Campbell River Water Use Plan

Monitoring Program Terms of Reference

- **JHTMON-5 Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment**

September 20, 2013

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1 Program Rationale

1.1 Background

In lakes and reservoirs, fish production is assumed to be proportional to overall aquatic productivity, but there is considerable uncertainty over the extent to which fish production is driven by littoral vs. pelagic production. BC Hydro affects littoral production through drawdowns, and pelagic production through alterations of water residence time (e.g., by manipulating inflows and outflows). This Monitor is designed to assess the extent to which fish production is driven by littoral vs. pelagic production and how this relates to BC Hydro operations. The study has two main components, one concentrating on the reservoirs, and the other on the diversion lakes:

1) Effect of water levels on energy flows to fish in reservoirs.

   Evaluation of operating alternatives for the Campbell River reservoirs has concentrated on the effect of water levels, with the assumption that fish production is correlated with littoral productivity, an assumption that has not been tested. This hypothesis will be tested directly.

2) Effect of water residence time on energy flows to fish in diversion lakes.

   Given general relationships between residence time and productivity we expect there to be direct influences of diversion on biological productivity in diversion lakes, though the extent of this influence is unknown.

Though the study components are treated separately for the purposes of this document, the data collection methods are identical and the results are expected to be complementary.

1.2 Management Questions

The Consultative Committee (CC), following the recommendations of the Fish Technical Committee, identified the following two management questions:

1) To what extent do stabilized reservoir levels, as affected by BC hydro operations, benefit fish populations?

   A general assumption made during the Water Use Plan (WUP) process was that fish production in Upper and Lower Campbell Reservoirs was negatively impacted by large fluctuations in water level through its effect on littoral production (see Monitor 4). Reservoir stabilization was assumed to negate loss of littoral productivity and hence have a positive influence on fish production. Whereas Monitor 4 investigates the effect of operations on littoral primary production, this monitor tests the assumption that improvements in littoral production lead to corresponding increases in fish production.

2) What is the relationship between residence time (as affected by diversion rate) and lake productivity?

During the WUP process, the Fish Technical Committee (FTC) hypothesized that short water residence time of the diversion lakes as a result of the BC Hydro operations negatively impacts pelagic productivity. Simple chemostat modelling exercises showed that high inflows flush pelagic organisms from the system. The loss in pelagic productivity from high inflows was thought to have an impact on fish production in these lakes. However, the hypothesis could not be tested during the WUP due to time and resource constraints. The FTC therefore assumed that there was no impact for decision making purposes, but strongly recommended that the test of this hypothesis be part of a monitoring program.

1.3 Summary of Impact Hypothesis

This study will use stable isotope analysis (SIA) of fish tissues and other components of the aquatic food web to assess relative energy flows to fish from littoral vs. pelagic areas (Hecky and Hesslein 1995; Cabana and Rasmussen 1996). Figure 5.1(below) represents a conceptual framework where energy flow through the aquatic food web (i.e., trophic level) is described by ^{15}N and energy source is described by ^{13}C. Figure 5.1b represents a natural system where fish receive quantities of energy from benthos and plankton at some natural system-specific ratio. When littoral production is negatively affected (relative to pelagic production), the peak of the triangle is shifted to the left, as fish obtain relatively more energy from plankton than benthos (Figure 5.1a). When pelagic production decreases (relative to littoral production) the peak is shifted to the right (Figure 5.1c) as energy production becomes increasingly dominated by benthos. The magnitude of the peak shifts will define the effect of the treatment impact.

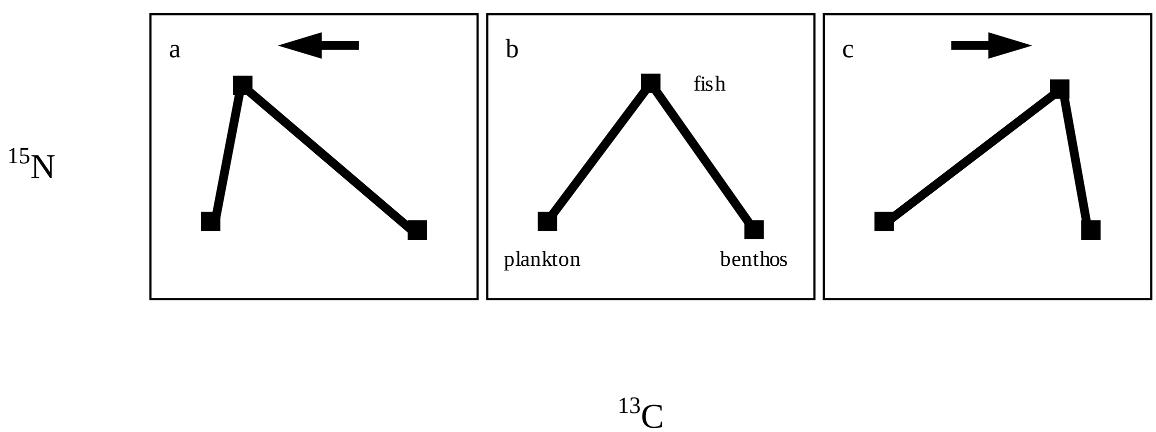

Figure 5.1 **Conceptual framework for the interpretation of stable isotope analysis (SIA) data where b) is the pre-treatment state, a) dominance of pelagic-derived energy in fish diet and c) dominance of benthos-derived energy in fish diet.**

For the two large reservoirs where changes in littoral productivity are expected, the SIA data will be used to address the following null hypothesis:

$H_0 1$: The extent of littoral development in lakes, as governed by the magnitude and frequency of water level fluctuations, is not correlated with the ratio of littoral versus pelagic energy flows to reservoir fish populations.

This hypothesis will be tested by comparing SIA data from upper and lower Campbell Reservoirs, data collected from several diversion lakes, and data from two local "control" lakes (i.e., no diversion or drawdown). Inter-annual differences in the SIA data will also be exploited to expand the data set, though such variance may only be meaningful to organisms that complete their life cycle within one year. The SIA will be carried out separately for different species and age classes of fish, as well as collectively for all species.

The null hypothesis can also be related for the diversion lakes component of the Monitor, but with reference to pelagic productivity and water residence times rather than water level fluctuations.

$H_0$2: The extent of pelagic production in lakes, as governed by the average water residence time, is not correlated with the ratio of littoral vs. pelagic energy flows to reservoir fish populations.

The hypothesis will be tested using the same data set collected for H01.

The test of $H_0$1 relies on measures of littoral productivity, based on the Effective Littoral Zone (ELZ) performance measure (Monitor 4) to quantify the treatment impact (i.e., magnitude, frequency and duration of water level fluctuations). A similar variable is also needed to quantify the impact of residence time on pelagic productivity. Based on discussions with J. Stockner, a simple but effective biological indicator would be the annual or seasonal average standing crop of pelagic bacteria. These bacteria grow rapidly enough in coastal oligotrophic reservoir environments to serve as a useful indicator of biological production. When water residence times approach bacterial production rates, standing crop drops proportionately until a riverine state prevails and pelagic productivity is lost entirely. This process, referred to here as a de-coupling of the energy cycle, has not been well investigated in BC waters, and would require confirmation that it does indeed respond as hypothesised (J. Stockner, pers. comm.). This leads to a third null hypothesis:

$H_0$3: Standing crop of pelagic bacteria is not correlated with water residence time.

Like in H01 and H02, the hypothesis will be tested by comparing the standing crop data of upper and lower Campbell Lake reservoirs, the diversion lakes, and two local control lakes. Differences among years and seasons in the standing crop data will also be exploited to expand the data set.

1.4 Key Water Use Decision

During development of the Campbell River WUP, evaluation of reservoir operations relied heavily on the ELZ Performance Measure (PM) with the assumption that increasing littoral development would lead to increases in fish productivity. This assumes a strong link between littoral and fish production. The results of this study will be used in conjunction with other monitoring work (e.g., Monitors 4 and 8 to directly assess how BC Hydro operations affect fish production in the reservoirs. This information will then be used to directly evaluate the impact of the Campbell River WUP on reservoir fish production, help refine reservoir-related PMs and assess their relative importance for future WUP review processes. If deemed necessary, the understanding gained through the present monitoring program may also help guide the development of alternative strategies for reservoir operations.

Evaluation of diversions on lake productivity was examined indirectly during the Campbell River WUP by using simple chemostat models, and through expert judgment. Both sources indicated a likely effect of diversions on lake productivity, but the magnitude of effect needs to be assessed directly. FTC recommendations to implement operational changes with respect to diversion lakes were deferred due to insufficient data with the provision that the issue is considered for direct study during subsequent monitoring. Information collected by this study will be used to evaluate the Campbell River WUP and its impact of the diversion lakes, as well as help refine PMs for future WUP reviews.

2 Program Proposal

2.1 Objective and Scope

The objective of this Monitor is to address the management questions presented in Section 1.2 by collecting data necessary to test the impact hypotheses outlined in Section 1.3. The following aspects define the scope of the study:

1) The study area will consist of selected study sites in Upper Campbell, Lower Campbell and John Hart Reservoirs, at least three diversion lakes, and two control lakes in the region.
2) The Monitor will consist of two components, a stable isotope analysis to map the food web dynamics leading to fish production, and a bacteria production component that investigates the decoupling of a lake's energy cycle due to operational changes in water residence times.
3) The SIA component of the monitor will be carried out in Years 2, 5 and 10 of the monitoring period. The monitoring study will be preceded by a pilot study to assess sampling and analysis techniques, which would preferably be completed in Year 1 of the monitor. All study work must be completed and results available prior to the next WUP review period (10 years following WUP implementation).
4) The pelagic bacteria density component of the monitor will be carried out over three consecutive years. The study must be completed and results available prior to the next WUP review period (10 years following WUP implementation).
5) Sampling will be carried out in a standardized manner and follow a specified schedule to ensure consistency among years in data quality and collection procedures. To minimize bias, all sampling and laboratory analyzes should be carried out by the same team of investigators.
6) Data reports will be prepared annually, including the results of the pilot work that summarizes the year's findings. All data will be archived according to BC Hydro protocols.
7) A final report will be prepared at the end of the Monitor that summarizes results of the entire Monitor, discusses inferences that can be drawn pertaining to the impacts of the WUP over time, and presents conclusions concerning the impact hypotheses and management questions in Sections 1.2 and 1.3.

2.2 Approach

This monitor has two components: stable isotope analysis of food webs in reservoirs and diversion lakes, and production estimates of phototrophic bacteria in reservoirs and diversion lakes. Data from these two study components will be analyzed both separately and together to assess linkages between benthic and pelagic production and the effect of BC Hydro operations on fish production in reservoirs and diversion lakes. This terms-of-reference provides a description of the studies as they are presently conceived, but contractors are encouraged to suggest improvements, provided there is a good rationale for doing so.

1) **Stable isotope analysis (SIA).** Samples will be taken from the three main reservoirs, several diversion lakes, and two control lakes and examined for carbon and nitrogen isotope ratios. Samples will include fish (several species and size/age classes), invertebrates (zooplankton and benthic invertebrates) and plants (phytoplankton, macrophytes and epiphytes). Samples will also be taken of representative tributary inputs, including invertebrate drift and terrestrial leaf litter. Stable isotope ratios will be analyzed to describe food web structure in the lakes and reservoirs, with the ultimate goal of identifying and quantifying sources of energy for fish, and the effect of BC Hydro operations on fish production. Samples will be collected over a period of four years, the first of which will be used as a pilot study to improve sampling and analysis techniques.

   Study respondents may also wish to consider alternate tools to SIA, such a microchemistry analysis, to quantify the sources of energy for fish. Suggestions for alternate approaches should be supported with example(s) of their success in a similar setting and for a similar objective.

2) **Estimates of autotrophic bacteria production.** Repeat density estimates will be made of pelagic bacteria in the reservoirs, diversion lakes and control lakes. These estimates will be used to assess the effect of inflows and water residence time on pelagic bacterial standing stock density in these water bodies. The estimates will be analyzed in conjunction with SIA data to identify and quantify sources of energy for fish, and the effect of BC Hydro operations on fish production. Samples will be collected over a period of four consecutive years, the first of which will be used as a pilot study to improve sampling and analysis techniques.

2.3 Methods

2.3.1 Data Capture

Where applicable, sample collection and data analysis methods should follow *Standard Methods* (APHA, AWWA, WEF 2005).

2.3.1.1 Stable Isotope Analysis

Sampling Strategy

Stable isotope analysis requires that tissue samples or whole organisms be collected throughout the food web, and then be processed in the laboratory for analysis in a mass spectrometer. Ideally, the tissues of individual animals or whole organisms would each be subjected to this basic SIA protocol, leading to a collection of data for each type of ecosystem component (pelagic, littoral, and allochthonous inputs), species or some other functional grouping, and age or size-class. However, because SIA sample are to be collected at a minimum of eight sites (reservoirs, diversion lakes and control lakes), this approach to sampling was deemed to be cost prohibitive. Instead, individual tissue samples and organisms collected for each category (strata) of SIA sampling will be pooled to create a single ‘integrated’ sample for analysis. With this approach, there will be roughly 53 integrated SIA samples for each study site to characterize energy flows to fish. The categorical breakdown of samples is summarized in Table 5.1 and discussed in greater detail below.

Similarly, at each study site, tissue and organism sampling should ideally occur at a number of locations within each ecosystem component to account for potential spatial variations in local food web dynamics. Again, because of the large number of study sites to investigate, this approach is cost prohibitive. Thus for this monitor, all samples will be collected from 'representative' sampling locations where ecosystem conditions reflect that of the study site in general.

All sampling should occur at the same time of the year, preferably in September as the summer growing period draws to a close. Sampling will occur in Years 1, 2, 5 and 10 of the monitor to track changes through time. This is different than the approach described in the Campbell River WUP CC report, where the three years of data collection were to occur consecutively. Spreading the sampling out over a 10-year time frame would dramatically improve the information content of the study by adding a temporal element to the analysis without increasing total sampling effort. The full scale sampling schedule should be preceded by a year of pilot study (in Year 1) to refine methods of sampling, laboratory procedures, logistics for sample processing, and data analysis techniques. In the pilot study, only one reservoir, diversion lake and control lake will be sampled. To control bias in sampling, all study work should be performed by the same team of investigators for the duration of the monitor.

In the sections that follow, greater detail is given on site selection, the collection of SIA tissue and whole organism samples and laboratory analysis. The methodologies provided are brief with just enough detail to be able to define the scope of the monitor and provide a cost estimate. Contractors are encouraged to refine the methods as required, paying particular attention to the lessons learned during the pilot study work.

Table 5.1 Categorical breakdown of integrated SIA samples to be collected from each study site.

Ecosystem Component	Type	Sub-Category	Sub-Total
Pelagic	Fish	3 species, 2 size classes, 2 tissue types	12
	Zooplankton	2 size classes, 3 functional groups	6
	General (includes phytoplankton and other organic particles)	None	1
Littoral	Fish	5 species, 2 size classes, 2 tissue types	20
	Benthos	2 size classes, 4 functional groups	8
	Epiphytes	None (all species are pooled)	1
	Macrophytes	None (all species are pooled)	1
	General (soil and detritus)	None	1
Allochthonous	Invertebrate Drift	2 size classes	2
	Detritus	None	1
		Total /Site	**53**

Site Selection

At a minimum, samples will be taken from each of the three reservoirs, at least three diversion lakes, and at least two control lakes. Study sites will be selected with input from BC Hydro and agency staff, based on considerations such as access, safety and security, distribution of representative habitats, and general biogeoclimatic features. A list of potential study lakes are as follows:

Reservoirs	Buttle/Upper Campbell, Lower Campbell, John Hart
Diversion Lakes	McIvor, Fry, Whymper, Brewster, Gray, Upper Quinsam, Middle Quinsam, Lower Quinsam, Snakehead, Gooseneck, Crest, Upper Drum, Lower Drum
"Control" Lakes	Paterson, Boot, Merrill, Long, Gentian, Beavertail, Amor, Mohun, Roberts, Gosling

Samples will be taken from 'representative' open water pelagic sampling locations and near shore littoral locations, which will be mapped (GPS located), briefly described, and recorded with representative photographs. Sampling locations will be selected with input from BC Hydro and agency staff to ensure consensus on their 'representative' state.

In addition to pelagic and littoral samples, samples of allochthonous inputs (detritus and invertebrate) will also be required, and will be taken from primary tributaries.

SIA Samples

Pelagic samples will consist of fish, zooplankton and phytoplankton. Fish will be captured by gill net (panel and mesh size combinations to be determined by the contractor in consultation with BC Hydro staff and Agency staff), identified to species, measured for length and weight and then sampled for muscle and liver tissues. In the reservoirs, it is currently believed that cutthroat and rainbow trout are the primary fish species utilizing the pelagic zone, although sticklebacks are likely also common and are a primary prey species for cutthroat. The goal will be to obtain cutthroat and rainbow trout from at least two size/age classes, very young and a moderately older age. An equivalent sample of sticklebacks will also be taken in the pelagic zone if this species is present; this sampling may require open water seines or floating gee traps. In addition to tissue samples for SIA, fish stomachs will be preserved for gut content analysis. A different suite of species may be present in some of the diversion lakes, and adjustment to the species sampled may be required.

Zooplankton will be obtained from vertical plankton tows through the thermocline to roughly 1 m below the surface. The sample will be separated into size classes using mesh filters, and divided into functional groups using a dissecting microscope. For example, *Chaoborus* would represent a higher trophic level than *Daphnia*. Samples will be kept live in lake water for enough time to allow samples to void gut contents, which may confound isotope readings. Phytoplankton will also be obtained from vertical plankton tows, subsequently separated into size classes using mesh filters. Where possible, phytoplankton samples should include species that are a forage base of zooplankton. One additional sample type will be taken, a general particulate organic carbon sample that does not differentiate among particles in the water column.

Littoral samples will be taken from a representative site from the littoral region of sample lakes and reservoirs. Littoral samples will consist of fish, invertebrates, epiphytes and macrophytes. Fish will be captured by gill net and gee trap, identified for species, measured for length and weight and then sampled for muscle and liver tissues. Use of littoral habitats in the reservoirs is not well known, particularly for different age classes. At present we expect that the nearshore environment is used primarily by cutthroat and rainbow trout, stickleback, Dolly Varden, and sculpin. The goal is to obtain representative samples of each species, from at least two size/age classes, very young and a moderately older age. A different suite of species may be present in some of the diversion lakes, and adjustment to the species sampled may be required.

Benthic invertebrates will be obtained from littoral areas by an appropriate method such as grab sampling. As in the zooplankton samples, benthic samples will be kept live in lake water for enough time to allow samples to void gut contents, which may confound isotope readings. Samples will be rinsed, separated from detritus, and divided into functional groups using a dissecting microscope. For example, molluscs would represent a lower trophic level than odonate nymphs. Samples of epiphytes will be obtained from hard surfaces such as rocks. (Note that ^{13}C signatures depend in part on boundary layer characteristics [Hecky and Hesslein 1995, France 1995], so surfaces should be "typical" of benthic substrates in the water body.) If present, macrophytes should be sampled; these samples should be scraped or scrubbed clean of epiphytes. One additional sample will be taken, a general sample of benthic soils and detritus.

As a measure of allochthonous energy inputs, samples will be taken from lake tributaries, in the form of invertebrate drift and detritus. It is expected that these samples can be obtained using instream drift samplers for invertebrates and direct sampling of detrital material. During the first year pilot study, appropriate methods and sample sites will need to be selected but at this point it is expected that larger tributaries, such as Elk River, will be the appropriate sampling locations.

All samples should be stored on ice once collected and processed as soon as possible in the laboratory, where they are oven dried and ground into a powder. The number of samples to be collected should be large enough to meet five times the mass need to carry-out the SIA (10 to 75 mg of dried powder, see below). Another criterion to keep in mind is that the powdered sample should be derived from several individuals to get a better indication of population wide trends. Precise sample sizes (e.g., number of fish, mass of macrophyte or benthos) to meet these SIA sampling requirements will be a key outcome of the pilot study work scheduled for Year 1.

Laboratory Analysis

Details of lab analysis will be described only briefly here; a list of references is provided at the end of the Terms of Reference, which can be used as a guide to detailed methods for lab analysis, along with a large number of articles available in the primary literature. In general, samples are prepared in a lab prior to shipping to a stable isotope laboratory where samples are analyzed with a mass spectrometer. A list of some of the stable isotope labs in Canada can be found in Jardine et al. (2003) and there are a number of contracting labs in the US that analyze samples for stable isotopes. Researchers should contact labs directly to ascertain costs and requirements for sample preparation, shipping and turn-around times.

In general, the range of required sample sizes is roughly 2.0 - 15.0 mg. Jardine et al. (2003) recommend obtaining five times the amount of tissue required for a single analysis, which allows for replicate samples and controls. In many cases (e.g., plankton) pooling of multiple individuals will be needed to reach the required mass. Researchers should assess the need for “internal standards” (e.g., a large tissue sample divided into multiple smaller samples) to draw comparisons across runs (i.e., QA/QC process).

The detailed sample preparation requirements should be discussed with the lab prior to sample collection. Generally, prior to shipping to a stable isotope lab, biological samples are dried in an oven and ground to a fine powder, then placed in individually labelled tin capsules for combustion in a mass spectrometer. Given the very small mass of samples required for mass spectrometry analysis, extreme care must be taken to avoid cross contamination of samples. Additional preparation may also be necessary. There is some evidence that body lipids are ^{13}C-depleted relative to other tissues, and may therefore distort data (Kling et al. 1992). There is also evidence that adhering inorganic carbonate (e.g., crustaceans, macrophytes) can confound isotopic signatures (Beaudoin et al. 2001). Researchers should therefore investigate these effects and the necessity to prepare samples appropriately. For example, this may be an appropriate question to answer during the pilot study phase of the program. It should be understood however, that the focus of this study is fish, and the flow of total energy to this trophic level. Acceptable accuracy for most ecological work is ± 0.1 to 0.2 ‰, (Peterson 1999) and it is possible to obtain this resolution with dual isotope methods, which have the advantage of substantially cheaper SIA runs.

Stomach Contents

Fish stomach contents will be analyzed to obtain diet composition data. This data will be used to direct sampling effort of each following year of data collection, as well as help interpret SIA results. Contents will be analyzed using a dissecting microscope, and sorted to genus (or family where this is deemed not feasible). Taxa will also be assigned to functional group (e.g., benthic scraper, shredder). The samples will only be collected from dead fish to a maximum of 10 fish per species and age class. All samples will be stored in glass jars and preserved in minimum 70% ethanol solution.

2.3.1.2 Estimates of Autotrophic Bacteria Standing Stock

Study Sites

Study sites will be selected with input from BC Hydro and agency staff, based on considerations such as access, safety and security, distribution of representative habitats, and general biogeoclimatic features. See earlier table for a list of potential study lakes.

Bacteria Samples

Samples will be taken from the epilimnion (at least 2 m below the surface) at pelagic sites using Van Dorn water bottles. All sites will be mapped (GPS located), briefly described, and recorded with representative photographs. A minimum of three samples will be taken from each of the reservoirs, at least three diversion lakes, and at least two control lakes. In Year 1, a pilot study will be used to develop an appropriate sampling schedule, but it is expected that samples will be taken monthly for a duration of about 6 to 8 months, from spring through autumn. Depending on diversion schedules it may be appropriate to obtain some samples opportunistically, immediately before and/or immediately after large volume diversions into (or away from) some lake systems. The full sampling program will be carried out for a subsequent 2 years, likely in Years 2 and 3.

Maximum number of samples should not exceed 200 samples per year of study. This would allow 24 samples to be collected per sampling trip (three pelagic samples for each of the eight study sites) and allow a total of eight trips per year. As alluded to above, the schedule of sampling can be altered as necessary to study the impact of operational changes at different time scales.

Laboratory Analysis

Samples collected by Van Dorn water bottles will be pooled if necessary to obtain sufficient volume for analysis. Bacterioplankton will be counted and sized using epifluorescence microscopy and 4', 6-Diamidino-2-phenylindole (DAPI) staining (Porter and Feig 1980). Proponents should also be prepared to count unstained, autofluorescent picocyanobacteria from each sample (MacIsaac and Stockner 1993) as these microbes may constitute a substantial portion of the pelagic bacterial assemblages. Also, bulk water samples may require concentration to obtain more reliable bacterial density estimates. Samples will be fixed with 2% filtered (0.2 µm), buffered formaldehyde and stored cold. Replicate subsamples of known volume will be taken for bacteria counts, and will be stained with DAPI, filtered onto Irgalan-Black-dyed 0.2-µm, 25-mm-diameter polycarbonate filters (Nucleopore), rinsed, and enumerated at 1250× magnification with a suitable epifluorescence microscope equipped with an UV excitation filter set. Specific fluorescence can be used to distinguish among different picoplankters. Data will be recorded simply as densities. Details on sub-sampling procedures and quality assurance / quality control measures (QA/QC) for bacterial counts are to be provided in the project report.

2.3.2 Safety Concerns

A safety plan will be developed for all aspects of the study in accordance with Work Safe BC and BC Hydro procedures and guidelines. It is important to note that, because of the remoteness of some of the study areas and the large geographical area that must be covered, all field work must be carried out by a minimum two-person crew and that appropriate check-in and checkout procedures must be followed. Boat operators must be certified in compliance with applicable regulations, standards and guidelines published by Transport Canada, Coast Guard and BC Hydro. The boat must conform to Coast Guard and Transport Canada safety requirements and be of sufficient size to operate safely on these reservoirs and lakes during adverse weather conditions.

2.3.3 Data Analysis

2.3.3.1 Stable Isotope Analysis

SIA data will be expressed as $\delta^{13}C$ or $\delta^{15}N$, or differences from the given standards, expressed in parts per thousand or per mil (‰). The values are calculated according to the formula:

$$\delta X = [(R_{sample}/R_{standard}) - 1] * 1000$$

where (using carbon as an example) R_{sample} = $^{13}C/^{12}C$ of the sample, and $R_{standard}$ = $^{13}C/^{12}C$ of the chosen standard (see discussion of isotope standards in Jardine et al. [2003]). R represents the ratio of the abundance of the ions of mass 45 ($^{13}C^{16}O^{16}O$ + $^{12}C^{16}O^{17}O$) to mass 44 ($^{12}C^{16}O^{16}O$); thus a correction factor for ^{17}O is required (Craig 1953). Similar calculations can be performed comparing samples and standards for nitrogen [R = $^{15}N/^{14}N$, as measured by the ratio of the abundance of ions of mass 29 ($^{14}N^{15}N^{+}$) to mass 28 ($^{14}N^{14}N^{+}$) (Mariotti 1984)]. The use of ratios magnifies differences among samples, increases resolving power and permits comparisons across analytical laboratories and studies (Peterson and Fry 1987).

Analysis of SIA data should utilize both graphical and numeric analytical techniques. Standard SIA diagrams should be produced, showing mean and standard errors for different functional or taxonomic groups; the literature can be utilized as a guide for appropriate analysis. When organisms have two or more sources of energy for growth (e.g., littoral vs. pelagic sources), mixing models have been employed to determine the relative contribution of the sources. Such models should be used where appropriate to ascertain the relative energy inputs to the food web from littoral, pelagic, and allochthonous sources. Where fish species are shown to have significantly different isotope signatures, mixing model analyzes should be performed separately for each species. Finally, comparisons should be made among the different lake/reservoir types, which can be thought of as experimental “treatments,” with attempts to understand the ecological effects of different management regimes.

2.3.3.2 Stomach Contents Analysis

Fish stomach contents will be analyzed to obtain diet composition data, and be used to both corroborate and explain patterns in the SIA study. Beaudoin et al. (2001) provide a good example of how stomach content analysis can be used in conjunction with SIA.

2.3.3.3 Estimates of Autotrophic Bacteria Production

Bacterial standing stock data will be several time series of densities. In conjunction with these data will be inflow records to the water bodies being studied; a portion of this inflow will be related to BC Hydro operations. The task of the analysis will be to explore relationships between bacteria densities and inflow rates. The analysis will start with simple graphical and statistical summaries of bacteria density time series and inflow time series. In addition to summarizing seasonal trends in density and inflow, the summaries will initiate a comparison between the two.

To test for correlations between residence time and bacterial standing stock several analyzes will likely need to be performed, only some of which can be outlined here. Some flexibility and exploratory data analysis will likely be required to ascertain the appropriate numerical analysis. The analysis will likely require the development of indicators of residence time, since data are likely to be on daily time steps, whereas bacterial densities are expected to be on monthly time steps. One potential mode of analysis will be to ignore possible autocorrelations and pool data, treating each observation as independent. Regression, ANOVA and simple correlation techniques can then be used to assess the relation between residence time and bacterial densities. Alternatively, there may be the need to use time series techniques to directly assess the effect of autocorrelation. All results should be compared to values found in the scientific literature.

2.3.4 Reporting

Reporting will begin with a detailed report of pilot study results that will include results of a review of recent literature of like studies, comprehensive descriptions of the methods and laboratory procedures used, recommendations for methodology refinement, and issues to be aware of or taken into consideration when collecting data in the future. This report will guide the development of final sampling strategies and methods for use in the monitor proper.

Following the pilot work, project reporting will consist of annual data reports for the first two years of the monitor (Years 1 and 5), and a final report at its conclusion in Year 10. Annual data reports will summarize the year's findings and include a short discussion of how the year's data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyzes. At the conclusion of the Monitor, a final comprehensive report will be prepared from all of the data and/or annual reports written to date that:

1) Re-iterate the objective and scope of the monitor,
2) Present the methods of data collection and data analysis,
3) Describe the compiled data set and present the results of all analyzes,
4) Discuss the results as they pertain to the hypotheses in Section 1.3 and the Management Questions in Section 1.2.
5) Discusses the consequences of these results as they pertain to the current WUP operation, and how it may influence future WUP reviews, and
6) Include an executive summary that summarizes the results of the monitor and their consequences as they relate to the success/failure of the WUP decision. It should include recommendations for remedial work if any, as well as the scope for future study work.

Each report will be due in spring of the year following the data collection period. This should provide sufficient time in integrate findings in those years that multiple study component are simultaneously carried out.

2.4 Interpretation of Results

2.4.1 Impact Hypothesis $H_0 1$

This hypothesis tests the effect of water level fluctuations on energy flows to reservoir fish. With a maximum of three water bodies to study (Buttle/Upper Campbell, Lower Campbell and John Hart) it is quite possible that a statistical comparison will prove to be not significant. On the other hand, the “treatments” are broad, from deep drawdowns to highly stable reservoir elevations, which increase the chances of correlating management regime with ecological effect. It is nevertheless expected that the test of this hypothesis will be largely qualitative in nature, through the comparison of food web diagrams among reservoirs. Should the mixing model analysis prove to be useful, it may be possible to use the results to quantitatively test the correlation between drawdown and relative littoral vs. pelagic energy source in fish.

Failure to reject $H_0$1 would suggest that differences in water management among reservoirs (water level fluctuations) have no measurable impact on energy flow to juvenile and adult trout. There may be a number of reasons for such a result:

1) Stable isotope techniques are inappropriate for addressing this question,
2) There was only a minimal response to the treatments used,
3) The resolution of the Monitor was too low to detect a difference (e.g., too small a sample size),
4) The difference in reservoir operations was too small to illicit a measurable ecological response (too small a treatment effect),
5) There is some other limiting factor that masks the ecological response to operational changes, or
6) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for differences in energy flow to fish population and will put the results of the Monitor into the proper statistical context.

2.4.2 Impact Hypothesis $H_0$2

This hypothesis tests the effect of water residence time on energy flows to lake fish. With a maximum of three reservoirs and only two or three diversion and control lakes selected it is quite possible that a statistical comparison will prove to be not significant. On the other hand, the “treatments” are broad, from high inflows to low inflows, which increase the chances of correlating management regime with ecological effect. It is nevertheless expected that the test of this hypothesis will be largely qualitative in nature, through the comparison of food web diagrams among lakes. Should the mixing model analysis prove to be useful, it may be possible to use the results to quantitatively test the correlation between water residence time and relative littoral vs. pelagic energy source in fish.

Failure to reject $H_0$2 would suggest that differences in water management among lakes (water residence time) have no measurable impact on energy flow to juvenile and adult trout. There may be a number of reasons for such a result:

1) Stable isotope techniques are inappropriate for addressing this question,
2) There was only a minimal response to the treatments used,
3) The resolution of the Monitor was too low to detect a difference (e.g., too small a sample size),
4) The difference in diversion operations was too small to illicit a measurable ecological response (too small a treatment effect),
5) There is some other limiting factor that masks the ecological response to operational changes, or
6) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for differences in energy flow to fish population and will put the results of the Monitor into the proper statistical context.

2.4.3 Impact Hypothesis $H_0$3

This hypothesis tests the effect of water residence time on standing stock of lacustrine autotrophic bacteria in diversion lakes. With a maximum of four reservoirs and only two or three diversion and control lakes selected it is quite possible that a statistical comparison will prove to be not significant. On the other hand, the “treatments” are broad, from high inflows to low inflows, which increase the chances of correlating management regime with ecological effect. In addition, the data will be collected over a series of months for each water body, creating a significant data resource. It is therefore expected that the test of this hypothesis will be quantitative, through the numerical comparison of bacteria densities among lakes.

Failure to reject $H_0$3 would suggest that differences in water management among lakes (water residence time) have no measurable impact on standing stock of autotrophic bacteria. There may be a number of reasons for such a result:

1) The chosen techniques are inappropriate for addressing this question,
2) There was only a minimal response to the treatments used,
3) The resolution of the Monitor was too low to detect a difference (e.g., too small a sample size),
4) The difference in diversion operations was too small to illicit a measurable ecological response (too small a treatment effect),
5) There is some other limiting factor that masks the ecological response to operational changes, or
6) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for differences in energy flow to fish population and will put the results of the Monitor into the proper statistical context.

2.4.4 General

Results of this monitor will be used to assess the pathways by which WUP operations ultimately impact fish populations. Within the context of the present monitoring program, it would provide the information necessary to hypothesize the mechanism of change in situations where trends are observed in other monitors, particularly those that track fish population through time. By knowing the mechanism of change, more effective proposals for operational change can be devised in future WUP review processes, and would allow for prioritization of operational activities that could improve the overall operating strategy, both in terms of power generation and environmental benefits.

2.5 Schedule

The Salmon River diversion canal has been out of service since 2010 due to dam safety deficiency concerns. BC hydro had initiated a project to address the dam safety deficiencies identified on Salmon River diversion structure and the canal. However, no firm timeline has been scheduled for completion of the dam safety project. In the absence of diversion, there is no diversion related- WUP impacts to be monitored for Salmon River section of this monitor. Consequently the implementation of this monitor hinges on whether the canal upgrade project gets implemented in advance of the schedule set in this TOR for implementation of this monitor. Therefore, the schedules designed for this monitor is conditional on and will be driven by the canal upgrade project implementation schedules.

2.5.1 Stable Isotope Analysis

The SIA component of the monitor will begin with a pilot study carried out in Year 1. Results of this pilot work will lead to important refinements to various aspects of this monitor's methodology. The pilot study work will be summarized into a report due winter/spring of the following year, well in advance of the Year 2 monitoring work.

The actual SIA monitoring study will commence in the year following the pilot study (Table 5.2). The second year of data collection will occur in Year 5 to coincide with a 5-year review process, which will be followed by a third year of data collection in Year 10. Because the plan proposed in the Campbell River WUP CC report assumed 5-year duration, only three years of data collection were proposed. Since then, the duration of the monitoring program was increased to 10 years, requiring that an additional year of data be collected so that the results are meaningful at the conclusion of the monitor. This added year of work dramatically increases the information content of the monitor, allowing a greater period of time for changes to materialize following WUP implementation. It also allows the SIA data to be directly linked to the results of Monitors 3 and 4. All annual and final reports will be due in spring of the year following data collection.

2.5.2 Estimates of Pelagic Bacteria Production

The bacteria production component of the monitor will be carried out over three consecutive years. For planning purposes, the work is planned for Years 7 to 9, but can be started anytime provided that it is completed for presentation in Year 10. As with the SIA component, all annual and final reports are due in spring of the year following data collection.

2.6 Budget

The total cost of the energy flow relationships monitor is estimated to be $868,865 based on a 2014 start.

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