A modelling framework to predict relative effects of forest management strategies on coastal stream channel morphology and fish habitat

by

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Abstract

The long-term objective of this research is to identify potential trade-offs between forest management strategies and acceptable bounds of aquatic stream habitat conditions in coastal British Columbia. The question is not only how much we harvest in these coastal watersheds, but how and where we log. Cumulative effects of forest harvesting over many years are considered one of the major threats to salmon populations. Productive freshwater habitat can play a critical role in aiding salmon populations during periods of unfavourable ocean conditions. Preservation of aquatic habitat is thus a critical link in preserving native salmon stocks.

I have developed an integrated modelling framework to qualitatively contrast effects of forest management on channel morphology and fish habitat, using the example of coho salmon (*Oncorhynchus kisutch*), in small and intermediate streams. I attempt to represent the major coastal watershed processes and forest management activities. The model uses operationally available ecological information about forest stand dynamics. It simulates storm peakflow events that drive the system. Debris slides act as the input mechanism of coarse sediment into the channel network and bedload transport in channels is simulated. The recruitment of large woody debris into channels from hillslopes, riparian zones, and upstream channels, and the dynamics of log jams as critical elements for channel morphology and aquatic habitat in coastal streams are also simulated. Changes in channel morphology are tracked and coho salmon habitat capability of the channels is rated. Forest harvesting is simulated to produce diverse cutting patterns across the landscape in terms of harvest volume, spatial and temporal pattern, cutblock size, yarding system and road network. I applied the pixel-based, stochastic modelling framework to a watershed on Vancouver Island. I use this heuristic simulation as an experimental platform to explore alternative management strategies by addressing 'what if' questions.

The modelling framework produces expected trends in regard to log jam numbers, bedload yield, and coho salmon habitat capability rating. In the absence of riparian buffers log jam numbers decrease with increasing harvest volume. Bedload yield increases with increasing debris slide rates and decreasing log jam numbers. Coho salmon habitat capability rating tends to decrease with decreasing log jam numbers. Thus, if we want to create a forest sustainable in terms of productive fish stream habitat, forest resource managers have to plan to provide large woody debris from headwater streams through rivers.

More work must be done in subsequent research to better parameterize this modelling framework. Overall, the system dampens most effects of parameter changes. Results are very sensitive to assumptions about the storm threshold, initial average stand age, frequencies of channel morphology states, maximum channel depth, log jam parameters and the maximum passable channel gradient for coho salmon. Due to the steepness of the channel network in the watershed, channels were degraded rapidly and the habitat capability rating for coho salmon was low.

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6 Conclusions

I have developed an integrated modelling framework to qualitatively contrast effects of forest management on stream channel morphology and coho salmon habitat. The modelling framework uses operationally available ecological information about forest stand dynamics. It simulates storm peakflow events that drive the system. Debris slides as the input mechanism of coarse sediment into the channel network and bedload transport in channels are modelled. The recruitment of large woody debris into channels from hillslopes, riparian zones, and upstream channels, and the dynamics of log jams as critical elements for channel morphology and aquatic habitat in coastal streams are simulated. Changes in channel morphology are tracked and the coho salmon habitat capability of the channels is rated. Forest harvesting is simulated to produce diverse cutting patterns across the landscape.

The modelling framework produces expected trends in regard to log jam numbers, bedload yield, and fish habitat capability rating. In the absence of riparian buffers log jam numbers decrease with increasing harvest volume. Bedload yield increases with increasing debris slide rates and decreasing log jam numbers. Coho salmon habitat capability rating tends to decrease with decreasing log jam numbers. A key finding is that LWD input limits coho salmon habitat quality. Thus, forest managers may need to consider large woody debris input to the channel and log jam dynamics in addition to sediment input when attempting to create a forest that is sustainable in terms of aquatic stream habitat.

Road network length is primarily determined by spatial harvesting pattern and harvest volume. Given a certain harvest volume, dispersed harvesting leads to a longer road network with concomitant negative impacts on stream habitat. Given the magnitude of the debris slide increase due to roads, road network length should be minimized.

Overall, the system dampens most effects of parameter changes. More work must be done in subsequent research to better parameterize this modelling framework and to do additional sensitivity analyses by changing several parameters at the same time. In addition, the number of runs should be increased significantly up to 200-1000 runs. In addition, future work should address the possibility of non-linear effects of parameter changes. Model results are very sensitive to assumptions about the storm threshold, initial average stand age, frequencies of channel morphology states, maximum channel depth, log jam parameters and the maximum passable channel gradient for coho salmon. It was surprising to me how quickly the steep channels became degraded and how low the coho salmon habitat capability was rated in the modelling framework.

Future work should address the variability of stands, especially in the riparian zone. Streambank stability should be simulated to account for additional input and deposition of sediment and large woody debris. The formation of side- and off-channels as critical coho salmon habitat should be modelled.

The modelling framework provides a viable relative comparison of forest management strategies with regard to aquatic stream habitat. The model is automated to analyse multiple scenarios (with multiple runs) successively. A 100-year harvest scenario run on 3,000 grid cells takes 20 seconds, including saving results and loading data for a new run. Given increasing computer power, I speculate that I can run the model on a larger area without any significant problems regarding model run times.

I suggest continuing to use the Russell Creek watershed as an experimental platform as more can be learned from this steep coastal watershed. Because applying the model in a new watershed requires a modest amount of preparation, a second watershed with lower gradients and therefore better coho salmon habitat should be added to further test the model.

The question is not only how much we harvest in these coastal watersheds, but how and where we log. As more watersheds on the central coast of British Columbia are being slated for harvesting, I hope to inform the decision making process by using and further improving this research and communication tool.

Finally, I caution the reader that this modelling framework, like other models that forecast natural systems, does not fully capture the complexity and uncertainty of those systems. However, to move forward, we must proceed with the best information available and improve our knowledge of natural systems and the techniques we use to model them.

6.1 Recommendations for future work

6.1.1 Data and research needs

The predictive power of any model depends on the quality of data. The modelling framework needs to be better parameterized by looking for empirical data in the literature. If these data are not available, field data collection should be initiated.

- Estimate precipitation threshold above which peakflows result in bedload movement.
- Obtain empirical estimates for tree and snag fall rate in riparian zone (compare with existing riparian LWD recruitment models).
- Estimate stand attribute variability over time for hillslope and riparian stands.
- Improve estimation of transition probabilities for stand successional pathways.
- Determine windthrow probability of tree species at forest edges and riparian zones (for example, mistletoe infestation of older hemlock leads to higher windthrow probability).
- Obtain better estimates of breakage of falling trees from the literature.
- Estimate LWD breakage rates when LWD pieces are entrained by a debris slide, transported in a stream channel, or released from a disintegrating log jam.
- Estimate number of log jams at Russell Creek prior and after logging through air-photos.
- Improve estimation of log jam parameters by reviewing literature.
- Obtain better debris slide initiation and deposition probability estimates.
- Estimate (topography-dependent) road multipliers for debris slide initiation function.
- Search for validation of the Channel Assessment Procedure (CAP): are all fish-related conditions and processes represented? Compare with other channel classifications.
- Obtain estimates of channel state frequencies according to the CAP by regional data or watershed assessments.
- Obtain data to validate the qualitative coho salmon habitat capability rating for the CAP channel morphology states. Cross-check coho salmon response to CAP channel dynamics method with other salmonid habitat models.

6.1.2 Model development

Any model framework only shows results for processes that are built into it. What follows is a list of suggested model improvements.

- Simplify the model wherever possible (for example, replace antecedent precipitation by existing water balance computation).
- Simulate baseflow to improve peakflow estimates.
- Link soil infiltrability to material texture of surficial material instead of drainage classes.
- Link geomorphic process information (gullies) to debris slide initiation.
- Implement stand attribute variability into modelling framework.
- Introduce LWD piece breakage rules for log jam break-up.
- Simulate (episodic) changes in channel width due to aggradation and degradation.
- Include streambank stability and sediment/LWD input from and deposition on banks.
- Model channel avulsion and side- and off-channel formation (compare with CAP).
- Track origin of LWD (hillslope, upstream, or riparian) in channel network.
- Simulate constraint of sediment in steep channels by boulder-step formation.
- Incorporate rules for riparian buffer width.
- Speed up model by improving code (for example, switch off map display during runs).

6.1.3 Further analysis

More sensitivity and management analysis runs should be conducted in the future.

- Generate an equilibrium landscape that has no transient initiation effects.
- Analyse channel network pattern and interactions as a measure of stream performance.
- Further explore effects of individual harvesting scenarios.
- Do sensitivity analysis with multiple factors changing to explore parameter interactions.
- Increase the number of runs significantly up to 200-1000 runs per scenario.
- Do sensitivity analysis on ‘multipliers’.
- Address the possibility of non-linear effects of parameter changes.
- Do partial tests of the modelling framework by collaborating with other researchers.
- Apply the modelling framework in a different watershed with a less steep topography and better coho salmon habitat.