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Footprint Impacts of Hydroelectric Development on Coarse Woody Debris: An Assessment for Vancouver Island Watersheds

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Executive Summary

The creation of hydroelectric reservoirs in the Campbell, Puntledge, Jordan and Ash watersheds on Vancouver Island resulted in the loss of forested habitat and associated wildlife. An important attribute of forested ecosystems used by numerous wildlife species is coarse woody debris (CWD), which is defined here as woody material >10 cm in diameter lying on the ground, including stumps <2 m tall. The effects of this habitat loss on terrestrial wildlife species that use CWD have not been assessed; therefore, we reviewed existing literature to: 1) characterize areas and volumes of CWD lost to reservoir construction; 2) assemble a list of terrestrial vertebrate species that use CWD and were likely affected by this habitat loss; and 3) review strategies to restore or enhance CWD.

The area of forests flooded in the 4 watersheds totalled 4577 ha within the CWHxm1, CWHxm2 and CWHmm1 biogeoclimatic subzone variants. Coarse woody debris volumes are poorly characterized in these subzones; however, available data suggest that CWD volumes are considerably lower in the relatively dry CWHxm and CWHmm1 than in the wetter CWHvm characteristic of western and northern Vancouver Island.

Twenty-two terrestrial vertebrate species that use CWD are present in CWH forests of Vancouver Island. Of these, 3 are amphibians, 15 are mammals of 9 different families, and 5 are birds. Species differ in their reliance on CWD. For example, salamanders constitute the only CWD-dependent species group, while shrews, deer mice (*Peromyscus maniculatus)*, mustelids, and black bears (*Ursus americanus*) use CWD extensively but are not dependent on CWD to meet life history requirements. Some species are likely to respond to CWD manipulations only where other habitat features co-occur (*e,g,* Vancouver Island water shrew, *Sorex palustris brooksi*, and riparian habitat).

There are two main opportunities for restoring and enhancing CWD in watersheds affected by BC Hydro activities: 1) negotiating changes in forest management with licensees; and 2) improving the value of existing volumes of CWD. Forest management practices that increase CWD are generally those that encourage old forest attributes, such as longer rotations combined with retention systems. The value of existing CWD can be improved by modifying existing CWD so that it decays more quickly, or provides qualities characteristic of larger or more decayed CWD.

Projects that manipulate volumes or characteristics of CWD should include pre- and post-treatment monitoring to assess the response of target wildlife species to manipulations.

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Introduction

Coarse woody debris (CWD) is defined in the *Biodiversity Guidebook* (BC Ministry of Forests 1995) as: "sound and rotting logs and stumps that provide habitat for plants, animals and insects and a source of nutrients for soil development" (page 74). Coarse woody debris is an important component of forests and contributes significantly to the structure and function of forest ecosystems (Harmon et al. 1986, Caza 1993, Stevens 1997, Clark et al. 1998). It also provides important habitat for a variety of coastal forest-dwelling wildlife species (Corn and Bury 1991a, 1991b, Craig 1993, Bunnell 1995, Bull et al. 1997, Bunnell et al. 1999).

The creation of hydroelectric reservoirs in the Campbell, Puntledge, Jordan and Ash watersheds on Vancouver Island resulted in the direct loss of CWD habitat (BCRP 2000a). The extent of this loss is both a function of characteristic volumes of CWD found in coastal ecosystems, and the size of areas flooded in each watershed.

Volumes of CWD in forested ecosystems are influenced by many factors. Recruitment of trees into CWD occurs through a number of processes: wind, fire, insects, disease, stand suppression and competition, slope failures and senescence (Stevens 1997). Volumes are also influenced by the decay rate of recruited trees. Mechanical disturbance and climate are important factors affecting rates of decay (Stevens 1997). Although the importance of these processes and resulting rates of recruitment and decay are site-specific, general patterns are definable by biogeoclimatic ecosystem classifications and by disturbance history. These general patterns in the amount of CWD can then be related to terrestrial wildlife communities.

The goal of the Bridge-Coastal Fish and Wildlife Restoration Program (BCRP 2000a, 2000b) is to restore, to the extent possible, fish and wildlife resources that have been adversely affected by reservoir creation, watercourse diversion, and dam construction associated with the development of hydroelectric facilities. The purpose of this needs analysis was to determine the extent of the habitat loss (in terms of area and volume of CWD), the terrestrial vertebrate species directly affected by this habitat loss, and management prescriptions to enhance remaining CWD habitat.

Methods

The minimum size of log considered CWD has varied among studies (Lofroth 1998). Here we consider CWD to be woody material >10 cm in diameter lying on the ground, including stumps <2 m tall that result from standing dead trees breaking off close to the ground.

We reviewed existing literature and consulted regional experts to answer the following questions:

1. How much coarse woody debris habitat has been lost as a direct result of reservoir construction?

Footprint impacts were assessed as part of the BCRP strategic planning process. We estimated the proportion of flooded areas that fell into different biogeoclimatic (BEC) subzone variants (Meidinger and Pojar 1991) by examining BEC coverages of reservoir areas in relation to maps of historic and current hydrology (BCRP 2000b).

2. What are the characteristic volumes of coarse woody debris in habitats flooded by reservoir construction?

We reviewed literature and consulted experts to collect information on coarse woody debris volumes in seral stages and disturbance histories found in BC Hydro-managed watersheds. Information was collected for structural stages 6 and 7 and stratified by BEC subzone variant, where data were available (BC Ministry of Environment, Land and Parks and BC Ministry of Forests 1998).

We characterized CWD by volume, based on van Wagner's (1982) equation:

$$V = (k / L) \sum d^2$$

where V is the CWD volume, k is a constant equal to 1.234, L is length of the sampling transect, and d is the diameter of a piece of CWD where the transect intersects the wood. We also report volumes of large diameter (*i.e.* >40 cm) CWD, where data were available.

CWD data are incomplete for BEC subzone variants on Vancouver Island (Feller, *unpublished*, Stevens 1997). As a result, we also summarized data available for the CWH zone by broad moisture regimes, following the methods of Qiwei (1997).

3. What species have been affected?

We focused our analysis on the relationship between CWD and terrestrial vertebrate wildlife species. Craig (1993) compiled species lists of native forest-dwelling vertebrates that use CWD for breeding, stratified by BEC zone. Areas flooded by reservoirs on Vancouver Island are in the Coastal Western Hemlock (CWH) zone. We used amphibian, reptile, bird and mammal lists for the CWH zone from Craig (1993) as the basis for our analysis of species impacts. We also reviewed the literature to compile information on the effects of CWD changes on terrestrial vertebrate species found in affected watersheds.

We used ranges described and/or mapped by Cowan and Guiguet (1965) to determine whether affected watersheds were within species' ranges. We noted subspecific designations only where species were "blue" or "red" listed by the BC Conservation Data Centre (http://www.env.gov.bc.ca/rib/wis/cdc/list.htm).

Species vary in their dependence on CWD. Dependence is most obvious among species that use CWD for breeding, and secondarily among species that forage on insects that are abundant in CWD (Bunnell et al. 1999). Other species will use CWD if it is available, but do not require it and are unlikely to respond to manipulations (Bunnell et al. 1999). Some species are likely to respond to CWD manipulations only where they co-occur with other habitat features (*e.g.* riparian areas).

We grouped species into high, medium, and low classes according to their dependence on coarse woody debris (Table 1), and noted any dependence on co-occurring habitat features. Because virtually all forest birds can glean insects from CWD as well as other forest features, we assessed the relationship between bird species and CWD based only on nesting habitat.

Table 1. Criteria for classifying species according to their dependence on coarse woody debris.

CWD-dependence category	Description
High	CWD required for breeding or foraging habitat; species affected by levels of CWD
Moderate	CWD an important habitat component for breeding, foraging, or cover; species likely to respond to levels of CWD
Low	CWD used if present; response to CWD manipulations will depend on availability of substitutable habitat resources

4. What are the management options to increase coarse woody debris?

We reviewed management options for increasing and/or altering CWD and investigated research and monitoring requirements to determine the effectiveness of CWD manipulations on CWD-dependent guilds or species.

Results

1. How much coarse woody debris habitat has been lost?

CWD habitat was lost as a direct result of flooding upland and lowland deciduous and coniferous forests (Table 2). Of the 4 affected watersheds on Vancouver Island, most CWD habitat was lost in the Campbell. Footprint impacts are restricted to 2 CWH subzones: the Very Dry Maritime (consisting of 2 variants, CWHxm1 and CWHxm2 that are generally not differentiated [Green and Klinka 1994]) and the Submontane Moist Maritime Variant (CWHmm1; Table 3).

Habitat along 116 km of streams (again, mostly in the Campbell) was also affected by flooding, although the impact on CWD is difficult to quantify.

Table 2. Estimated habitat flooded by reservoir construction in 4 Vancouver Island watersheds (from BCRP 2000, Appendix 1).

	Area flooded (ha)			
Watershed	**Upland habitat**	**Lowland deciduous**	**Lowland coniferous**	**Total**
Campbell	647	350	2880	3877
Puntledge	133	90	0	223
Ash River	21	26	252	299
Jordan	178	0	0	178
Total	979	466	3132	4577

Table 3. Estimated area flooded by reservoir construction in 4 Vancouver Island watersheds, by biogeoclimatic subzone variant.

	Biogeoclimatic subzone variant flooded						
	CWHxm1		CWHxm2		CWHmm1		
Watershed	**Proportion[1]**	**Area (ha)**	**Proportion[1]**	**Area (ha)**	**Proportion[1]**	**Area (ha)**	**Total**
Campbell	0.15	582	0.85	3295	0	0	3877
Puntledge	0.20	45	0.80	178	0	0	223
Ash River	0	0	0.40	120	0.60	179	299
Jordan	1	178	0	0	0	0	178
Total		805		3593		179	4577

[1]Estimated proportion of the flooded area of each watershed that falls within the BEC subzone variant boundary

2. What are the characteristic volumes of coarse woody debris in habitats flooded by reservoir construction?

Flooded portions of the Campbell, Puntledge and Jordan watersheds fall within the CWHxm subzone, which is characterized by warm, dry summers and moist, mild winters with relatively little snowfall. Growing seasons are long, and sites are dominated by overstories of Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), with understories consisting primarily of salal (*Gaultheria shallon*), Oregon grape (*Mahonia nervosa*) and red huckleberry (*Vaccinium parvifolium*, Green and Klinka 1994).

Habitat flooded in the Ash River watershed falls within the CWHmm1 subzone variant, which is typically found at higher elevations than CWHxm. As a result, summers are cooler than in the CWHxm but still relatively dry, and western hemlock is dominant in the forest canopy, along with amabalis fir (*Abies amabalis*) and some Douglas fir.

Both the CWHxm and CWHmm1 are classified as Natural Disturbance Type 2, which is characterized by infrequent stand-initiating events with mean return intervals of 200 years (BC Ministry of Forests 1995). Coarse woody debris in the CWHxm and CWHmm1 are poorly characterized. We found volume data for only 3 plots in the CWHxm (Wells and Trofymow 1997, Feller, *unpublished*) and none in the CWHmm1 (Table 4). With respect to broad moisture regimes, the highest volumes of downed wood were found in wet or mesic CWH sites, while drier sites had the lowest volumes (Table 4).

Using a conservative estimate of 100 m^3/ha in the both the CWHxm and CWHmm1, >450,000 m^3 of CWD was lost as a result of reservoir flooding in the 4 Vancouver Island watersheds.

3. What species have been affected?

Twenty-two terrestrial vertebrate species that use CWD are present in the CWH forests of Vancouver Island (Cowan and Guiguet 1965, Craig 1993; Table 5). Of these, 3 are amphibians, 15 are mammals of 9 different families, and 5 are birds.

Table 4. Coarse woody debris (CWD) volumes recorded at sites in the Coastal Western Hemlock biogeoclimatic (BEC) zone of British Columbia. Data are summarized by broad moisture regimes. Natural Disturbance Types (BC Ministry of Forests 1995) are abbreviated "NDT".

Broad class	BEC subzone/variant	NDT	Number of sites	Mean CWD volume m^3/ha	Mean CWD volume >40 cm diameter	Range	Reference
CWH dry	CWHxm	2	4	119		55-149	Wells and Trofymow (1997) and Feller (*unpublished*)
CWH wet	CWHvm	1	4	650		307-698	Wells and Trofymow (1997) and Feller (*unpublished*)
CWH wet	CWHvm1 and CWHvm2	1	106	573	161	41-1428	Qiwei (1997) and Stevens (1997)
CWH mesic	CWHvm1 and CWHvm2	1	55	868	321	13-1788	Qiwei (1997) and Stevens (1997)
CWH dry	CWHdm	2	30	179	146	41-440	Qiwei (1997)

Table 5. Species that use coarse woody debris (CWD) in the Coastal Western Hemlock biogeoclimatic (BEC) zone of Vancouver Island. Species were rated according to their dependency on CWD based on the criteria listed in *Table 1*. "CDC Status" references species of concern listed by the BC Conservation Data Centre.

Class	Order	Family	Species	Common name	Other habitat features	CDC Status	CWD rating	Reference
Amphibia	Caudata	Plethodontidae	*Aneides ferreus*	Clouded Salamander	More abundant in riparian habitat		High	Whitaker et al. (1986), Bury and Corn (1988), Dupuis et al. (1995), Bunnell et al. (1999)
			Ensatina eschscholtzii	Ensatina Salamander	More abundant in riparian habitat		High	Aubry et al. (1988), Bury and Corn (1988), Dupuis et al. (1995)
			Plethodon vehiculum	Western Red-backed Salamander	More abundant in riparian habitat		High	Aubry et al. (1988), Dupuis et al. (1995)
Mammalia	Insectivora	Soricidae	*Sorex monticolus*	Dusky Shrew			Moderate	Corn et al. (1988), Craig (1995)
			Sorex palustris brooski	Vancouver Island Water Shrew	Require riparian habitat	Red	Moderate	Craig and Wilson (2001)
			Sorex vagrans	Vagrant Shrew			Moderate	Corn et al. (1988), Craig (1995)
	Rodentia	Castoridae	*Castor canadensis*	Beaver	Require riparian habitat		Low	Lofroth (1998)

Class	Order	Family	Species	Common name	Other habitat features	CDC Status	CWD rating	Reference
		Cricetidae	*Peromyscus maniculatus*	Deer Mouse			Moderate	Carter (1993), Carey and Johonson (1995), Craig (in review)
		Sciuridae	*Tamiasciurus hudsonicus*	Red Squirrel			Low	Maser et al. (1979)
	Carnivora	Canidae	*Canis lupus*	Gray Wolf	Adequate prey base		Low	Keisker (2000)
		Felidae	*Felis concolor*	Cougar	Adequate prey base		Low	Van Dyke et al. (1986), Keisker (2000)
		Mustelidae	*Gulo gulo vancouverensis*	Vancouver Island Wolverine		Red	Low	Bunnell et al. (1999)
			Lontra canadensis	River Otter	Require riparian habitat		Moderate	Lofroth (1998)
			Martes americana	Marten	Forest canopy cover		Moderate	Lofroth (1993), Bunnell et al. (1999)
			Mustela erminea anguinae	Ermine		Blue	Moderate	Mowatt et al. (1998), Keisker (2000), Oregon Department of Foresty (2001)
			Mustela vison	Mink	Require riparian habitat		Moderate	Lofroth (1998)

Class	Order	Family	Species	Common name	Other habitat features	CDC Status	CWD rating	Reference
		Procyonidae	*Procyon lotor*	Raccoon			Low	Oregon Department of Forestry (2001)
		Ursidae	*Ursus americanus*	Black Bear			Moderate	Davis (1996a)
Aves	Galliformes	Phasianidae	*Dendragapus obscurus*	Blue Grouse			Low	Craig (1993), Campbell et al. (1990)
			Bonasa umbellus	Ruffed Grouse			Low	Craig (1993), Campbell et al. (1990)
		Scolopacidae	*Actitus macularia*	Spotted Sandpiper	Freshwater edges		Low	Craig (1993), Campbell et al. (1990)
		Laridae	*Larus canus*	Mew Gull	Freshwater edges		Low	Craig (1993), Campbell et al. (1990)
	Passeriformes	Troglodytidae	*Troglodytes troglodytes*	Winter Wren			Low	Craig (1993), Campbell et al. (1997)

The salamanders are the only CWD-dependent species (CWD rating "high"), while shrews, deer mice (*Peromyscus maniculatus)*, mustelids, and black bears (*Ursus americanus*) constitute the *moderate* group. Seven amphibian and mammal species are either more abundant in, or dependent on, the presence of riparian habitat in addition to CWD. All breeding bird species were rated *low* for CWD use, and 2 of 5 species nest near edges of freshwater lakes and rivers.

Discussion

Volumes of coarse woody debris in habitats lost to flooding and hydroelectric activities

The CWH zone has the highest volumes and longest persistence times of CWD of any BEC zone in British Columbia (Feller, *unpublished*). This is due to the large CWD logs that result from high volumes of standing wood – a consequence of long growing seasons, abundant rainfall, and long intervals between stand-initiating fires. In addition, some species common to the CWH are resistant to decay (*e.g.* Western redcedar, *Thuja plicata*). In the CWH, gap dynamics (occasional death of individual trees or groups of trees within the forest) is the primary process through which CWD is added to the system.

Few studies have explicitly examined the characteristics of CWD in the CWH on Vancouver Island, and data are incomplete for BEC subzone variants (Feller, *unpublished*, Stevens 1997). Studies focussed on other aspects of forest ecology have collected some CWD data (*e.g.* Huggard 2000); however, data collection methods and reporting vary. A broad literature search of forest ecology and wildlife studies conducted on Vancouver Island with, in some cases, a reanalysis of the authors' original data, might address some existing data gaps; however, the task is beyond the scope of this analysis. As a result, characteristic volumes of CWD must be extrapolated from few data, or from similar subzone variants, in order to estimate what has been lost as a result of flooding.

Summarized by broad moisture regime, dry CWH sites have lower volumes of CWD than wetter sites. This pattern is characteristic among all BEC zones in the Province where data are available (Qiwei 1997). Poorer site productivity and more frequent stand-initiating fires on drier sites (dry CWH subzone variants are NDT 2 as opposed to NDT 1 in wetter variants) are responsible for the lower CWD volumes.

Coarse woody debris data suggest that the CWHxm has the lowest CWD volumes of any CWH subzone variant. No data were available for the CWHmm1, but its climate and stand characteristics suggest that it is most similar to the CWHdm, at least among subzone variants where CWD data are available. Both the CWHmm1 and CWHdm occur adjacent to, but at higher elevations than, the CWHxm. The CWHmm1 typically occurs on east facing slopes of south-central Vancouver Island while the CWHdm is characteristic of western-facing terrain on the sunshine coast (Green and Klinka 1994). From this we conclude that CWD volumes in the CWHmm1 are likely higher than those reported in the CWHxm, and perhaps in the range of those reported for the CWHdm.

Characteristics of coarse woody debris

The usefulness of CWD to mammals is heavily influenced by piece size. In general, some requirements of the smallest mammals such as shrews and mice can be satisfied by pieces as small in diameter as 6 cm (Craig 1995); however, larger species such as the black bear require logs >100 cm in diameter (Davis 1996a). Available data suggest that sites in the CWH with the most CWD are also the sites with the highest volumes of CWD in large pieces, although dry sites (with lower characteristic volumes of CWD than mesic or wet sites) have proportionately higher volumes in large pieces (>80% of total volume in pieces >40 cm).

The stage of decay of CWD also influences its function for wildlife. Decay characteristics of CWD and the ecological roles of CWD in the forest throughout the decay process have been exhaustively reviewed by other authors (Maser et al. 1979, Maser and Trappe 1984, Bartels et al. 1985, Carey and Johnson 1995, Harmon et al. 1996). Decay stages are normally described as a series of either 3 (Hope 1987) or 5 (Maser et al. 1979) stages. Maser et al. (1979) described changes in the composition of a log over time from one with intact bark and twigs and needles to one that is largely incorporated into the forest floor:

- Decay class 1 – Logs are solid with intact bark, branches, twigs, and needles. Once a log like this falls, there can be a delay of 1-2 years before decomposer organisms are able to invade (Grier 1978)
- Decay class 2 – Bark is still intact, but needles are gone, twigs are missing, and only large segments of branch remain
- Decay class 3 – Bark is loose and starting to slough off, and all remaining branches have broken off. The smaller end of the log is starting to be incorporated into the ground, and any piece off the ground is starting to sag. The log is starting to soften, and breaks into large hard pieces
- Decay class 4 – The entire log is touching the ground, and most of it is partially incorporated in the ground. The log is fairly soft, and breaks into small blocky pieces
- Decay class 5 – The log is soft and is fully incorporated into the ground. Only a small mound identifies it from the rest of the forest floor

The rate of CWD decay and, consequently, the time it remains available as wildlife habitat, depends on the climate, piece size, species (Maser et al. 1979), and whether it is located in a terrestrial or aquatic environment (Harmon et al. 1986). Stone et al. (1998) reported that Vancouver Island Douglas-fir logs <20 cm diameter had fully decayed within 65 years, and that decay rates were slower for larger pieces. In aquatic environments, microbial decay of CWD is slow while physical abrasion by water is significant, leading to faster rates of decay in streams than on land (Aumen 1985).

Decay occurs primarily through 3 processes (Harmon et al. 1986):

- Leaching of nutrients via water transport from the log to the ground
- Fragmentation, where the log is gradually broken into smaller pieces that decay more rapidly. Fragmentation normally occurs through the interactive effects of gravity, water, decay organisms such as microbes and invertebrates, and the actions of plants and animals

- Respiration by microbes (primarily basidiomycetes terrestrially, and actinomycetes in aquatic environments), which releases matter

The importance and function of downed wood to wildlife varies by decay class:

- Class 1 – Logs can be used for cover by deer mice and terrestrial shrews, and perching sites for squirrels (Maser et al. 1979). They can also be important structural elements in streams and larger waterbodies for species such as water shrews (*Sorex palustris brooksi*; Craig and Wilson 2001)
- Class 2 and 3 – As a result of insect colonization, logs provide foraging sites for shrews, deer mice and black bears (Maser et al. 1979). Spaces under loose bark on late class 2 and decay class 3 logs provide important thermal and security cover for amphibians and small mammals (Maser et al. 1979). Class 3 logs rest on the ground, and small mammals construct runways beside logs and under overhangs that offer cover from aerial predators (Craig 1995, Hayes and Cross 1987)
- Class 4 and 5 – Small mammals burrow into logs to create nest sites, which are subsequently used by amphibians, weasels, and squirrels (Maser et al. 1979). Shrews and squirrels will also cache food in these decayed logs (Maser et al. 1979). Decay class 4 and 5 logs provide forage for species seeking invertebrates and mycorrhizal fungi (Maser et al. 1979). Decay class 5 logs normally host well-developed tunnel or burrow systems; shrews travel extensively underground in tunnels in well-decayed logs (Craig 1995), as do other small mammals and amphibians (Maser et al. 1979)

The time required for logs to completely decay is correlated with mass (Feller 1997). Mean mass of CWD on old-growth sites in the CWH is higher than in other coastal BEC zones. Consequently, logs in the CWH also have the longest decay times – sometimes >800 years. As a result, CWD in coastal ecosystem might be a more significant habitat for wildlife than CWD in other ecosystems.

Coarse woody debris in stream habitats

The lack of CWD in downstream habitats has been identified by BC Hydro as a consequence of hydroelectric activities (BCRP 2000). The presence of CWD inhibits the movement of sediments such as silt, which can smother natural substrates and adversely affect the aquatic environment (Davies and Nelson 1994, Vuori and Joensuu 1996). Coarse woody debris is important to aquatic invertebrates as a substrate (Smock et al. 1989), and as a food source (Wallace et al. 1999). In addition, CWD influences channel morphology and structure (Robison and Beschta 1990), and is important for creating pools (Hilderbrand et al. 1998). The extent of CWD loss associated with streams is difficult to quantify without detailed reconnaissance data, but the losses have important consequences for species closely tied to riparian habitats.

Affected species

CWD influences abundance and diversity of terrestrial vertebrates providing: 1) shelter for reproduction; 2) substrate, energy and nutrients for foraging; 3) aquatic habitat diversity; 4) runways for small mammals; and 5) access for small predators into snow cover. Large pieces of CWD are important for larger mammals such as black bears and marten (*Martes* *americana*; Bunnell et al. 1999). Among all BEC zones in the Province, the diversity of the terrestrial vertebrate community increases as CWD accumulates (Bunnell et al. 1999).

Vancouver Island has a simple terrestrial vertebrate community structure compared to nearby mainland areas (Cowan and Guiguet 1965), and the list of species that use CWD is relatively short; however, in rating species according to their dependence on CWD, we had to reconcile several issues.

First, although it is relatively easy to assemble a list of species that occur in habitats characterized by CWD, it is more difficult to establish the degree to which species are dependent on CWD, and how likely they are to respond to CWD manipulations. Most studies are correlative, and by definition don't measure population responses to CWD levels. Those that do manipulate CWD levels usually do so in the context of harvest manipulations, which create additional micro- and macroclimate changes.

Second, studies have reported equivocal results regarding the relationship between CWD levels and vertebrate abundance, perhaps because relationships are weak or masked by other important habitat components, or because threshold CWD volumes required to demonstrate effects are typically lower than volumes that exist on most sites (Bunnell et al. 1999).

Finally, even where studies establish fine-scale relationships between species and CWD, the relationships may not hold when extrapolated to population-level responses. For example, Hayes and Cross (1987) related mean log diameter and size of log overhang to western red-backed vole (*Clethrionomys gapperi*) abundance, but Craig (in review) failed to detect increases in red-backed vole populations following an experimental increase in CWD.

Species rated **high**

Plethodontid salamanders are the terrestrial vertebrate species most dependent on the presence of CWD (Harmon et al. 1986). Salamanders are an important component of forest biodiversity and can occur at high densities on Vancouver Island (1550 salamanders/ha; Dupuis et al. 1995). Salamanders lack lungs and rely on transpiration through the skin for oxygen. This makes them susceptible to desiccation (Shoemaker et al. 1992). As a result, they are usually found in moist habitats. Logs represent an important source of moisture that is available throughout the year (Feder 1983). Plethodontid salamanders are terrestrial; they lay eggs on land and are not dependent on a water source for breeding or for any stage of their life cycle, although they occur at higher densities in riparian habitats (Dupuis et al. 1995). Plethodontid salamanders spend much of their time in CWD (Aubry et al. 1988, Davis and Gregory 1993, Leonard et al. 1993, Dupuis et al. 1995, Davis 1996b, 1998), consume terrestrial macroinvertebrates that are closely associated with CWD (Harmon et al. 1986), and lay their eggs in logs (Maser and Trappe 1984, Davis and Gregory 1993). Salamanders are most closely associated with logs >10 cm in diameter (Aubry et al. 1989) and clouded salamanders (*Aneides ferreus*) are found primarily in decay class 3 logs (Maser and Trappe 1984).

Species rated **moderate**

The majority of terrestrial vertebrates on Vancouver Island that rely on CWD to satisfy some aspect of their life history requirements are in the moderate category. The terrestrial shrew species of Vancouver Island (dusky, *Sorex monticolus,* and vagrant, *Sorex vagrans,* shrews) use CWD for cover while travelling (Terry 1981, Craig 1995), eat insects that tend to be associated with CWD (Maser and Trappe 1984), and use CWD to cache and consume prey (McLeod 1966, Yoshino and Abe 1984). Shrews require logs >6 cm, and prefer logs >12 cm in diameter for travelling (Craig 1995). Shrews are most closely associated with logs of decay classes 3-5 where insect communities are large and diverse, and where wood is soft, allowing shrews to cache prey and use tunnels for travelling.

The Vancouver Island water shrew is a red-listed species that lives on land but forages primarily in water. Water shrews rely on CWD to provide important in-stream structure, and to provide nutrients for their prey – aquatic and terrestrial macroinvertebrates (Conaway 1952, Craig and Wilson 2001). Water shrews also cache prey in logs (Banfield 1974, Beneski and Stinson 1987, Nagorsen 1996), and construct nests under logs (Nagorsen 1996).

Deer mice use CWD for nest sites (Harmon *et al.* 1986) and for travel corridors (Graves *et al.* 1988, Barnum *et al.* 1992, Planz and Kirkland 1992, Carter 1993, McMillan and Kaufman 1995). CWD also provides foraging habitat (Harmon *et al.* 1986). Most authors reported a positive correlation between deer mouse abundance (or capture rates) and downed wood (Goodwin and Hungerford 1979, Kaufman *et al.* 1983, Carter 1993, Lee 1993, Carey and Johnson 1995 but see Meierotto 1967).

CWD also provides important denning sites for larger mammals such as the river otter (*Lontra canadensis*), marten (*Martes americana*), ermine (*Mustela erminea*), mink (*Mustela vison*), and black bear (Maser and Trappe 1984, Buskirk et al. 1989, Davis 1996a, Bull et al. 1997, Lofroth 1998, Mowat et al. 1998). Black bears use stumps, tree roots and fallen logs for den sites (Lindzey and Meslow 1976, Davis 1996a), but also use cavities in trees, caves and crevices under boulders, and cavities excavated in hillsides (Erickson et al. 1964). For these species the availability of larger pieces of CWD is very important; marten use logs >50 cm in diameter (Raphael and Jones 1997), and black bears select logs >100 cm in diameter for denning (Davis 1996a). Marten and weasels often use CWD as an access point to subnivean habitats for hunting (Buskirk et al. 1989, Corn and Raphael 1992). Insects associated with logs of decay class 3 and 4 can comprise a substantial portion of black bears' diets (Bull et al. 1997).

Species rated low

Most species rated low in their dependence on CWD will use logs, where present, for cover and/or denning sites (Stevens 1997, Bunnell et al. 1999, Keisker 2000, Oregon Department of Forestry 2001). Whether these species respond to manipulations of CWD will depend on the availability of alternative resources that can serve the same ecological roles.

Red squirrels (*Tamiasciurus hudsonicus*) will use larger CWD logs (>20 cm diameter) of decay classes 1-4 for perches while feeding, and will use logs of decay classes 4 and 5 for nest sites or to cache food (Maser et al. 1979). Red squirrels are not considered dependent on CWD because they will also use live trees.

Beavers (*Castor canadensis*) will use small to moderate-sized pieces of decay class 1 or 2 CWD for building dams and lodges (Lofroth 1998); however, if CWD is not readily available, they will fall live trees.

Raccoons (*Procyon lotor*) rely primarily on cavities in snags for denning; however, they also use logs, stumps, caves, and excavated cavities (Oregon Department of Forestry 2001). Raccoons are omnivorous, and often forage along streams for aquatic invertebrates and small fish. Being a highly adaptable species, raccoons are adept at using available resources to fulfil their life history requirements.

Wolves (*Canis lupus*), cougars (*Felis concolor*), and the Vancouver Island wolverine (*Gulo gulo vancouverensis*) will use stumps, rootwads, or large hollow logs for denning (Keisker 2000), but they will also use other habitat features such as caves. The abundance of large, wide-ranging carnivores such as wolves and cougars are more closely related to prey abundance (*e.g.* black-tailed deer; *Odocoileus hemionus columbianus*) than to specific habitat features like downed wood.

All bird species were rated low because they are either secondary cavity-nesters that will occasionally use logs and stumps (*i.e.* Winter Wren, *Troglodytes troglodytes*; Campbell et al. 1997) or are ground nesters that sometimes used CWD for nest cover (all other species listed; Craig 1993, Campbell et al. 1990). Woodpeckers were not included in the list because they do not nest in CWD; however, their abundance is strongly related to snags (Campbell et al. 1990), from which CWD logs are recruited.

Managing for coarse woody debris

There are two main opportunities for CWD management in watersheds influenced by BC Hydro activities:

- Cooperate with forest companies that manage the forested land surrounding BC Hydro-managed reservoirs and watercourses in order to increase CWD
- Improve the value of existing volumes of CWD

The Forest Practices Code (FPC) requires companies to address CWD management in Forest Development Plans. Guidelines encourage companies to leave logs with a diversity of attributes (species, decay class, size) on sites after harvesting. Piling and burning are discouraged (BC Ministry of Forests 1995). There might be opportunities to exceed these guidelines with cooperative licensees under agreements that resemble those that address harvesting guidelines in other sensitive areas such as community watersheds.

CWD is created when either live or dead trees fall. Large trees that will eventually become CWD are primarily in old forests, or veteran trees in younger stands. Practices such as leaving protected areas along riparian corridors, leaving green patches while harvesting, or using a shelterwood or seed tree silviculture system will leave mature trees behind which eventually become snags and then CWD. Longer rotations combined with retention systems encourage stands with older forest attributes. Burning destroys most of the smaller downed wood and case-hardens larger pieces, making them less susceptible to colonization by insects and hence, less useful to wildlife.

Downed wood often comes from fallen snags. Intensive forest management practices that increase the abundance of snags include:

- Using a chain saw to create deep scars in large live trees to encourage decay
- Girdling trees
- Drilling holes to the centre of trees with heartrot, improving access for tree-denning mammals and encouraging decay

Intensive management activities can be used to improve the value of existing volumes of downed wood for wildlife. These include altering decay class 1 logs to create habitat characteristics common to later decay classes by:

- Using chain saws to create tunnels and hollow chambers in logs. These features are immediately available to species that use CWD for denning or travelling. The tunnels and chambers also increase the rate of colonization by insects, which increases the rate of decay
- Cutting narrow slits on the underside of logs. These features provide habitat for salamanders and mimic loose bark

Medium-volume CWD pieces can be created by bundling together several small logs. Wooden spacers can be used to generate hollow centres, which can be filled with compost and planted with native plants to encourage decay.

CWD can also be redistributed within the forest in order to maximize benefits to wildlife.

These intensive techniques cannot create large pieces of CWD (>50 cm diameter), heavily decayed wood, or large stumps. The only method of encouraging these characteristics is through cooperation with forest companies.

Riparian areas

Activities of BC Hydro directly influence riparian areas around reservoirs and in downstream habitats. Seven terrestrial vertebrate species that use CWD in the watersheds are also associated with riparian habitat (Table 5, Bunnell et al. 1999). Projects that restore spawning and rearing habitat for salmon by providing in-stream CWD are likely to benefit terrestrial species associated with riparian habitats (*e.g.* Craig and Wilson 2001). Coarse woody debris placed in-stream should be longer than the average channel width to enhance stability (Hilderbrand et al. 1998). Species will also benefit from management that maintains and/or enhances CWD in riparian zones associated with creeks, lakes and reservoirs. In addition to obvious benefits for species that use specific elements of riparian habitats, other species might use riparian areas as travel corridors in managed landscapes.

Coarse woody debris manipulations and spatial scale

Terrestrial wildlife species that use CWD habitat do so at characteristic spatial scales. For example, water shrews have home ranges of 0.2-0.3 ha (Buckner and Ray 1968) while wolverines can range for hundreds of kilometres (Krebs and Lewis 1998). To be effective, habitat enhancement involving CWD must be accomplished at appropriate scales to benefit target wildlife species. Practical constraints on the spatial extent of habitat manipulations will limit the benefits accrued to species that use habitats at broad spatial scales.

Research and monitoring

The principle knowledge gap identified in our review was the lack of data regarding volumes and characteristics of CWD in the CWHxm and CWHmm1. Fortunately, CWD data are relatively easy to collect and methods are well established (*e.g.* Feller 1997, Qiwei 1997). Data should be collected in both old- and second-growth forests in order to establish natural ranges of variability of CWD volumes and characteristics. These ranges can then form the basis of benchmarks that can be used to guide CWD management in the watersheds.

Linear riparian features should be sampled in order to assess the characteristics of CWD along streams and creeks affected by BC Hydro activities. This sampling could be coordinated with fisheries restoration activities.

Any CWD manipulations attempted in the watersheds should be associated with an appropriate research and monitoring program to assess the benefits to wildlife. At a minimum this should include at least 1 year pre- and several years post-treatment sampling for target wildlife species. Realistically, population and habitat responses to CWD manipulations will be detectable only for species that range at relatively small spatial scales.

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