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Reducing soil erosion associated with forestry operations through integrated research: an example from coastal British Columbia, Canada

S. C. CHATWIN

British Columbia Ministry of Forests, Research Branch, 1450 Government Street, Victoria, British Columbia, Canada V8W 3E7

R. B. SMITH

Forestry Canada, Pacific Forestry Centre, 506 West Burnside Road, Victoria, British Columbia, Canada V8Z 1M5

Abstract In the late 1970s, several intense rainstorms occurred on the Queen Charlotte Islands triggering many landslides. Some of these slides were associated with clearcut forest harvesting and several impacted directly on salmon-spawning streams. To defuse a growing conflict among resource users and managers, several government agencies developed and funded the Fish/Forestry Interaction Program (FFIP). This programme was initiated in 1981 with the first phase completed in 1986 and the second phase currently in progress. The paper summarizes findings and conclusions relating to the extent and severity of mass wasting and its impact on fish habitat and forest site productivity, the feasibility of rehabilitating damaged streams and forest sites, and the potential to reduce adverse impacts by better harvest planning and by employing alternative silvicultural and logging systems.

BACKGROUND

In October 1978, a series of storms hit the Queen Charlotte Islands, British Columbia. Intense precipitation triggered over 500 landslides in one three day storm, many of which directly impacted salmon spawning streams. Landsliding on previously logged slopes was particularly severe. As a result, the events gave rise to an intense jurisdictional dispute between Provincial government authorities responsible for forest harvesting, and their Federal government counterparts, responsible for the protection of the fishery resource.

In the aftermath of this event, an intergovernment research initiative – the "Fish-Forestry Interaction Program (FFIP)" was established. The mandate of the research programme was to (a) determine the extent and severity of mass wasting and assess its impact on fish habitat and forest sites and (b) to investigate measures for avoiding or mitigating damage attributed to logging related slope failures. The programme was jointly funded by the Federal Department of Fisheries and Oceans, Provincial Departments of Forestry and Environment, as well as other cooperating agencies such as Forestry Canada, FERIC, and industry. The budget for the entire 10-year programme is $2.5 million.

Nine years of research have now been completed in the 10-year programme. This paper summarizes the results of research undertaken to date and discusses the forest management modifications affected by the research.

LOCATION

The Queen Charlotte Islands, an island archipelago about 275 km in length, are located 80 km off the coast of British Columbia (Fig. 1). The glaciated terrain varies from rugged mountains on the west and south up to 1250 m in elevation to lowlands in the northeast. Mean annual precipitation varies from 1150 mm in the northeast to over 4500 mm in the southwest (Karanka, 1986; Hogan & Schwab, 1990).

Forests of western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), yellow cedar (*Chamaecyparis nootkatensis*) and Sitka spruce (*Picea sitchensis*) cover most of the islands. Red alder (*Alnus rubra*) is an important colonizer of disturbed ground. Nearly 200 small streams provide habitat for pink, chum and coho salmon (*Oncorhynchus* sp.) as well as rainbow and cutthroat trout (*Salmo* sp.) important to the sport and commercial fishery (Poulin, 1984).

STUDY DESIGN

A synoptic research design was initially selected for the project. The advantages of this approach were felt to be (a) an opportunity to obtain quick results to a pressing environmental problem (b) better representation of the various physiographic zones of the islands, and (c) provision of a complement to the intensive site-specific basin studies undertaken at Carnation Creek on Vancouver Island. In fact, a range of scales of study have taken place.

IMPACTS AND PROCESSES

Physical impacts

Studies initiated in 1981 were aimed at documenting the amount of damage to fish habitat and forest site productivity resulting from mass wasting and determining the processes involved (Poulin, 1984). Mass wasting occurs naturally throughout the Queen Charlotte Islands but is particularly frequent in the western portions associated with steep terrain, high annual precipitation and five-year return, one-day rainfalls up to 180-200 mm (Karanka, 1986). Gimbarzevsky (1988) identified 8328 debris slides, debris avalanches, debris flows and debris torrents visible on 1:50 000 panchromatic aerial photographs (greater than 0.5 ha in size). Within the active area, frequency of occurrence averaged 2.6 km^{-2} with a maximum of 18 km^{-2}. For the whole Queen Charlotte Islands, the average frequency of mass wasting events was 0.8 km^{-2}. However, working on a smaller area but with more detailed 1:10 000 airphotos, Rood (1984) estimates that the true number of landslides (greater than 0.02 ha in size) is up to 10 times larger.

Hogan & Schwab (1991), using dendrochronological methods, dated every landslide in two large watersheds, and concluded that the frequency of landslide activity is highly episodic. Their dating indicated that four storms in 1891, 1917, 1935, and 1978 were responsible for more than 85% of all landslides that have occurred on the Queen Charlottes in the last century. All but the most recent pre-date local logging.

Two separate studies have investigated site factors associated with landsliding. Rood (1990), based on the study of 1337 landslides on 1:10 000 scale aerial photographs, demonstrated that open slope debris slides increased in

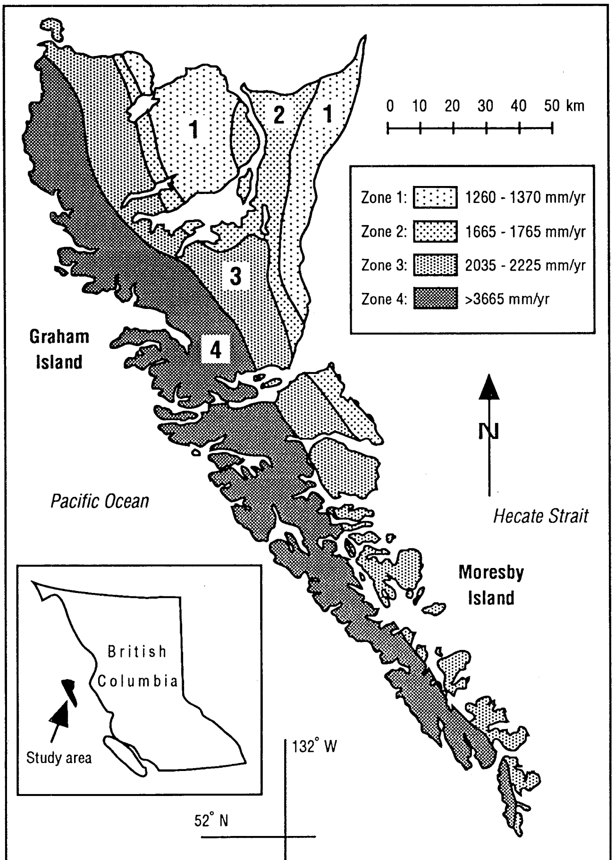

Fig. 1 The Queen Charlotte Islands: location, size, shape and 95% confidence limit precipitation ranges (adapted from Hogan & Schwab, 1990).

frequency as the percentage of area occupied by slopes over 70% increased and that more landslides were initiated on concave slopes than on convex slopes. Niemann & Howes (1991) have further developed this relationship between hillslope geometry and landslide incidence. Working with 25 m digital elevation data, they were able to create maps predicting landslide risk over a broad area. Their approach was to create algorithms that described hillslope shape in terms of gradient, two-dimensional curvature, and distance from drainage divide, and then to create computer-generated maps that indicated landslide hazard. In "blind tests" very good comparisons have been made with actual landslide occurrence.

Actual hillslope sediment yield was estimated by Rood (1984), who concluded that clearcut logging and associated road construction (average age of 7 years) increased the frequency of mass wasting events by 34 times and the volume of soil moved by 35 times over that experienced on adjacent unlogged terrain. Approximately 39% of the soil mass wasted from forested terrain and 47% from clearcut areas entered stream systems (Rood 1984). In total, sediment delivery to stream channels in logged areas was increased by 23 times. Roberts (1987) determined that this type of material plus erosion from streambanks contributed about 70% of the volumes in sediment wedges located in the mid-reaches of streams in logged basins. These wedges of sediment are transported downstream in waves, but, because they are often broader than the stream channels, considerable volumes of the wedge material can end up as fairly stable terraces. Much of the volume of sediments was attributed to outdated logging practices such as felling across streams, yarding through or across streams and locating roads along streams.

Hogan (1986) concluded that relative to unlogged and recently logged basins, old (>20 years) logging practices increased the down-channel orientation of large organic debris, thus reducing the pool to riffle ratio, and produced larger sediment volumes located in fewer storage sites with a consequent decrease in channel stability. According to him, these changes would reduce the quality of habitat for salmonid incubation and rearing. From his work, he offered guidelines on pool depths, pool/riffle spacing and proper placement of large organic debris (LOD).

The crucial importance of log jams in controlling channel morphology has also been described by Hogan (1987). The age of the jam is the primary factor controlling channel morphology. The jams interrupt the transfer of sediment and therefore control the morphology of the stream. However, because the debris breaks down over time, the structure's functional role is altered as the jam ages. It was shown that severe morphological alterations persist during the first decade following landslide damage, but that the channel begins to develop more normal characteristics about 30 years after disturbance.

Rice (1991) has completed detailed work on the role of log jams in logged and unlogged streams, in controlling gravel texture. Unlike "normal" streams, where streambed textures become finer with distance downstream, streams affected by the landslide and jams, have a surface sediment texture which is significantly finer upstream of recent jams. In contrast, the pattern is reversed near older jams where coarser sediment occurs upstream. Older jams evidenced significantly less scour and fill than younger jams. This work has important implications to fish spawning success.

Biological impacts

Surveys of 44 streams undertaken by Tripp & Poulin (1986a) indicated that stream reaches directly affected by debris torrents had 20-24% less pool depth, 38-45% less pool area, 57% less large organic debris cover and 76% less undercut bank cover. Even without debris torrents, logging was found to reduce undercut bank cover considerably, but had less effect on the other habitat features. Tripp & Poulin (1986b) showed that logging with or without mass wasting increased fine sediment levels, causing a decline in coho salmon egg to fry survival of 15-20%, i.e. from 26% to 6-11%.

Tripp & Poulin (in press) found, however, that summer and fall coho fry densities were significantly higher in logged reaches, and that, surprisingly, fish in streams affected by mass wasting exhibited faster growth rates and larger sizes. However, reduction in the over-winter survival rates by two thirds in the streams with logging and mass wasting nullified any gains in production.

In addition to effects on fish production, mass wasting, particularly debris slides and avalanches, was estimated to reduce forest productivity on the slide scars by 70% over the first 50 years (Smith *et al.*, 1986). This was primarily due to the scouring of soil from the upper portion of the slides and to the colonization of the lower portions with red alder, a seral short-lived tree species. Rates of recolonization of slide scars and plant composition were related to position on the slope and bedrock type. To increase wood production, the authors recommended early planting of Sitka spruce and at least partial control of red alder on the relatively stable and productive lower slopes of landslide scars. On upper slopes, enhancement of nitrogen-fixing plants such as Sitka alder (*Alnus sinuata*) should accelerate recovery processes and reduce long-term soil erosion problems.

AVOIDANCE AND MITIGATION OF LANDSLIDES

Improvements in forest harvesting

Clearcutting, is the predominant harvesting system in the Queen Charlotte Islands (Sanders & Wilford, 1986). For harvesting old-growth stands, these authors recommend modifications to the current system to reduce mass wasting, rather than any significant shift to partial cutting systems, except for particularly sensitive sites. The yarding systems most in use at the time of the study were the portable steel spar employing a highlead or modified highlead (scabline) system and the mobile yarding crane employing a grapple or chokers (Sauder & Wellburn, 1987). Skyline systems are used for increased yarding distance and where there is a need to suspend logs fully over sensitive terrain. Sauder & Wellburn (1989) stressed the importance of planning for a combination of logging systems to match terrain conditions to road corridors and landings. They used intensive ground mapping data from two basins to demonstrate good harvest planning on sensitive terrain, including the provision of a series of alternative logging plans aimed at minimizing potential mass wasting. Of 102 landslides surveyed by Krag *et al.* (1986), 31 originated at or near roads, 66 began off-road and five originated in natural forest. Most of the road-associated failures had their origin in overloaded fillslopes, lack of drainage control and inadequate road maintenance. The direct causes of off-road failures were more difficult to pinpoint but gouging, stump damage and uprooting during yarding, windthrow, post-logging root decay, rainstorms and seismic activity were all implicated.

A new experiment, begun in 1990, is assessing the potential for large capacity helicopters (Sikorsky Skycrane) to log steep slopes without the mass wasting impact of conventional logging. At three sites, cutblocks have been divided into treatment blocks with various levels of helicopter partial cut logging (10-50% tree harvest) as well as clearcutting. The results may show whether the combined benefits of partially retaining the forest, i.e. to maintain root strength and intercept rainfall, and reduced soil disturbance can reduce the incidence of landslides. Silviculturists are monitoring natural regeneration and the growth of planted stock in the partially cut stands.

Early in the FFIP programme, it became apparent that harvesting around gullies creates the greatest risk of introducing sediment to channels. Some 87% of landslides affecting fish streams are transported down gullies. Current research is addressing the application of helicopters as well as skyline logging systems in reducing sediment and logging slash inputs to gullies. A second experiment is examining the role of woody debris in controlling gully erosion, sediment output and storage. A series of gullies is being completely cleaned of woody debris, and compared with forested gullies and logging slash filled gullies. A third gully project is studying the use of inexpensive reinforced earth berms and dykes to control debris flows, and reduce the amount of sediment reaching streams.

Stream and hillslope rehabilitation

Rehabilitation opportunities for streams following mass wasting include gravel cleaning, gabions, log sills, removal of log jams, boulder placement and development of side pools and channels (Bustard, 1984). Klassen (1984) installed and monitored tandem V-shaped gabion weirs in damaged streams. Those installed in low gradient (1%) stream reaches were successful in producing moderate quality salmonid spawning habitat. At a 3% gradient, the gabions were not successful in stabilizing the gravel during storm flows. The gabions have not withstood the test of time, however, with the wire breaking down after five years and posing a hazard to spawning fish.

Tripp (1986) tested an alternative approach to stream rehabilitation, in which large organic debris in the form of logs were placed and secured with logging cable in six streams previously affected by debris torrents. The emplaced logs triggered a rapid development of new pool habitats and a consequent increase in the over winter survival and smolt production of coho salmon. Off-channel habitat was also developed by excavating or blasting streamside ponds. Scour, new debris torrents, and siltation have rendered some of the structures inoperative. A field evaluation of all the structures is currently underway and a "Field Guide for Stream Rehabilitation Structures" is planned.

Many landslides and channel impacts are now occurring in basins where logging was finished a number of years ago. With discontinuance of road maintenance, many drainage structures are failing, creating widespread sediment problems. A procedure for basin scale hillslope rehabilitation plans was developed by Carr & Wright (1991) who present a methodology for mapping, prioritizing, costing and scheduling of erosion control on a basin planning unit. The assessment procedure is based on a matrix calculation of size of the erosion source, its risk to fishery streams and the ability to rehabilitate the site.

Rehabilitating landslide scars and roads mainly involves the use of mechanical site preparation, erosion control fabrics and mulches, and planting and hydroseeding to establish vegetation (Carr, 1985). In 1984, Beese (1988) established trials to test methods of erosion control and conifer establishment on landslide scars.

Recommendations for rehabilitation measures have been summarized in a practical field-oriented handbook (Chatwin *et al.*, 1991). The manual has specific prescriptions for slope stability assessment, prevention and stabilization of landslides, and hillslope rehabilitation.

APPLICATION OF RESULTS

It is difficult to isolate the influence of this research project on forest management practices. Certainly increased public awareness, increased interest in environmentally sensitive management, and concern for sustainable forestry have all developed during the nine years of the FFIP. In the specific area of management of landslide prone terrain, however, some changes can be attributed at least partially to the research programme:

(a) *Reductions in timber supply areas because of concern for slope stability.* These reductions can be substantial; for example on the Queen Charlotte Islands, the available operable forest has been reduced by 16% (approximately 40 000 000 m^3 of wood).

(b) *Slope stability mapping.* Today, virtually all coastal timber land is field mapped for landslide risk using a five class terrain hazard system.

(c) *Harvest planning and logging guidelines.* Slope stability maps are now used extensively to plan road locations and cutblocks to avoid sensitive areas. A set of guidelines "The Coastal Fishery-Forestry Guidelines" issued in 1988, partly based on FFIP results, gives detailed logging prescriptions to avoid environmental impact. Now all planned cutting blocks must be referred to Fisheries agencies for prior approval.

(d) *Alternate harvesting systems.* More companies are now purchasing and using skylines and helicopters for steep slope logging.

(e) *Improved road building practices.* Dramatic decreases in road-related landslides have resulted through greater planning and use of backhoes instead of bulldozers for road construction. Road related failures are less than 20% of the levels recorded at the beginning of FFIP.

Beyond these specific management improvements, there has also been a greater awareness amongst all agencies – forestry and fisheries – of the natural role of landslides. Landsliding has been a feature of coastal British Columbia for centuries, and the channel morphology and fish habitat is largely the result of landslide activity. Not surprisingly, salmon have adapted to this environment and in fact to a degree require it. Our integrated management challenge however is to understand thresholds and to operate within them.

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