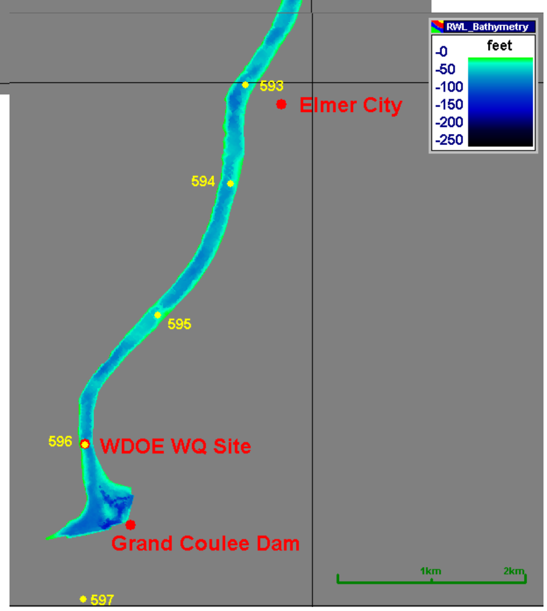


Figure 27. Elmer City to Grand Coulee Dam, Columbia River miles 593-596.

The EASy model has considerably more information available than simple geographic locations, however. We have included a range of additional GIS points that contain GIS locations of various aspects of our study, including trout tracking stations (TTS), suction dredge sites (SDS), periphyton sites (not shown here), and photographic images (represented as a camera icon in EASy). Each of these, along with geographic locations and river miles, can be turned on or off at will as a series of overlays, shown in the upper right-hand legend in Figure 28.

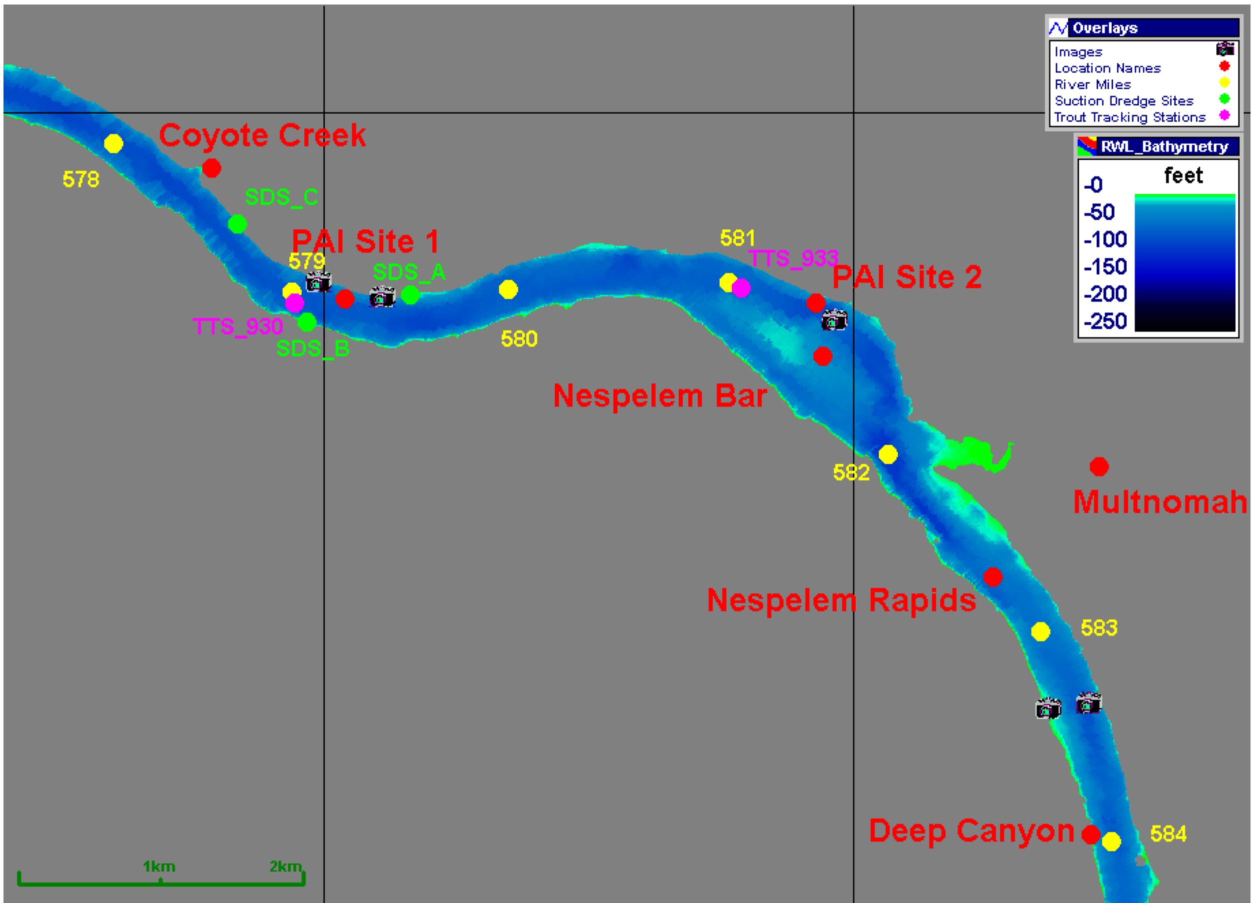


Figure 28. Example of multiple GIS overlays.

Likewise, Figure 29 illustrates a zoomed in image of the GIS showing Nespelem Bar and locations to click on for photographic images.

The EASy GIS system also has modeling and analytical features, for example a trout growth model described later in this report can be installed to run within the GIS.

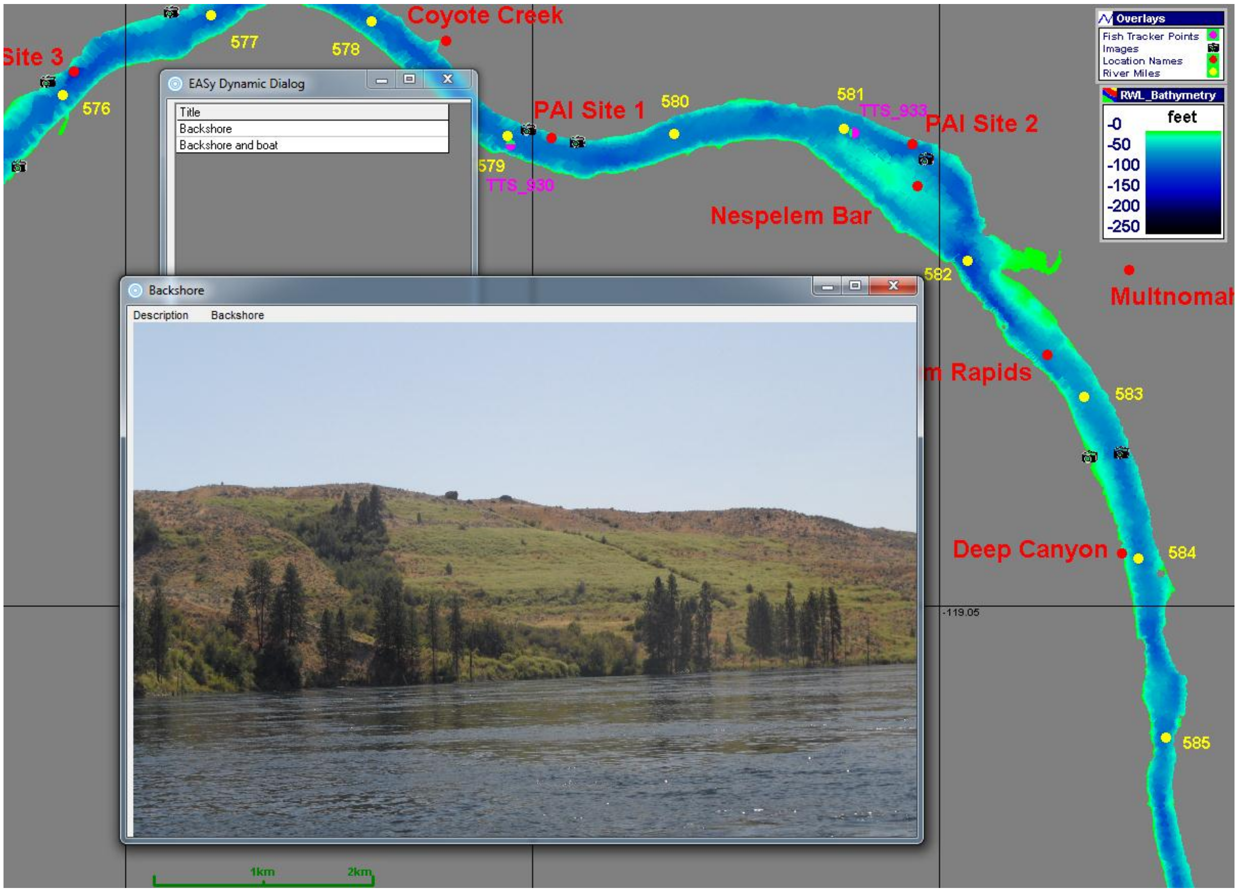


Figure 29. Zoomed-in image of the EASy GIS model showing Nespelem Bar area and locations to click on for photographic images (represented by camera icons) and location of trout tracking stations (TTS) used in the acoustic tagging study. Photo shown is one of two images available by clicking on right bank camera icon between river mile 583 and 584.

Our EASy model also has the ability to generate a variety of morphometric information for a user-selected area or transect, and to generate a 3-dimensional bathymetric plot of any user-selected area of the reservoir. Figure 30 depicts a selected area of Chief Joseph Pool and a resulting pop-up window displaying morphometic statistics and a 3-D bathymetric plot. Figure 31 shows a 2-D bathymetric transect bisecting Buckley Bar and RWL. Figure 32 provides another example of the 3-D bathymetric plot, this time generated around Grand Coulee tailrace. We can easily observe the deeper waters in the tailrace adjacent to Grand Coulee Dam, compared to the more shallow areas to the east and north of deep sections.

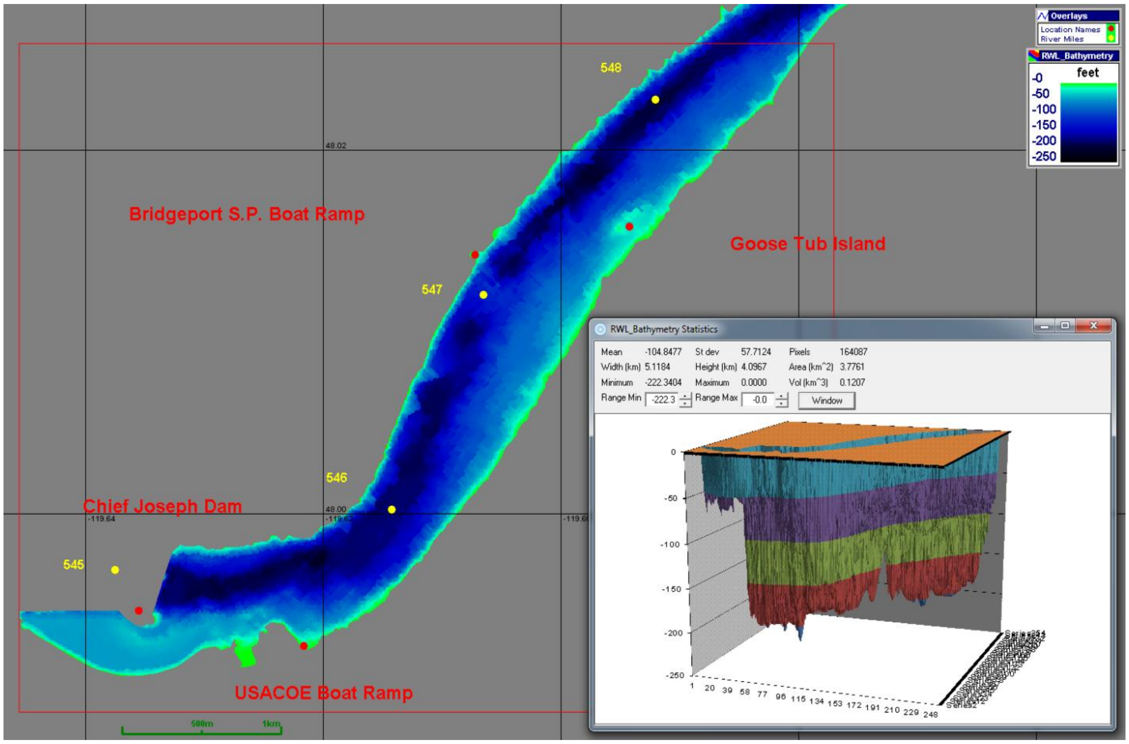


Figure 30. Zoomed-in image of lower Chief Joseph Dam pool, with image statistics window showing a 3D bathymetric profile of the area enclosed by the thin red rectangle.

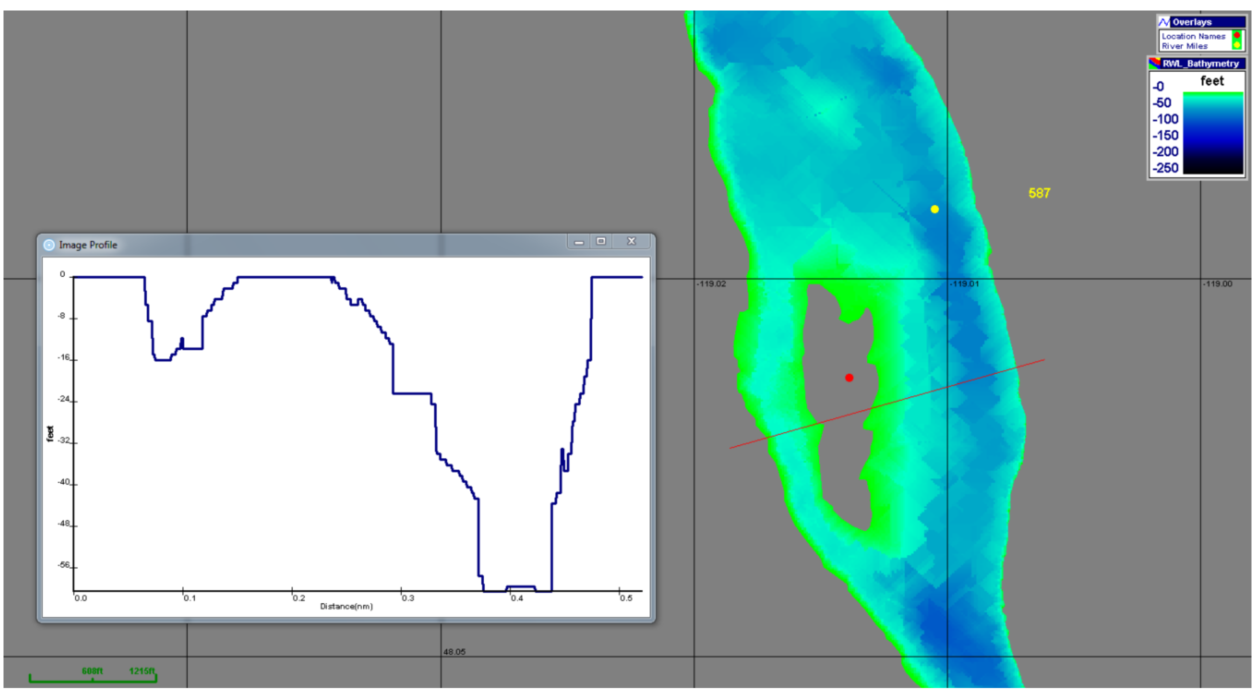


Figure 31. Zoomed-in image of Buckley Bar, with image profile window showing a 2D bathymetric transect along the thin red line bisecting the reservoir and Buckley Bar.

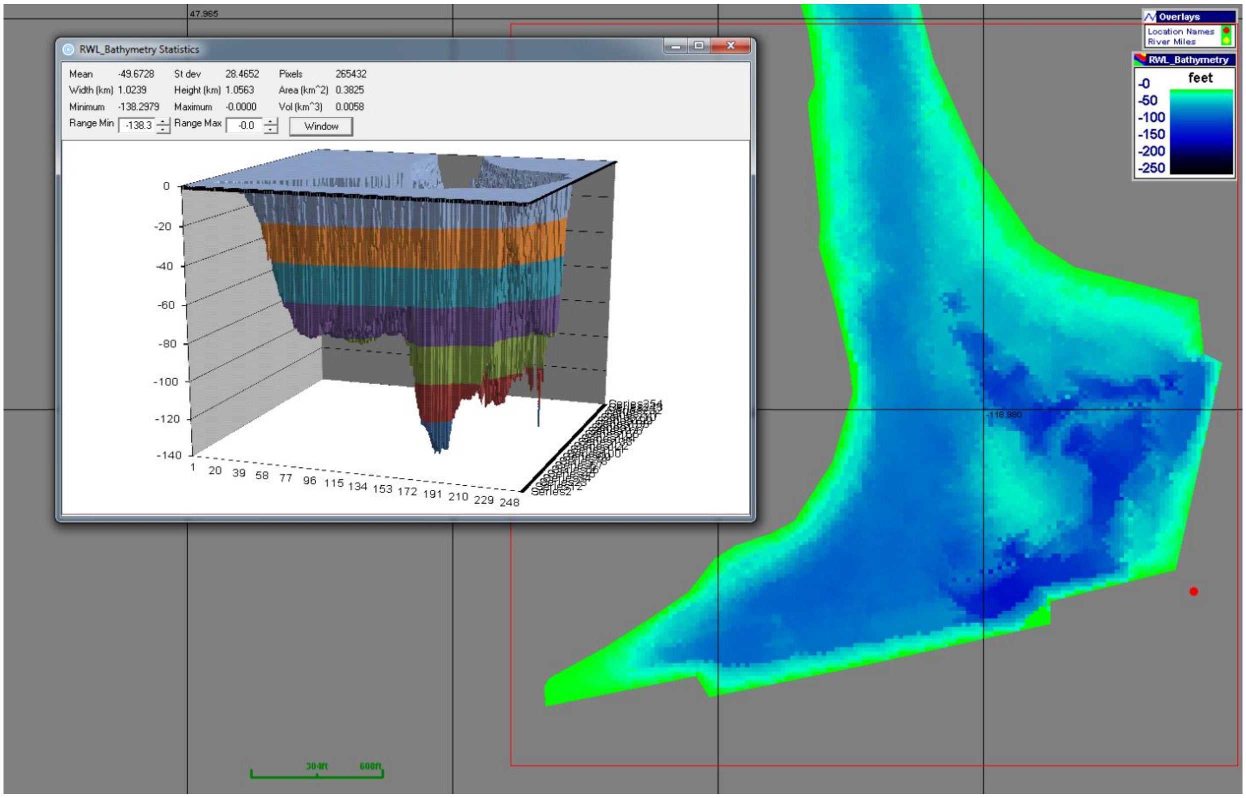


Figure 32. Zoomed-in image of Grand Coulee Dam tailrace, with image statistics window showing a 3D bathymetric profile of the area enclosed by the thin red rectangle.

Morphometric reservoir data were generated using Environmental Assessment System (EASy) software bathymetry and statistical tools, supplemented with data from Google Earth, USGS Grand Coulee Dam hourly outflow discharge data, and Microsoft Excel as described in the method section. Area and volume of the entire reservoir and subsections are indicated in Table 1.

Total volume results were compared to other estimates (Wikipedia, source undocumented) that lists the volume of Rufus Woods Lake at 0.64 km^3, which is within 10% of our value of 0.71 km^3 (Table 4). It is possible that the Wikipedia value dates from before Rufus Woods Lake level was raised by approximately 10 feet around 1978. Adjusting EASy to discount the top 10 feet of the lake yields a volume of 0.70 km^3, somewhat closer to the Wikipedia value.

The U.S. Army Corps of Engineers (R. Fischer, personal communications email to J. Rensel, Feb. 2010) indicated that the Chief Joseph Dam project brochure reports a total reservoir volume of 593,000 acre feet (equivalent to 731,454,000 m^3) which compares favorably with our estimate of 705,800,000 m^3, although 3.5% more. This value was apparently taken from Stober 1997, although that author provided no methods for the estimate. Attempts to locate bathymetric records or other related data from the Seattle Branch of the USACE were unsuccessful.

Table 4. Area and volume calculations of Rufus Woods Lake.

See bullet list below for definitions.

	Entire Reservoir		Upper		Middle		Lower	
Depth (ft)	**Area (km^2)**	**% of total**	**Area (km^2)**	**% of total**	**Area (km^2)**	**% of total**	**Area (km^2)**	**% of total**
<18	3.76	11%	0.54	23%	2.58	11%	0.61	7%
18 to <50	9.24	28%	1.25	53%	6.62	29%	1.45	18%
50 to <100	12.42	37%	0.55	23%	9.42	42%	2.41	29%
100+	7.90	24%	0.02	1%	4.07	18%	3.83	46%
Total	33.32	N/A	2.35	N/A	22.69	N/A	8.30	N/A
Depth (ft)	**Volume (km^3)**	**% of total**	**Volume (km^3)**	**% of total**	**Volume (km^3)**	**% of total**	**Volume (km^3)**	**% of total**
<18	0.011	2%	0.002	6%	0.007	2%	0.002	1%
18 to <50	0.098	14%	0.014	52%	0.069	16%	0.016	6%
50 to <100	0.271	38%	0.010	39%	0.206	47%	0.055	22%
100+	0.326	46%	0.001	2%	0.153	35%	0.173	71%
Total	0.706	N/A	0.026	N/A	0.435	N/A	0.245	N/A

- "Upper" was defined as the area between Grand Coulee Dam and Seaton's Grove (~10km downstream of Grand Coulee Dam);
- "Lower" was defined as Chief Joseph Pool upstream to where the reservoir narrows (~12.6km upstream of Chief Joseph Dam);
- "Middle" was chosen to be the area bounded by the upstream and downstream areas.

Table 5 includes the same volume and area estimates with maximum length and width, mean and maximum depth and hydraulic retention time, also known as flushing rate. The largest subsection of the reservoir was the middle region in terms of volume and area, but only because of the extensive length of this subarea (58.3 km, 36.2 miles). Within this region it is possible to further subdivide based on other morphometric aspects, but clearly the middle region is dissimilar from both the Grand Coulee Dam tailrace and revetment zone we designate as "upper". Because of the limited depth of the upriver region, it had the greatest percent littoral zone (0' to 18') designation of 23% as well the greatest percent sublittoral zone (18' to 50') at 53%. In contrast, the downriver section had the least in both of these same categories, due to the relatively great depth in the Chief Joseph Dam pool area.

Table 5 also includes river discharge summaries for the relatively low flow 2000 decade, and comparison to the much larger flows of 2010 and especially 2011. During the former set of years the annual hydraulic retention time averaged about 3 days, but was reduced to < 2 days during the 2011 period of record. These physical factors were of paramount importance in controlling biological characteristics of the reservoir in recent years, as discussed later in this report.

Table 5. Morphometric characteristics of Rufus Woods Lake

Rufus Woods Lake Morphometry	Entire Reservoir		Upper		Middle		Lower	
River mile range	544.6 - 596.6		589.8 - 596.6		553.0 - 589.8		544.6 - 553.0	
Volume (km^3)[1]	0.71		0.03		0.44		0.24	
Area (km^2)[1]	33.32		2.35		22.69		8.30	
Littoral Area Percentage (%)[1]	11%		23%		11%		7%	
Littoral Volume Percentage (%)[1]	2%		6%		2%		1%	
	km	miles	km	miles	km	miles	km	miles
Maximum Length[2,3]	82.9	51.5	12.6	7.9	58.3	36.2	9.8	6.1
Maximum Width[2]	0.9	0.6	0.3	0.2	0.9	0.6	0.8	0.5
	meters	feet	meters	feet	meters	feet	meters	feet
Mean Depth[1]	21.2	69.5	11.0	36.2	19.2	63.0	29.5	96.7
Maximum Depth[1]	67.1	220	41.8	137	67.1	220	66.8	219
Ratio of Mean Depth : Max Depth	0.32		0.27		0.29		0.44	
Mean Outflow (KCFS) 2000-2009[4]	95.5		N/A		N/A		N/A	
Mean Outflow (KCFS) 2010[4]	82.5		N/A		N/A		N/A	
Mean Outflow (KCFS) 2011[5]	148.1		N/A		N/A		N/A	
	hours	days						
Hydraulic Retention Time (2000-09)	72.5	3.0	N/A		N/A		N/A	
Hydraulic Retention Time (2010)	83.9	3.5	N/A		N/A		N/A	
Hydraulic Retention Time (2011)	46.8	1.9	N/A		N/A		N/A	

[1] Environmental Assessment System (EASy) statistics routine
[2] Google Earth
[3] Entire lake length calculated with river mile estimates; other values estimated with Google Earth
[4] Hourly data from USGS 12436500 Columbia River at Grand Coulee, WA
[5] Hourly data from USGS 12436500 Columbia River at Grand Coulee, WA, data through 24 September 2011

The tabular data above pales in comparison to Figures 33 and 34 that highlight the lack of littoral or sublittoral area and volume of RWL. The shifting distribution of both parameters is also apparent in these figures. These data are used later in this report to make first order biological estimates of standing stock or productivity.

Overall, the digital bathymetric map provides a good representation of the lake bottom and overall morphometrics of RWL. However, the accuracy can be improved without further field work by manual interpolation of waypoint depth data along the shoreline in selected areas. The interpolation system involved in contouring has difficulty along the edges of such an unusually long and narrow water body and we found experimentally that we could markedly reduce the appearance of anomalies nearshore by filling in between observations, despite the fact that they were regularly and closely spaced.

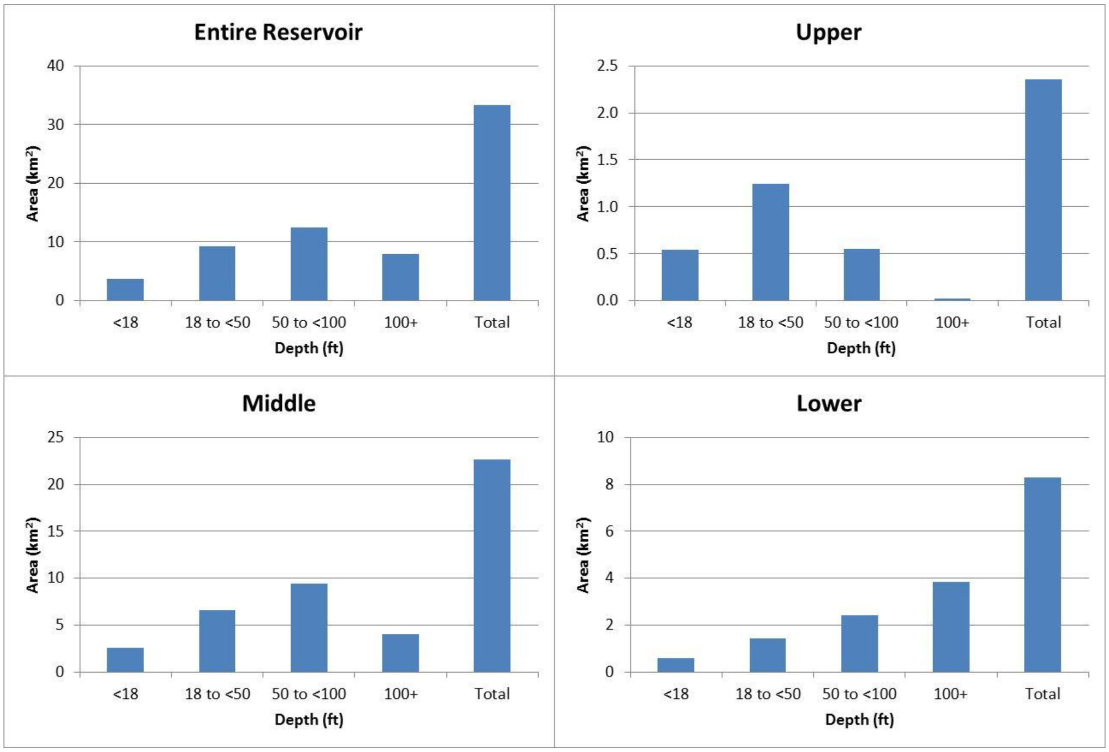


Figure 33. Area estimates for different sections and depth strata of Rufus Woods Lake. Note that each figure's Y-axis uses a different scale, because each represents different areas of varying size.

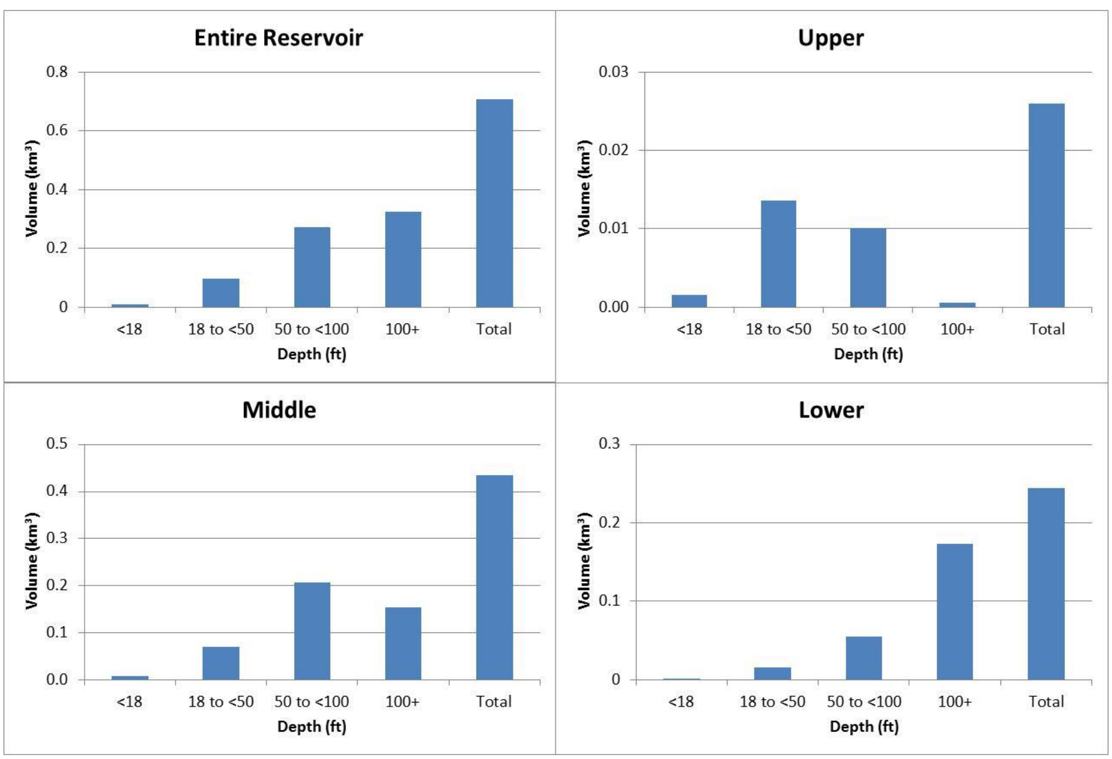


Figure 34. Volume estimates for different sections and depth strata of Rufus Woods Lake, calculated with Environmental Assessment System (EASy). Same note from prior figure applies here.

Littoral and Shoreline Habitat Classification

The results of habitat classification at the nearshore locations discussed in the method section show a variety of sediment substrate, vegetation and types of littoral zones (Figures 35-40).

These data may be summarized by stating:

- A mixture of fine sediment (silt+clay+sand), gravel and cobble are the dominant substrate type in the nearshore littoral zone of most or Rufus Woods Lake (i.e., lower and middle reaches).
- Hard bottom, in the form of artificially placed revetment on the right bank and natural rock are the dominant substrate type of upper RWL in the narrow, extremely fast flowing reach below Grand Coulee tailrace.
- Left and right bank substrate composition is similar except for the lower reservoir left bank (looking downstream) had more cobble and macrophytes mixtures than the right bank.
- Lower RWL has slightly more cobble compared to middle RWL that had slightly more fines and gravel.
- While our data may be accurately estimating these habitat components, there could be a need for further sampling to be sure of these data in terms of representativeness. This could be done through a simple sensitivity analysis, comparing measurements over shorter intervals with those of the approximate 0.5 km increment practiced for this study.

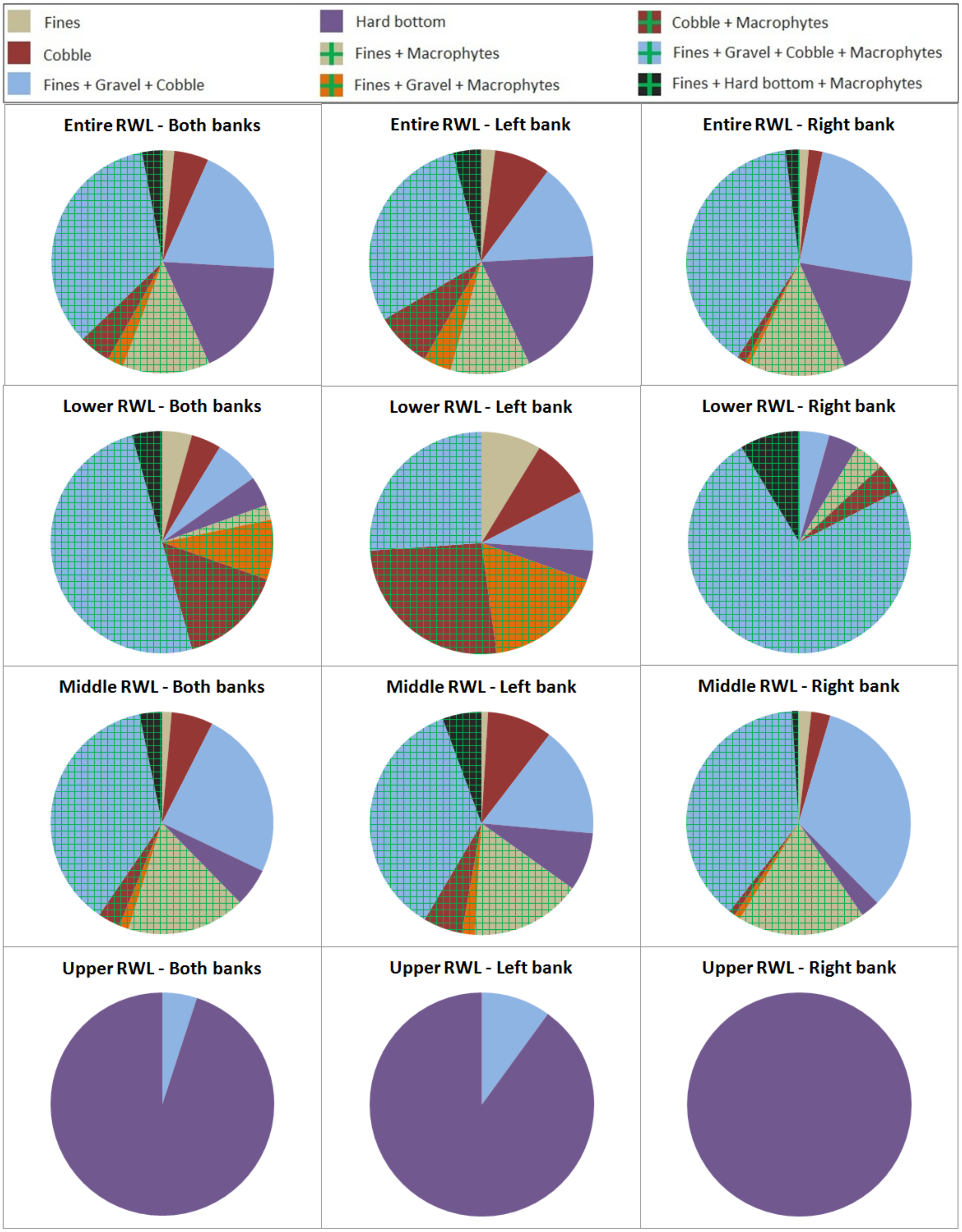


Figure 35. Habitat class summary for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study.

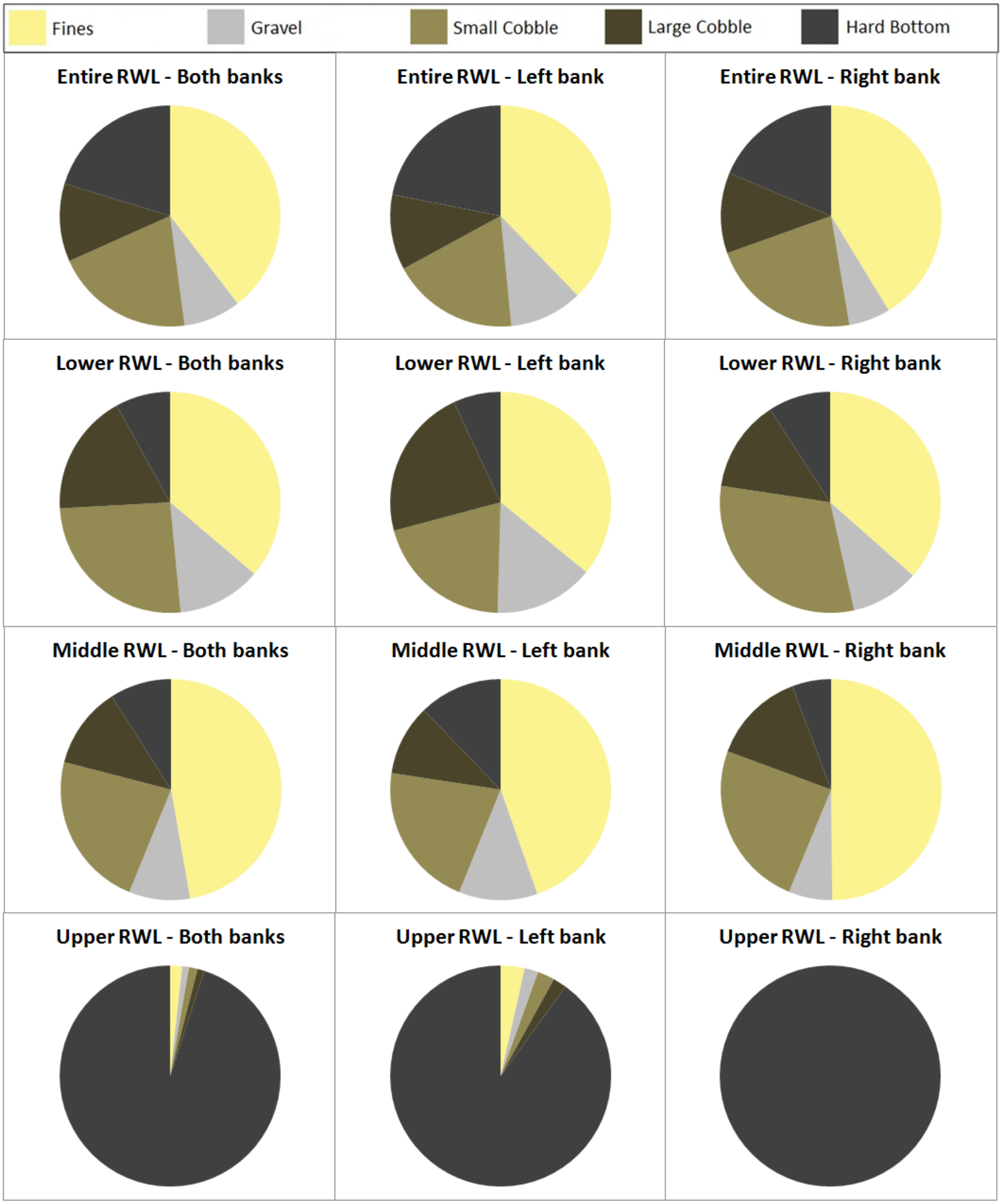


Figure 36. Sediment substrate summary for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study.

Figure 37. Littoral vegetation summary for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study.

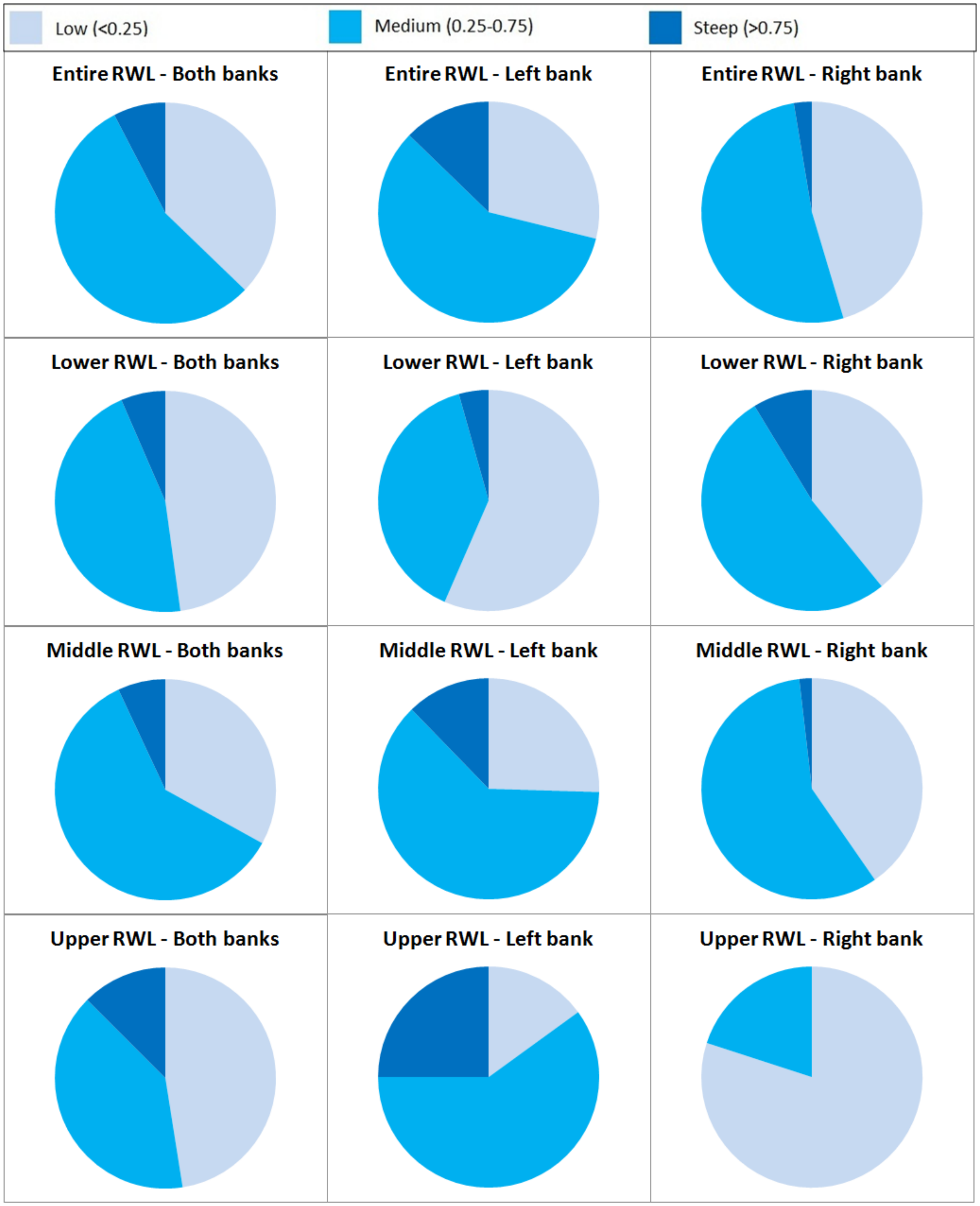


Figure 38. Littoral slope summary for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study.

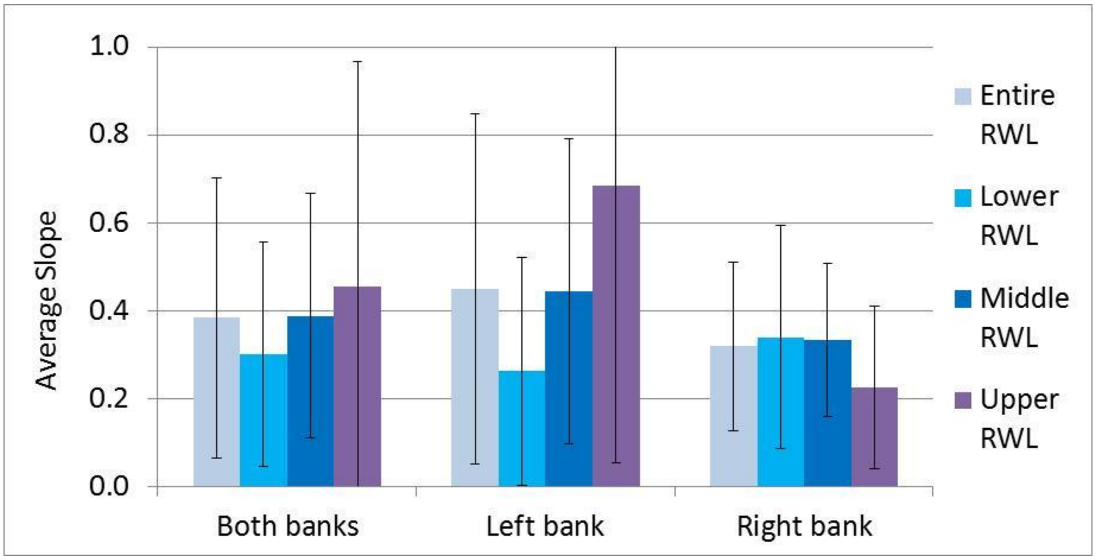


Figure 39. Average littoral slope values for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study. Error bars represent ±1 standard deviation.

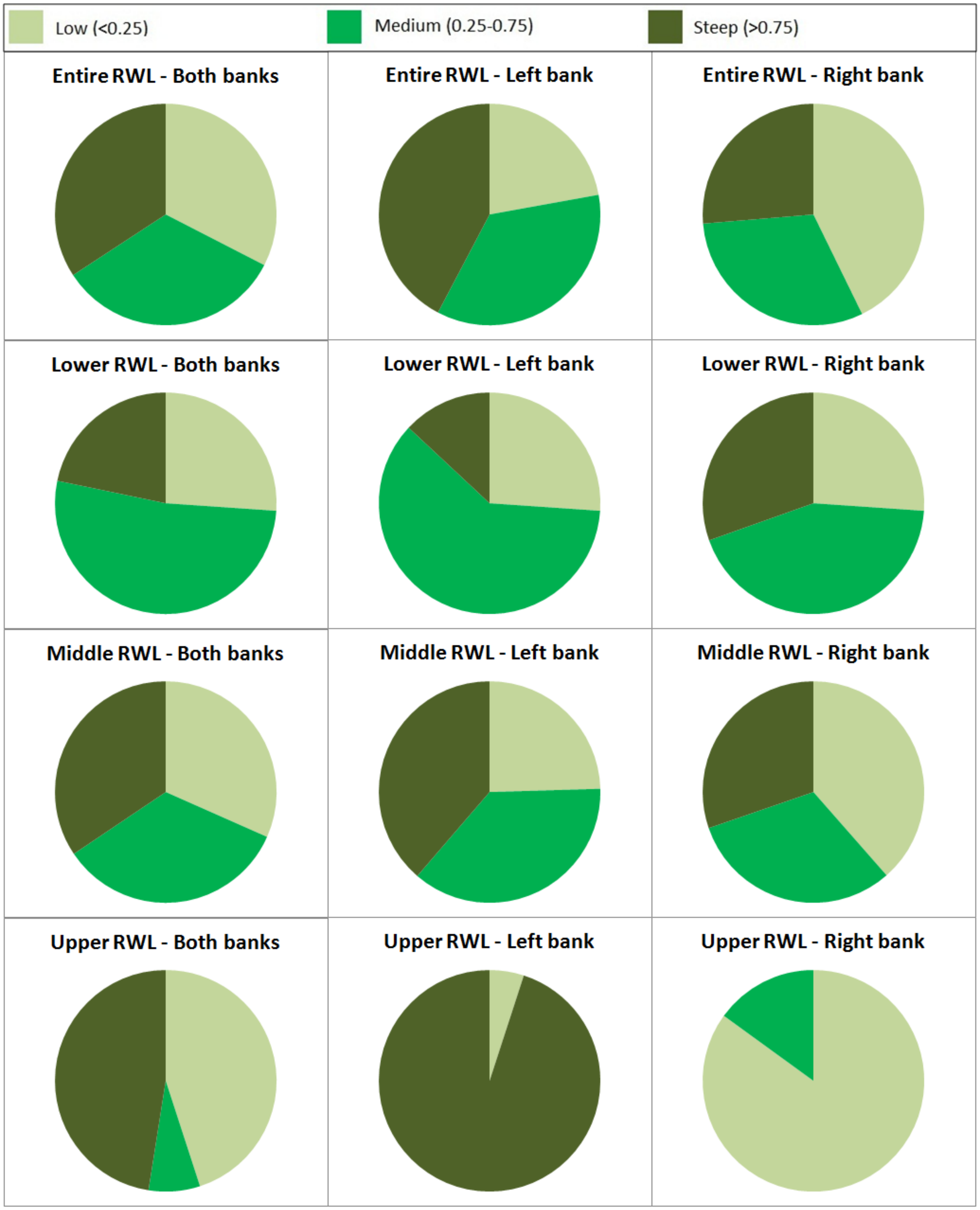


Figure 40. Backshore slope summary for total, right and left bank locations for the three divisions of Rufus Woods Lake determined in this study.

Table 6 summarized macrophyte data from the EASy GIS system for RWL. Macrophyte colonization increases with distance downstream as shown in the table and is virtually non-existent in the upper reservoir, due to the high current velocities that severely restrict the amount of fines in the riparian zone.

Table 6. Macrophyte morphometric statistics for Rufus Woods Lake.

	Entire Reservoir	Upper	Middle	Lower
0-3 ft shoreline zone (area, in km^2)[1]	0.33	0.03	0.21	0.05
3-18 ft macrophytic zone (area, in km^2)[2]	3.40	0.53	2.39	0.58
habitat with macrophytes (%)[3]	57%	0%	63%	82%
estimated area of macrophytes (km^2)[4]	1.94	0.00	1.51	0.47

[1] Shoreline water surface elevation fluctuation zone; calculated using EASy statistics routine
[2] Area directly below shoreline zone, prime macrophytes habitat; calculated using EASy statistics routine
[3] Percentage of habitat nearshore locations with macrophytes present
[4] Habitat with macrophytes multiplied by macrophyte zone area

A major purpose of preparing the above morphometric information was to be able to eventually apply the stratified data to estimates of primary and secondary benthic and epibenthic productivity and produce standing stock or productivity estimates for the entire reservoir.

However, we were not able to collect enough biological information throughout the reservoir to make reasonably accurate expanded estimates for the entire reservoir. Moreover, our station spacing for the littoral zone sampling was about 1/3 of a mile. This produces reasonable accuracy in some areas, but in areas of diverse habitat on small scales, it is certainly inadequate to represent the diversity of conditions and therefore not as reliable as we would have preferred. But the EASy GIS is a tool, not an end product and we believe with limited effort in the future additional data can be acquired, particularly as satellite imagery improves and remote sensing ability such as chlorophyll sensing become available on a fine scale. Such remote sensing is already available in some cases, as in the case of the French satellite system known as MERIS.

Periphyton Studies

All Data Combined

Seventy six (76) distinct periphyton taxa were identified in this study (N = 36 samples) (Table 7). This represents a wide array of taxa which can support a wide array of secondary producers (e.g. benthic macroinvertebrate assemblages) and a diversity of higher trophic assemblages. The periphyton samples also included several potentially noxious or toxic algae: *Spirogyra* sp. and *Cladophora* sp. (noxious filamentous green algae) and *Oscillatoria* sp., (potentially toxic blue green alga that occurs in both pelagic and benthic forms with different names) and one cobble scrape produced 2 cells of *Didymosphenia gemenata* an extremely problematic nuisance species (Table 7). Outbreaks of *Didymosphenia gemenata* have been documented at several Columbia River headwater rivers including the Kootenai and Flathead Rivers and have had major ecological impacts (Marshall 2007, Richards 2010).

Table 7. Taxonomic list and total corrected natural unit counts of periphyton collected in Rufus Woods Lake separated by soft bodied algae, diatoms, and 'others'. This list includes taxa that were not "rolled up". For example, *Ankistrodesmus* sp. and *Ankistrodesmes falcatus* were not combined.

SOFT-BODIED ALGAE	COUNT	DIATOMS	COUNT	OTHER	COUNT
Ankistrodesmus falcatus	1	Achnanthes sp.	1230	Peridinium sp.	1
Ankistrodesmus sp.	4	Achnanthidium sp.	5	Trachelomonas sp.	1
Aphanocapsa sp.	2	Amphora sp.	2		
Botryococcus sp.	2	Asterionella formosa	5		
Chlamydomonas sp.	1	Asterionella sp.	8		
Chlorella sp.	325	Aulacoseira sp.	43		
Chlorococcum sp.	16	Caloneis sp.	1		
Chromulina sp.	3	Cocconeis sp.	1057		
Chroococcus sp.	22	Coscinodiscus sp.	12		
Cladophora sp.	192	Cyclotella sp.	116		
Coelastrum sp.	7	Cymatopleura sp.	1		
Coleochaete sp.	4	Cymbella sp.	973		
Cosmarium sp.	1	Diatoma sp.	90		
Crucigenia sp.	3	Didymosphenia sp.*	2		
Cryptomonas sp.	10	Ellerbeckia sp.	36		
Gloeocapsa sp.	2	Encyonema sp.	3		
Gomphosphaeria sp.	2	Epithemia sp.	8		
Komma sp.	10	Fragilaria crotonensis	29		
Leptolyngbya sp.	2	Fragilaria sp.	1727		
Lyngbya sp.	13	Frustulia sp.	4		
Microcystis sp.	5	Gomphoneis sp.	2		
Microspora sp.	2	Gomphonema sp.	901		
Mougeotia sp.	140	Gyrosigma sp.	3		
Oedogonium sp.	7	Melosira sp.	696		
Oocystis sp.	8	Melosira varians	193		

SOFT-BODIED ALGAE	COUNT	DIATOMS	COUNT	OTHER	COUNT
Oscillatoria sp.	91	Meridion sp.	2		
Pandorina sp.	1	Navicula sp.	865		
Pediastrum boryanum	2	Neidium sp.	1		
Pediastrum sp.	5	Nitzschia sp.	311		
Phormidium sp.	399	Pinnularia sp.	243		
Pseudoanabaena sp.	6	Pleurosira laevis	1		
Pyrenomonas sp.	23	Rhoicosphenia sp.	289		
Rhizoclonium sp.	4	Staurosira sp.	175		
Scenedesmus quadricauda	1	Surirella sp.	2		
Scenedesmus sp.	17	Synedra sp.	95		
Schroederia sp.	8	Tabellaria sp.	31		
Sphaerocystis sp.	1	unknown centric sp.	3		
Spirogyra sp.	202	unknown pennate diatom	3		
Staurastrum sp.	1				
Stichosiphon sp.	1				
Ulothrix sp.	82				
unknown crysophyte	2				
Volvox sp.	1				
ALGAE TOTAL	**1625**	**DIATOMS TOTAL**	**9164**	**OTHER TOTAL**	**2**

* Didymosphenia found at N 48 09.171 W 119 07.842

Periphyton assemblage structure using NMS ordination

Our best NMS model had a 3-dimensional solution using a Sorenson distance measure. This model resulted in a final stress of 8.62 and final instability of 0.00 at 115 iterations. Stress in this context is a measure of the optimality of an ordination solution (i.e. the relationship between the similarity in species composition and the closeness in ordination space) used as part of the algorithm of NMD. McCune and Grace (2002) suggested that most ecological assemblage data sets will have NMS solutions with stress between 10 and 20 and that values in the lower half of this range are quite satisfactory. Final stress between 5 and 10 is considered to be “a good ordination with no real risk of drawing false inferences” (Clarke’s (1993) “rules of thumb” for NMS in McCune and Grace (2002)). Our post hoc analysis of coefficients of determination resulted in an R^2 of 0.69 for Axis 1, 0.14 for Axis 2 and 0.13 for Axis 3. All three axes cumulatively explained 0.95 of the variability in macroinvertebrate assemblages in the data. Figure 41 (ordinated by sample) and Figure 42 (ordinated by taxon) show the relationship of the periphyton assemblages in RWL using Axis 1 and Axis 2. NMS ordination values for all three axes and graphical representations of the periphyton assemblage structure using Axis 1 and Axis 3 are in Appendices 1-4.

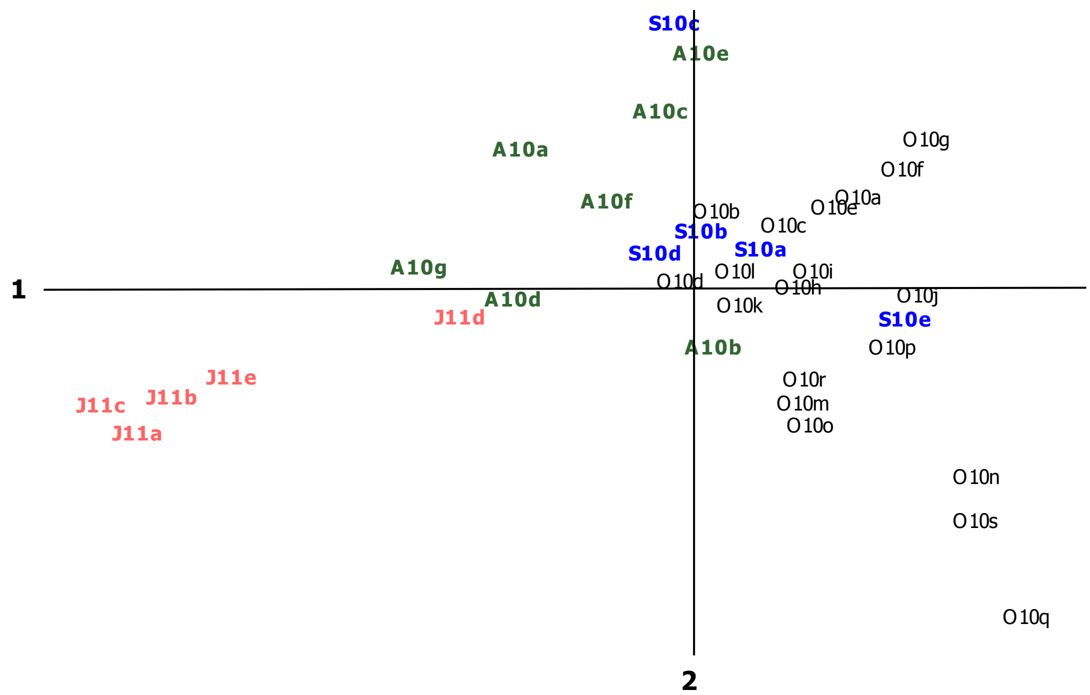


Figure 41. Axis 1 and Axis 2 of NMS ordination of periphyton assemblages using all samples collected in RWL, sampled in August, September, October 2010 and July 2011. Samples labels have two code values: A10 = August 2010, S10 = September 2010, O10 = October 2010, and J11 = July 2011; lower case letters following the month label are sample and site locations. Refer back to Table 1 for descriptions of samples. Post hoc analysis of coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space for Axis 1 was 0.69 and Axis 2 was 0.14 for a total of 0.83.

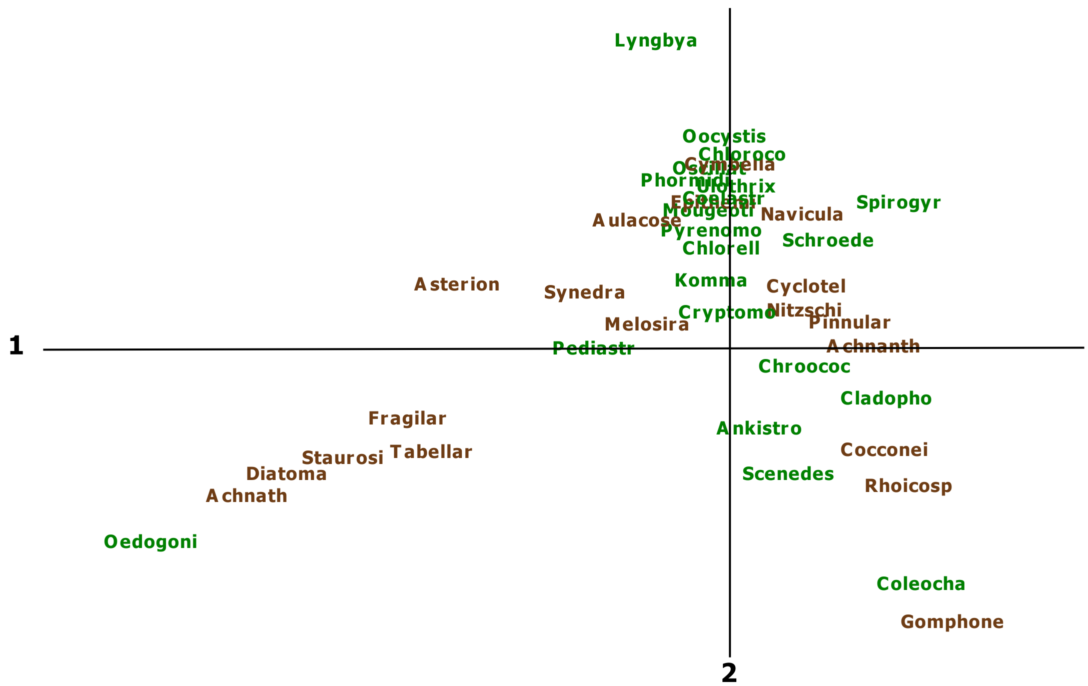


Figure 42. Axis 1 and Axis 2 of NMS ordination of periphyton assemblages using all data. Diatoms are in brown, soft bodied algae are in green.

A brief explanation for interpreting (visualizing) ordination follows.

The NMS ordination graphs (Figures 41 and 42) show how the periphyton assemblages (communities) in RWL are related. Samples that are farther apart on an axis are least similar to each other. This could be due to high abundances of taxa in either one of the samples or low abundances or absences of taxa in one sample but not the other or a combination of the two. This relationship occurs along each axis but because we usually plot the axis that explains the most variability as Axis 1, followed by Axis 2, and then Axis 3 as the amount of explanatory power decreases; the most important visualization axis is usually Axis 1.

Remember the x-axis, Axis 1 explained almost 5 times the amount of variability as Axis 2 (y-axis). In our ordination of macroinvertebrate samples, the very furthest apart along the x-axis (Axis 1) were samples J11c, J11a, J11b, and J11e (far left end of axis 1) and O10q, O10s, and O10n etc. (farthest samples away from the origin (x-y intercept) on the right). It may help to visually 'squeeze' all of the samples straight up or down onto the x-axis to visualize the importance of Axis 1 in explaining the macroinvertebrate assemblages. Likewise, Axis 2 explained an additional 14% of the variability in the assemblages. Variability explained by Axis 2 was mostly due to the differences between abundances or absences of certain taxa again in samples O10q, O10s, O10n (very bottom of the graph, Figure 41) but this time with abundances/absences of taxa in samples S10c and A10e.

Samples that ordinated near the origin (x-y axis) did not have relatively large abundances or absences of any taxa and more or less shared all taxa with the other samples (not too few or not too many of any particular taxa). These taxa near the origin can be considered the overall 'generalized' or 'typical' assemblage in RWL.

To determine which taxa influenced the ordination, we need to examine the second figure (Figure 42) which shows how the individual taxa were related to one another in RWL. Species that are close together on the plot occurred together spatially and temporally in RWL, while species that are at great distances from each other were not commonly found together in RWL". Remember that the scales in the two figures are not the same. The scale in the taxa based figure (Figure 42) has been expanded for better visualization. Here we can see that the periphyton taxa that were furthest apart on the x-axis (Axis 1) were those on the lower left hand side of the origin e.g. *Oedogonium* sp., *Achnanthidum* sp., *Diatoma* sp., *Staurosira* sp. *Tabellaria* sp., and *Fragilaria* sp. etc. These six taxa also clumped together. This means that these six taxa were almost always associated with each other in RWL during our study. In addition, we can see that *Gomphonema* sp. and *Coleochaete* sp. plotted at the bottom of the y-axis (Axis 2) and *Lyngbya* sp. plotted at the top of Axis 2. This means that *Gomphonema* sp and *Coleochaete* sp. were spatially and temporally associated with each other and that *Gomphonema* sp. and *Coleochaete* sp. were spatially and temporally disassociated with *Lyngbya* sp. If they did occur together, one was much less abundant than the other in a sample. Keep in mind that Axis 1 explained substantially more of the differences in the periphyton taxa assemblages than did Axis 2 (or Axis 3).

In addition, we can see that several taxa occurred close to the origin (e.g. *Melosira* sp., *Cryptomonos* sp.). These taxa occurred more or less throughout RWL and were often not super abundant or absent. These taxa could be considered, 'background' taxa in RWL. All of this explanation is based on relative terms and it cannot always be directly determined which taxa occurred most in any sample. For example even though *Oedogonium* sp. occurred away from other taxa (Figure 42, lower left quadrant) and four of the J11 samples also plotted in the lower left quadrant in Figure 42); these samples may not have had the highest abundances of *Oedogoniumi* sp. (but they probably did). These four J11 samples in addition to having high abundances of *Oedogonium* sp. may also have had low abundances of *Gomphonema* and *Spirogyra* sp.

Results from the NMS ordination show that periphyton assemblages differ from each other both spatially and temporally in RWL and to some extent whether they were dominated by diatoms or soft bodied algae (Figure 42). Sampling methods also influenced our results. This was because periphyton collected from tiles tended to be early successional colonizing taxa and periphyton on cobbles tended to be late successional.

Downstream assemblages on tiles collected in October 2010 were mostly different from the upstream tile assemblages from October 2010. Most of the downstream October 2010 tile periphyton assemblages occurred in the lower right quadrant, while the upstream October 2010 tile periphyton assemblages occurred in the upper right quadrant (Figure 41). This was mostly due to the greater abundances of *Gomphonema* sp. (slime forming diatom) and *Coleastrum* sp. (soft bodied green alga sometimes associated with nuisance blooms) downstream, and *Spirogyra* sp. (a noxious, filamentous green alga that was infesting macrophytes extensively in 2010 and 2011 in RWL) upstream. NMS ordination is not designed to determine cause and effect of species assemblages (e.g. taxa niches, competition, selective grazing, etc.). We do not have enough information to speculate on the cause(s) of these differences but we do know from extensive observations of *Spirogyra* sp. on macrophytes that even within a single small cove there were major differences in *Spirogyra* sp. distribution related to water current exposure. Macrophytes in slow moving waters were more commonly infested versus those exposed to stronger currents, e.g., further toward the center of the river and the thalwag.

The August 2010 cobble scraped periphyton assemblages grouped closer together than other assemblages including the September 2010 cobble scraped periphyton assemblages. Again, this further illustrates that there were location and monthly differences in periphyton assemblages. At the finer scale, samples S10b and S10d were quite a bit different than the other samples ordinated on Axis 3 (Appendix 3) where they both clumped together in the upper end of Axis 3. This was because both had the highest abundances of *Chlorella* sp. (a single-celled, soft bodied alga). The soft bodied, filamentous green algae, *Oedogonium* sp. occurred at low abundances and only in the downstream July 2011 tile samples. As a mature form it usually is free floating but prefers quiet, backwater areas when first established. Periphyton scraped from aquatic macrophytes (epiphytic algae) (sample: S10e) was more similar to October 2010 tile samples that to the other cobble scrape samples (Figure 41 and Appendix 3).

Clearly periphyton assemblages in RWL vary in taxon abundances both spatially and temporally. However, for the most part, assemblages were dominated by the most common taxa that occurred throughout RWL during our study (e.g. *Achnanthes* sp., *Cocconeis* sp., *Cyclotella* sp., *Cymbella* sp., *Fragilaria* sp., *Gomphonema* sp., *Gyrosigma* sp., *Melosira* sp., *Navicula* sp., *Nitzschia* sp., *Pinnularia* sp. etc.). This was to be expected given the well-known community ecological principal (law) that most assemblages of organisms have just a few taxa at high abundances and many more taxa with low abundances (Darwin 1859, McGill et al. 2007, Magurran and Henderson 2011). Due to the significant changes in water quality and flow during our study period, and our observations of nuisance and noxious algae and even toxic blue green algae, we believe that these observations are not indicative of most recent decades, e.g., 2000-2009 where such problems were not observed (R. Fischer, USACE pers. Comm. to J. Rensel).

A more detailed, finer resolution of relationships between periphyton assemblages follows. The results that follow are based on the October 2010 tile samples. By analyzing these results separately, we eliminated seasonal affects and sample method bias.

October 2010 Data

Periphyton assemblage relationships

Our best NMS model for the October 2010 tile data had a 2-dimensional solution using a Euclidean distance measure. This model resulted in a final stress of 8.76 and final instability of 0.00 at 30 iterations. Our post hoc analysis of coefficients of determination gave an R^2 of 0.60 for Axis 1 and 0.34 for Axis 2. Both axes cumulatively explained 0.94 of the variability in periphyton assemblages in the data. Figures 43 and 44 show the relationship of the periphyton assemblages in RWL based on the October, 2010 data Site D was not included in the NMS ordination because there was very little periphyton growing on tiles and there was not enough remaining after chlorophyll *a* extraction to conduct the taxonomy needed for NMS.

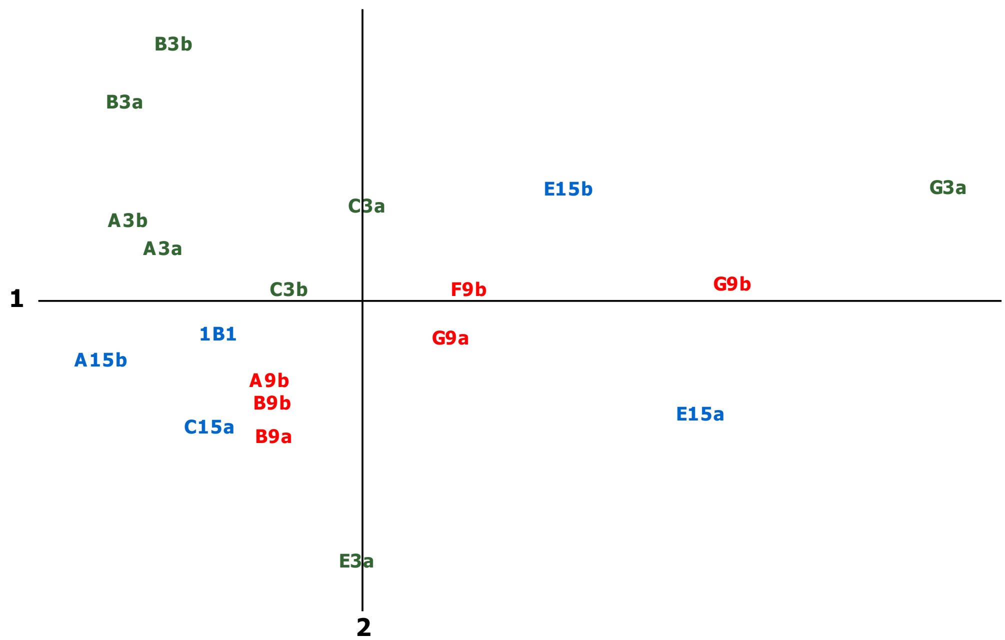


Figure 43. NMS ordination of periphyton assemblages in relation to location and depth. Abbreviation codes are as follows: the first letter is the location starting upstream at A to furthest downstream at G. The number is the depth: 3 m (green), 9 m (red), and 15 m (blue). The last letter is the replicate number.

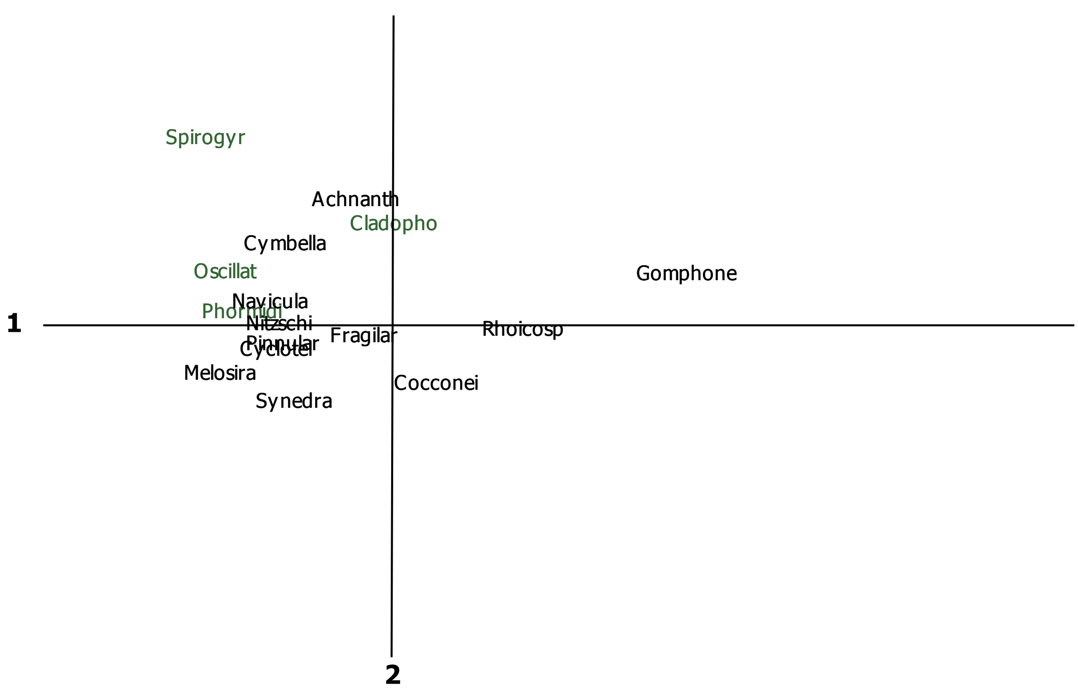


Figure 44. NMS ordination of periphyton taxa. Taxa labeled in green are soft bodied algae.

Figures 43 and 44 provide an excellent interpretation of the periphyton assemblage relationships in RWL during October, 2010 based on our tile data. There was an obvious difference between periphyton assemblages in the upstream section (samples A, B, and C) and the downstream assemblages (samples E, F, and G). All samples in the upstream section plotted in the left half of the ordination of Axis 1 and all samples in the downstream locations plotted in the right half of Axis 1 (Figure 43). Periphyton assemblages were also influenced by depth, particularly at the 3 m depth. Most of the samples collected from the 3 m depths (the number 3 in Figure 43). There was not a clear separation of periphyton assemblages between 9 and 15 m. Replicate samples from the same site and depth also tended to clump closely together (i.e. A1a and A1b; A2a and A2b; and B2a and B2b), as expected. Samples in the upper left quadrant (Figure 43) (upstream shallow) tended to have more soft bodied algae including; *Spirogyra* sp., *Cladophora* sp., and *Oscillatoria* sp. (Figure 44). The most downstream site (G1a) was dominated by *Gomphonema* sp. None of these species are desirable and indicate the degraded conditions that existed during the sampling period. These species probably were not as abundant during the prior decade based on anecdotal observations such as the routine surveys of macrophytes conducted for the Colville Tribe by consultants as a requirement of the fish farm discharge permits. Parametrix, Rensel Associates and University of Idaho (2001) reported from Rocky Reach Reservoir downstream of RWL that taxa of blue green algae occurred in their samples in a yearlong study.

Note that we modified the location code in Table 1 for the following analysis of the October 2010 data. We did this to simplify the codes and for easier interpretation. The following table (Table 8) contains the location codes for October 2010 data.

Table 8. Location of seven sites used for October 2010 periphyton assemblage analysis.

Site	Latitude N	Longitude W
A	48 01.395	118 57.436
B	48 01.694	118 58.052
C	48 08.371	119 06.485
D	48 08.473	119 06.336
E	48 09.025	119 08.383
F	48 03.242	119 31.542
G	48 02.960	119 33.024

Periphyton Chlorophyll *a*

The concentration of periphyton chlorophyll *a* (mg/m^2) varied by site and depth (Figure 45). ANOVA p-values were 0.06 and 0.09 for site and depth effects, respectively (Table 9). We consider these p-values to be indicative of strong location and depth affects. Location effect on chlorophyll *a* was particularly evident and significant between locations at the 3 m depth (Figure 45, Appendix 5), as was also illustrated in NMS ordination (Figure 43).

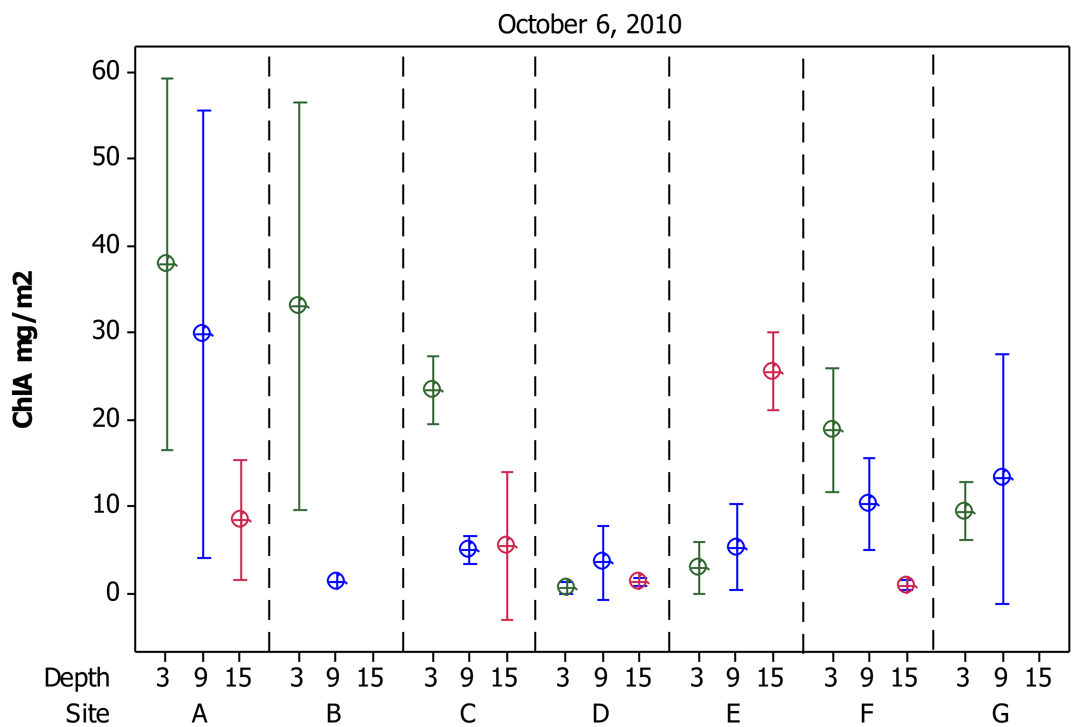


Figure 45. Tile periphyton chlorophyll *a* (mg/m^2) at seven locations and three depths, October 6, 2010. Circle = mean, bars = 2 SE. N = 2 reps/site except no samples available from site B at 15 m.

Table 9. GLM ANOVA of the effects of locations (site) and depth on chlorophyll *a* at the seven sites.

	DF	Seq SS	Adj SS	Adj MS	F	P
Site	6	1834.2	1801.1	300.2	2.31	0.06
Depth	2	671.0	671.0	335.5	2.59	0.09
Error	29	3762.7	3762.7	129.7		
Total	37	6267.9				

Sites A and B (upstream of Seaton's Grove, fast flowing section downstream of Grand Coulee Dam) produced the most chlorophyll *a* (Figure 45). Chlorophyll *a* at sites D and E were for the most part much lower than the other sites. Our GLM ANOVA model with those two sites removed showed a much greater effect of location and depth on chlorophyll *a* densities (Appendix 6). At four of the seven sites (Sites A, B, C, and F) there was a noticeable decrease in chlorophyll *a* at increased depths. At site E, chlorophyll *a* was greater at 15 m than any other 15 m sample or even 9 m depth samples (Figure 45). This station was right bank and therefore subjected more to sunlight than the left bank stations (A, B, C and F). Station D (about 560 m downstream of fish farm Site 1) was similarly exposed to sunlight and had similar 3 and 9 m depth concentrations of chlorophyll *a*, but had much lower 15m depth chlorophyll *a* concentrations.

Limited studies of reservoir circulation using drift objects (drogues) released from the middle of Net Pen Site 1 showed no right bank shore impingements in the past near Station D (Rensel 2010). But the river morphology changes on the left bank significantly near Site E and we noticed extensive growths of both macrophytes and periphyton in this region in both 2010 and 2011 that is probably related to more ideal growing conditions. As shown in Figure 46 from the EASy GIS, Station D is medium slope littoral zone (dark blue pie chart) and without macrophytes and Station E (turquoise color) is low slope littoral shore with macrophytes (green colored part of pie chart). Other GIS information, such as presence of fines and macrophyte dominance, indicates the increased likelihood that Station E is a good periphyton growing location, but one other factor should be considered: The area near Station E is the first area downstream of net pen Site 1 where water from the pens would be expected to impinge on the shoreline area because of the sinuosity of the reservoir at that point. We do not know if ammonia and urea from the fish influenced these results, but it could be determined through stable isotope analysis. We believe it may not be a significant factor given other analyses (i.e., relative nutrient loading analysis done for a NEPA environmental analysis) but no direct proof is presently available.

Power analysis showed that ANOVAs had moderate power (Type II error) in the range of $\beta = 0.45$ to 0.60. Moderate power was due to the small number of replications and the large variability in chlorophyll *a*.

For comparison to our periphyton abundance data that ranged from near zero to about 50 mg/m^2, (mean = 12.8 mg/m^2, 1SE = 2.2, minimum = 0.20, Q1 = 1.4, median = 7.9, Q3 = 2.0, maximum = 50.0) the standing stock of periphyton were within ranges of other northwest United States rivers. Naiman and Sedell (1980) measured 31 to 90 mg/m^2 for the McKenzie River, a 7th order (relatively large), cool (3-12 °C), open canopy (few trees) and nutrient rich river system of the State of Oregon. Kim and Richardson (2000) measured chlorophyll *a* around 10 to 12 mg/m^2 in the open canopy of two creeks in SW British Columbia.

Parametrix, Rensel Associates and University of Idaho (2001) studied water quality, plankton and periphyton dynamics of the mid-Columbia River for one year in Rocky Reach Reservoir (two reservoirs below RWL). They found that littoral attached benthic algae had relatively high standing stock with the overall mean of 89.7mg/m^2 monochromatic chlorophyll *a* that indicated a eutrophic range. Values were in the range of the mesotrophic/eutrophic lower Snake River. Attached benthic algae peaked in April; annual lows were in August. No significant upstream/downstream trends in attached benthic algae were apparent. Autotrophic Index values were very low, indicating an efficient algal community operating at fairly high physiological nutrient loading to cells.

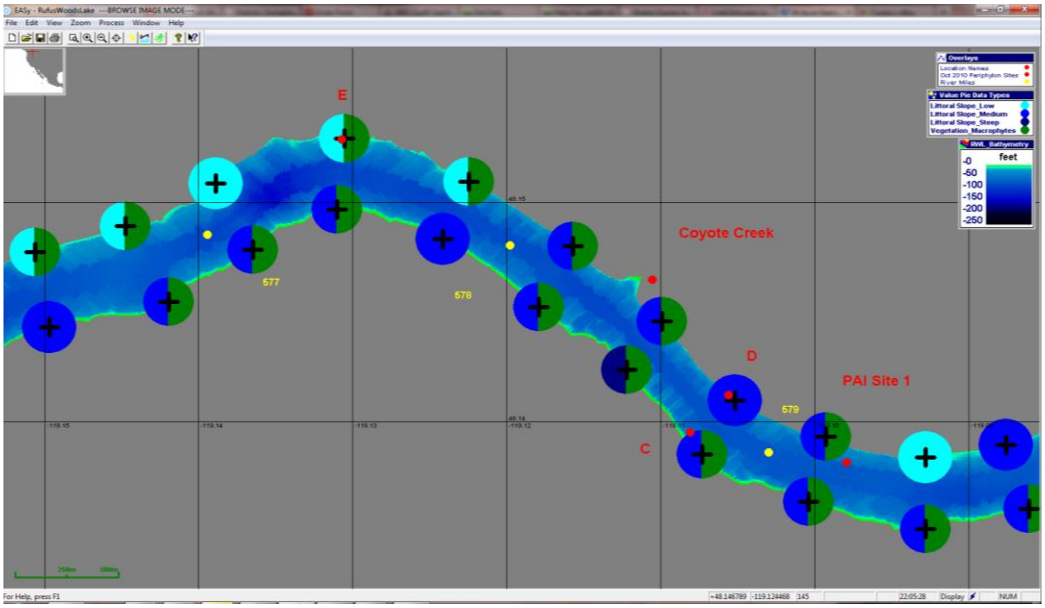


Figure 46. EASy GIS showing littoral zone slopes and macrophyte presence to illustrate differences between periphyton stations D and E.

Ash Free Dry Mass (AFDM)

We could not detect significant effects of location or depth on AFDM (mg/m^2) using ANOVA because of the limited number of replicates; however it appeared that as with our chlorophyll a results, Sites A and B produced the most AFDM at the 3 m depth (Figure 47). There was not enough periphyton biomass on any samples at Site D (1km downstream of net pens on same side of river) to conduct AFDM or AI %.

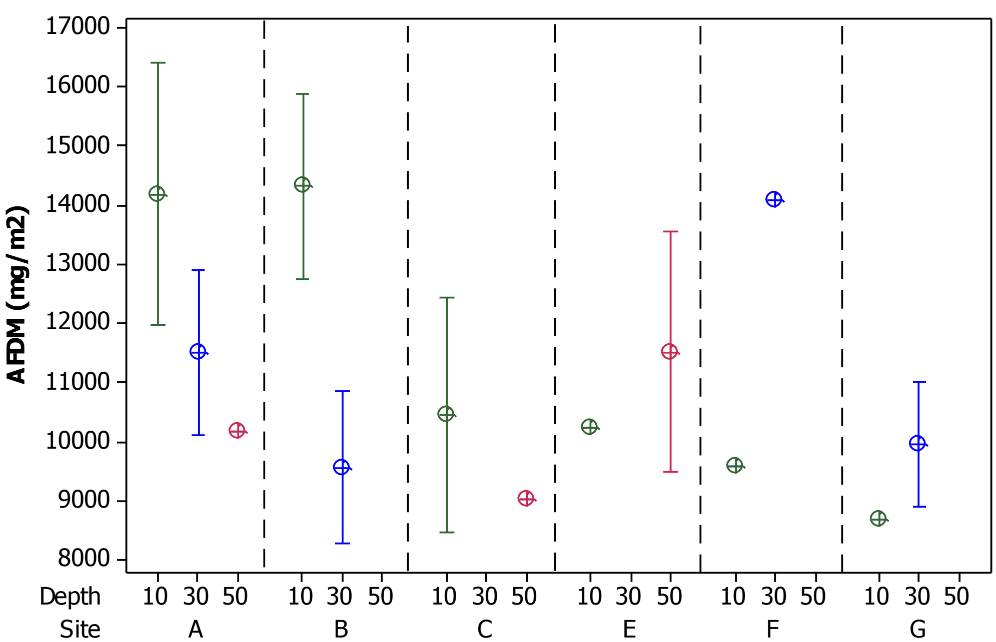


Figure 47. Tile periphyton ash free dry mass (AFDM)(mg/m^2) at six locations and three depths, October 6, 2010. Circle = mean, bars = $\pm$2 SE. The number of replicates available depended on whether enough periphyton remained after chlorophyll *a* analysis. No samples were available at Site B at 15 m. There was not enough periphyton in the samples to conduct AFDM analysis at Site D.

Autotrophic Index (AI)

In this study, we used a version of autotrophic index that was the ratio of chlorophyll a to AFDM as a percentage. This measure of AI is typically around 0.1% (Flotemersch et al. 2006). Values much less suggest heterotrophic conditions, whereas values higher suggest increased blue green/green algal production. It appears that in October 2011 algal production was high in the majority of locations; however, at several locations heterotrophic conditions prevailed, particularly on tiles > 3 m depths (Figure 48). We did not detect significant location and depth differences due to small N and large variability. Dominance of algal production was also apparent in our estimates of taxa densities and metrics where there were often high densities of algae including nuisance algae; *Cladophora* sp., *Oscillatoria* sp., and *Spirogyra* sp.

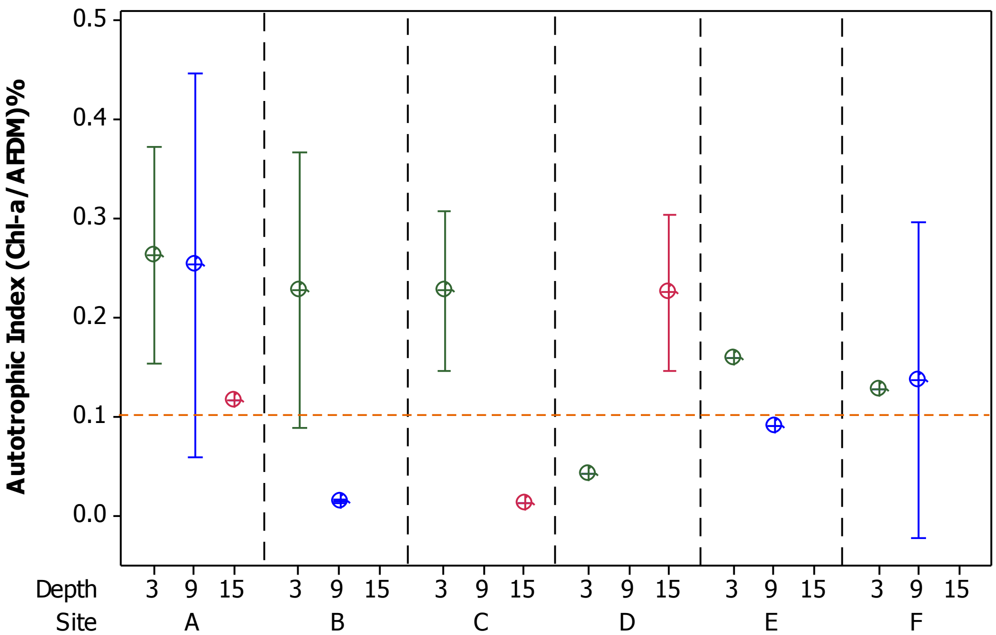


Figure 48. Tile periphyton Autotrophic Index % (Chl-*a*/AFDM) at six locations and three depths, October 6, 2010. Circle = mean, bars = ± 2 SE. AI% is typically 0.1% (Flotemersch et al. 2006). Values <<0.1 suggest heterotrophic autochthonous production, whereas values >>0.1 suggest increased blue green/green algal autochthonous production.

Table 10. Descriptive statistics for Chl-*a*, AFDM, and AI % (all October 2010 samples combined).

	N	Mean	SE	StDev	C.V.	Q1	Median	Q3
Chl-*a* (mg/m2)	38	12.39	2.11	13.02	105.03	1.36	7.62	21.36
AFDM (mg/m2)	20	11239	464	2074	18.45	9485	10494	12951
AI %	20	0.16	0.02	0.10	64.22	0.07	0.16	0.25

Table 11. Growth rates Chl-*a* (mg/m²/day) and AFDM (mg/m²/day)(all October 2010 samples combined).

	N	Mean	SE	StDev	C.V.	Q1	Median	Q3
Chl-*a* (mg/m²/day)	38	0.34	0.06	0.35	103.15	0.04	0.22	0.57
AFDM (mg/m²/day)	20	305.4	12.20	54.60	17.87	267.9	295.90	353.4

Soft bodied algae abundance and occurrence

Spirogyra sp. and *Cladophora* sp. were the most abundant soft bodied algal on the tiles that had enough periphyton growth to conduct metric analyses (N = 19) in the October 2010 assays (Figure 49). To understand the effect of log+1 transformation in this figure, we estimated a total of > 6 million *Spirogyra* sp. cells and > 4 million *Cladophora* sp. cells on the available tiles (N = 19 tiles) as contrasted with about a total of 317 cells of *Pediastrium* sp. (Figure 49). Densities/m² of the soft bodied algae from October 2010 tiles are illustrated in Figure 49.

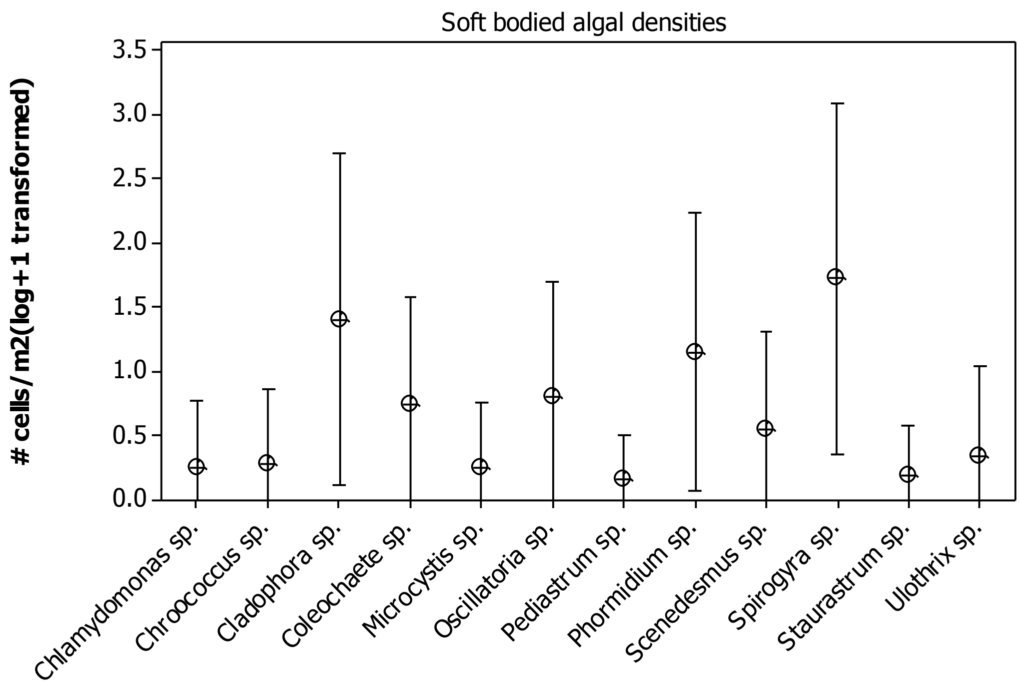


Figure 49. Mean (± 2SE) number of soft bodies algal cells/m² (log +1 transformed) on tiles retrieved in October 2010.

Six soft bodied algal taxa occurred at more than 30% of the six sites including at least three nuisance soft bodied algal taxa: *Cladophora* sp., *Oscillatoria* sp, and *Spirogyra* sp (Figure 50). *Cladophora* sp. and *Spirogyra* sp. occurred at ≥ 50% of the sites in October 2010 (Figure 50).

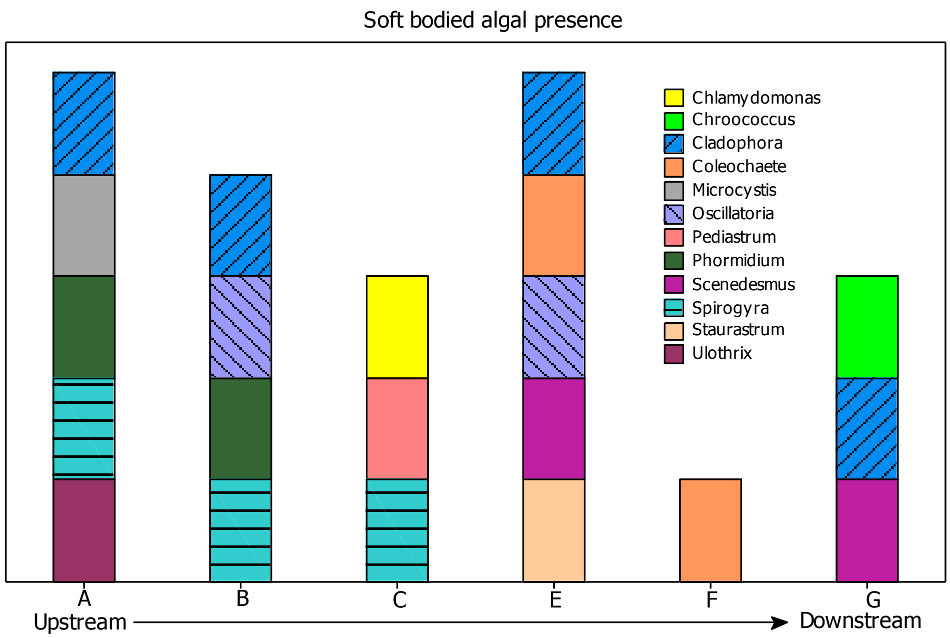


Figure 50. Presence (occurrence) of soft bodied algal taxa from upstream to downstream at six sites. There was not enough periphyton growth on tiles at Site D to conduct taxonomic analyses.

Results of chlorophyll *a* in this study are somewhat similar to what others have found. For example, our mean of 33.6 nanograms chlorophyll *a*/cm^2/day (0.34mg/m^2/day) (median = 21.8 ng chlorophyll *a*/cm^2/day) is similar to what Smoot et al. (1998) observed. They found that periphyton growth rates ranged from 6.0 to 80.0 ng chlorophyll *a*/cm^2/day, and were locally enhanced (2.5× that of ambient station) down-current of a freshwater net-pen. Also, Kevern et al. (1966) found the average growth rate of periphyton on plates in the streams over a single exposure period was 0.31 g/m^2/day. (= 310 mg/m^2/day).

Our estimates of chlorophyll *a* and AFDM mean growth rates included the unknown time it took for the periphyton (and other initial colonizers like bacteria) to first colonize the tiles and grow. Thereafter, growth rates are not uniform but can increase rapidly then taper off. Also, grazers, particularly snails, occurred at low densities on many of the tiles and may have affected our estimates. Although grazing obviously reduces periphyton standing crop, low to moderate intensity grazing often increases periphyton growth rates. We did not investigate grazing pressure or secondary consumer affects on primary production in this study.

Sloughing of periphyton (i.e., the process where the distal end of the filaments breaks off) from tiles in October 2010 seemed unlikely because of the slow growth rates we observed on cobbles. However, we frequently observed sloughing from cobbles that may be due to long term growth (1 year), increased flows, etc.

Autochthonous primary production in RWL was relatively low compared to river primary production elsewhere but within the range of other stream/river systems, at least within the shallow littoral zone in October, 2010. During this time, autochthonous production was often dominated by soft bodied algal production, particularly at shallow depths and was often dominated by several noxious taxa. Periphyton assemblages generally were affected by the interaction between location and depth with assemblages noticeably different upstream than downstream that is due, at least in part, to differences in morphology and water velocity/circulation known to exist in RWL. In addition to other primary production sources, adequate periphyton resources in the littoral zone appear to be available to secondary consumers (grazers) and through the food web to predators, although in 2010 and probably 2011 the noxious forms may have been more refractory of higher food web use than in prior years of lower flows and better water quality. These observations are manifested in the following sections regarding secondary production (Cobble Basket Studies and Suction Dredge Studies) and fish diets (Fish Stomach Analysis).

Cobble Basket Studies

Over 100,000 organisms were identified from the baskets (N = 86 basket contents examined). On several occasions a few taxa occurred at abundances >> 1000 including; hydra, flatworms, scuds, snails, and segmented worms (Table 12). Two baskets collected in January contained an estimated 92,000 and 5,600 organisms after adjusting for subsampling. These highly abundant taxa were mostly flatworms, scuds, and hydra. Another basket collected in March contained an estimated 37,500 organisms most of which were hydra. After removing these three samples from further analysis; mean abundances of invertebrates in baskets was 128 (SE = 16.9, Minimum = 0, Q1 = 25, median = 84, Q3 = 168, maximum = 925). Most of these baskets had cobbles that were predominantly colonized by flatworms and hydras but many other invertebrates also occurred (Table 12 and Figure 51).

Table 12. Total number of organisms and the most abundant 25 taxa collected from cobble baskets between October 2010 and July 2011.

TOTAL	**146,639**
Turbellaria	43561
Hydridae	41314
Asellidae	17661
Oligochaeta	15538
Lymnaeidae	9528
Hydra sp.	5080
Planorbidae	4164
Chironomidae	1888
Crangonyctidae	1659
Sphaeriidae	1289
Glossiphoniidae	962
Dicrotendipes sp.	712
Leptoceridae	704
Paratanytarsus sp.	620
Hygrobatidae	518
Physidae	443
Planariidae	156
Orthocladius sp.	124
Caecidotea sp.	90
Stagnicola sp.	82
Physa sp.	70
Hyalella sp.	55
Gyraulus sp.	51
Hygrobates sp.	41
Hyalellidae	40

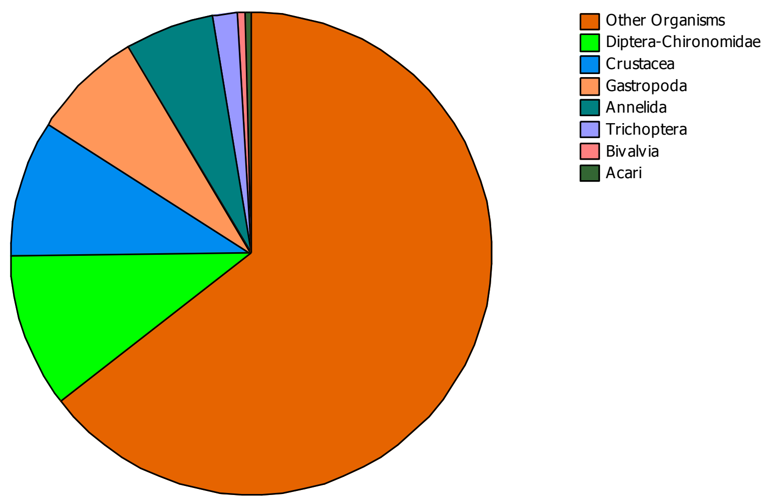


Figure 51. Relative abundance of invertebrate taxa found on cobbles in baskets. 'Other' organisms included: hydra, nematodes, and flatworms.

ANOVA results showed no significant differences in total abundances in cobble baskets due to depth or location; however, there was a significant difference in invertebrate abundances at retrieval month (Table 13 and Figure 52). This was due to the low abundances that occurred in October and the high abundances that occurred in January 2011. The January 2011 cobbles had almost 3 months of invertebrate colonization, whereas the others typically had one month of invertebrate colonization (except for May samples which had two months of colonization). The October 2010 low abundances could have been due to river wide seasonal low abundances of the most common taxa such as hydra and flatworms, cobbles selected at the initiation of the study were from <1 m depth within the fluctuation zone and did not have sufficient periphyton growth, or other factors. There was no significant difference in mean number of organisms/basket between February and July 2011.

Table 13. GLM ANOVA comparing effects of location, depth, and month retrieved of mean total abundances of invertebrates in cobble baskets.

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Location	7	229926	161500	23071	1.17	0.33
Depth	4	15745	80529	20132	1.02	0.402
Month	6	499580	499580	83263	4.23	0.001
Error	68	1337934	1337934	19676		
Total	85	2083186				

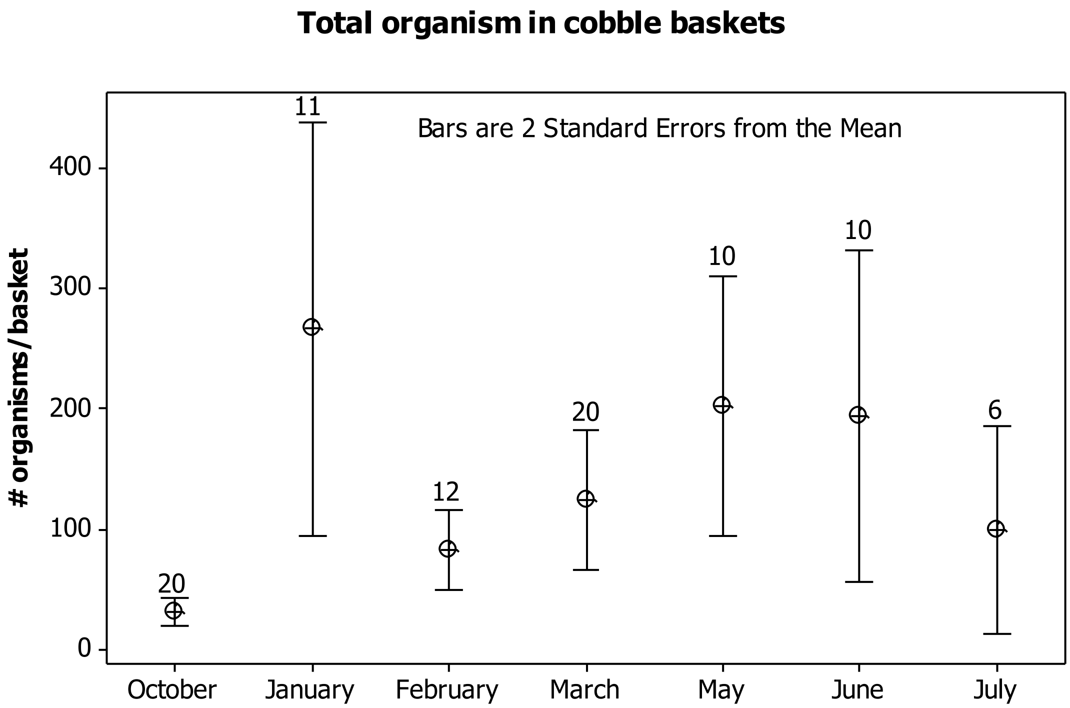


Figure 52. Mean (+ 2SE) number of organisms/basket at seven collection dates. Number above error bar is the number of samples.

The relative abundances of taxa collected in cobble baskets was quite similar to that found in our suction dredge results if the rapid colonizer taxa such as flatworms and hydra were not included in the analysis. Also, the cobble basket samplers did not seem particularly well suited for capturing crayfish. Only four crayfish were collected out of over 100,000 organisms (all of which were invasive crayfish, Family Cambaridae).

There were a few additional problems associated with cobble basket sampling that if alleviated could vastly improve results from future studies. Cobble sizes and the amount of volume in the baskets needs to be consistent for each basket. Estimates of densities can be made if volumes of cobbles in baskets are kept consistent. Depths at which baskets are deployed also need to be consistent and depth finders should be used to estimate the depths at which baskets are deployed. We observed some depth related differences in benthic macroinvertebrate assemblages in our suction dredge analysis; however, these differences were not consistent and we did not statistically test for these differences. Certainly there were no significant depth differences in abundances in the cobble basket samples. Baskets should not be placed directly in macrophyte beds and shallow depth baskets should be deployed at depths below macrophyte beds. If these problems are reduced or eliminated, then cobble basket sampling of invertebrates could be a very useful method and much more efficient than other methods. Utilization of cobble baskets, if done correctly and consistently, can help answer many questions concerning biodiversity, secondary production, and other ecological interactions in RWL. Their continued use is recommended. In particular, monitoring abundances (and densities) of rapid colonizers and other taxa that occur in cobble baskets can be used in future studies concerning spatial and temporal changes in secondary production.

Suction Dredge Studies

Our best NMS model had a 3-dimensional solution using a Sorenson distance measure. This model resulted in a final stress of 7.81 and final instability of 0.00 at 60 iterations. Our post hoc analysis of coefficients of determination resulted in an R^2 of 0.68 for Axis 1, 0.20 for Axis 2 and 0.08 for Axis 3. All three axes cumulatively explained 0.96 of the variability in macroinvertebrate assemblages in the data. Figures 53 and 55 show the relationship of the macroinvertebrate assemblages in RWL based on our suction dredge sample results using Axis 1 and Axis 2. Although Axis 3 was important for our best NMS model, it only explained 8% of the variability and we elected not to include figures of Axis 1 vs. Axis 3 or Axis 2 vs. Axis 3. Values for all three NMS axes by sampling location/date and by taxa are in Appendices 7 and 8.

Benthic macroinvertebrate assemblages in RWL were primarily driven by location and season with most replicates clumping together within a site (Figure 53, Axis 1 and 2). In general, assemblages at Site A in October 2010 were much different than most of the other assemblages and particularly with Sites D and E in July 2011 (Figure 53). This was mostly due to the abundance of non-native crayfish combined with the absence of odonates (dragonflies) and snails in October 2010 and July 2011 at Site A and the abundance of odonates (dragonflies) combined with the absence of crayfish at Sites D and E in July 2011 (Figure 55). Crayfish were absent from Sites D and E in July 2011 primarily because we sampled poor crayfish habitat (i.e. sand/fines with very few cobbles) in these two sites. Crayfish prefer cobble/boulder habitats for refugia and they are not averse to burrowing through sand if cobbles are slightly embedded. Dragonflies were mostly absent from Sites A, B, and C because we sampled primarily in cobble habitats and not macrophytes. A few dragonflies occurred at Site B probably because there were more macrophytes in that area at that site. Dragonfly larvae are predators and are almost always associated with macrophytes. They also are usually green to use the vegetation as camouflage.

Site A benthic assemblages were also different than nearby Sites B and C for all seasons than were Sites B and C with each other (Figure 53). We presume that this may have been due to the differences in physical habitat between Site A with Sites B and C. Results of the NMS ordination highlight the differences in benthic macroinvertebrate assemblages that occur between the upstream mostly cobble, moderate slopes and moderate velocities with the downstream sites comprised mostly of macrophyte beds, fine substrates, gentle slopes, and lower velocities. NMS results also reflect the seasonality of the benthic assemblage, depth of the benthos, and the amount of heterogeneity within the sites.

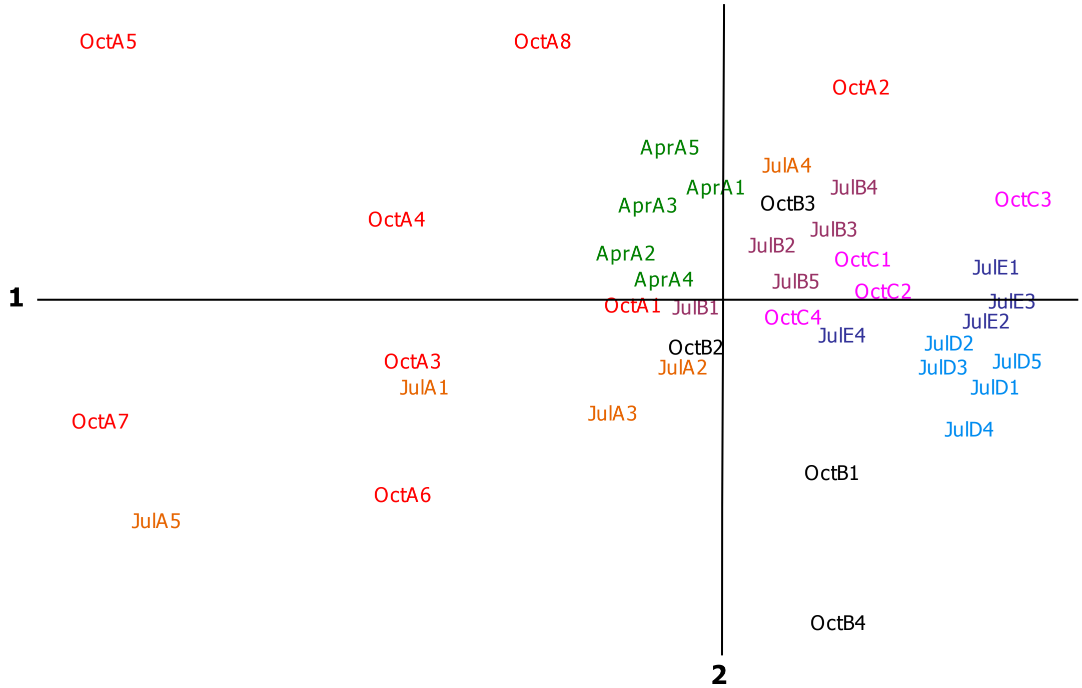


Figure 53. Axis 1 and Axis 2 of NMS ordination of macroinvertebrate assemblages by site and season at five sites in RWL, sampled in October 2010, April 2011, and July 2011.

Samples labels have three code values: Oct = October 2010, Apr = April 2011, Jul = July 2011; capital letters following the month label are the site locations; numbers following the capital letter are the sample replicates. Post hoc analysis of coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space for Axis 1 was 0.68 and Axis 2 was 0.20 for a total of 0.88.

October 2010 Site A samples (N = 8) were widespread and mostly occurred in the top and bottom quadrants of the left side of the ordination (except for sample OctA2) (Figure 53). This was because of the large heterogeneity of substrate at Site A compared with the other four sites. Randomly selected suction dredge samples at Site A could have landed entirely on a large boulder, or in cobbles, or in sand/fines or a combination of these. Site A is primarily a shallow shelf that extends about 10-15 meters from shore and then drops off rapidly (Figure 54).

Figure 54. Site A showing area between the pins that were suction dredge sampled and the shelf that occurs out to about 15 m from shore.

In addition, benthic assembles were affected by depth, with samples taken from similar depths 'mapping' more closely than at different depths (Figure 53). For example, samples OctA5 and OctA8 were collected at the greatest depths (6.1 m) at that site during October 2010. Although OctA5 and OctA8 were relatively spread apart compared with samples collected at different sites and dates, they clumped more together in the upper left quadrant than the other OctA samples (Figure 53). Also OctB2 and OctB3 were closer together than they were to OctB1 and OctB4. OctB2 and OctB2 were sampled from 6.1 and 7.9 m depths respectively, whereas OctB1 and OctB4 were sampled from 3.1 and 0.9 m depths, respectively. Other samples also separated out by depths but not as obviously (i.e. JulB2, JulB3, and JulB4 from JulB1 and JulB5; JulD2 and JulD3 from JulD1 and JulD4) (Figure 53).

Figure 55 illustrates the relationships of the benthic invertebrate assemblages by taxa (common names used). For the most part the assemblages were relatively similar at all sites except for differences in abundances of crayfish (Decopoda), bugs (Hemiptera), beetles (Coleoptera), and dragonflies/damselflies (Odonata) that grouped out separately (Figure 53). The bugs and beetles, although never in very large abundances at any of the sites, occurred primarily in samples from Site B in October 2010 (Figures 53 and 55). As explained earlier crayfish were more abundant at Site A.

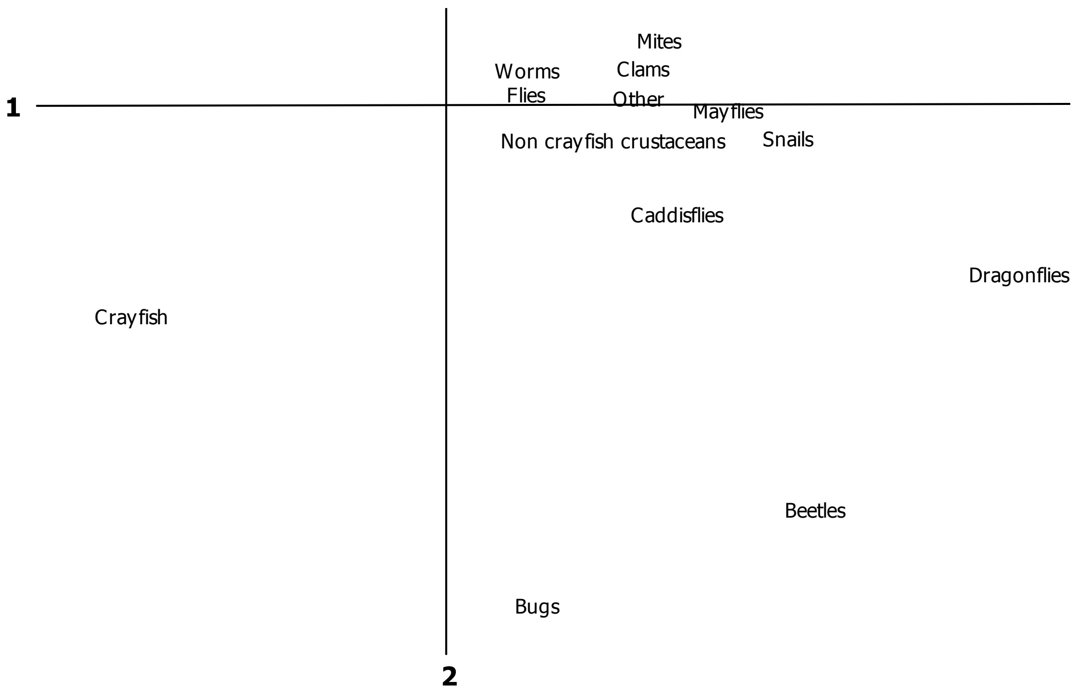


Figure 55. Axis 1 and Axis 2 of NMS ordination of macroinvertebrate assemblages by taxa group at five sites in RWL, sampled in October 2010, April 2011, and July 2011.

The NMS ordination and all of the following analyses are based on only five locations, three suction dredge sampling times, and cover less than one year. Macroinvertebrate abundances can be highly variable both spatially and temporally. We do not know what the variability is at different locations or what the annual variability is at other sites or times. Understanding the spatial and temporal variability of the benthic community is extremely important from an ecological and fisheries management perspective. We have collected suction dredge samples from these same locations in September and October 2011, however the samples have not yet been analyzed, are part of another project, and will not be included in this report.

Benthic macroinvertebrate assemblages and RBT diet

Seasonal and location differences in benthic macroinvertebrate assemblages directly affect RBT diets and their distribution in RWL. Benthic macroinvertebrates account for a large portion of RBT diets in RWL (see Fish Stomach Analysis section). In order to survive and grow; RBT must learn to recognize, track, and successfully forage for these benthic assemblages as they vary by location and season.

Benthic Macroinvertebrate densities

Based on our limited data, some sections of RWR have greater standing crop than others even within the relatively short distances between sites (Figure 56). The differences were, however, particularly evident between the mid and lower section of RWL. Seasonal variation in densities also was apparent but not significantly (notice error bar overlap in Figure 56). The overall mean density was 2385/m^2 (SE = 390, Min = 48.7, Q1 = 957, Median = 1542, Q3 = 3340, Max = 10,415). Densities typically were greater in the downstream sites (Sites D and E) which were mostly sampled from macrophyte and fine sediments and at Site C which were mostly sampled from loose unconsolidated cobbles (Figure 56).

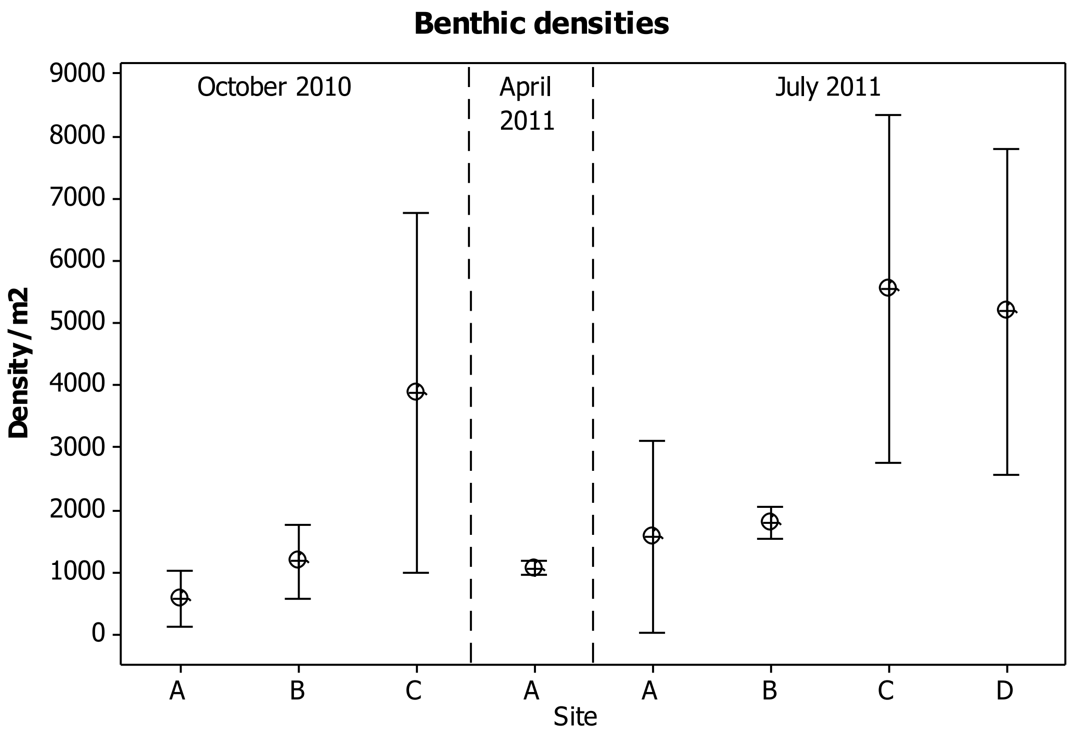


Figure 56. Densities/m^2 (mean and 2 SE) of benthic fauna collected in suction dredge samples in October 2010, April 2011 and July 2011.

We consider these densities to be within the normal range for many trout fisheries but tending towards the low end, particularly at Sites A and B (Table 14). For example, some very productive trout fishery rivers can have benthic macroinvertebrate densities > 25,000/m^2 and Snyder and Minshall (1996) reported densities in Coeur d'Alene River, ID (a tributary of the Columbia River) at 63,000/m^2 (Table 14). However, benthic macroinvertebrate densities in RWL are similar to densities reported for several regulated and unregulated Columbia River tributaries including Priest River, ID, Clark Fork River, MT, and Kootenai River, MT (Table 14). RWL benthic macroinvertebrate densities were very similar to but slightly higher than densities reported in the Flathead River, MT; another tributary to the Columbia River. Richards (2010) compiled historic benthic macroinvertebrate data (N = 30 estimated densities) from five locations on the Flathead River and calculated mean densities in the Flathead River at 1517/m^2 (SE = 203, median = 2372/m^2, min = 47/m^2, and max = 4291/m^2). The Flathead River samples were however from sections upstream of Flathead Lake, MT and the Flathead River has much less flow volumes and habitat conditions than RWL.

McKinney et al. (1999) reported *Gammarus lacustris* (amphipod similar to *Hyalella* sp. found in RWL) at densities 300-1000/m^2 and Chironomidae (midges) at densities from 200-2,600/m^2 in the Colorado River downstream of Glen Canyon Dam, a popular trout fishery (Table 14). Their values are somewhat higher than what we have found for these two taxa in RWL but within the same range. Both amphipods and midges are important food items in RBT diets in both the Colorado River and RWL.

Table 14. Benthic macroinvertebrate densities/m^2 in other rivers vs. Rufus Woods Lake.

River, State	Density/m^2	Citation
Green River, UT[1]	10,000	Vinson 2001
Kootenai River, MT[2] **Pre dam** **Post dam**	 3,500 900	Bonde and Bush 1975 Snyder and Minshall 1996 Royer et. al. 1997
Priest River, ID	3,900	Snyder and Minshall 1996 Royer et al. 1997
Salmon River, ID	38,000	Snyder and Minshall 1996, Royer et al. 1997
Coeur d'Alene River, ID	63,000	Snyder and Minshall 1996 Royer et al. 1997
Clark Fork River, MT **Pre enrichment** **Post enrichment**	 9,000 27,000	McGuire 1990
Gibbon River, Madison River, Firehole River, and Nez Pierce Creek, YNP, WY	10,000-40,000	Kerans et al. 2005
Colorado River, AZ[3] **Unconsolidated cobble**	*Gammurus lacustris* 500 - 1,000 Chironomidae 1,400 - 2,600	McKinney et al. 1999
Colorado River, AZ[3] **Cobble bars**	*Gammurus lacustris* 300-600 Chironomidae 200-500	McKinney et al. 1999
Rufus Woods Lake	2,400	This study

[1] downstream of Flaming Gorge Reservoir
[2] downstream of Libby Dam
[3] downstream of Glen Canyon Dam

About 33 families of benthic invertebrates were collected in suction dredge samples (Table 15). This is a fairly diverse group of benthic organisms with different life cycles, habitat preferences, and seasonal abundances, although many typical, large-river, cold-water mayfly, stonefly, and caddisfly taxa were absent. This benthic diversity translates to the presence of RBT diet items throughout the year.

Table 15. List of benthic invertebrates collected in suction dredge samples.

Order (Common name)	Family
Ephemeroptera (Mayflies)	Baetidae
Odonata (Dragonflies)	Coenagrionidae
Hemiptera (Bugs)	Corixidae
Coleoptera (Beetles)	Dyticidae
Diptera (True flies)	Chironomidae Ceratopogonidae
Trichoptera (Caddisflies)	Hydroptilidae Lepidostomatidae Limnephilidae Polycentropodidae
Gastropoda (Snails)	Ancylidae Lymnaeidae Planorbidae Physidae Lymnaeidae Valvatidae

Order (Common name)	Family
Bivalvia (Clams)	Sphaeriidae
Annelida (Segmented worms)	Glossiphoniidae Oligochaeta
Acari (Mites)	Acari Hygrobatidae Lebertiidae Limnesidae
Crustacea (crayfish and scuds)	Asellidae Cambaridae Crangonyctidae Hyalellidae Ostracoda
Other Organisms (unsegmented worms, ribbon worms, flatworms, etc.)	Nematoda Hydridae Nemertea Turbellaria

The following figure (Figure 57) illustrates the proportional abundances of taxa found in the suction dredge samples from different sites and seasons.

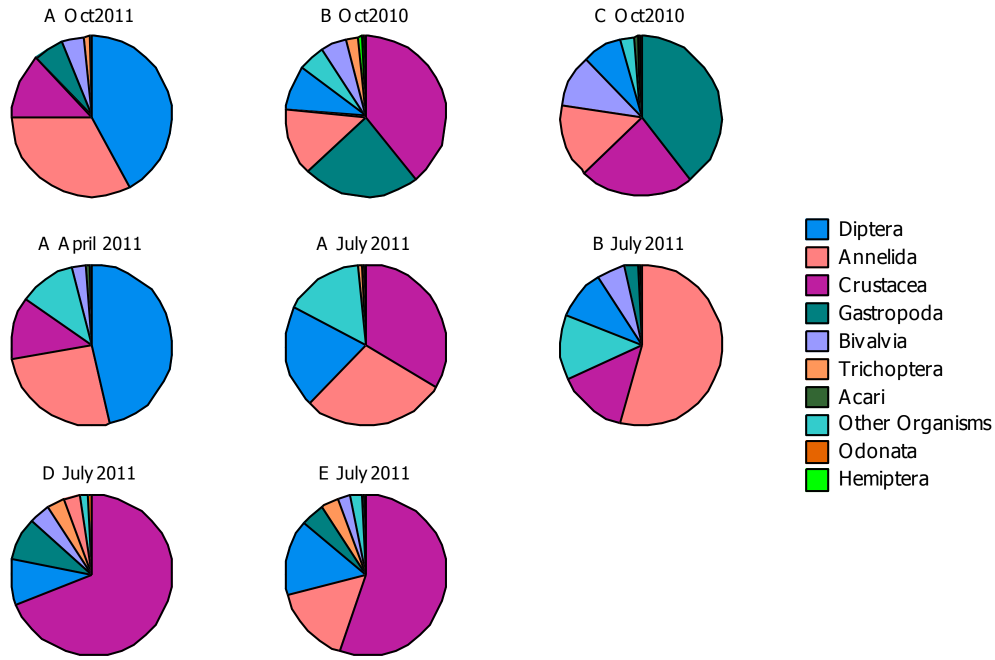


Figure 57. Proportional occurrence of benthic taxa in suction dredge samples for April 2011 and October 2010. Individual pies are arranged clockwise from most abundant to least abundant. 'Other' category is all taxa that occurred < 1% combined.

Sculpin density estimates

Sculpins were observed within the majority of site samples (immediately prior to suction dredge sampling) in all the upstream sites (Sites A, B, and C) but not in any of the downstream sites (Sites D and E). Sculpins are almost exclusively associated with cobble habitat. In general, we estimated that sculpin density ranged from about 1-10/m^2 in the upstream sites. Sculpins were almost always seen on the tops of cobbles, which seemed to be an unusual behavior for a species that is considered to be primary prey for large trout. Sculpins were uncommon in RBT stomachs (see Fish Stomach Analysis), which suggest a gross underutilization by trout of an otherwise commonly utilized prey.

Dry weights, energy densities, and calories

We directly measured dry weights (mg) of the fifteen suction dredge samples collected in October 2010. Dry weights were highly variable due to occasional large crayfish, caddisflies, or snails. The mean dry weight of the October 2010 samples was 4.29 grams/m^2 (1SE = 0.43, Q1 = 0.15, Median = 1.66, and Q3 = 7.26). We applied low values (15.94 joules/mg) and high energy density values (26.28 joules/mg) from Hanson et al. (1997) as shown in Appendix B-Prey Energy Densities and converted to calories (1 joule = 0.239 calories) to estimate the amount of energy (calories) of standing crop benthic macroinvertebrate biomass per square meter of substrate (Table 16). Because we sampled from approximately 1 m to 8 m depth we consider these energy density estimates to be representative only for the littoral zone of RWL.

Table 16. Estimated dry weights (g/m^2), energy densities ($joules/m^2$) and $calories/m^2$ of benthic macroinvertebrates from October 2010 suction dredge samples.

Parameter	Dry weight (mg/m^2)	$Joules/m^2$		$Calories/m^2$	
		low	high	low	high
Mean	4	68	113	16	27
-1SE	3	46	75	11	18
+1SE	6	91	150	22	36
Q1	0	2	4	1	1
Median	2	26	44	6	10
Q2	7	116	191	28	46

We also estimated individual dry weights (mg) for several taxonomic groups that were weighed in the October 2010 suction dredge samples (Table 17). This allowed us to explore the relationships of individual food items in RBT diets.

Table 17. Estimated dry weight values of individual taxa (mg/individual) found in this study in October 2010.

Taxa	N	Mean	SE	StDev	Min	Q1	Median	Q3	Max
Acari (mites)	4	0.28	0.08	0.16	0.13	0.16	0.25	0.44	0.50
Bivalvia (clams)	14	0.97	0.21	0.80	0.50	0.52	0.68	0.83	3.03
Chironomidae (midges)	16	0.21	0.07	0.26	0.06	0.10	0.13	0.21	1.18
Ephemeroptera (mayflies)	2	0.75	0.25	0.35	0.50	NA	0.75	NA	1.00
Gastropoda (snails)	12	5.92	1.63	5.64	0.89	1.61	3.23	10.29	16.48
Oligochaeta (worms)	16	0.18	0.06	0.23	0.02	0.05	0.10	0.24	1.00
Other	9	0.32	0.06	0.17	0.06	0.18	0.33	0.46	0.60
Trichoptera (caddisflies)	9	4.73	4.41	13.23	0.08	0.17	0.40	0.50	40.00

Crustaceans can vary widely in size and dry weights and were analyzed as one group. Therefore, we did not calculate individual weights but used estimated low and high dry weight values suggested by Dieterman et al. (2004) or Hanson et al. (1997) (Table 18).

Table 18. Low and high estimated dry weights (mg) of individual crustacean taxa found in RWL (modified using Dieterman et al. 2004 and Hanson et al. 1997).

Taxa	Low (mg)	High (mg)
Caecidotea sp.(isopod)	0.02	11.69
Cambaridae (introduced crayfish)	0.65	82258.22
Crangonyx sp. (small crustacean)	0.03	4.79
Hyalella sp.(scud)	0.01	4.12
Orconectes sp.(native crayfish)	3.50	15545.90

Dry weights for the April 2011 Site A samples (N = 5) were measured for the entire sample combined and not individual taxa groups. We estimated the mean dry weight at Site A in April 2011 to be 0.15

g/m^2 (0.05 2SE) for four of the samples that did not have crayfish. The fifth April 2011 sample, in addition to the suite of taxa present at similar abundances in the first four samples, contained two large crayfish. The estimated dry weight for the sample with the two crayfish was 34 g/m^2. We did not estimate dry weights or calculate energy densities for the suction dredge samples that were collected in July 2011 because dry weights were not measured.

It is apparent that dry weights of benthic invertebrates can vary seasonally and within individual taxon, often by many orders of magnitude. Crayfish are an obvious example. Crayfish are often extremely abundant in RWL, especially in the middle to upstream sections. Thus, estimation of caloric values of benthic invertebrate standing crop is very problematic and our estimates are most likely low compared to the true values. However, crayfish were uncommon in RBT stomachs (see Fish Stomach Analysis) and thus their importance to standing crop biomass, as far as RBT diets is concerned, appears to be of limited importance, although one of the authors (Richards) observed two angler caught 'wild' RBT from upstream of Seaton's Grove in August 2010 with stomachs and esophagus' filled with medium to large sized crayfish. Crayfish are also much less digestible than other RBT food items particularly midges and sculpins (See Fish Stomach Analysis). On the other hand, crayfish disproportionately influence benthic assemblage ecology, because they are aggressive predators/omnivores and because of their ability to attain very large sizes compared to other aquatic freshwater invertebrates.

Benthic macroinvertebrate ecology

We also explored the benthic macroinvertebrate ecology in the section of RWL from the suction dredge data. We did this to further understand their dynamics and to relate this to RBT ecology.

Functional Feeding Groups (FFG)

Functional Feeding Groups analysis (FFGs) relates the types of feeding strategies of organisms in relation to the food resources. The use of FFGs in understanding community dynamics, food webs, and other ecological relationships is well developed and accepted in stream ecological studies.

Our FFG analysis showed that grazers were by far the most important in the benthic assemblages for all locations (Figures 58 and 59). They accounted for about 70-90% of the benthic organism abundances in both October 2010 and July 2011. Grazers are a diverse group and are considered to be more generalists than the other FFGs. In RWL the most prominent gatherers were midges, worms, and, scuds.

Scrapers mostly feed on algae and reflect conditions with ample algal growth (primary productivity) mostly as a result of increased sunlight, temperature, and time. For example, scrapers were a greater proportion of the benthic community in October 2010 than in July 2011 (Figures 58 and 59) most likely due to the amount of time algae had to grow following high water flows and the clear water of late summer and fall that transmits more light for macrophyte and periphyton production. As noted in the water quality section, phosphorus levels were higher than normal in 2010 which also may have contributed to this part of the food web. Scrapers also occurred at greater percentages at Site C than Site A in the October 2010 samples. The most common scraper taxa in the samples were snail taxa.

Shredders occurred at very low percentages or were absent from our samples, which reflects the limited amount of course particulate organic matter (CPOM) mostly in the form of allochthonous (i.e., originating in another place than where found) leaf input. Filterers were almost completely absent, as well. Filterers collect food items in the drift and their low proportion of the FFG illustrates the limited amount of drifting fine particulate organic matter (FPOM) in RWL. The most common filterers were fingernail clams. Predators occurred in relatively low abundance but within the range of normal percentages, typically around 10%.

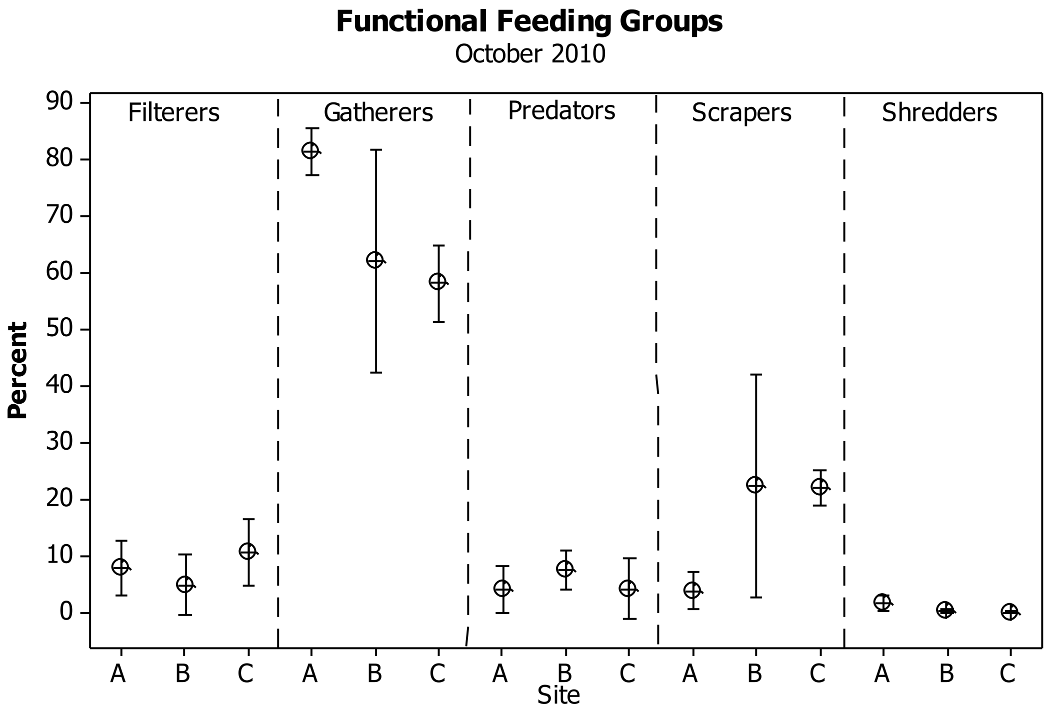


Figure 58. Mean (± 2 SE) of percent functional feeding groups collected in October 2010 suction dredge samples.

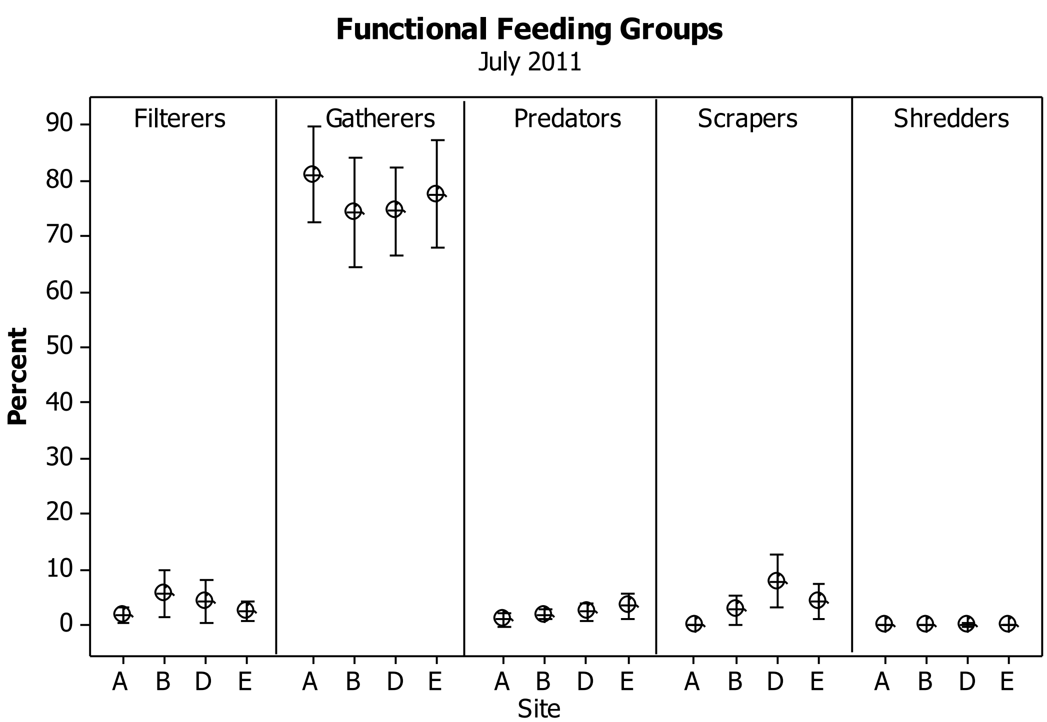


Figure 59. Mean (± 2 SE) of percent functional feeding groups collected in July 2011 suction dredge samples.

The mean percent of the three dominant taxa found in each of the suction dredge samples was 75% (± 2SD = 21%), which is somewhat high for unregulated lotic systems. This suggests that water quality conditions, as a function of 'biological integrity', are possibly compromised in RWL; this is most likely due to the effects of the impoundments both upstream and downstream. Oligochaetes (worms), crustaceans, midges, and snails were typically the most dominant taxa (Table 19).

Table 19. Most dominant taxa in all suction dredge samples collected in October 2010 at the three sites.

Phylum	Class/Family	Lowest taxa resolution	Common name	Functional Group	# times in top 3 most dominant taxa
Annelid	Oligochaeta	Oligochaeta	Segmented worm	Gatherer	21
Crustacean	Isopoda	*Caecidotea* sp.	Pillbug (sowbug)	Gatherer	10
Crustacean	Amphipoda	*Hyalella* sp.	Scud	Gatherer	6
Crustacean	Decopoda	*Orconectes virilis*	Invasive crayfish	Omnivore	6
Diptera	Chironomidae	3 taxa	Midge	Gatherer	17
Mollusk	Gastropoda	4 taxa	Snail	Scraper	10
Mollusk	Bivalve	*Pisidium* sp.	Clam	Filterer	2

The RBT fishery is primarily dependent on these dominant taxa because of their disproportionate large abundances as food items. For example, oligochaetes (segmented benthic worms) were often the dominant taxa in the benthos. However, oligochaetes appear to be mostly absent in RBT diets (see Fish Stomach Analysis). This is because RBT are visual predators and rarely search within the sediments for worms. On the other hand, crustaceans, snails, and midges also occur at high abundances and because they are visually available made up a large portion of RBT diets (see Fish Stomach Analysis).

Invasive crayfish

Estimated mean densities of the invasive crayfish in suction dredge samples for all sites was 34/m^2. The highest densities were at Sites A, B, and C in July 2011 with a mean of 412/m^2. High densities in these sites were most likely due to a reproductive event with many small juvenile crayfish collected. We did not measure individual crayfish.

Nonnative Cambaridae crayfish are highly invasive and when established can have far reaching effects on biodiversity, community structure, energy transfer, food webs, effects on fisheries, and severe effects on the structure and functioning of river ecosystems (Lodge et al. 2000, Gutierrez-Yurrita et al. 1998, Geiger et al. 2005, Crehuet et al. 2007, Larson and Olden 2011, Leib et al. 2011). All fisheries management programs on the Columbia River and associated reservoirs (e.g. RWL) need to be concerned about this invasion and monitor invasive crayfish populations closely. Researchers and managers must also study and monitor ecosystem effects of invasive crayfish, particularly in relation to fisheries.

Cambaridae crayfish are mostly omnivores that feed on large quantities of invertebrates, plants, and detritus (Feminella and Resh 1989; Huner and Barr 1991; Ilheu and Bernardo 1993a, b, 1995; Correia 2002, 2003; Alcorlo et al. 2004; Rudnick and Resh 2005). However, invasive Cambaridae crayfish are prone to prey on slow moving invertebrates, mostly mollusks (snails and clams), because mollusks are easy to capture and are expected to provide more energy in the long run than other more elusive prey (Nystrom et al. 1999, Stenroth and Nystrom 2003). It has also been suggested that, in the presence of other prey, mollusks might also be exploited by crayfish as sources of minerals (e.g. calcium carbonate) needed for crayfish growth (Crehuet et al. 2007).

We noted that snails and clams were strongly disassociated with crayfish in our NMS ordination results and discussion (Figure 55). To statistically test these relationships, we conducted non parametric Spearman rank correlation between crayfish and snails and clams. Snail abundances were significantly negatively correlated with crayfish abundances (-0.33; $p = 0.02$; $N = 48$) as were clams (-0.53; $p = < 0.01$; $N = 48$). Correlations do not infer causal relationships and other factors besides predation of invasive crayfish on mollusks (snails and clams) may have been involved, including habitat preference differences.

In addition, the invasive virile crayfish *O. virilis* has only recently been reported in RWL in 2009, only two years prior to our suction dredge survey (Larson et al. 2010). Most likely this invasive species was established in RWL sometime before 2009 because its populations are very high. However, given its invasiveness and the potential ecological impacts that it can have, its invasion is of extreme concern.

Our suction dredge samples failed to produce any signal crayfish, *Pacifastacus leniusculus* (Family Astacidae); the only crayfish native to the Columbia River (Figure 60). Instead only non-native, crayfish (Family Cambaridae) were collected (N = 431 Cambaridae). These were mostly *Orconectes* sp., and all were most likely *O. virilis*, the virile crayfish because it is the only *Orconectes* sp. to have been reported in RWL (Figure 61); however, our taxonomists were unable to definitively determine species because specimens were preserved in alcohol and many were juveniles with key morphological characteristics lacking or indiscernible. Specimens that could only be identified to *Orconectes* sp. may possibly have been *O. rusticus*, the rusty crayfish but it has not been reported in RWL.

Figure 60. The signal crayfish, *Pacifastacus leniusculus* (Family Astacidae); the only crayfish native to the Columbia River. This specimen was photographed near Pacific Aquaculture net pens in September 2009. Courtesy of Pacific Aquaculture.

Figure 61. The non-native invasive *Orconectes* sp. (Family Cambaridae). This specimen was photographed near Pacific Aquaculture net pens in September 2009. Courtesy of Pacific Aquaculture.

Benthic assemblage below littoral zone

We did not quantify the benthic assemblages below the littoral zone (e.g. benthic, profundal zones) but assume that standing crop biomass is less than that found in the littoral zone. However, because RWL is a regulated river, flushing and scouring of sediments during flood events is reduced and sediment accumulation occurs, particularly in the downstream sections. Benthic assemblages below the littoral zone are adapted to low light conditions and a detritus (sediment) based economy. We expect many of the 'gatherer' taxa that occurred in our suction dredge samples in the littoral zone (and other that were not found in our suction dredge samples) to also occur beneath the littoral zone. Many of these taxa including; midges, scuds, crayfish, worms, and sculpins (and occasionally snails) are often found in the benthos below the littoral zone.

Tribal biologists have observed (with the use of video cameras) RBT, sculpins, and northern pike minnows at depths > 100 ft. in RWL (Ed Shallenberger, personal communication). However, in the middle reservoir approximately river mile 576.1, near China Bar, one of us (Rensel) recorded over an hour of underwater video with and without lighting in the 50 to 110' depth range in late fall 2010 without spotting a single fish or invertebrate among the large cobble/sand habitat. Light conditions at these depths are extremely diminished but because several fish taxa are sometimes observed at this depth, we speculate that some food items also occur at these depths, including those food item taxa mentioned above. However, we do not know at what densities, diversity, or biomass the benthos below the littoral zone provides to the RBT fisheries. Abundance of sediment derived food resources are not directly governed by light or temperature and the benthic taxa occurring at depths below the littoral zone should not be as seasonally food limited as those taxa found in the littoral zone.

Invasive carp

Although we did not capture any carp in our samples, RWL has a large population of carp. This species is an "ecosystem engineer" an often alters river ecosystems for the worse. Carp uproot macrophytes, increase turbidity, eat benthic food items and game fish eggs. We suggest initiating a carp removal /reduction plan in RWL. It should not be difficult to reduce carp populations. Carp are group spawners and many of their spawning locations are known. For example an intermittent tributary to RLW on the left bank near China Bar (and River mile 576) is a prime spawning location for carp (Appendix 14). This backwater area could easily be netted off when carp are spawning and the fish removed. This would eliminate millions of potentially destructive carp fry from the system. Other spawning locations can also be located and netted.

Rainbow Trout Stocking Program

Sterile (triploid) rainbow trout (RBT) have been stocked intentionally and as accidental releases from the commercial net pens in RWL for many years Shallenberger (2009). We know of no single comprehensive database of hatchery fish released, intentionally and accidentally, into RWL or Lake Roosevelt and upstream that may immigrate into and emigrate out of RWL.

Anecdotal observations and CCT Fish and Wildlife data indicate that many of the fish caught by anglers are clearly of RWL net pen fish farm origin (up until recently, mostly Trout Lodge stock), due to their large size and high weight to length ratios. But many other types of trout and salmonids occur in Rufus Woods Lake including kokanee and (fin clipped) rainbow trout from Lake Roosevelt. However, prior to 2006 only a portion of the RBT stocked were triploid (Peone 2006), which may have resulted in some natural production in either or both lakes. For example, we collected a ripe female RBT, apparently killed by gas bubble disease in the vicinity of China Bar in June 2011 (see photo appendix). The Lake Roosevelt RBT are thought to generally be less than 0.5 kg in the RWL catch (E. Shallenberger, pers. Comm. to J. Rensel Oct. 2011). Redband trout are native to the Columbia River and have been stocked in RWL in recent years. Brown trout are also known to exist in the reservoir, apparently naturally reproducing. RWL is presently considered bull trout habitat too, although it is unclear if any of these fish remain and unlikely according to some accounts. The existence of various salmonids from the river upstream of Lake Roosevelt cannot be ruled out. Anglers catch some of these fish but creel census study has only been practiced for a few years and samples only a small percentage of the catch.

Couple the above with occasional small or large accidental releases of fish farm sterile triploid trout and it results in a potentially confusing array of fish that may interact with other salmonids and wild fish including exotics such as walleye. Nevertheless, we here report the fish morphometric data for the available creel census result in 2010 below. Figure 62 illustrates the length and weight relationships for both the 2010 RBT creel census data (blue diamond shapes and fitted power equation line) and standard RBT data that represent the mean of 81 different lake RBT studies analyzed by Simpkins and Hulbert (1996). The chart shows that RWL fish above approximately 45 cm in length (~1.2 kg) begin to diverge in the length and weight line compared to the mean of all the other studies combined.

In 2010 there were few reported accidental releases of net pen fish and none below a mean size of about 1 kg. We believe many of the creel census fish were a result of the intended net pen releases due to the timing of acoustically tagged fish occurrences from the Battelle study not yet completed. The mean size of these fish from six separate releases ranged from 1.4 to 2.0 kg. We calculated a weighted mean of 1.58 kg weight for these fish that stemmed from total releases of 12,414 fish and 179 recoveries shown in Figure 62.

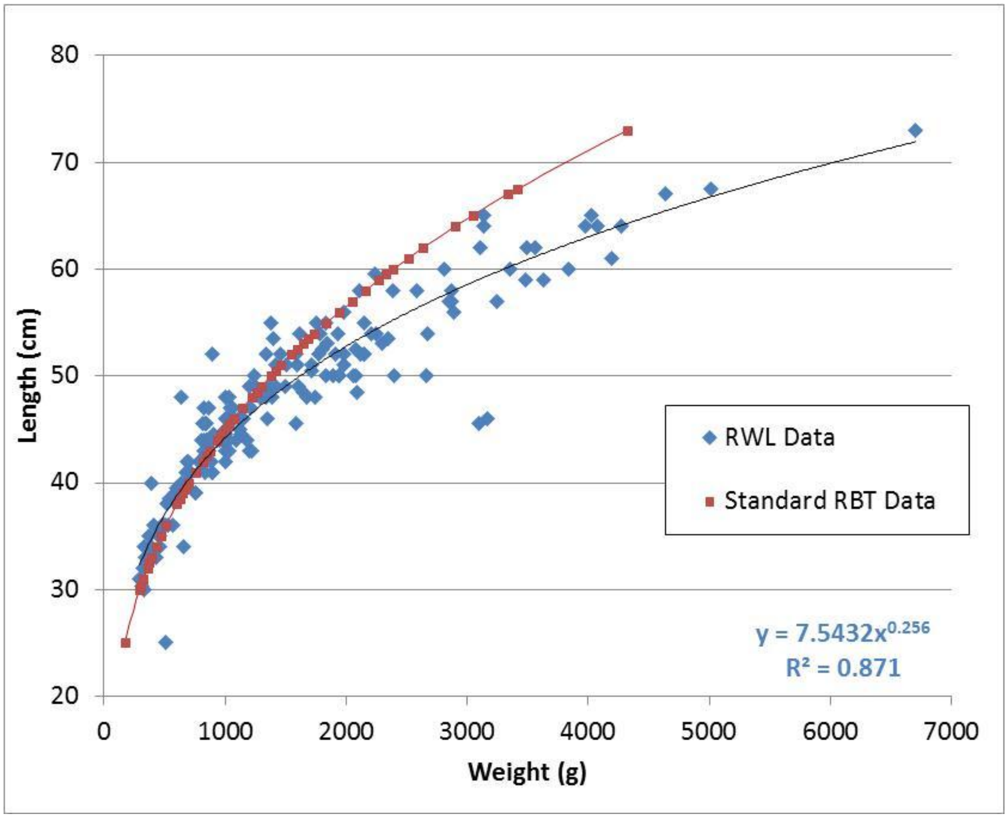


Figure 62. RWL rainbow trout versus length and weight data from 2010 creel census report compared to standard RBT data described in the text. Length is total length for both data sets.

The same RBT data shown in Figure 62 are used in Figure 63 to compare size to the 23 creel census measured walleye reported. Note that the walleye observations fell along the L x W line and slightly above, indicating they were had similar condition index and the largest walleye reported was 53 cm, not much different than the mean of ~ 48 cm. Larger walleye may exist in RWL as some anglers release large females, but these data give some guidance on the relationship of the two competitive species that may help guide in the choice of release size for RBT in the future. In general, RBT should be at least 1/3 to maybe 1/2 the length of some proportion of the larger walleye to escape predation.

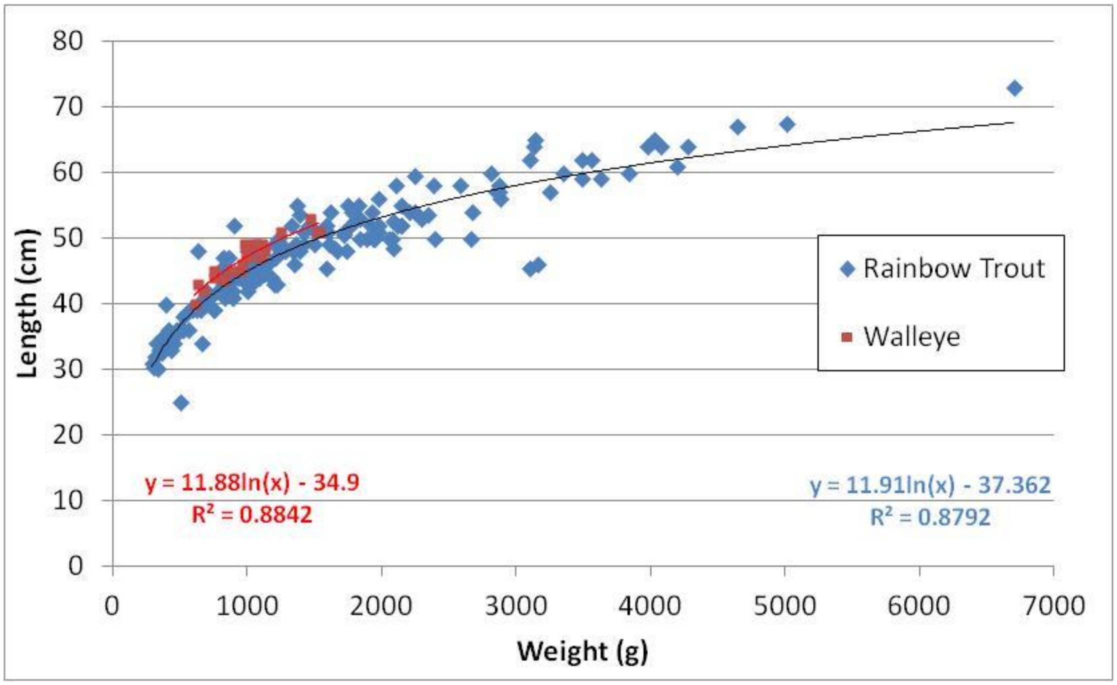


Figure 63. Length vs. weight plot of 2010 creel census rainbow trout and walleye from Rufus Woods Lake.

Table 20 reports the size and duration results of acoustically tagged RBT from the yet to be completed study by Battelle in RWL. Note that the total N of these data is limited, but most of the fish were large and all of the fish lost weight during their short (mean 17 day) stay in RWL except one fish that was caught after one day and was therefore about the same as at release.

These data, although very limited, are potentially very powerful as they indicate that both small (~500 g) and large (~ 2kg+) pen reared fish lost weight and therefore apparently had not the skill or ability to feed effectively on the available food resources. Note too that the timing of these observations included November, January and April, 2010 through 2011. So, we must be careful about extrapolating the results to all seasons.

Smaller fish remained longer in the reservoir, but it is not possible to make significant conclusions based on the small number of observations. In addition, the acoustic tracking records for all tagged fish are more extensive and conflict with the data of Table 20, showing much longer residence time in the reservoir (months), but that is the subject of a separate report by Battelle presently in preparation. The possibility of stress of the tagged fish cannot automatically be discounted either.

A major issue with the study of RBT in RWL is the possibility of several contributing stocks of fish to the catch. In addition to RWL net pen fish released intentionally or accidentally, fish could originate from Lake Roosevelt hatchery and net pen programs. We cannot discount the possibility of natural production of RBT in RWL because there may be suitable gravels for spawning and in the past Lake Roosevelt hatchery fish were often diploid (not sterile). CCT managers have thought there is little natural RBT production in RWL, but no dedicated study of the issue has occurred. One of us (JR) has documented other wild Chinook salmon spawning in the mainstem below Wells Dam where gravels were highly suitable for salmonid spawning.

Table 20. Acoustically tagged net pen RBT at release and recapture.

Tag ID	Release Date	Release Weight (g)	Capture Date	Elapsed Days in RWL	Capture Weight (g)	Delta Weight (g)	Delta Weight (%)
G7253D18B	11/1/2010	2062	11/16/2010	15	1,940	-122	-5.9%
G72546C2A	11/1/2010	1559	1/28/2011	88	1,516	-43	-2.8%
G724638ED	11/1/2010	2138	11/29/2010	28	2,082	-56	-2.6%
G724A60B9	1/13/2011	2320	1/14/2011	1	2,232	-88	-3.8%
G72460AEF	1/13/2011	3318	1/28/2011	15	2,975	-343	-10.3%
G7245D4F2	1/13/2011	1428	1/15/2011	2	1,400	-28	-2.0%
G7243FA64	1/13/2011	2088	1/14/2011	1	1,974	-114	-5.5%
G7243F3F8	1/13/2011	2390	1/14/2011	1	2,400	10	0.4%
G7245EC8E	3/24/2011	608	4/11/2011	18	570	-38	-6.3%
G7245E6F0	3/24/2011	646	4/10/2011	17	570	-76	-11.8%
G72400165	3/24/2011	1006	4/1/2011	8	940	-66	-6.6%
G7245C78D	3/24/2011	1136	4/2/2011	9	1,120	-16	-1.4%
Mean	1/18/2011	1,724.9	2/4/2011	**16.9**	1,643.3	-81.7	-4.9%
Std. Deviation		805.7		23.9	752.6	90.9	3.6%
Minimum		608.0		1.0	570.0	-343.0	-11.8%
Maximum		3,318.0		88.0	2,975.0	10.0	0.4%

Fish Stomach Analysis

Overview

Diets of the fish we examined varied significantly among three species of fish within and between time periods samples. At least 96 separate prey taxa (mostly grouped by family level) were found in the stomach samples (Table 21) including 56,273 individual organisms in RBT stomachs, 5,428 organisms in walleye stomachs, and 175 organisms in northern pike minnow (Appendices 9, 10, and 11).

Table 21. List of taxa found in stomach samples.

Scientific Name		Common name
Ephemeroptera	Baetis tricaudatus	Baetid mayfly (aquatic)
	Caenidae	Mayfly (aquatic)
Odonata	Coenagrionidae	Narrow winged damselfly (aquatic)
	Libellulidae	Skimmer dragonfly (aquatic)
	Libellulidae/Corduliidae	Skimmer dragonfly (aquatic)
Plecoptera	Plecoptera	Stonefly (aquatic)
Hemiptera	Aphididae	Aphid (terrestrial)
	Cicadellidae	Leaf hopper bug (terrestrial)
	Coreidae	Leaf footed bug (terrestrial)
	Corixidae	Water boatman bug (aquatic)
	Hemiptera	True bugs (aquatic/terrestrial)
	Notonectidae	Backswimmer bug (aquatic)
	Reduviidae	Assassin bug (terrestrial)
Coleoptera	Anthicidae	Ant like flower beetle (terrestrial)
	Carabidae	Ground beetle (terrestrial)
	Chrysomelidae	Leaf beetle (terrestrial)
	Coleoptera	Beetles (aquatic/terrestrial)
	Curculionidae	Weevil (terrestrial)
	Dytiscidae	Predaceous diving beetle (aquatic)
	Gyrinidae	Whirligig beetle (aquatic)
	Haliplidae	Crawling water beetle (aquatic)
	Scarabaeidae	Scarab beetle (terrestrial)
	Staphylinidae	Rove beetle (terrestrial)
	Tenebrionidae	Darkling beetle (terrestrial)
Diptera	Chironomidae	Midge (aquatic)
	Acalyptratae	Muscoid fly (terrestrial)
	Ceratopogonidae	No- see- um biting midge (aquatic)
	Chloropidae	Grass fly (terrestrial)
	Tipula sp.	Cranefly (aquatic)
Trichoptera	Hydroptilidae	Micro caddis (purse case caddis)(aquatic)
	Lepidostomatidae	Little brown/green sedge (aquatic)
	Leptoceridae	Long horned caddisfly (aquatic)
	Limnephilidae	Caddisfly (aquatic)
	Phryganeidae	Caddisfly (aquatic)

Scientific Name		Common name
Lepidoptera	Lepidoptera	Butterfly/moth (aquatic/terrestrial)
Megaloptera	Sialidae	Alderfly (aquatic)
Other Insecta	Apidae	Bee (terrestrial)
	Apoidea	Bee/wasp
	Archaeognatha	Bristletail (terrestrial)
	Arthropoda	Arthropod (aquatic/terrestrial)
	Chrysididae	Cuckoo wasp
	Dermaptera	Earwig (terrestrial)
	Formicidae	Ant (terrestrial)
	Hymenoptera	Ants, bees, wasps (terrestrial)
	Ichneumonidae	Ichneumon wasp (terrestrial)
	Isoptera	Termite (terrestrial)
	Neoptera	Winged insects (aquatic/terrestrial)
	Orthoptera	Grasshopper (terrestrial)
	Raphidiidae	Snakefly (terrestrial)
	Raphidioptera	Snakeflies (terrestrial)
Gastropoda	Gastropoda	Snail(aquatic)
	Gyraulus sp.	Gyraulus snail(aquatic)
	Lymnaeidae	Lymaeid snail(aquatic)
	Physa sp.	Physa snail(aquatic)
	Physidae	Physa snail(aquatic)
	Planorbidae	Planorbid snail(aquatic)
	Valvatidae	Valvata snail(aquatic)
Bivalvia	Sphaeriidae	Fingernail clam(aquatic)
	Veneroida	Clam (aquatic)
Annelida	Glossiphoniidae	Leech (aquatic)
	Oligochaeta	Segmented worm (aquatic)
	Rhynchobdellida	Leech (aquatic)
Acari	Arrenuridae	Mite (aquatic)
	Hydrachnidae	Mite (aquatic)
	Hydrodromidae	Mite (aquatic)
	Lebertiidae	Mite (aquatic)
	Limnesiidae	Mite (aquatic)
	Pionidae	Mite (aquatic)
	Unionicolidae	Mite (aquatic)
Crustacea	Asellidae	Isopod (aquatic)
	Astacidae	Crayfish (aquatic)
	Astacidea	Crayfish (aquatic)
	Astacoidea	Crayfish (aquatic)
	Caecidotea sp.	Pillbug (aquatic)
	Calanoida	(aquatic)
	Cambaridae	Crayfish (aquatic)
	Cladocera	Water flea (aquatic)

Scientific Name		Common name
	Copepoda	Copepod (aquatic)
	Crangonyctidae	Amphipod (aquatic)
	Cyclopidae	Copepod (aquatic)
	Daphniidae	Daphnia (aquatic)
	Decapoda	Crayfish (aquatic)
	Diplostraca	Cladocera (aquatic)
	Gammaridae	Scud (aquatic)
	Hyalella sp.	Scud (aquatic)
	Isopoda	Isopod (aquatic)
	Leptodoridae	Cladocera (aquatic)
	Ostracoda	Seed shrimp (aquatic)
Other Organisms	Arachnida	Spider (terrestrial)
	Araneae	Spider (terrestrial)
	Diplopoda	Millipede (terrestrial)
	Nematoda	Unsegmented worm (aquatic)
	Salticidae	Jumping spider (terrestrial)
	Turbellaria	Flatworm (aquatic)
Fishes	Cypriniformes	Ray finned fish (aquatic)
	Gasterosteidae	Stickleback (aquatic)

Rainbow Trout Prey

The number of prey taxa that occurred in stomachs varied from fish to fish. Twenty five percent of the RBT stomachs (N = 73) were empty. Of the remaining 75%, most had < 4 different kinds of prey taxa in their stomachs (Figure 64). However, one RBT had 14 prey taxa in its stomach and another had 20 prey taxa in its stomach (Figure 64).

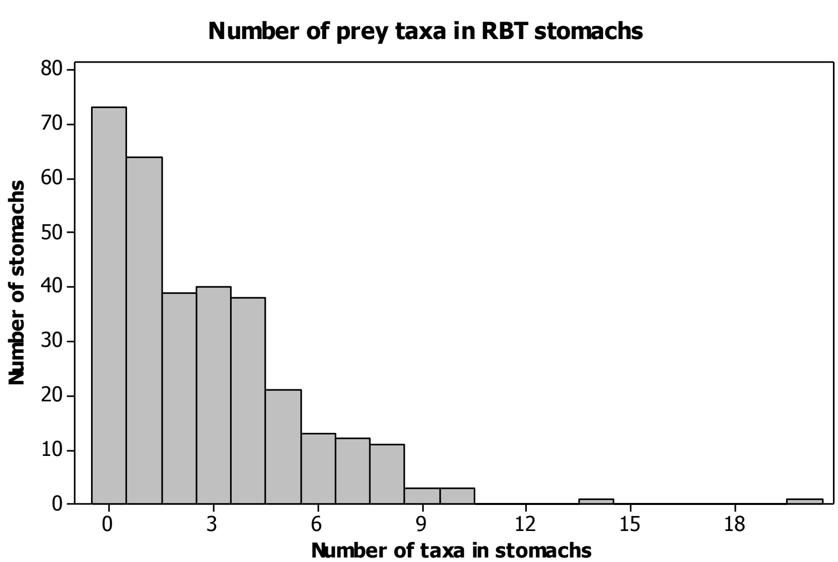


Figure 64. Number of prey taxa in RBT stomachs collected between April 2010 and August 2011 (N = 297).

The mean number of taxa occurrence in RBT stomachs varied between months with the overall mean = 2.6 taxa. RBT stomachs collected in April/May 2010, April/May 2011, June/July 2010, and June/August 2011 had greater mean number of taxa than the average total and August 2010 had substantially fewer (Figure 65). We combined August 2011 stomach data with June and July 2011 because there were only 4 verifiable RBT stomachs collected in August 2011 (i.e. not enough data points for August 2011).

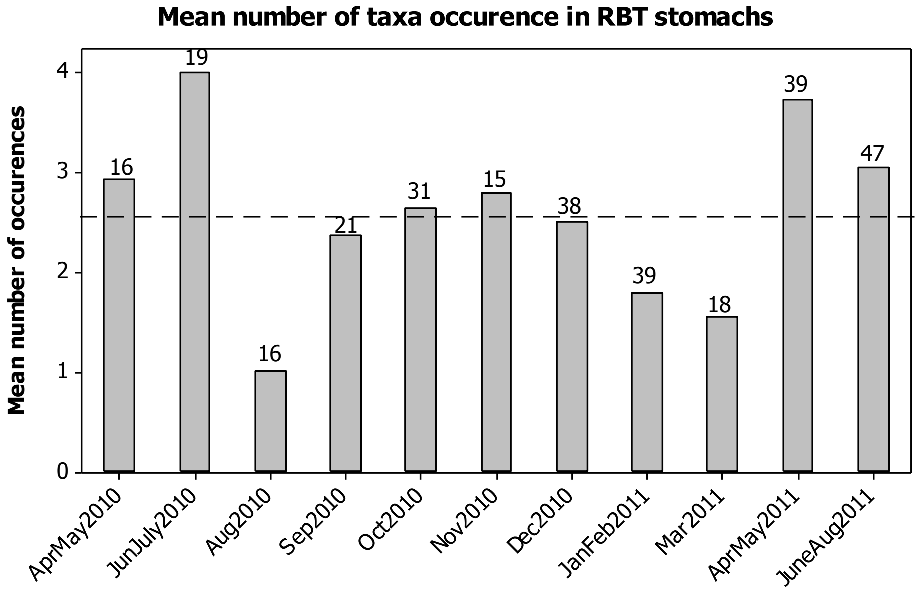


Figure 65. Mean number of taxa occurrences in RBT stomachs separated by monthly group. Samples were collected between April 2010 and August 2011. Stomach samples from August 2011 were combined with June and July 2011 samples because of the limited number of verifiable samples from August 2011 (N = 4). The dotted line is the overall mean number of taxa occurrences = 2.6. The number above the bars is the number of stomach samples for that time period.

The percent of RBT empty stomachs is shown in Figure 66. An empty stomach designation meant that no prey items were found, although fish pellets, fishing bait, vegetation, or other items could have been present. In 2010 and 2011, April through July samples had the fewest empty stomachs, while August 2010 had the greatest number of empty stomachs (Figure 66).

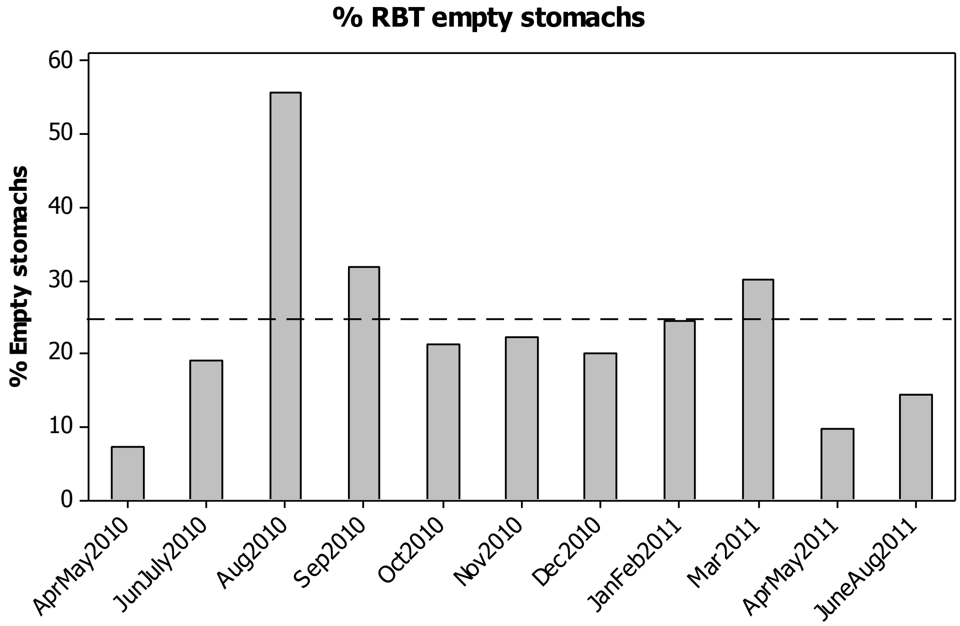


Figure 66. Mean percent of empty RBT stomachs separated by monthly group. Samples were collected between April 2010 and August 2011. Stomach samples from August 2011 were combined with June and July 2011 samples because of the limited number of verifiable samples from August 2011 (N = 4). An empty stomach means no prey items were found, although fish pellets, vegetation, or other items could have been present. The dotted line is the overall mean of empty stomachs = 25%.

It appears that in April/May of 2010 and 2011 RBT started to increase foraging effort from the previous winter months of January –March (Figures 65 and 66) when water temperatures were coldest (see Figure 9 in Water Temperature section). Feeding rates of RBT in RWL are most likely greater when water temperatures are optimal and rising in the spring (May to July) than any time of year and even when water temperatures are optimal but decreasing in autumn (November to December) (Figures 65 and 66). Data from RWL commercial net pen feeding rates show that RBT consume and assimilate more feed during spring than in autumn at similar optimal temperatures (Ed Shallenberger, Fisheries biologist, CCT, personal communication).

It is unclear why RBT stomachs collected in August 2010 had highest percentage of empty stomachs and fewest food items. This could be due to increased metabolism when water temperatures were greater and there was faster digestion and shorter retention time of food items in the gut or it could be due to some other unknown factor.

Aquatic based food items made up more of the RBT diet than did terrestrial food items but terrestrial food items were almost always present in stomachs except in Jan/Feb 2011 and March 2011 samples (Figure 67). There was also an obvious seasonal shift in diets (Figure 67). Given the assumption that the majority of the RBT stomachs examined were ultimately from net pen released fish, this shows that at least some of the net pen raised RBT eventually learn how to capture and consume natural food items from different habitats, trophic levels, and from a wide range of sizes.

The following charts (Figures 67 and 68) show the taxa found in RBT stomachs by proportion of total taxa occurrences by presence/absence. Individual taxa were combined into groups that are easily identified by non-specialists and that represent potentially different RBT feeding strategies, including a terrestrial insects group.

In these figures, grouping is by taxa that represent potentially different RBT feeding strategies. Aquatic invertebrate taxa included: beetles (Coleoptera), bugs (Hemiptera), flies (Diptera), caddisflies (Trichoptera), dragonflies (Odonata), hellgrammites (Megaloptera), mayflies (Ephemeroptera), mites (Acari), stoneflies (Plecoptera), worms and leeches (Oligochaetes), and benthic crustaceans (e.g. scuds, isopods, etc.). Pelagic crustaceans included: copepods, daphnia, ostracods, etc. The terrestrial component was expanded from the pie to help differentiate between terrestrial based food items and aquatic based food items.

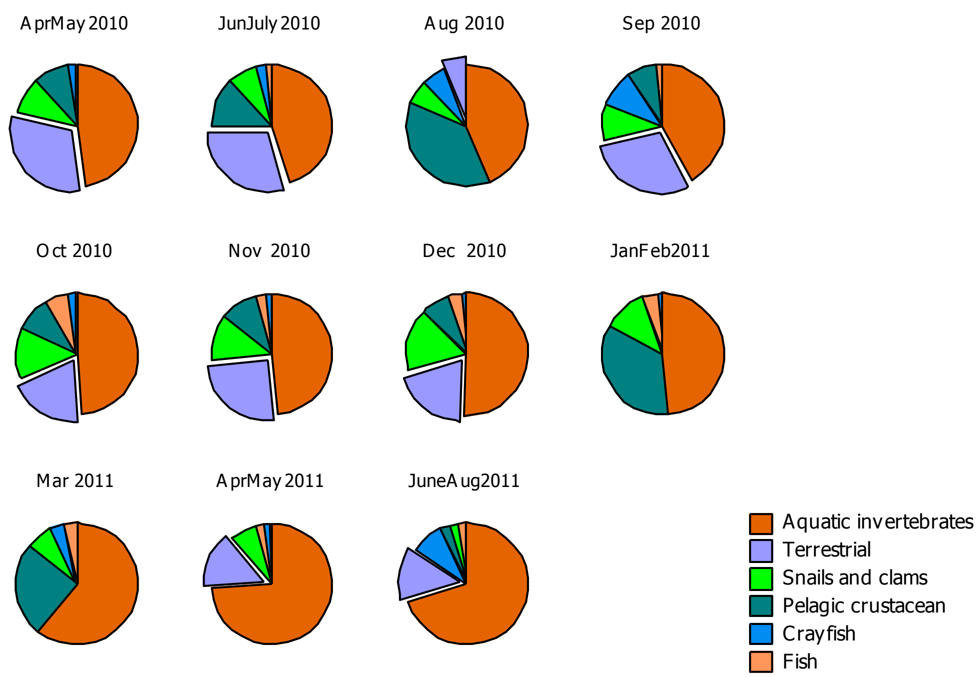


Figure 67. Proportion of food items in RBT stomachs collected between April 2010 and August 2011 by proportion of total taxa occurrences based on presence absence and grouped by months.

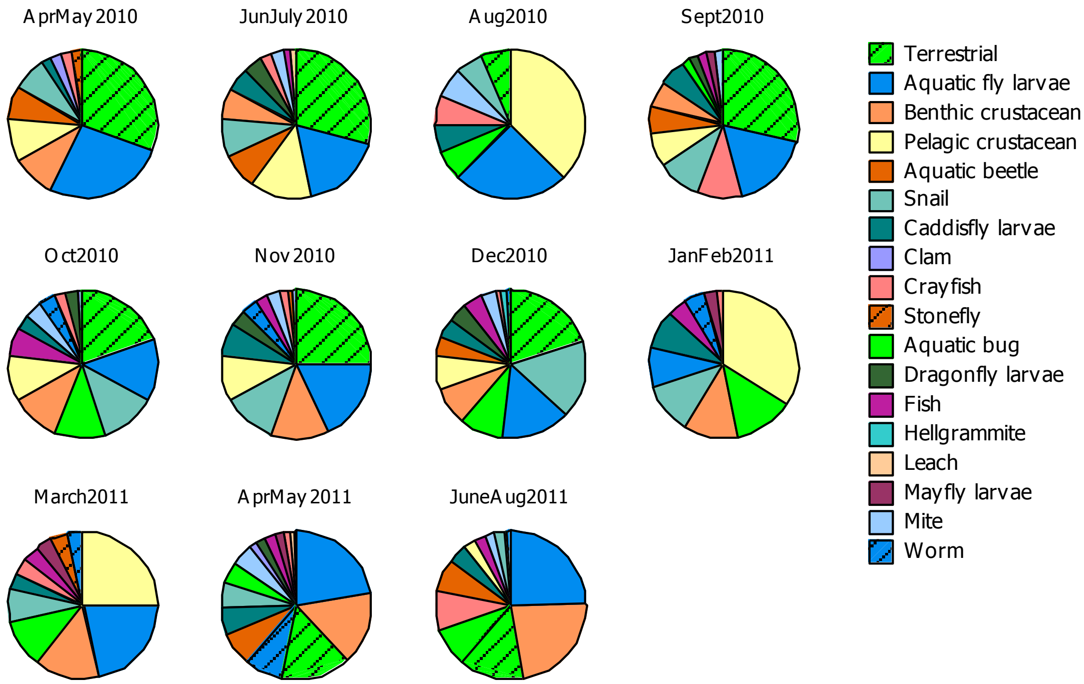


Figure 68. Proportion of food items in RBT stomachs collected between April 2010 and August 2011 by proportion of total taxa occurrences based on presence absence and grouped by months. Grouping is by taxa that represent potentially different RBT feeding strategies and is at a finer resolution than Figure 67.

We also examined RBT stomach contents by abundances of food items for all samples combined (Figure 69). The vast majority of individual organisms in stomachs were very small pelagic crustaceans (e.g. daphnia, copepods, ostracods, etc.) followed by diptera (midges and flies), snails, and terrestrial arthropods (insects and spiders).

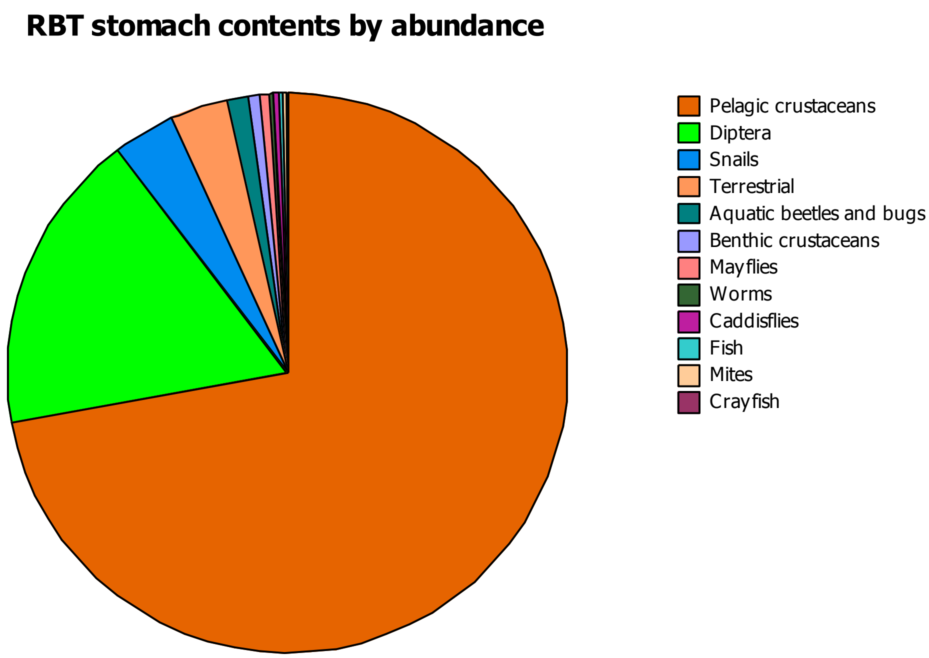


Figure 69. Proportion of food items in RBT stomachs collected between April 2010 and August 2011 based on abundances.

Optimal foraging, digestion rates and bioenergetics

There are tradeoffs (costs) between food energy content, the amount of time and effort needed to capture and handle food items (optimal foraging theory (MacArthur and Pianka 1966, Kamil et al. 1987)) and their digestibility digest (the digestive rate model (Verlinden and Wiley 1989)). Optimal foraging theory suggests that RBT in RWL will forage in such a way as to maximize their net energy intake per unit time. RBT should find, capture and consume food items that contain the most calories while expending the least amount of time doing so. In addition, RBT will also selectively choose food items that are easier to digest (the digestive rate model (Verlinden and Wiley 1989)). That is, RBT will select food items that make optimal use of their digestive tract (maximize digestion rate) rather than maximize their food ingestion rate. Thus, optimal foraging suggests that food ingestion rate is the limiting factor, whereas the digestion rate model suggests that digestion is the rate limiting process. Most likely it is a combination of the two that determine how effectively RBT in RWL forage. These two ideas are also related to the simple mass balance bioenergetics equation of consumption where energy consumed by RBT is balanced by total metabolism, waste losses, and growth:

$$\text{Consumption} = (\text{metabolism}) + (\text{waste}) + (\text{growth})$$

or more detailed:

$$C = (R + A + S) + (F + U) + (\Delta B + G)$$

where: C = consumption, R = respiration, A = active metabolism, S = specific dynamic action; F = egestion; U = excretion; Δ B = somatic growth and; G = gonad production (Hanson et al. 1997).

Egestion (waste loss)(F) can vary between prey taxa. Therefore, dry weight biomass does not always equate to the amount of energy an RBT can derive from a prey item (see Suction Dredge results for tables of estimated dry weights and energy densities of taxa found in RWL).

The following discussion pertaining to food items found in RBT stomachs from RWL and suction dredge sampling is based on these three ideas; bioenergetics model, optimal foraging theory, and the digestive rate model

Crayfish and fish as RBT prey

Crayfish and fish were less abundant food items in RBT stomachs than other taxa but obviously are much larger than almost all of the other food items. About 14% of the RBT stomachs examined contained crayfish (9%) or fish (5%) (Table 22). Ten additional RBT had cycloid scales in their stomachs in the November/December samples which we consider indicative of ingesting a fish. This would increase the percent of RBT stomachs examined that contained fish to 8%. Fish in RBT stomachs were not identified to taxa in this study; however, Baldwin and Polacek (2002) reported that RBT fish diets in Lake Roosevelt included only three taxa; sculpins, suckers, and minnows. As noted in Table 22 below, several RBT had more than one crayfish in its stomach but 64% of the fish consumed were by only four RBT. This could indicate that few RBT had acquired the skill or ability to feed on this often abundant food source in RWL, particularly in light of the fact that most of the RBT were large fish (> 40 cm).

Table 22. Number of crayfish and fish in RBT stomachs and the number of RBT with crayfish or fish in stomachs in parentheses (N = 297 RBT stomachs examined).

	2010							2011				
	Apr May	Jun July	Aug	Sept	Oct	Nov	Dec	Jan Feb	Mar	April May	Jun Aug	Total
Crayfish												
Astacoidea[1]	0	0	0	2(2)	3(1)	0	1(1)	0	0	0	0	6(4)
Cambaridae[2]	0	0	1(1)	8(3)	0	0	0	0	0	0	0	9(4)
Decapoda[3]	1(1)	1(1)	0	0	1(1)	0	0	1(1)	9(1)	8(2)	15(12)	36(19)
Fish	0	0	0	1(1)	40(4)[a]	0	1(1)	3(3)	2(2)	75(2)[b]	4(3)	126(15)[c]
Total	**1(1)**	**1(1)**	**1(1)**	**9(6)**	**44(5)**	**0**	**2(2)**	**4(4)**	**11(3)**	**83(4)**	**19(15)**	**177(42)**

[1]Native crayfish taxa
[2]Non native crayfish taxa
[3]Unidentified crayfish taxa
[a]Three RBT stomachs accounted for 39 of the 40 fish
[b]One RBT had 74 fish in its stomach
[c]Ten additional RBT stomachs had cycloid fish scales.

Pursuing crayfish (or fish) obviously requires more energy expenditure than feeding on small invertebrates in the drift, even though a large crayfish (or fish) can have orders of magnitude more useful biomass energy.

The amount of useful energy per gram of dry weight is less for crayfish than sculpins or other fish prey because of their hard chitinous exoskeleton. However the thickness and hardness of crayfish exoskeletons varies seasonally and is thinnest and softest for several days directly after molting before the exoskeleton can harden. Crayfish are more reclusive and less likely to be captured during and directly after molting but may be more sought after by RBT at this time.

Fish taxa vary in their digestibility to RBT depending on the type of scales, spines, and amount of bones. For example, northern pike minnows have more bones than many other prey fish and sticklebacks have three spines that make it difficult to ingest.

Based on optimal foraging theory, the digestive rate model, our understanding of crayfish, prey fish, RBT behavior, and the similar percentages of crayfish (8%) and fish (5 to 8%) in RBT stomachs; we suggest that although crayfish are for the most part harder to digest than fish, they are either more abundant or are easier to capture and handle. Easier capture and handling time of crayfish is also supported from our suction dredge sampling results where sculpins and other fish were near impossible to collect, whereas crayfish were not.

Differences in digestibility between prey fish taxa are obviously not as great as the difference between prey fish and crayfish digestibility. Selection and consumption of prey fish by RBT should therefore mostly be dependent on relative abundances, capture rates, and handling times (i.e. optimal foraging theory) of individual fish taxa and not by as much by digestive rates.

From our visual observations, SCUBA, snorkeling, and suction dredge sampling there seems to be a large abundance of potential large prey items for RBT, in particular: sculpins in the upstream portions of RWL, very large abundance of crayfish throughout RWL, and numerous other 'baitfish' (mostly northern pike minnows, juvenile suckers, carp, etc.) in the mid and lower sections. These food items occur throughout the year in RWR. Released RBT that can adapt to consume these larger prey items, should be able to survive and some may attain large sizes.

Snails as RBT prey

Snails are abundant in RWL and provided a substantial portion of RBT diets though out the study (optimal forage) but they have indigestible calcareous shells which do not provide food energy (digestion rate limitation). Snail shell thickness and hence digestibility can vary seasonally but mostly varies by taxon. For example, two of the most abundant snail taxa in RWL, Lymnaedae and Physidae, have different shell thickness with lymnaeid and planorbid snails having much harder shells than fragile shelled physa snails. Some snail taxa (i.e. Family Hydrobiidae) have opercula that allow snails to seal themselves into their shells. Several studies have shown that the highly invasive New Zealand mudsnail (Family Hydrobiidae) can pass directly through RBT digestive systems unharmed (Vinson and Baker 2005). Because of their hard shell and opercula, fish gain very little energy from ingesting NZ mudsnails (McCarter 1986). Fortunately NZ mudnsails have not been found in RWL but it is probably only a matter of time because NZ mudsnails have invaded many rivers in the area, including the lower Columbia River (New Zealand Mudsnail in the Western USA http://www.esg.montana.edu/aim/mollusca/nzms/). None of the snail taxa found in suction dredge samples or fish stomachs were from the family Hydrobiidae and none had opercula. Snail taxa in RWL are more likely to be digested by RBT than hydrobiid snails and are often found in RBT diets wherever the two co-occur. In this study, we were unable to determine if RBT selectively fed on different snail taxa due to shell thickness (digestibility) (or other factors). This was because most snail shells in the stomachs were fragmented and were unidentified past the taxonomic level of gastropod (snail).

Lymnaed, planorbid, and physid snails were the three most abundant snails in our suction dredge samples (Table 23). Fingernail clams were also found in small quantities in RBT stomachs and have softer shells than many other native clam taxa. Fingernail clams (Sphaeriidae) were the third most numerous mollusk in our suction dredge samples (Table 23).

Table 23. Most common mollusk (snails and clams) and percent abundance in suction dredge samples.

Mollusk taxon	Total abundance	Percent abundance
Lymnaeidae	3223	26.41
Planorbidae	3068	25.14
Sphaeriidae	2756	22.58
Physidae	2391	19.59
Valvatidae	724	5.93
Ancylidae	41	0.34

We suggest that all mollusk taxa are important RBT food items in RWL, based on this study and our knowledge of freshwater mollusks and RBT feeding strategies. Also, lymnaeid and physid snails are not as cryptic as planorbid snails and should be easier to detect (capture rate) by RBT. Lymnaeid snails and physid snails should be the preferred snail taxa food items because of their relative abundance (lymnaeid snails) and because of their fragile shells (physid snails). An example of RBT feeding on lymnaeid snails is illustrated in the following photos (Figures 70 and 71).

Figure 70. This 'wild' RBT was approximately 46 cm long and was apparently a net pen released triploid from Lake Roosevelt.

Figure 71. RBT stomach from fish shown in Figure 70 caught in October 2011 containing live snails.

The RBT was approximately 46 cm long and was apparently a net pen released triploid from Lake Roosevelt (its adipose fin was clipped and its dorsal fin was almost non-existent). It most likely was released/escaped when it was much smaller and had survived and grown to its capture length over several years (Ed Shallenberger, Fisheries biologist, CCT personal communication). Its stomach contained 16 lymnaeid snails, all of which were alive.

Aquatic Invertebrate Prey

EcoAnalysts, Inc. lab also reported stomach contents by number of individuals (abundances) of each taxon. For the most part, number of individuals of each taxon does not represent caloric value to the fish because individuals of each taxon can vary in biomass by many orders of magnitude. For example, an individual pelagic crustacean can weigh < 0.01 mg dry weight while a crayfish (crustacea) can weigh > 1000 mg dry weight (Tables 16, 17 and 18 in Suction Dredge Results Section). A fish would have to eat 10^5 pelagic crustaceans to equal the biomass of a single large crayfish. However, both cladocera and other crustaceans were important components of RBT diets and many of the RBT stomach samples had thousands of small prey items. For example, one RBT had 9000 cladocerans in its stomach (approx. 2 mg dry weight) and many RBT stomachs had hundreds of chironomid (Diptera) larvae.

Most of the other taxa consumed by RBT in this study were more or less similarly digestible to RBT depending on if they were soft bodied as larvae or adults (more digestible) (e.g. mayflies, dragonflies, worms, etc.), hard bodied larvae or adults (less digestible) (e.g. scuds, beetles, etc), their availability as adults when emerged (low to moderate capture rates), (e.g. dragonflies, mayflies, caddisflies, etc.) or if they were cryptic or in habitats mostly unavailable to RBT (low capture rates) (e.g.worms). All of these taxa require less energy to capture and handle than do crayfish and fish. Their proportion of RBT diets should more or less be related to their relative abundances, availability, capture rates, and handling times; all of which are supported by the stomach sample data.

Terrestrial invertebrate Prey

Consumption of terrestrial food items trapped on the water surface can be an energy efficient strategy particularly if water velocities are minimal (less RBT respiration) and enough individual food items are available (optimal forage). Surface feeding by RBT on terrestrial invertebrates occurred throughout the study, even in early winter (December 2010) (Figures 67 and 68) and many relatively large sized (> 40 cm) RBT consumed terrestrial insects. Generally RBT begin feeding on fish in lakes at about 15 cm length and in rivers at about 27 cm and they become predominantly piscivorous at about 31 cm (Keely and Grant 2001). Reasons for larger RBT in RWL feeding on terrestrials and not mostly fish or crayfish are unclear.

Competition between RBT and Walleye and Northern Pike Minnows (NPM)

We summarized stomach content data from 28 walleye stomachs. Diets between walleye and RBT were similar if measured by the abundances of individual organisms in their stomachs (Figures 72 and 69, respectively). Proportionally, walleye had substantially more pelagic crustaceans than did RBT in their diets but the other taxa consumed were almost identical between walleye and RBT (Figures 72 and 69). However, 36% of the walleye stomachs contained fish as compared with 8% of the RBT stomachs (one walleye had 6 crayfish in its stomach). This is understandable because walleye are known to be more piscivorous than RBT at an earlier size class. These results suggest that competition between large RBT and large walleye may occur, particularly for crayfish and fish. However, walleye and RBT have different temperature preference ranges and walleye distribution seems to be limited to a few kms between Seaton's Grove and the confluence with the Nespelem River. In addition, walleye are a top predator of RBT and the primary piscivore on salmonids in Lake Roosevelt (Baldwin and Polecek 2002) and most certainly are able to prey on small RBT in RWL.

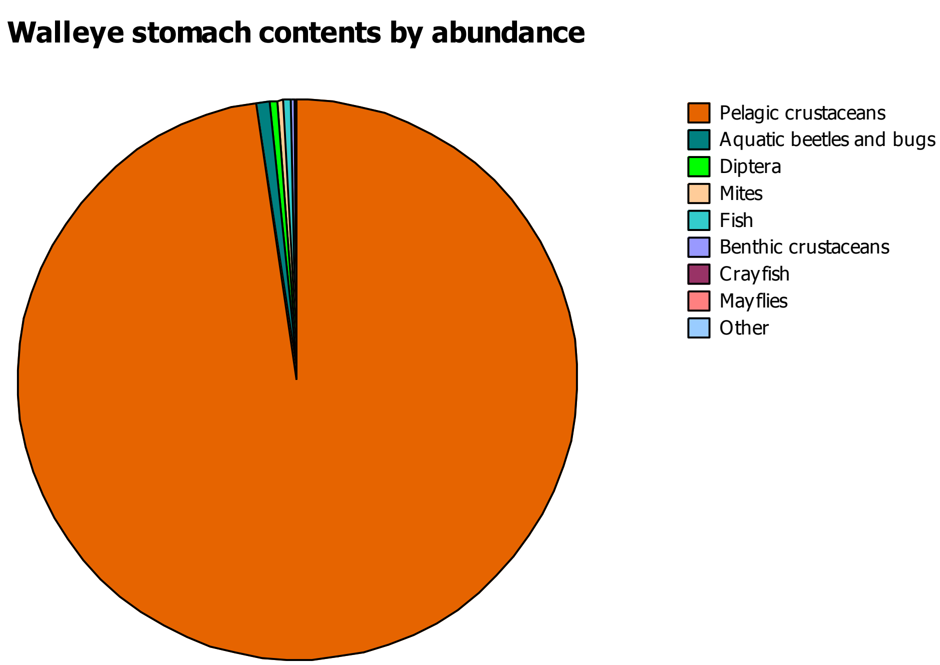


Figure 72. Abundances of food items in walleye stomachs (N = 28 stomachs examined).

Northern pike minnow (NPM) diets were more similar to RBT than to walleye (Figures 69, 72 and 73) but only 15 NPM stomachs were examined and only in August 2011. Most of the food items found in RBT and walleye diets were also found in NPM but at different percentages. It appears that all three species RBT, walleye, and NPM diets overlap to some extent which can have strong management implications. Of course, all three taxa can also be prey items for each other at smaller size classes, although Baldwin and Polecek (2002) did not find any RBT in NPM diets in Lake Roosevelt in 1998 and 1999.

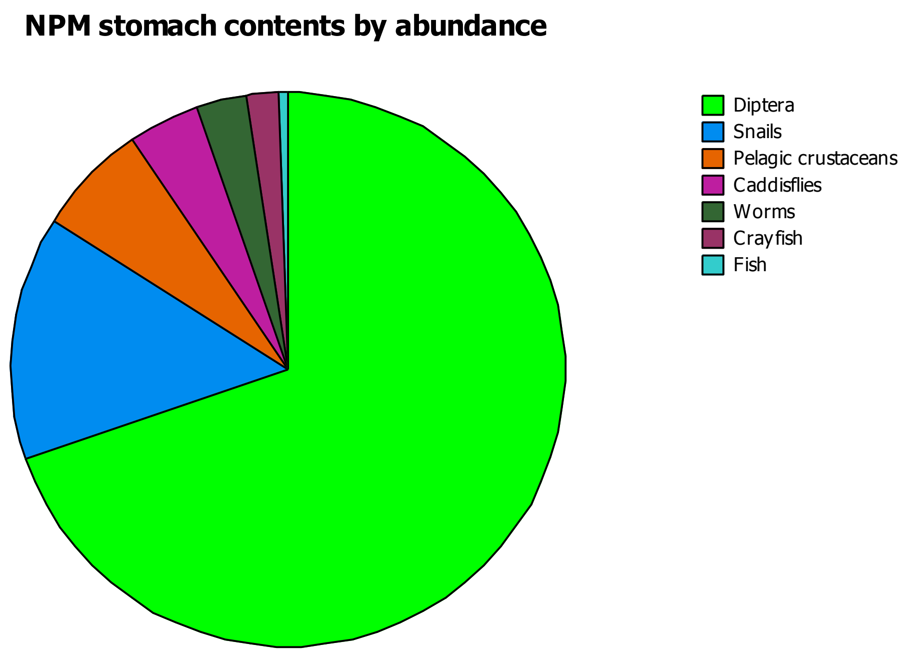


Figure 73. Abundances of organisms in northern pike minnow stomachs (N = 15 stomachs examined).

Competition between crayfish and RBT for snails

We discussed at length the potentially large negative impacts that the newly arrived invasive crayfish, *Orconectes* sp. (Family Cambaridae) may have on the RWL food web and ecosystem functioning, including their fondness for mollusks (see Suction Dredge Studies). We suggest that there is already direct competition between crayfish and RBT for mollusk prey items in RWL and that if invasive crayfish increase in abundance, so too will competition.

EASy Rainbow Trout Growth Estimation

We have developed a bioenergetics model of rainbow trout, *Oncorhynchus mykiss,* in order to address the question of the likely fate of trout raised in local fish farms and then released into Rufus Woods Lake. Specifically, the model should help answer questions:

1) What are the metabolic needs of the released fish of different ages or sizes?

2) Can these metabolic needs be met by food supplies in the Lake over the annual cycle? Will the fish grow, and if so at what rate? Or will the fish only be able to meet basal metabolism needs?

3) Is there an optimal age or size for released fish, and if so what is it?

While our model provides answers to the first question, we do not have sufficient information to answer questions 2 and 3. Question 2 not only requires information from the bio-energetic model but also information of food availability, food preferences by the fish, prey digestability of individual food items, prey energy densities, and optimal foraging equations, which have been difficult to obtain. However, we have made preliminary estimates of prey energy densities and generalizations of the other unknowns in RWL (see Suction dredge and Stomach Analysis sections). Question 3 requires a complete description of the physiological ecology of the fish; this includes not only information on metabolic and growth rates, but also food availability, and estimates of losses due to predation.

Our model of RBT metabolism is based upon the metabolic routine found in AquaModel, software that simulates the operations and environmental impact of fish farms. This metabolic growth routine is outlined below and a more detailed mathematical description found in Appendix 12. This routine has been successfully applied to the growth and metabolic rates of Atlantic salmon (*Salmo salar*), Cobia (*Rachycentron canadum*), Striped Bass (*Morone saxatilis*), and Moi (*Polydactylus sexfilis*). In order to obtain the coefficients required to model the metabolism of *Oncorhynchus* mykiss, we tuned the model to measurements of growth rates of fish in the fish farms of RWL, incorporated information on fish morphometric and growth into the Van Bertlanaffi equation, and assumed values for swimming and basal respiration in *Oncorhynchus* were similar to those for *Salmo*.

The general features of our model are illustrated in the graphs below. Figure 74 shows the fit between the average measured weights of fish that were introduced into the RWL trout farm and the weights predicted by the tuned model. The fish were introduced to RWL on julian day 152 (early June), and measurements concluded 482 days later. The model predictions are good with the exception that the growth rate of the fish during the fall appears to be too high**.**

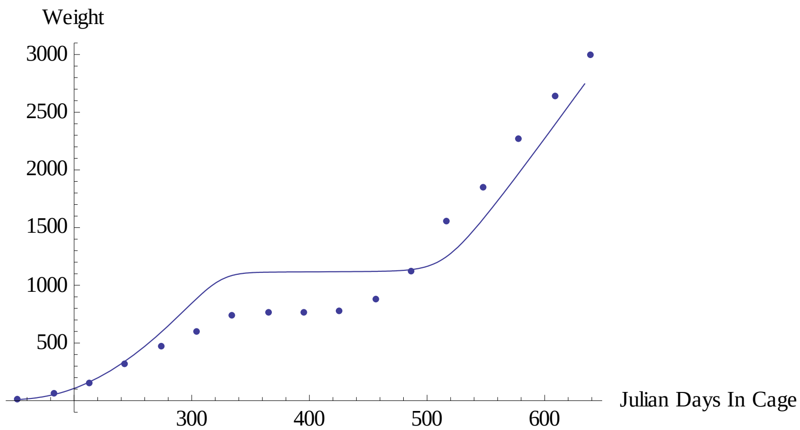


Figure 74. Average weight of fish in RWL farm. Dots are measured weights and line is the weights predicted by the model.

At this point, the changes in fish weight predicted by the model are causes solely by water temperature. Feeding rate, current velocity, and oxygen concentrations are all assumed to be sufficient for maximal growth rates. The annual water temperatures range between 3 to 19 degrees centigrade.

It is possible to vary the food ration within this model e is to apply such a model as shown below.

Figure 75 shows the maximum specific growth rates of *Oncorhynchus* as a function of fish weight. The units of specific growth rate are 1/day- in other words the daily fractional change in body mass (e.g. daily increase in body mass divided by body mass). We note that the maximum daily specific growth rate a fish weighing 10 grams is greater than 8% while an older fish weighing 3 Kg is less than 0.5%.

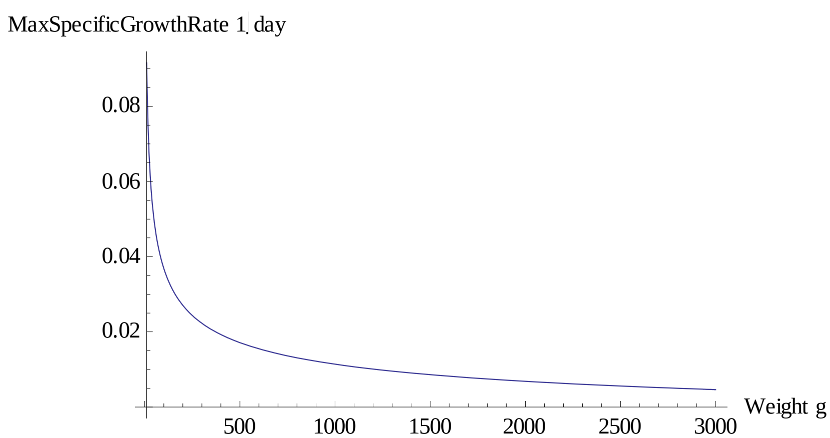


Figure 75. The daily maximum specific growth rate of fish of a given weight predicted by the model.

Figure 76 shows the dependence of specific growth upon water temperature. Specifically, the figure shows the predicted growth rate of 500 gram fish that is growing in water temperatures between 0 and 20 degrees centigrade. Feed rate, oxygen, and current speed are assumed to be optimal. We note that under such conditions the maximum growth rate of *Oncorhynchus* is 0.17/day at a temperature of 17 degrees centigrade. We also note that growth stops below 3 degrees.

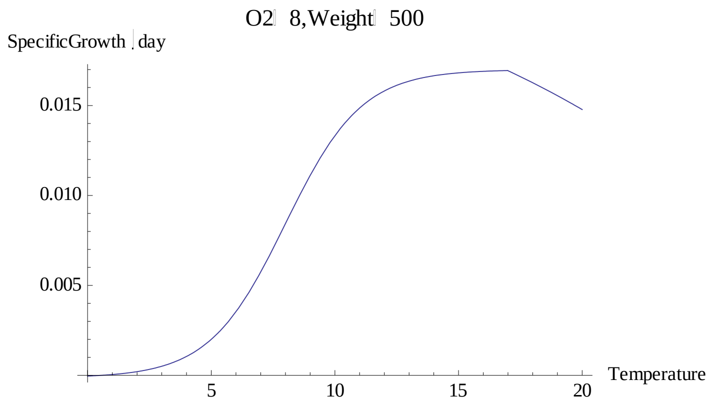


Figure 76. Predicted growth rate *Oncorhynchus* as a function of temperature.

The plots in Figure 77 show the seasonal minimum daily carbon demand of a fish that weigh 500 g and 1500 g respectively. Here we define minimum daily carbon demand is the grams of carbon in food that meets the catabolic needs of an individual fish under ambient conditions defined by water temperature, current speed, and oxygen concentration. If the supply of food carbon falls below the minimum demand the fish will lose weight, and if the supply of food carbon exceeds the minimum demand the fish will gain weight. The upper limit of a daily gain in weight is determined by the maximum specific growth rate as shown in figure 76. In these two figures the minimum carbon demand is plotted for one year after the fish is released on Julian day 152 (i.e. during the first week of June). The minimum daily carbon demand can converted into the minimum daily caloric demand (kcalories/day) by multiplying the carbon demand by 10. This calculation is key to addressing questions 1 through 3 above.

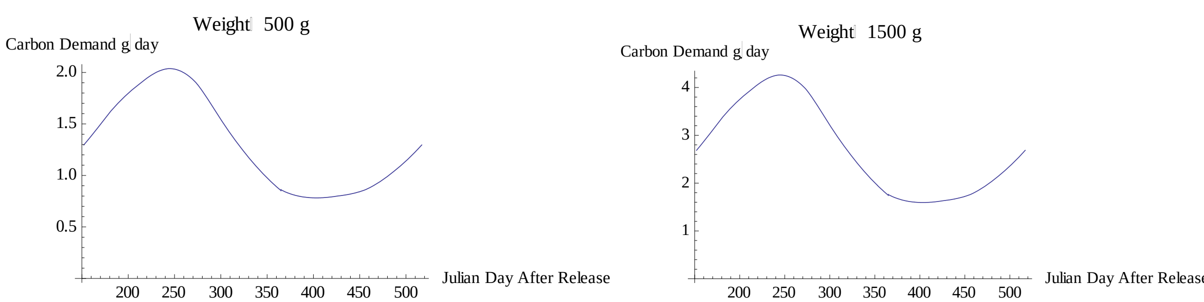


Figure 77. The daily minimum carbon food demand of a fish released in early June at a weight of 500 grams (left) and 1500 grams (right). The plots show the needed assimilation of carbon food each day (grams carbon/day) to keep the fish alive for 1 year after its release from a farm.

Outline of Model Structure

The model used in these calculations is based upon an extensive review of the literature describing the growth and metabolism of commercial species (e.g. see Brett's work on sockeye salmon in references). This information has been supplemented by our own unpublished laboratory experiments and has been incorporated into a series of equations that track the transformations of oxygen, carbon, and nitrogen. (See Rensel, Kiefer, and O'Brien 2006; Rensel et al., 2007; O'Brien, Rensel and Kiefer 2011 for more background.) The routine includes a simple formulation of oxygen-limited metabolism- an important feature since fish are raised at high densities, and in some cases fish farms are found in ambient waters of moderate or low dissolved oxygen concentration.

As indicated in Figure 78, the routine includes the processes of ingestion, egestion, assimilation, respiration, excretion, and growth. Carbon, nitrogen, and oxygen fluxes are all computed, and of course the rates of these fluxes vary with operational and environmental conditions. The operational independent variables are listed above while the environmental variables that determine metabolism are:

- Water temperature
- Ambient oxygen concentration which is one of the determinants of the concentration of oxygen with a cage
- Ambient current velocity, which is another determinant of oxygen concentration within the cage as well as a determinant of the respiration rate required of the fish to swim at a speed in order maintain their position within the cage.

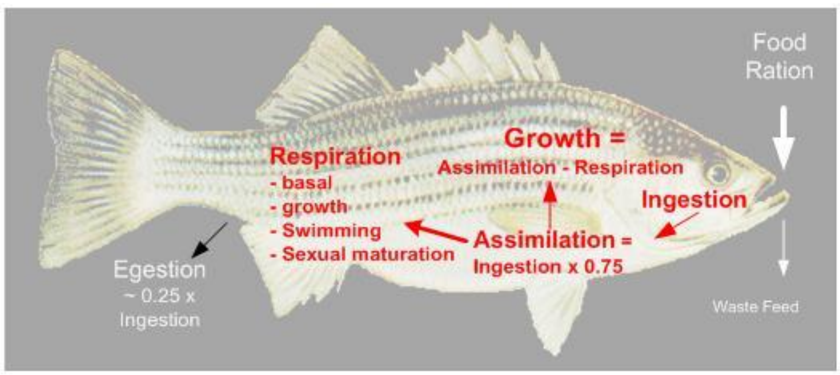


Figure 78. Metabolic processes described by our metabolic routine for fish metabolism. (*Background drawing by Duane Raver, USFWS*).

The rainbow trout routine consists of a series of functions describing the fluxes of carbon, nitrogen, and oxygen as determined by the basic features of metabolism, ingestion, egestion, assimilation, respiration, and growth. Specifically, each element is tracked according to these 5 basic features, which are related to each other by conservation of mass:

1. ingestion rate = egestion rate + assimilation rate
2. rate of growth = assimilation rate - rate of respiration
3. respiration rate = resting rate of respiration (i.e. basal) + respiration rate of activity (i.e. swimming) + respiration rate of anabolic activity (i.e. growth)
4. rate of feces production = egestion rate
5. rate of loss of uneaten feed = feed rate – ingestion rate

The functions for the 5 basic metabolic processes can be summarized as follows. Ingestion rate is determined by both the rate of supply of food and rate at which the fish can assimilate ingested food (Equation 1). If the rate of supply of food exceeds the sum of the rate of egestion and the rate of assimilation, then a fraction of the food will be uneaten and contribute to the particulate waste produced by the cage (Equation 5). As indicated in Figure 78, egestion is assumed to be a fixed fraction of ingestion; the value of this fraction is determined largely by the nutrient composition of the feed. The rate of egestion is in fact the rate of feces production (Equation 4). The assimilation rate of the fish will be a function of the size (age) of the fish, the temperature of the water, and the concentration of oxygen within the cage. The assimilated nutrients are then either consumed by respiration or contribute to the growth of the fish (Equation 2). (We assume that there are no reproductive demands within the cage.) The rates of respiration, which include both the consumption of oxygen and excretion of nitrogen, are determined by three processes, basal metabolism, swimming metabolism, and anabolic metabolism demanded by growth (Equation 3). Basal metabolism is a function of water temperature and the size of the fish, swimming metabolism is a function of the fish size and its swimming speed, and anabolic metabolism is proportional to growth rate. The growth rate of the fish is simply calculated by subtracting the rate of respiration from the rate of assimilation. The key equations of the routine are described in detail in Appendix 12.

Information on rainbow trout, *Onchorynchus mykiss*, metabolism that we used to determine the values for coefficients found in the system of equations came from a number of sources including publications of growth and metabolism in the laboratory and field and FishBase, which distributes data over the Internet on morphometrics, respiration rates, and growth rate. Data from these sources were used to tune the equations of the metabolism by searching for coefficient values that provided the best fit to the data.

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Appendices

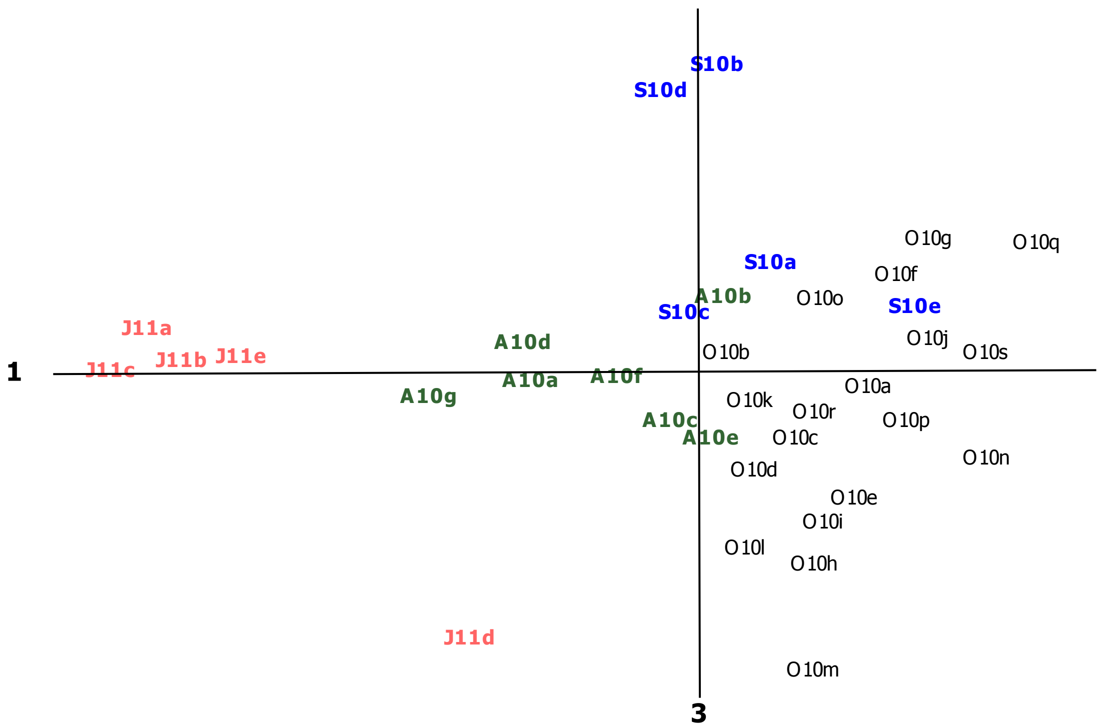
Appendix 1. NMS ordination values for the three site axes used in our periphyton study.

Site	Axis 1	Axis 2	Axis 3
A10a	-0.55428	0.60631	-0.01319
A10c	-0.11019	0.76527	-0.1465
A10e	0.02784	1.00701	-0.20653
A10f	-0.27681	0.38425	-0.00131
A10g	-0.88266	0.10467	-0.06711
S10a	0.21634	0.18114	0.39225
S10b	0.02517	0.25793	1.02722
S10c	-0.06287	1.06089	0.22082
S10d	-0.12198	0.16486	1.01912
A10b	0.06109	-0.23281	0.27189
A10d	-0.57989	-0.03393	0.11413
S10e	0.68559	-0.19494	0.17643
O10a	0.53208	0.3974	-0.02974
O10b	0.07744	0.33986	0.08257
O10c	0.26724	0.19488	-0.18374
O10d	0.16733	0.07803	-0.31665
O10e	0.45627	0.35679	-0.45563
O10f	0.60698	0.40352	0.25012
O10g	0.73055	0.55988	0.46737
O10h	0.34234	0.01691	-0.55269
O10i	0.38905	0.08973	-0.49678
O10j	0.72312	-0.01684	0.12864
O10k	0.15154	-0.06141	-0.07815
O10l	0.13475	0.08803	-0.58433
O10m	0.34605	-0.40553	-0.94648
O10n	0.91454	-0.78907	-0.27979
O10o	0.37899	-0.56671	0.26675
O10p	0.64593	-0.23626	-0.06597
O10q	1.07628	-1.37822	0.45536
O10r	0.36387	-0.36963	-0.11945
Oa0s	0.92546	-0.85152	0.17565
J11a	-1.81925	-0.52098	0.23229
J11b	-1.67942	-0.44736	0.05797
J11c	-1.91401	-0.48225	0.02343
J11d	-0.75402	-0.10532	-0.88762
J11e	-1.49047	-0.36459	0.06962

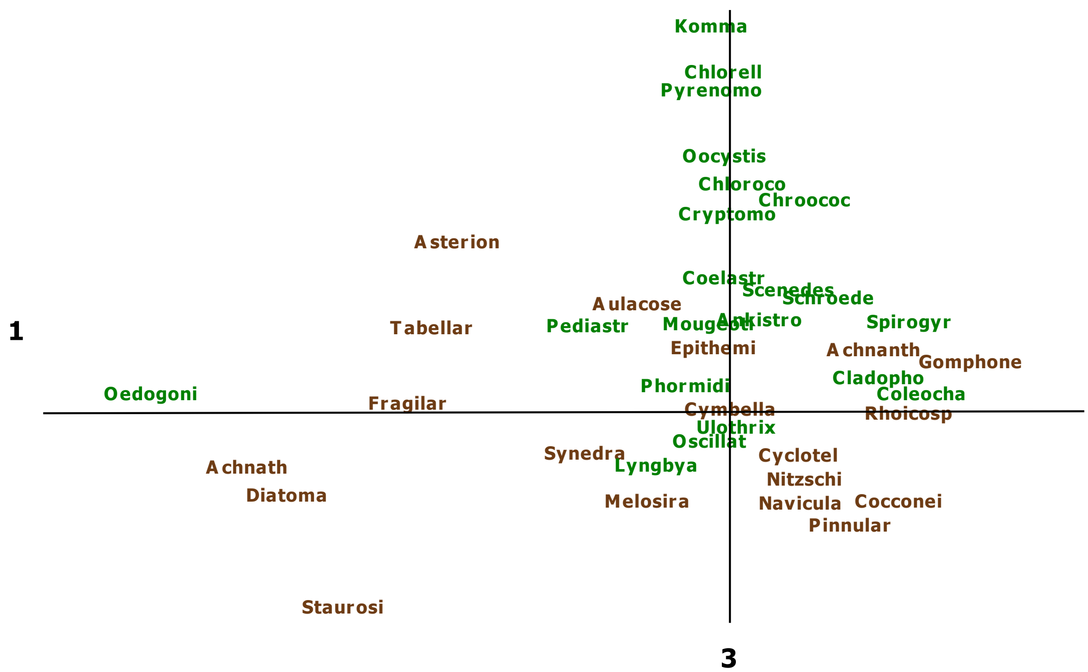
Appendix 2. NMS ordination values for the three taxa axes used in the periphyton study.

Achnanth	0.43799	0.01038	0.1573
Achnath	-1.42739	-0.33599	-0.13355
Ankistro	0.0968	-0.17972	0.23271
Asterion	-0.8013	0.15049	0.42
Aulacose	-0.26436	0.29983	0.26823
Chlorell	-0.01269	0.23505	0.80895
Chloroco	0.05021	0.45303	0.56621
Chroococ	0.23117	-0.03913	0.52273
Cladopho	0.47841	-0.11188	0.06937
Cocconei	0.47089	-0.23102	-0.25668
Coelastr	-0.00457	0.35072	0.33329
Coleocha	0.57922	-0.54017	0.04743
Cryptomo	-0.0179	0.16042	0.5694
Cyclotel	0.23976	0.09397	-0.1861
Cymbella	0.01403	0.4321	0.01133
Diatoma	-1.30735	-0.2876	-0.20027
Epithemi	-0.04044	0.34186	0.161
Fragilar	-0.94762	-0.15871	0.02491
Gomphone	0.67465	-0.62922	0.10296
Komma	-0.04502	0.16355	0.94962
Lyngbya	-0.20834	0.71552	-0.1299
Melosira	-0.23337	0.05857	-0.21521
Mougeoti	-0.05293	0.32506	0.22023
Navicula	0.22713	0.2905	-0.1465
Nitzschi	0.23162	0.09435	-0.15971
Oedogoni	-1.71547	-0.44597	0.05066
Oocystis	-0.00325	0.4972	0.63424
Oscillat	-0.0532	0.42117	-0.06663
Pediastr	-0.35475	0.03797	0.28731
Phormidi	-0.12459	0.39546	0.06905
Pinnular	0.3707	0.06509	-0.27433
Pyrenomo	-0.04748	0.27729	0.79379
Rhoicosp	0.54121	-0.31452	-0.00221
Scenedes	0.18391	-0.28758	0.3049
Schroede	0.30497	0.25655	0.28455
Spirogyr	0.51727	0.34409	0.20266
Staurosi	-1.14082	-0.25189	-0.47561
Synedra	-0.41849	0.13307	-0.09608
Tabellar	-0.87599	-0.23831	0.2098
Ulothrix	0.03164	0.38007	-0.03695

Appendix 3. Axis 1 and Axis 3 of NMS ordination of periphyton assemblages using all samples collected RWL, sampled in August, September, October 2010 and July 2011. Samples labels have two code values: A10 = August 2010, S10 = September 2010, O10 = October 2010, and J11 = July 2011; lower case letters following the month label are sample and site locations. See Table 1 for descriptions of samples.



Appendix 4. Axis 1 and Axis 3 of NMS ordination of periphyton assemblages using all data. Diatoms are in brown, soft bodied algae are in green.



Appendix 5. GLM ANOVA examining effect of site location on chlorophyll *a* (mg/m^2) at 3 m depth

	DF	Seq SS	Adj SS	Adj MS	F	P
3 m	6	2515.71	2515.71	419.29	5.36	0.02
Error	7	547.69	547.69	78.24		
Total	13	3063.40				

Appendix 6. GLM ANOVA examining affects of site location and depth on chlorophyll *a* with sites D and E removed.

	DF	Seq SS	Adj SS	Adj MS	F	P
Site	4	0.61	0.74	0.19	2.58	0.07
Depth	2	1.29	1.29	0.65	8.95	0.002
Error	19	1.37	1.37	0.07		
Total	25	3.28				

Appendix 7. NMS ordination values for the three axes by site in suction dredge study.

	1	2	3
OctA1	-0.17897	0.10125	-0.63758
OctA2	0.42041	0.93955	-0.43737
OctA3	-0.93246	-0.26897	-0.36097
OctA4	-0.9802	0.35965	0.1576
OctA5	-1.8458	1.14101	-0.84168
OctA6	-0.96115	-0.85715	-0.60468
OctA7	-1.87211	-0.52899	-0.40611
OctA8	-0.53578	1.14043	-0.24995
OctB1	0.33551	-0.75815	-0.06314
OctB2	-0.07721	-0.20351	-0.27821
OctB3	0.19975	0.42617	0.0371
OctB4	0.35326	-1.41746	0.06612
OctC1	0.42763	0.18453	-0.22438
OctC2	0.48738	0.04277	-0.28326
OctC3	0.91073	0.44457	0.19864
OctC4	0.21748	-0.06965	-0.48328
AprA1	-0.01456	0.50116	0.47844
AprA2	-0.2902	0.2122	0.58087
AprA3	-0.2225	0.41544	0.54551
AprA4	-0.17047	0.0971	0.2713
AprA5	-0.15447	0.57975	0.39853
JulA1	-0.89716	-0.38203	0.69194
JulA2	-0.11469	-0.2935	0.8851
JulA3	-0.3295	-0.4925	0.71459
JulA4	0.19697	0.59596	0.51634
JulA5	-1.70264	-0.96877	0.188
JulB1	-0.07405	-0.03293	0.29033
JulB2	0.15175	0.24368	0.14447

JulB3	0.31885	0.38477	0.14507
JulB4	0.28447	0.44046	0.30281
JulB5	0.22788	0.08035	0.10878
JulD1	0.82705	-0.38471	-0.36581
JulD2	0.81129	-0.25442	-0.52043
JulD3	0.66944	-0.29746	-0.16585
JulD4	0.74744	-0.57129	0.18185
JulD5	0.89508	-0.26591	-0.78628
JulE1	0.82669	0.02232	-0.20188
JulE2	0.79724	-0.09418	-0.05738
JulE3	0.88374	-0.05567	0.00348
JulE4	0.3639	-0.15586	0.06133

Appendix 8. NMS ordination values for all three axes by taxon in suction dredge study.

Ephemeroptera	0.30826	0.01047	-0.35239
Odonata	0.73385	-0.39043	-0.24178
Hemiptera	0.11844	-1.16261	0.03956
Coleoptera	0.47357	-0.93629	0.0618
Diptera	0.10452	0.02777	0.01591
Trichoptera	0.29689	-0.25251	-0.11352
Gastropoda	0.43897	-0.07396	-0.15114
Bivalvia	0.25905	0.12651	-0.08068
Annelida	0.1065	0.08404	0.03791
Acari	0.27463	0.15329	0.18539
small crayfish	0.21596	-0.07813	0.00169
Crayfish	-0.39924	-0.48642	0.28042
Other	0.24827	0.01618	0.16

Appendix 9. Total abundances of organisms found in RBT stomachs (N = 326 RBT stomachs examined)

Ephemeroptera	Baetis tricaudatus	3
	Caenidae	1
	Ephemeroptera	275
Odonata	Coenagrionidae	21
	Libellulidae	0
	Libellulidae/Corduliidae	1
	Odonata	13
Plecoptera	Plecoptera	20
Hemiptera	Aphididae	13
	Cicadellidae	2
	Coreidae	0
	Corixidae	100
	Hemiptera	471
	Notonectidae	0
	Reduviidae	2
Coleoptera	Anthicidae	3

	Carabidae	2
	Chrysomelidae	1
	Coleoptera	81
	Curculionidae	1
	Dytiscidae	2
	Gyrinidae	2
	Haliplidae	5
	Scarabaeidae	2
	Staphylinidae	3
	Tenebrionidae	127
Diptera-Chironomidae	Chironomidae	1522
Diptera	Acalyptratae	0
	Ceratopogonidae	1
	Chloropidae	0
	Diptera	8288
	Tipula sp.	2
Trichoptera	Hydroptilidae	2
	Lepidostomatidae	1
	Leptoceridae	3
	Limnephilidae	3
	Phryganeidae	40
	Trichoptera	155
Lepidoptera	Lepidoptera	216
	Megaloptera	1
	Sialidae	0
Other Insecta	Apidae	66
	Apoidea	4
	Archaeognatha	1
	Arthropoda	1
	Chrysididae	1

Appendix 10. Total abundances of organisms found in walleye stomachs (N = 28 stomachs examined)

Ephemeroptera	Baetis tricaudatus	0
	Caenidae	3
	Ephemeroptera	0
Odonata	Coenagrionidae	1
	Libellulidae	3
	Libellulidae/Corduliidae	0
	Odonata	0
Plecoptera	Plecoptera	0
Hemiptera	Aphididae	0
	Cicadellidae	0
	Coreidae	1
	Corixidae	9
	Hemiptera	0
	Notonectidae	4

	Reduviidae	0
Coleoptera	Anthicidae	0
	Carabidae	0
	Chrysomelidae	0
	Coleoptera	0
	Curculionidae	0
	Dytiscidae	0
	Gyrinidae	0
	Haliplidae	13
	Scarabaeidae	0
	Staphylinidae	0
	Tenebrionidae	0
Diptera-Chironomidae	Chironomidae	19
Diptera	Acalyptratae	0
	Ceratopogonidae	0
	Chloropidae	0
	Diptera	5
	Tipula sp.	0
Trichoptera	Hydroptilidae	0
	Lepidostomatidae	0
	Leptoceridae	0
	Limnephilidae	0
	Phryganeidae	0
	Trichoptera	0
Lepidoptera	Lepidoptera	0
	Megaloptera	0
	Sialidae	12
Other Insecta	Apidae	0
	Apoidea	0
	Archaeognatha	0
	Arthropoda	0
	Chrysididae	0
	Dermaptera	0
	Formicidae	0
	Hymenoptera	0
	Ichneumonidae	0
	Insecta	0
	Isoptera	0
	Neoptera	0
	Orthoptera	0
	Raphidiidae	0
	Raphidioptera	0
Gastropoda	Gastropoda	0
	Gyraulus sp.	0
	Lymnaeidae	0
	Physa sp.	0
	Physidae	1

	Planorbidae	0
	Valvatidae	0
Bivalvia	Bivalvia	0
	Sphaeriidae	0
	Veneroida	0
Annelida	Glossiphoniidae	0
	Oligochaeta	0
	Rhynchobdellida	0
Acari	Acari	0
	Arrenuridae	8
	Hydrachnidae	0
	Hydrodromidae	1
	Lebertiidae	0
	Limnesiidae	2
	Pionidae	10
	Unionicolidae	0
Crustacea	Amphipoda	1
	Asellidae	4
	Astacidae	0
	Astacidea	0
	Astacoidea	0
	Caecidotea sp.	0
	Calanoida	0
	Cambaridae	6
	Cladocera	0
	Copepoda	0
	Crangonyctidae	0
	Cyclopidae	3
	Daphniidae	5,294
	Decapoda	0
	Diplostraca	0
	Gammaridae	0
	Hyalella sp.	1
	Isopoda	7
	Leptodoridae	0
	Ostracoda	0
Other Organisms	Arachnida	0
	Araneae	0
	Diplopoda	0
	Nematoda	0
	Salticidae	0
	Turbellaria	0
Ichthyoplankton	Acanthopterygii	4
	Actinopterygii	13
	Cypriniformes	1
	Gasterosteidae	1
	Gasterosteiformes	1
Total		5,428

Appendix 11. Total abundances of organisms found in northern pike minnow stomachs (N = 15 stomachs examined)

Ephemeroptera	Baetis tricaudatus	0
	Caenidae	0
	Ephemeroptera	0
Odonata	Coenagrionidae	0
	Libellulidae	0
	Libellulidae/Corduliidae	0
	Odonata	0
Plecoptera	Plecoptera	0
Hemiptera	Aphididae	0
	Cicadellidae	0
	Coreidae	0
	Corixidae	0
	Hemiptera	0
	Notonectidae	0
	Reduviidae	0
Coleoptera	Anthicidae	0
	Carabidae	0
	Chrysomelidae	0
	Coleoptera	0
	Curculionidae	0
	Dytiscidae	0
	Gyrinidae	0
	Haliplidae	0
	Scarabaeidae	0
	Staphylinidae	0
	Tenebrionidae	0
Diptera-Chironomidae	Chironomidae	0
Diptera	Acalyptratae	0
	Ceratopogonidae	0
	Chloropidae	0
	Diptera	118
	Tipula sp.	0
Trichoptera	Hydroptilidae	0
	Lepidostomatidae	0
	Leptoceridae	0
	Limnephilidae	0
	Phryganeidae	0
	Trichoptera	7
Lepidoptera	Lepidoptera	0
	Megaloptera	0
	Sialidae	0
Other Insecta	Apidae	0
	Apoidea	0

	Archaeognatha	0
	Arthropoda	0
	Chrysididae	0
	Dermaptera	0
	Formicidae	0
	Hymenoptera	0
	Ichneumonidae	0
	Insecta	0
	Isoptera	0
	Neoptera	0
	Orthoptera	0
	Raphidiidae	0
	Raphidioptera	0
Gastropoda	Gastropoda	24
	Gyraulus sp.	0
	Lymnaeidae	0
	Physa sp.	0
	Physidae	0
	Planorbidae	0
	Valvatidae	0
Bivalvia	Bivalvia	6
	Sphaeriidae	0
	Veneroida	0
Annelida	Glossiphoniidae	0
	Oligochaeta	5
	Rhynchobdellida	0
Acari	Acari	0
	Arrenuridae	0
	Hydrachnidae	0
	Hydrodromidae	0
	Lebertiidae	0
	Limnesiidae	0
	Pionidae	0
	Unionicolidae	0
Crustacea	Amphipoda	0
	Asellidae	0
	Astacidae	0
	Astacidea	0
	Astacoidea	0
	Caecidotea sp.	0
	Calanoida	0
	Cambaridae	0
	Cladocera	0
	Copepoda	0
	Crangonyctidae	0
	Cyclopidae	0
	Daphniidae	0
	Decapoda	3

	Diplostraca	11
	Gammaridae	0
	Hyalella sp.	0
	Isopoda	0
	Leptodoridae	0
	Ostracoda	0
Other Organisms	Arachnida	0
	Araneae	0
	Diplopoda	0
	Nematoda	0
	Salticidae	0
	Turbellaria	0
Ichthyoplankton	Acanthopterygii	0
	Actinopterygii	1
	Cypriniformes	0
	Gasterosteidae	0
	Gasterosteiformes	0
	TOTAL	175

Appendix 12. Key governing equations in the EASy rainbow trout growth model.

SPECIFIC GROWTH RATE FUNCTIONS

1. SpecificGrowth =
 Min[WeightLimSpecificGrowth[Weight], EnvironmentalSpecificGrowth[Temperature, Oxygen, CurrentSpeed, FeedRate, Weight]]

2. EnvironmentalSpecificGrowth =

$$\frac{1}{1+\text{SpecificAnabolicResp}}\left(\text{SpecificAssim[Temperature, Oxygen, FeedRate, Weight]} - \text{SpecificCatabolicResp[Temperature, CurrentSpeed, Weight]}\right)$$

3. WeightTempLimSpecificGrowth =

$$\frac{\text{WeightLimSpecificGrowth[Weight]}}{1+\text{Exp[SlopeTempLim} * (\text{KTempLim} - \text{Temperature})]}$$

4. WeightAge =

$$\frac{\text{Log}\left[-\frac{\text{Lmax}-\text{Lmin}}{-\text{Lmax}+\left(\frac{\text{Weight}}{\text{LengthWeightScalar}}\right)^{\frac{1}{\text{LengthWeightExpo}}}}\right]}{k}$$

5. WeightLimSpecificGrowth =

$$\frac{e^{-\text{WeightAge[Weight]}\,k}\,k\ \text{LengthWeightExpo LengthWeightScalar}\left(\text{Lmax}-e^{-\text{WeightAge[Weight]}\,k}(\text{Lmax}-\text{Lmin})\right)^{-1+\text{LengthWeightExpo}}(\text{Lmax}-\text{Lmin})}{\text{Weight}}$$

SPECIFIC ASSIMILATION RATE FUNCTIONS

6. SpecificAssim = Min[FeedLimSpecificAssim[FeedRate], OxygenLimSpecificAssim[Oxygen, Weight], TempLimSpecificAssim[Temperature, Weight]]

7. FeedLimSpecificAssim = FeedRate * AssimilationEfficiency

8. TempLimSpecificAssim = If[Temperature > OptimalTemperature, MaximumSpecificDemand[OptimalTemperature, Weight],
 MaximumSpecificDemand[Temperature, Weight]]

9. OxygenLimSpecificAssim =

$$\left(\frac{1}{1+\text{Exp[SlopeOxygenLim} * (\text{KOxygenLim} - \text{Oxygen})]}\right) * \text{MaximumSpecificDemand[OptimalTemperature, Weight]}$$

10. MaximumSpecificDemand = SpecificCatabolicResp[Temperature, VBodyLimitToMaxGrowth, Weight] +
 SpecificAnabolicDemand[WeightTempLimSpecificGrowth[Temperature, Weight]]

SPECIFIC RESPIRATION FUNCTIONS

11. SpecificCatabolicResp = SpecificSwimResp[VBody[SwimSpeed[CurrentSpeed], Weight]] + SpecificBasalResp[Temperature, Weight]

12. SpecificSwimResp = HrToDay * CarbonToOxygen * SwimResp[VBody] / (CarbonToWet * KgToGram * GramToMGram)

13. SwimResp = SwimScalar * $\text{VBody}^{\text{SwimExpo}}$

14. VBody = SwimSpeed / Length[Weight]

15. SwimSpeed = CageFlowFraction * CurrentSpeed

16. Length =

$$\left(\frac{\text{Weight}}{\text{LengthWeightScalar}}\right)^{\frac{1}{\text{LengthWeightExpo}}}$$

17. SpecificBasalResp = BasalScalar * Exp[BasalTempExpo * (Temperature - BasalTempNominal)] * $\text{Weight}^{\text{BasalWeightExpo}}$

18. SpecificAnabolicResp = SpecificAnabolicResp * SpecificGrowth

SPECIFIC DEMAND FUNCTIONS

19. CurrentSpeedAtVBodyLimitToMaxGrowth =

$$\frac{\text{VBodyLimitToMaxGrowth}\left(\frac{\text{Weight}}{\text{LengthWeightScalar}}\right)^{\frac{1}{\text{LengthWeightExpo}}}}{\text{CageFlowFraction}}$$

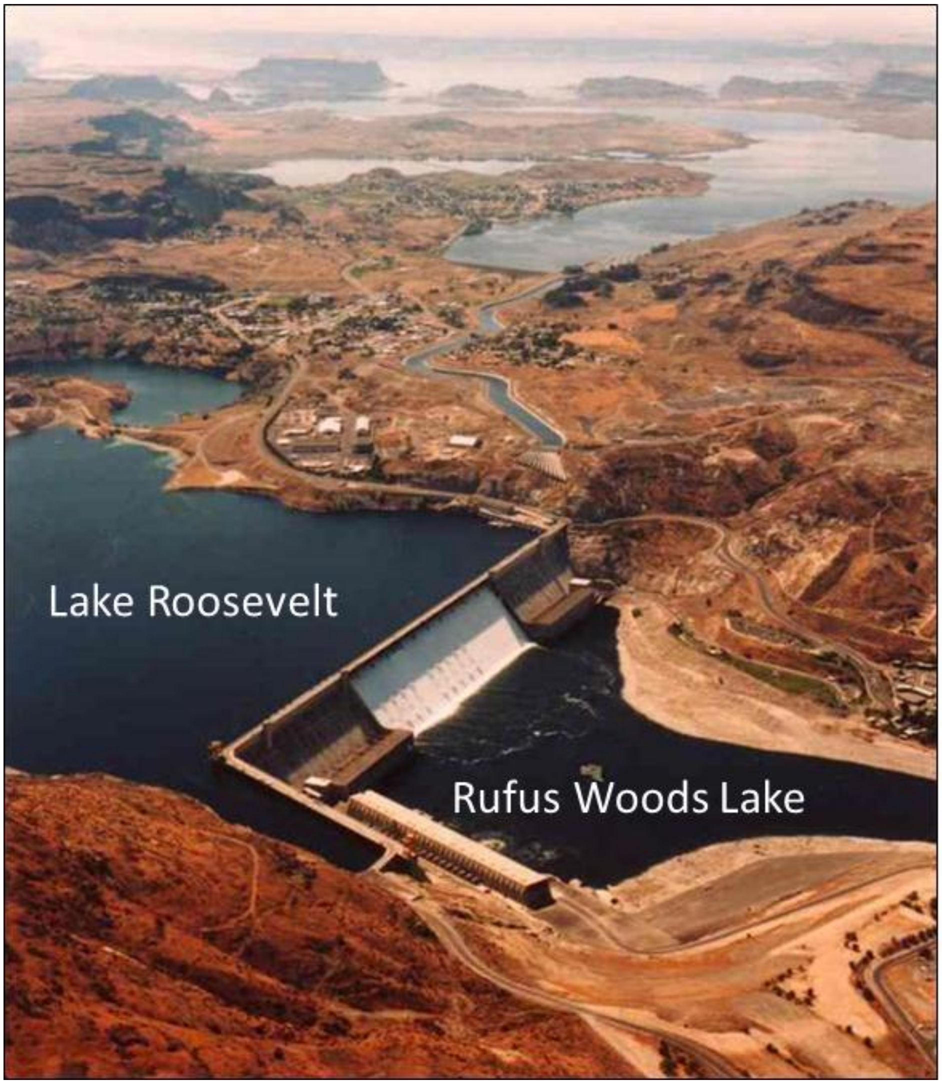
20. SpecificAnabolicDemand = SpecificGrowth * (1 + SpecificAnabolicResp)

21. SpecificDemand = SpecificCatabolicResp + SpecificAnabolicDemand

Photo Appendix

Female RBT apparently killed by gas bubble disease (note bubbles in operculum) collected near China Bar area on June 2011. This fish was full of ripe eggs.

Large invasive European carp hand netted in tributary (River mile 576, river left). There were perhaps hundreds of carp of this size spawning at the time of capture. These fish would be relatively easy to net and remove from the system.



Lake Roosevelt and Rufus Woods Lake looking south with Grand Coulee Dam spilling water over the top.

Winter rainbow trout catch from Rufus Woods Lake.

Pacific Aquaculture Inc. Site 1 cages and shore side support facility. Photo courtesy of John Bielka.

Cobble-gravel habitat near Buckley Bar in Rufus Woods Lake.

Approximately ½ mile downstream of Site 1 August 2009, macrophytes mostly without periphyton growth except note small areas of fuzzy green growth in center and center right of photo that is caused by a filamentous green alga such as *Cladophora* or *Spirogyra* spp.

Filamentous green algae (the fuzzy appearing, green growth) fouling macrophytes in 2011.

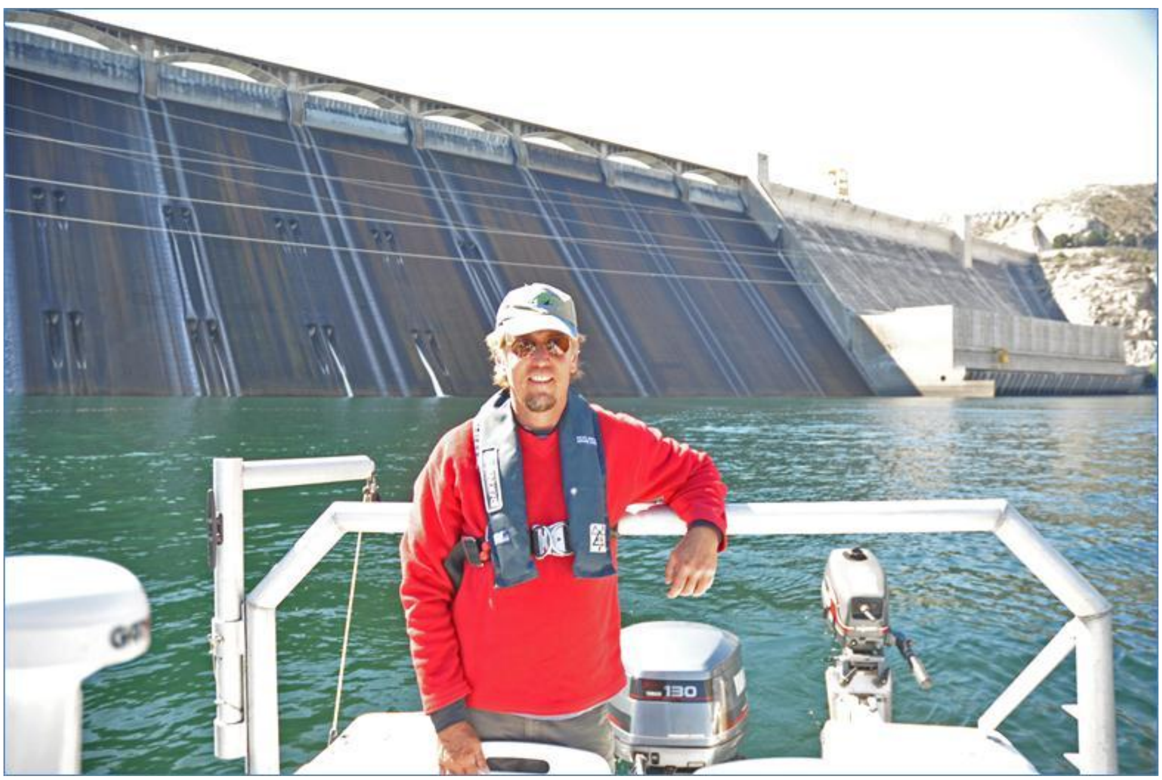
Snails and chironomid on rock from 50 ft. depth downstream of Pacific Aquaculture net pen Site 1.

Sponge growing on rock from downstream of Pacific Aquaculture Site 1. Sponge is relatively common on deepwater substrates such as cobble and boulders to a depth of 100 ft. or more in RWL.

Sculpin collected in the middle reaches of Rufus Woods Lake with a slurp gun from a previous project.

Coauthor Zach Siegrist collecting algal samples in July 2011.

Coauthor Jack Rensel near China Bar in sampling vessel in August 2011.



Coauthor David Richards during 2010 bathymetric survey in Grand Coulee Dam tailrace.