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Modeling the effects of Large Woody Debris inputs on juvenile anadromous cutthroat trout and coho abundance

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1. ABSTRACT

ABSTRACT: Large Woody Debris (LWD) recruiting to streams and rivers from the riparian forest has a major influence on channel structure and fish habitat throughout British Columbia and the Pacific Northwest. Harvest of riparian forest leads to changes in recruitment of LWD with subsequent long-term effects on both channel structure and fish abundance over decades to centuries. At present, long-term effects of current riparian management practices are unknown. The objective of this project is to develop a model linking riparian management (e.g. buffer width) to LWD input rates, small stream channel structure, and abundance of juvenile anadromous cutthroat trout and coho salmon, and is a direct extension of previous forestry-related research in coastal B.C. streams (Rosenfeld and Parkinson 1995, Rosenfeld et al. 2002, Rosenfeld and Boss 2001, Rosenfeld et al. 2000, Rosenfeld 2000). This model will serve as a management tool for coastal B.C. forest planning and should be applicable outside coastal B.C. when appropriate model parameters become available for other regions.

The primary goal of the first year (2001-2) of this 3-year project was development of the basic model structure. The primary goal of Year 2 (2002-3) was to have begun testing the impacts of different riparian management scenarios, but model development and programming has taken longer than expected because of the complexity of the model, and has taken up most of Year 2. We are now in the process of fitting the model to forest diameter, biomass, and growth rate parameters for Coastal Western Hemlock data for B.C.. Because of the delayed development of the primary model, all outcomes and deliverables for the rest of the project will be delayed by 6 to 12 months, but most identified deliverables will still be produced in Year 3. Nevertheless, the project may have to be extended to finish several of the originally proposed deliverables (e.g. modeling the long-term trajectory of habitat and fish populations at 30 representative cutthroat trout streams). The overall outcomes, impacts, and end-users of the project remain unchanged.

KEYWORDS: Large Woody Debris, LWD, stream habitat, cutthroat trout, coho salmon, fish habitat models

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3. INTRODUCTION

Streams are a key biological, cultural, and economic component of watersheds in British Columbia. Streams and their riparian zones are areas of high biological diversity, have strong cultural significance for both native and non-native residents, and are the primary rearing habitat for juvenile salmonids that support the culturally and economically significant salmon fishery in British Columbia. Streams are intimately linked to their terrestrial riparian ecosystems, and a clear understanding of how riparian forest harvesting affects ecological processes in streams is key to maintaining the biological, cultural, and economic benefits that accrue from stream ecosystems.

Wood in streams plays a dominant role in channel structure throughout British Columbia and the Pacific Northwest (Naiman 2001, Bilby and Ward 1989). Large Woody Debris (LWD) is the primary pool-forming agent in both small (Montgomery et al. 1996, Rosenfeld et al. 2000) and large (Collins et al. 2002) coastal streams, and pool abundance has been shown to be a major correlate of abundance of coastal salmonids (e.g. Connolly 1997), functioning as both summer rearing (Rosenfeld and Boss 2001) and overwintering habitat (Nickeleson et al. 1992). LWD also functions to stabilize the stream channel, provide cover from predators, retain organic matter that serves as the basis for fish and invertebrate production in coastal streams, and contribute to increased overall complexity of both structural and hydraulic habitat.

LWD in streams recruits from the adjacent riparian forest, and riparian harvesting or management (e.g. different buffer widths and variable retention) will directly influence input rates of LWD to the stream channel. Changes in LWD inputs have been demonstrated to affect channel structure, which will ultimately affect carrying capacity of streams for rearing resident or juvenile anadromous salmonids.

While it is believed that present Forest Practices Riparian guidelines in British Columbia are sufficient to permit adequate long-term recruitment of LWD to maintain stream habitat structure, the long-term effects of present and alternative riparian management strategies (i.e. presence of buffers, buffer width, selective harvest) are speculative. Both forest growth dynamics and LWD decay in streams operate over decades to centuries, and it is difficult to predict the long-term outcome of different riparian management practices through short-term observations. The only way to evaluate the long-term effects of riparian management on channel structure and fish abundance is to modeling these processes over appropriate time scales.

Prior to the advent of the Forest Practices Code in the mid-1990s, many low-elevation fish-bearing coastal streams were logged to the streambank. Many of these streams are beginning to structurally degrade (Slaney and Zaldokas 1997) as the pre-logging LWD in them decays without recruitment of new wood, which will await regrowth of riparian forest to a size where it is large enough to influence channel structure. The time course of habitat degradation and recovery are unclear, and the ability to model these process will provide the basis for anticipating future stream habitat conditions across forested landscapes, as well as the basis for assessing the long-term impacts on fish habitat of the present riparian forest practices.

Several models have been developed to predict the effect of different riparian management practices on LWD recruitment and channel structure in coastal streams in North America. The first of these (Murphy and Koski 1989, Fig. 1 below) was applied to Alaskan streams, and was the primary basis for recommending 30m buffers on anadromous waterways in that state.

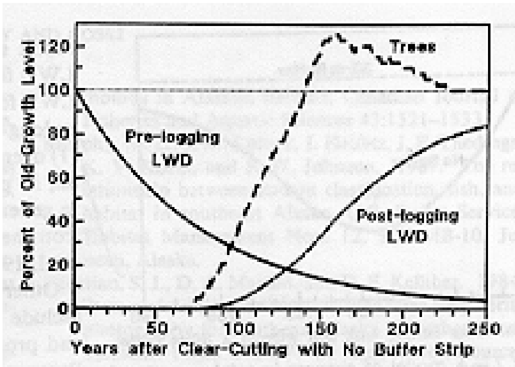

Fig. 1 Relative abundance of LWD in a hypothetical stream channel following logging to the stream bank (from Murphy and Koski 1989).

Several more detailed models have been recently developed, notably Riparian-in-a-Box (Beechie et al. 2000) and Streamwood (Meleason et al. 2000). Riaprian-in-a-Box is parameterized for Washington forests and streams, and Streamwood is parameterized for Oregon streams and forests. Both lack a simple submodel relating changes in channel structure to fish abundance.

Although these models were fairly well-developed and have taken years of research to develop, neither model can be directly applied to streams in British Columbia, since model predictions are extremely sensitive to forest growth rates and the relationships between LWD abundance and channel morphology, both of which may vary regionally. Because of our previous research on fish habitat relationships in small coastal streams (Rosenfeld et al. 2002, Rosenfeld and Boss 2001, Rosenfeld et al. 2000, Rosenfeld 2000), we were in a position to properly parameterize a model that is appropriate for coastal B.C., and extend the application of existing models by including a submodel relating channel structure to fish abundance.

The primary research objectives of this project are

i) to develop a model predicting the long-term effects of different riparian management practices on LWD recruitment rates, channel structure, and juvenile cutthroat and coho abundance in small streams.

The subsequent management objectives are

ii) to use the model to evaluate the long-term effects of current (Forest Practices Code) riparian management practices on juvenile cutthroat trout and coho abundance.

iii) to model the effects of alternate riparian management practices (e.g. varying buffer width or basal retention) on cutthroat trout abundance, and

iv) to use the model to project expected long-term trends in juvenile cutthroat trout abundance at 30 representative cutthroat trout streams sampled during 1997-1998.

v) to develop an interactive version of the model for use by resource managers

The expected outcomes from the Year 1 of the project were:

1) *A quantitative model to predict the effect of different riparian management strategies on LWD recruitment, channel structure, and cutthroat trout abundance.*

The expected outcomes from the Year 2 of the project were:

2) *A technical report (published in the Provincial Fisheries Research Branch Technical Report Series) describing the model and it's mathematical structure (see Appendix 1 for a draft version).*

3*) An evaluation of the long-term effects of current FPC riparian regulations on cutthroat and coho habitat structure and capacity in small streams.*

4) *An evaluation of alternate riparian management scenarios involving different degrees of riparian basal retention.*

The expected outcomes from the Year 3 of the project are:

5) *Estimation of the projected trajectory (average decrease or increase) of anadromous coastal cutthroat trout habitat capacity in southwestern B.C. based on modeled trends in channel structure on 30 representative cutthroat trout streams sampled during 1997-1998.*

6) *Publication of the model and research in an international peer-reviewed journal for a wider audience.*

7) *Presentation of the model and the results of the research at government workshops and regional and international conferences attended by resource managers and scientists.*

8) *Production of an interactive version of the model that can be used by regional managers to evaluate the long-term effects of different riparian practices on fish habitat.*

The benefits that will accrue from this model are a clearer understanding of the long-term effects of riparian harvesting in B.C., and a proper evaluation of the ability of current riparian forest regulations to maintain channel structure and fish habitat capacity. At present, the ability of current FPC riparian regulations to maintain long-term recruitment of LWD and channel structure remains speculative. Benefits of this research are consistent with the strategic and provincial research objectives of FRBC, which include evaluating whether current forest practices are effective in maintaining watershed processes and protecting aquatic biodiversity. The model will also serve as a useful diagnostic tool for assessing watershed condition, and for developing restoration strategies and benchmark objectives, also key strategic FRBC objectives. The results of this research will ensure that current and future forest practices provide adequate stewardship of aquatic resources and maintain both aquatic ecosystem health and biological carrying capacity in coastal streams.

4. ACTIVITIES & METHODS

Year 1

Activities during the first year of this project (2001/2) focused on **1)** the logic and structure of model development, and **2)** analysis of existing data on LWD-channel morphology relationships in small streams in British Columbia to parameterize the model.

Year 2

Activities during year two of the project (2002/3) have focused on **1)** finalizing the model structure **2)** model fitting and parameterization, and **3)** publishing the initial results of our LWD-channel structure relationship in the primary literature to make the information available to other researchers and mangers, and to give the model scientific credibility.

Methods are described below for each of the three primary activities identified above.

1) Development and programming of primary model structure

Dr. Leonardo Huato, a fisheries modeler with extensive experience in modeling ecological processes, was hired to undertake primary model development. Basic model structure involved modeling tree growth on the streambank, applying mortality factors and recruiting LWD to the stream channel, modeling the effects of LWD on channel structure, and modeling the effects of channel structure on fish abundance. Model development was based on previous published models of forest growth dynamics, LWD recruitment, and channel structure, with many additional modification and impovements. An outline of model structure is described below, but the reader is referred to the attached Appendix 1 for a more detailed account of the model, including the code. An executable file ("Forestdynamics") of the model is also included on floppy disc. The interface of the model at this stage is very simple, since the primary focus in the first year was to produce a functioning model, and production of an interactive model with a user-friendly interface and extensive visual output is an objective of the third year of the project.

Overview of Forest Growth Submodel

A forest gap model was adopted to simulate forest growth dynamics in the riparian zone. Forest gap models are individual-based models that simulate the recruitment, diameter growth, and mortality processes of individual trees on a small area (see reviews in Dale et al., 1985, and Urban and Shugart, 1992). Here we followed an adaptation of the JABOWA - FORET models (Botkin et al., 1972; Shugart and West, 1977) to the Pacific Northwest forests done by Dale et al. (1986). Their model (called CLIMACS) follows these processes in a pacific northwest forest stand on an annual basis. CLIMACS is not a spatially explicit model, and as such it treats the forest plot as a horizontally homogeneous environment although it explicitly considers the shading effects of taller trees on shorter trees on the plot (i.e. the model is vertically heterogeneous). In this model a tree does not interact directly with other trees, but rather each tree contributes to the forest plot environment (e.g. total above ground live biomass, total leaf area, etc.) which in turn affects the growth and mortality of each tree.

Because the recruitment of LWD to streams depends on distance of the tree from the stream, we required a model where tree position is explicitly represented in order to have a realistic representation of the dynamics of LWD and the effects of buffer width on stream habitat. To this end the CLIMACS structure was updated to provide a spatial location to each tree in the plot. These modifications ensure that only those trees that all with a suitable height, location, and distance from the stream are used to compute the effect of LWD on stream habitat.

Model Stand

Our model represents a stand of 100 m in length and 60 m in width measured from the shoreline of a small stream of fixed bankfull channel width (Figure 1, Appendix 1). The stream is assumed to run in a straight line down the slope. This plot is further divided into two areas relevant to management policies; the stream buffer strip adjacent to the stream, and the rest of the stand, which is subject to harvest. The model simulates tree dynamics in only one side of the stream, thus the predicted number of LWD per class size falling into the stream are multiplied by two.

Tree Growth Dynamics

Individual growth in CLIMACS is modeled as a logistic function that represents growth under optimal conditions and is also constrained by environmental factors like temperature and moisture and the effects of light, shade, and soil nutrients competition that affect growth independently (model formulation is given in Table 1, Appendix 1). This formulation ensures that the growth rate decreases as trees reach larger diameters.

Stand Regeneration

The birth process in the modeled forest stand simulates three processes: 1) Trees of one or several species can be planted in the stand after a harvest cycle. These trees are characterized by having a specified diameter at breast height (DBH), age, and plantation density in the stand; 2) Trees can also colonize the plot by sprouting (a species-specific trait); or 3) germinate naturally from seed sources depending on species specific tolerances for local temperature, moisture level, and shade level. The seedlings are generated from a seed bank composed by all the species of trees simulated. The effects that spatial availability and dispersal of seeds may have on seedling dynamics are not considered here. Any species of trees being represented in the model can recruit in a clearing. However, as canopy density increases in a given area, only those species with higher thresholds for shade tolerance can recruit to the forest stand.

Trees recruited from the seed bank enter the stand at 30 years of age. This simplification of the recruitment process from seeds was required to improve the computational performance of the model.

Tree mortality

The model considers four sources of mortality; competition, windthrown, bank erosion, and harvest, and, with the exception of harvest, all are stochastic in nature. Fire is not considered a major source of mortality in the coastal streams of British Columbia because of the high levels of rainfall of the region (Meidinger and Pojar, 1991). Pest attacks are also a source of mortality, but their significance as a source of mortality in the coastal forests of B. C. is not well documented. For this reason this source of mortality is not considered here (although it can be readily implemented as a species specific mortality factor).

Our research interest was on tree dynamics in the riparian zone of small, salmon-bearing streams near the coast of the British Columbia. Five species of trees are common to this area, red alder (*Alnus rubra*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) (Meidinger and Pojar, 1991). Thus, our forest gap model follows growth, mortality, and succession of individual trees belonging to these five species in a riparian stand. The parameter values used here for these 5 species are in Table 3 and were taken from Dale et al. (1986).

LWD-Channel Structure Dynamics

Large woody debris dynamics are represented in the model by a recruitment process and a depletion process. The depletion of LWD in a stream location occurs as a result of the decomposing of wood and exports to downstream locations. These two processes are represented as an exponential depletion process that removes a fraction of the LWD volume present in the stream on an annual basis. As the debris degrades and losses its volume over time it reaches a critical threshold and it is no longer considered a pool-forming debris (see below for an explanation on how this threshold value is defined). The current perception is that the depletion rate vary across tree species and sizes of LWD pieces (Stevens, 1997). He also points out that the decay rate is considered constant for pieces larger than 20 cm in diameter and increases for smaller pieces. However, there is a very limited amount of quantitative information published on the subject. Here I used a value of 1.5% as the annual decay rate in the simulations. This value corresponds to the mean annual decay rate (ranging from 0.5% to 3.5%) measured by Murphy and Kosky (1989) for conifer LWD in Alaska streams and is considered a reasonable estimate for pool-forming debris from most tree species in small streams (e.g. Beechie et al., 2000).

The recruitment of LWD comes from thick branches, crowns, or tree trunks falling into the stream (Harmon et al. 1986) and from exported debris transported from upstream locations. Since our model focuses on the effects of logging on LWD inputs on a forest plot we are not considering those debris generated elsewhere in the forest outside of our model plot. This assumption is, in effect, equivalent to an equilibrium condition between the export and import rates of LWD in the segment of stream under investigation. Furthermore, we simplified this process by assuming that all LWD inputs come only from the bole of the dead trees (see tree mortality above), and that the tree bole falls without breaking into pieces. This last assumption is a simplification that is partially substantiated by the results of McDade et al. (1990). They found that falling trees in forest stands with gentle slopes are less likely to break, which results in LWD up to 25% larger than those in stands with steep slopes.

We used the simple trigonometric approach in Van Sickle and Gregory (1990) to estimate which of the falling trees intersect the stream and how far the bole reaches into the stream. The model tracks only those LWD that reach the stream and are capable of creating a pond according to the criteria defined by Beechie and Sibley (1997). Their criteria is based on a statistical relationship between pool-forming LWD in streams and stream width, and was developed for streams in second growth forests of northwest Washington. They found that the minimum diameter d_{Min} (in m) of a LWD capable of forming a pool relates to the width of a stream in a linear fashion ($d_{Min} = 0.0057 + 0.028W$; $n = 24$, $r^2 = 0.65$, $p < 0.001$). In this model, the diameter value used to determine pool-forming capacity is $(d_a + d_b) / 2$, which is the mean diameter of the section of the bole in the water.

Beechie and Sibley (1997) also found that the pool spacing (measured in channel width units) also follows a linear relationship in relation to the number of LWD per metre (pool spacing = 4.3 - 6.2 LWD/m; $n = 17$, $r^2 = 0.41$; $p = 0.006$) for streams with low slopes (0.2% to 2%). Pool-forming capacity and pool spacing are treated as deterministic processes in the model.

As indicated before, the depletion process reduces the volume of the debris every year in the simulation. However the criteria to determine if a LWD can create a pool is the diameter of the debris. Thus this diameter (d) is calculated from a rearrangement of the formulation to estimate the volume of a cylinder $V = \pi\, HT\, (d/2)^2$. Here d is equivalent to $(d_a + d_b)/2$ which is the threshold value initially used to determine whether or not the LWD can form a pool in the stream.

A hard copy of the code for this model is provided at the end of Appendix 1 attached to this report.

2) Model fitting and paramaterization

The model fitting process began this year following completion of the forest growth and recruitment sub-modules. Model fitting at this stage involves three main processes: **i)** extracting length-DBH relationships for the five species of trees in the model using data from Ministry of Forests Coastal Western Hemlock inventory plots (obtained from Alf Kivari, BC Ministry of Forests), **ii)** fitting the growth parameters for the 5 species in the models so that they matched observed DBH relationships for low elevation Coastal Western Hemlock forests, and **iii)** fitting the estimated rates of bank erosion so that riparian tree mortality within 1 m of the stream bank is proportional to that observed coming from this source in the literature.

2) <u>Analysis of LWD-channel morphology parameters in B.C. streams</u>

Extensive information on habitat and LWD abundance was collected at 40 cutthroat trout/coho salmon streams in south coastal British Columbia (Rosenfeld et al. 2000) during a previous FRBC-funded research project (Rosenfeld 2000). This data has been analyzed to provide relationships to paramaterize the LWD-channel structure component of the model, although they have not yet been incorporated into the model. Specific relationships that were analyzed were:

i) probabililty of LWD scouring a pool as a function of LWD diameter-class and channel width

ii) pool-spacing as a function of LWD loading per linear m of stream channel.

Probability of LWD scour as a function of LWD diameter-class at a site was assessed simply by calculating the frequency of pool-formation for all of the LWD in a given diameter-class within surveyed reach. The relationship between probability of scour and LWD diameter-class and channel width were fitted both as a power function of channel width for different size-classes, and as a negative exponential function of channel width for different size classes. The power function was derived by back-transforming a log-log regression of probability of scour on diameter class and channel width, including an appropriate correction factor for bias in back-transformation (see Rosenfeld et. al. 2000 for detailed methods). All data analysis were performed using PC SAS version 8.0.

Pool-spacing as a function of LWD loading per linear m of stream channel was also fit as a power function by back-transforming a log-log regression as described above.

RESULTS & OUTPUTS

1) <u>Riparian forest – LWD recruitment – channel structure – fish abundance model</u>

Programming of the logic of the primary model structure is nearly complete. Only the last module relating channel structure to fish abundance remains to be programmed, and this will be comparatively simple, since channel structure will be related to fish abundance using existing empirical relationships between fish density and habitat type (Rosenfeld et. al. 2000). The model produces desired outputs including riparian forest composition, diameter at breast height (DBH) and height distribution, and LWD pieces per m of stream channel (see Appendix 1 for a more detailed description of model output).

Although the basic model structure is satisfactory, some of the output parameters (e.g. DBH size distributions, Appendix 1) are underestimated, and the model is in the process of being fitted to forest and channel parameters suitable for southwestern B.C. Reasons for the delay in completion of the model and required modifications are considered in more detail in the "Overview of Progress and Deliverables to Date" section below.

At present, the interface of the model is extremely simple, since the focus of model development has been on constructing a model that correctly models the processes involved and produces realistic output, rather than on producing a model with a complex visual interface. A more interactive model with a more detailed visual interface will be a product of the third and fourth year of this project. The visual interface of the present model can be viewed by double-clicking on the "Forestdynamics" VBA application file on the enclosed disc (this program must be accompanied by the other files on the disc in order to run).

2) Analysis of LWD-channel morphology parameters in B.C. streams

The analysis of LWD-channel structure relationships for south coastal B.C. streams is complete (see attached MS "*Relationship Between LWD Characteristics and Pool-Formation in Small Coastal British Columbia Streams*"). This information is key for paramaterizing the sub-model relating LWD inputs to channel structure so that the output applies to streams in B.C. The most important relationship is that between pool spacing and LWD abundance per linear m of stream channel (Fig. 4), which shows that

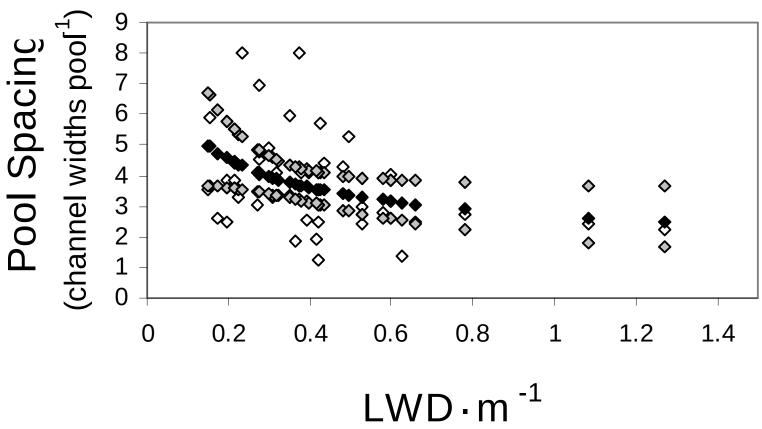

Fig. 4. Pool spacing versus LWD/m for south coastal B.C. streams. Open symbols are observed data and black diamonds are predicted means with 95% confidence intervals.

pool spacing decrease significantly with increased LWD abundance, consistent with observations in other studies.

Differences between our channel-structure LWD relationships and those of other researchers are considered in the attached manuscript.

5. OVERVIEW OF PROGRESS AND DELIVERABLES TO DATE

Overview Of Progress

1) <u>Development and programming of primary model structure</u>

The development and programming of the basic structure of the model is now largely complete (See Appendix 1 for more details on model structure and model code); only the final submodel relating channel structure to fish habitat remains to be programmed, and the final model needs to be fitted to forest biomass and channel structure data for B.C. Model development was not a trivial task, and has taken us much longer than anticipated. In particular, programming the competition between trees and developing adequate suppression of sapling growth by older trees has been very difficult, and was only possible through collaboration with S.L. Garman from Oregon State University. It should be emphasized that this is a very complex model and previous models (e.g. Beechie et al. 2000) have taken decades and multiple graduate theses to develop; given this context, our progress has been relatively rapid.

Our initial work in Year 1 benefited through significant support and assistance from researchers in the B.C. Ministry of Forests, notably Ken Mitchell and Ken Polson with the Forest Productivity Section, who provided useful advice on modeling, and also provided guidance in obtaining forest biomass data for model calibration. Alf Kivari, B.C. Ministry of Forest Data Analyst, also provided extensive support in obtaining data from Coastal Western Hemlock Forest Vegetation Inventory plots for model fitting purposes.

Development of the primary model has taken much longer than expected. We budgeted 14 months for this in the original proposal, and model parameterization is now only approaching completion after 24 months. This is partly due to the fact that funding for the project was delayed 3 months from the start of the fiscal in 2001, but the main reason is that the model has simply been more complex to program than we anticipated. It is difficult to judge in advance the myriad programming complexities that may arise during the course of a complex modeling project such as this, and there is no shortcut to dealing with them other than finding appropriate model parameters and algorithms in the literature, or consulting with other experts, and this takes time.

Nevertheless, the main structure of the model is complete, and programming of the fish habitat module will be a minor task compared to the programming of the individually-based forest growth module and the LWD recruitment-channel structure modules.

2) Model fitting and paramaterization

We are now fitting the model to data from British Columbia forests and small coastal cutthroat steams. Length-DBH relationships for the five species of trees in the model have been extracted from Ministry of Forests Coastal Western Hemlock inventory plot data (obtained from Alf Kivari, BC Ministry of Forests), which we will now use to parameterize maximum tree heights and diameters. We are currently in the process of fitting the growth parameters for the 5 species in the models so that they matched observed DBH relationships for low elevation Coastal Western Hemlock forests. Once this is complete, we will fit the estimated rate of bank erosion so that riparian tree mortality within 1 m of the stream bank is proportional to that observed coming from this source in the literature. This should be the last major model fitting task before the model can be applied to evaluate FPC regulations, although some fitting may be required to fit LWD biomass in the modeled stream channel to observed field values.

3) Analysis of LWD-channel morphology parameters in B.C. streams

Analysis of LWD-channel morphology parameters for small coastal streams is now complete. This information will be critical for calibrating the channel-structure habitat model submodel to streams in British Columbia. Relationships are similar to those found by previous researchers, with the main difference being the lower slope to our pool-spacing vs. LWD/m relationship. This is likely in part due to differences in the way different researchers classifed pools; while other researchers (eg. Montgomery et. al. 1995, Martin 2001) included secondary and tertiary pools (e.g. pocket-pools within larger channel-units) in their habitat inventories, we were relatively conservative in our pool classification and generally only included primary (channel-spanning) pools. This decision was driven by the need to assess fish densities in different habitat types, where sampling fish densities in secondary and tertiary pools would have been difficult as a consequences of the difficulty in isolating these habitats during sampling. In contrast, isolating entire channel units is relatively easy with upper and lower stop-nets. Consequently, our pool-spacing-LWD/m relationship may underestimates the effect of LWD on total habitat complexity relative to previous models.

The coastal streams that we sampled also included streams up to a much higher gradient (9-10%) than those sampled by most other workers (typically < 5%), and therefore included streams where a large proportion of LWD were in log jams; it is likely that as gradient increases and streams take on a step-pool (rather than pool-riffle) morphology where LWD is predominantly in jams, the relationship between LWD and pool-spacing alters. In particular, it is likely that more LWD is required to scour a step pool with a jam, effectively increasing the pool-spacing for a given quantity of LWD, which is consistent with the greater pool spacing at relatively high LWD loadings observed in our study.

There also appears to be an interesting disjunction between our probability of scour vs. channel width relationships, which show that the probability of scour is consistently higher in smaller streams for all but the largest diameter class, and previously published studies that conclude that the effect of LWD in forcing pool formation increases downstream (e.g. Montgomergy et al. 1995, Martin 2001). Our data indicates that LWD is most effective in small streams, which may partially explain why small streams have the highest densities of rearing juvenile salmonids along an upstream-downstream river continuum.

Deliverables to date

1) Finalized model structure – The overall structure of the model is now mostly finalized, although the model still needs to be fully parameterized.

2) Finalized data analysis of LWD-channel structure relationships for small cutthroat trout streams. – This is a key aspect of paramaterizing the model to conditions in cutthroat trout streams in B.C., and is now complete.

This data analysis and the supporting LWD-channel structure relationship and management implications are now in press in the North American Journal of Fisheries Management (copy enclosed), representing the first of several scientific publications that will be produced over the course of this project.

3) I have also include the MS "*Assessing the habitat requirement of stream fishes: an overview and evaluation of different approaches*" (in press with Transaction of the American Fisheries Society) as a partial deliverable from this project. The research that this paper is based on was largely funded through the FRBC project that was a precursor to the present one, and this publication is related to the goals of the present project in so far as it provides a synopsis of methods for fisheries resource managers to use for assessing the relationship between fish abundance and environmental factors. As this is essentially the basic goal of the present project, it can be considered a partial extension product of it.

Assessment Of Progress Relative To Original Milestones (Operational Variances)

Development of the primary model has taken much longer than expected. We budgeted 14 months for this in the original proposal, and model parameterization is now only approaching completion after 24 months. This is partly due to the fact that funding for the project was delayed 3 months from the start of the fiscal in 2001, but the main reason is that the model has simply been more complex to program than we anticipated. It is difficult to judge in advance the myriad programming complexities that may arise during the course of a complex modeling project such as this, and there is no shortcut to dealing with them other than finding appropriate model parameters and algorithms in the literature, or consulting with other experts, and this takes time.

In addition to model completion, the other key deliverable for Year 2 of the project was assessment of Forest Practices Code Riparian Regulations. Since this assessment can only take place after the model is operational, this deliverable remains incomplete.

The other deliverables identified for Year 2 in the original proposal were technical report writing, and submission of a peer-reviewed MS based on model development. These deliverables have been at least partly satisfied, with publication of a significant part of the model in the primary literature.

In effect, the project has been delayed by 6-12 months because of the greater time required for model development, programming, and fitting, a consequence of the extreme model complexity. This means that expected deliverables (see page 7) will also be effectively delayed by 6 months to a year for the duration of the project.

Although there has been a delay in completion of project deliverables, this does not mean that the deliverables will not be forthcoming. It simply reflects that fact that model completion is a necessary first step before any other deliverables can be produced. We are confident that once the model is complete we will be able to deliver on the remainder of the activities in the original proposal. However, this does require that the project be effectively extended for another year, with a new timeline for deliverables is outlined below:

The expected outcomes from the Year 3 of the project are:

1) *A final fully parameterized version of the model.*

2) *A technical report (published in the Provincial Fisheries Research Branch Technical Report Series) describing the model and it's mathematical structure (see Appendix 1 for a draft version).*

3*) An evaluation of the long-term effects of current FPC riparian regulations on cutthroat and coho habitat structure and capacity in small streams.*

4) *An evaluation of alternate riparian management scenarios involving different degrees of riparian basal retention.*

The expected outcomes from the Year 4 of the project are:

5) *Estimation of the projected trajectory (average decrease or increase) of anadromous coastal cutthroat trout habitat capacity in southwestern B.C. based on modeled trends in channel structure on 30 representative cutthroat trout streams sampled during 1997-1998.*

6) *Publication of the model and research in an international peer-reviewed journal for a wider audience.*

7) *Presentation of the model and the results of the research at government workshops and regional and international conferences attended by resource managers and scientists.*

8) *Production of an interactive version of the model that can be used by regional managers to evaluate the long-term effects of different riparian practices on fish habitat.*

The general overall outcomes, impacts, and end-users of the project remain unchanged. The model and associated management recommendations that will emerge from analysis of the long-term impacts of current riparian management practices will have a positive impact on BC's forest sector. Riparian-fish habitat modeling will ensure that managers have a clear understanding of the long-term impacts on fish habitat of selecting different riparian management options. This will go a long way towards addressing much of the uncertainty surrounding the long-term impacts of current riparian practices on fish habitat structure. Use of the model as a research and management tool will also ensure that riparian management under the new results-based code is science-based, and that forest practices in BC protect the long-term capacity of streams and rivers to produce the cultural and economic benefits associated with healthy and productive stream ecosystems.

Because final model development is still pending, no management conclusions can be drawn from the research to date. Similarly, extension products (communication of the effectiveness of different riparian practices through workshops, conference presentations, publications, and development of a user-friendly version of the model as an interactive tool for managers) must follow initial model development and are therefore planned as products of the third and fourth year of the project.

6. EXTENSION

Year 1. No extension activities were part of the original workplan for 2001-2002.

Year 2 (current reporting year). Extension activities originally planned for 2002-2003 included technical report and paper writing. Technical report writing is in progress and will be complete once the model that the report is based on is complete. Peer-reviewed publications based on the model are in press, fulfilling some of the identified deliverables for Year 2.

Future extension activities include in the original project proposal will include:

1) Publication of a technical report describing full model structure (Draft version as Appendix 1)

2) Publication of a research paper in the peer-reviewed literature describing the structure of the model and the long-term impacts of different riparian management practices on LWD dynamics and channel structure.

3) Presentations of the research results at regional and international workshops and conferences.

4) Development of an interactive version of the model as a management tool to be used by managers involved with decision-making with respect to riparian management.

7. SUMMARY AND CONCLUSIONS

The primary research objectives of this project are

i) to develop a model predicting the long-term effects of different riparian management practices on LWD recruitment rates, channel structure, and juvenile cutthroat and coho abundance in small streams.

The subsequent management objectives are

ii) to use the model to evaluate the long-term effects of current (Forest Practices Code) riparian management practices on juvenile cutthroat trout and coho abundance.

iii) to model the effects of alternate riparian management practices (e.g. varying buffer width or basal retention) on cutthroat trout abundance, and

iv) to use the model to project expected long-term trends in juvenile cutthroat trout abundance at 30 representative cutthroat trout streams sampled during 1997-1998.

v) to develop an interactive version of the model for use by resource managers

The primary objective of the first year (2001-2) of this 3-year project was development of the basic model structure. In addition to basic model programming, Year 1 activities also involved analysis of LWD-channel structure relationships in small low-gradient coastal B.C. streams, as a necessary step in calibrating the model for B.C.

The primary accomplishments of the second year (present reporting, 2002-3) of this 3-year project have been 1) near completion of model programming and structure, 2) A significant proportion of model parameterization is complete, 3) completion of analysis of LWD-channel structure relationships for small cutthroat streams 4) publication of this analysis in the North American Journal of Fisheries Management.

The original objective of Year 2 (present reporting year) of the project was to use the model completed in Year 1 to predict the long-term effects of FPC and alternative riparian management practices on juvenile cutthroat trout habitat and fish abundance. However, development and programming of the logic and structure of the model took considerably longer than expected. We budgeted 14 months for model development in the original proposal, and model parameterization is now only approaching completion after 24 months. The main reason for this delay is that the model has simply been much more complex to program than we anticipated – it is difficult to anticipate all of the complexities that may arise in a novel modeling exercise, and solving these problems takes time. Nevertheless, the main structure of the model is complete, and much of model parameterization is also complete, so that the model should be fully paramaterized within several months.

Because of the delayed development of the primary model, all outcomes and deliverables for the rest of the project will be delayed by 6 to 12 months. Consequently, the project will have to be extended for an extra year to finish several of the originally proposed deliverables (e.g. modeling the long-term trajectory of habitat and fish populations at 30 representative cutthroat trout streams), but most identified deliverables will still be produced in Year 3 (see Pg. 18 above). The overall outcomes, impacts, and end-users of the project remain unchanged.

The model and associated management recommendations that will emerge from analysis of the long-term impacts of current riparian management practices will have a positive impact on BC's forest sector. Riparian-fish habitat modeling will ensure that managers have a clear understanding of the long-term impacts on fish habitat of selecting different riparian management options. This will go a long way towards addressing much of the uncertainty surrounding the long-term impacts of current riparian practices on fish habitat structure. Use of the model as a research and management tool will also ensure that riparian management under the new results-based code is science-based, and that forest practices in BC protect the long-term capacity of streams and rivers to produce the cultural and economic benefits associated with healthy and productive stream ecosystems.

The abundance and health of fish in streams is intimately linked to processes and human activities like timber harvesting inside and outside of designated riparian zones. Because forest growth and large woody debris recruitment and decay operate at times steps of decades to centuries, the long-term impact of different riparian management activities is difficult to predict without models that track the complex processes involved over appropriate time scales. The model described in this report represents the first step towards understanding the long-term impact of different riparian management practices on channel structure and fish abundance in low-gradient coastal streams, and should provide a credible foundation for assessing the long-term impacts of current and alternative riparian management practices on fish populations in small streams in British Columbia.

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9. APPENDICES

Appendices 1 and 2 are large, and have therefore been included as separate files.

10. STATEMENT OF EXPENDITURES

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Budget for year 2:

RO2-33 Year 2 Budget
Name: Jordan Rosenfeld
Organization: BC Fisheries

The year 2 Budget for the Project was as follows:

Category	1 (Apr 1 –Jun 30)	2 (Jul 1 –Sept 30)	3 (Oct 1 –Dec 31)	4 (Jan 1 –Mar 31)	Year Total
a)Salaries and stipends Ecological Modeller	$ 10,334	$ 10,334	$ 10,334	$ 3,658	$35,726
b) Employee benefits	$ 1,565	$ 1,565	$ 1,565	$653	$5,217
c) Equipment	0	0	0	0	0
d) Travel	$100	$300	$300	0	$700
e) Materials, Supplies	$100	0	0	0	$100
f) Others	0	0	0	0	0
g) Indirect Costs	0	0	0	0	0
h) Administration Costs	$1,539	$1,539	$1,539	$512	$ 5,130
Year TOTALS	$1,368	$13,730	$ 13,838	$4,980	$46,137

There were no significant deviations from the original approved budget.