Comparison of the impacts of forest practices regulations on carbon storage in Washington, Oregon, California, and British Columbia

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Executive Summary

The generation of emission reduction units for climate mitigation through forest management activities requires the condition of additionality, which means that eligible activities must be above and beyond what is required by law. This analysis examines the relative degree to which forest practices regulations in California, Oregon, Washington, and British Columbia simultaneously enhance carbon sequestration and storage and constrain the ability of landowners to meet this condition. Forest practices regulations in all four of these entities were found to result in enhanced carbon sequestration and storage, especially by favoring the retention and growth of conifers, but to different degrees. Some of the most important forest practices regulations examined included requirements regarding riparian management areas, wetland protections, protection of individual habitat structures, retention requirements for harvest units, road construction and maintenance regulations, and protections for unstable slopes.

California had strong rules in place with respect to nearly all categories of activity, especially wildlife habitat protections. Washington's riparian buffers constitute a major influence on carbon storage and tradability in that state. British Columbia's landscape-level planning and wildlife protections are significant. Among the four entities, Oregon was found to be least constrained by regulations that impact carbon sequestration and storage on forest properties, but still had major commitments in the area of protection of wetlands and unstable slopes. Mechanisms may need to be established by which forest landowners can market ecosystem services provided by the implementation of forest practices regulations.

Introduction

The role of human activities to climate change is an area of current research and policy focus (Field and Raupach 2004; Keeling and Whorf 2003), with much attention focused on the potential contributions of forest-related carbon sequestration and storage in mitigating anthropogenic impacts on global climate (Noss 2001; Spittlehouse 1999). Certain forestry practices (e.g., planting and extended rotations) can result in increases in the amount of carbon stored in forest stands and landscapes (Harmon 2001). Under a cap-and-trade mitigation system, forest landowners can generate emission reduction units (ERUs) by increasing carbon storage on their lands, and then market these credits to enhance their revenue stream. However, the landowner must demonstrate that the alterations in forestry practice by which these credits are generated are in addition to standard practice, or "business as usual". This is the principle of 'additionality', which is central to a valid cap-and-trade system designed to reduce carbon emissions. Both the California Climate Action Registry (California Statutes Chapter 423, Sec. 2 (d)(1)) and the Chicago Climate Exchange (CCX 2008) require additionality to applicable regulation as a prerequisite for eligibility of credits, and this is likely to remain the standard into the foreseeable future.

Forest practices regulations, usually encoded in a forest practices act (hereinafter referred to as FPA) at the level of the state or province, have an impact on the carbon budget of the forest property by restricting activities such as timber harvest and road construction. An important example is the establishment of riparian reserves to protect aquatic ecosystems and water quality. Since leaving trees, and therefore carbon, in these reserves is required by law, additionality has been lost as far as the area with riparian reserves is concerned. The landowner is no longer able to generate emission reduction units by deferring timber harvest in these areas. The variation in riparian reserves across states and provinces means that landowners in states with more stringent regulations on timber harvest may be at a substantial disadvantage compared to landowners elsewhere. Resolution of these issues may become necessary to permit broad participation of forest landowners in the emerging carbon market.

Methods

The FPAs, and various legislation that affects forest operations, of three states of the United States of America (California, Oregon, and Washington) and one Canadian province (British Columbia) were reviewed for regulations that directly affect the ability of landowners to harvest timber, engage in various silvicultural activities, permanently remove timber as through road construction, or perform any other activity with implications for forest carbon storage. This work is intended to be a review of pertinent regulations, with general conclusions drawn about the impact of forest regulations on the ability of landowners to generate emission reduction credits. Modeling or quantifying the precise impacts of these regulations is outside the scope of this work, and might be difficult to perform due to variation in application of the regulations from property to property and the inherent biotic and abiotic heterogeneity of forest landscapes.

This analysis focuses on the private and state forestlands in California, Oregon, and Washington, and on Crown (provincial) lands in British Columbia, which make up the vast majority of managed timberlands in that province. Federal lands belonging to the United States government are managed under a different set of management plans, and are not addressed.

Where I must refer to the three states and the province together, I shall refer to them as "the four entities". Standard forest management terminology and abbreviations (e.g., 'tpa' for trees per acre) are employed throughout, and state-specific terms are identified as they are encountered. The acronym 'FPA' shall be used to refer in a generic sense to the forest practices regulations enacted by each state and province.

The regulations examined in this work are shown in Table 1. Specific references are cited by entity in Appendix 1.

Table 1

State/Province	Legislation establishing forest practices rules/regulations
California, U.S.A.	-Title 14, California Code of Regulations, Chapter 4, 4.5, and 10 -Z'Berg-Nejedly Forest Practice Act, Division 4, Chapter 8, Public Resources Code
Oregon, U.S.A.	-Oregon Administrative Rules, Chapter 629 -Forest Practices Act, Oregon Revised Statues 527.610 to 527.770, 527.990 (1) and 527.992
Washington, U.S.A.	-Washington Administrative Code (WAC) Chapter 222 -Additional requirements as found in the Forest Practices Board Manual
British Columbia, Canada	-Forest and Range Practices Act [RSBC 2002] Chapter 69 -Forest and Range Practices Act, Government Actions Regulation -Wildlife Act [RSBC 1996] Chapter 488 *(and other pieces of relevant legislation)*
Other pertinent legislation	Columbia River Gorge National Scenic Area Act (Oregon and Washington)

Riparian Management Areas (RMAs)

All three states and British Columbia have rules protecting riparian areas. All of these rules involve retention of live green trees, snags, or other structural elements within a certain distance of various classes of water bodies, such as streams and lakes. For all four entities, water bodies are further classified according to size, use for domestic water supplies, presence of fish, or other factors. Floodplains, or channel migration zones, are accorded special protection in Washington, California, and British Columbia. Washington, Oregon and British Columbia have established core zones immediately adjacent to the water body from which no timber may be removed, except in efforts to promote the establishment and growth of conifers in broadleaf-dominated riparian management areas. Where operations are permitted, retention requirements generally favor larger trees in order to generate higher levels of shade and large woody material for future aquatic habitat structure.

California specifies the width of riparian management areas, known as Watercourse and Lake Protection Zones (WLPZs), as a function of the watercourse classification and the slope angle of the adjacent land. This width (on one side of the watercourse) varies from 50 to 150 feet for Class I (domestic water use source) and Class II (fish-bearing) streams. Class III streams (no aquatic life present, but may deliver sediment) have a variable buffer width that is assigned by the consulting forester. Acceptable silvicultural prescriptions vary by watercourse classification. For Class I and II streams, this means leaving 50% canopy cover in a well-distributed manner in the WLPZ, with additional requirements. Most lakes likely fall into Classes I and II, and receive protection as specified for such waters.

Oregon's requirements include a 20' core no-harvest buffer for trees, a 10' buffer for understory vegetation, and variable density and basal area requirements in a riparian management area of variable width. The width is dependent on the stream type (fish-bearing, domestic water source, or neither fish nor domestic water source) and the size of the stream (based on flow volume, and classified as small, medium or large). Basal area targets are given for Oregon's RMAs, and include a standard target beyond which harvesting is allowed and an 'active management target', which represents a minimum permissible

condition. If management designed to achieve these basal area targets is implemented on Oregon's private and state lands, there will be significant carbon sequestration and storage in relatively large-diameter, long-lived conifers. Small non-fish bearing, non-domestic water use streams have either no buffer or a 10' buffer, depending on geographic region and watershed drainage size above the stream segment. Oregon also prescribes a 100' RMA for lakes greater than 8 acres, a 50' RMA for lakes that have fish use or are equal to or greater than 0.5 acres in size. Within this RMA, 50% of the live trees by species must be retained in several diameter classes (6-10", 11-20", 21-30", and 30+").

Washington's riparian management areas, known as Riparian Management Zones (RMZs), consist of three zones: the core zone, the inner zone, and the outer zone. These apply to "waters of the state" (Type S) and fish-bearing waters (Type F). The core zone is a no-touch buffer immediately adjacent to the high-water mark of the watercourse, and measures 50' in western Washington and 30' in eastern Washington. Management in the inner zone, which is of variable width depending on site class, must set the stand on a developmental trajectory towards a desired basal area target, and may consist of thinning 'from below' (in the lower range of the diameter distribution) or retaining trees adjacent to the core zone. A minimum of 20 riparian leave trees per acre must be retained in the outer zone in either a dispersed or clumped pattern. These riparian leave trees may be either conifers with diameters of 12" or greater in dispersed or clumped retention, or representative conifers or hardwoods with diameters 8" or greater if the clumped retention is located so as to protect sensitive environmental features. Perennial non-fish-bearing streams (Type Np) are partially or completely protected by 50' buffers depending on their length. In addition, Washington's FPA requires that headwall and side slope seeps, confluences of non-perennial streams, and headwater springs be protected with no-harvest buffers of 50-56', resulting in leave clumps of 0.18-0.23 acres where these features occur. Lakes and ponds of 0.5 acre or greater are classed as Type F waters (fish-bearing) and are protected accordingly.

Riparian management areas in British Columbia are divided into Riparian Reserve Zones (RRZs) and Riparian Management Zones (RMZs). Timber harvest is precluded in the Riparian Reserve Zone, while harvesting in Riparian Management Zones is required to leave a certain proportion of stand basal

area. Fish-bearing streams less than 5' in width and non-fish-bearing streams of any size have no RRZ, while all but the largest fish-bearing streams have substantial RRZs ranging from 66'-164'. The width of the RMZ is 328' for the largest rivers (active flood plain or stream width equal to 328' or greater), 66' for other fish-bearing streams larger than 5' in width, 98' for fish-bearing streams less than 5' in width and non-fish-bearing streams greater than 10' in width, and 66' for non-fish-bearing streams less than 10' in width. Basal area to be retained within RMZs is 20% of pre-harvest basal area for large fish-bearing streams, and 10% for fish-bearing streams less than 5' in width and non-fish-bearing streams of any size. Depending upon density, age, species composition, and other characteristics of the pre-harvest RMZ, more carbon may be sequestered and stored if the retained basal area is distributed as dispersed vigorous leave trees with a good crown ratio (typically 1/3 or greater). This will have similar effects to a thinning, which can enhance individual tree carbon sequestration by reducing inter-tree competition. However, the removal of too many stems can reduce net volume growth, thus negatively impacting carbon storage. For smaller channels, any trees contributing to bank stability must be retained. This also will enhance carbon storage and decrease carbon loss due to subsurface flow. Lakes are protected according to size, with RMAs ranging from 33' to 98'.

Wetland Protections

Wetlands, defined as areas where high water tables and poor drainage result in the presence of a hydrophytic plant community, have ecological importance that is disproportionate to their area in the landscape (Mitsch and Gosselink 2000). Restrictions on timber harvest in the vicinity of wetlands will result in reductions in the amount of carbon available for generation of ERUs. Among the four entities, California has the least area of wetland (434,000 acres; Dahl 1990), while British Columbia has the greatest (7,760,400 acres; Canadian Wetlands Conservation Task Force 1993). Washington and Oregon have comparable amounts (938,000 and 1,393,900 acres, respectively; Dahl 1990).

California does not have specific protections for wetlands in its FPA. However, many of California's wetlands that are in the vicinity of forest vegetation are likely situated in riparian areas,

which already receive protection. In Oregon, "significant wetlands" (greater than 8 acres in size, estuaries, bogs, and "important springs in eastern Oregon") receive protection in the form of a buffer ranging from 50-200', in which 50% of live trees in each of several diameter classes must be retained. In addition, all snags and downed woody debris must be retained. Riparian Management Areas for streams must be expanded to include stream-associated wetlands. Washington's FPA requires retention of 75 trees greater than 6" dbh in western Washington and > 4" diameter in eastern Washington in wetland management zones. Twenty-five of these trees shall be greater than 12" dbh, and five shall exceed 20" dbh, if these are present. The width of these zones ranges from 50-100', depending on the size and class of wetland. If a forested wetland is included in the unit, then 30-70% of the trees kept in compliance with the upland retention requirement must be located in the forested wetland. British Columbia has established a similar set of buffers for its wetlands, which are fairly prominent elements of high-latitude landscapes. The reserve zone, a no-harvest buffer, is either 0' or 33' in width, and the riparian management zone varies from 65.6' to 131.3'. Therefore, British Columbia is likely to be substantially impacted by wetland regulations.

Unstable Slope Protections

Washington requires approval of timber harvest or road construction on potentially unstable slopes via mechanisms in both its FPA and its State Environmental Protection Act. The Watershed Analysis process (WAC 222-22) requires that unstable slopes that may be negatively influenced by timber harvest activities be identified, and appropriate mitigation or management alternatives be implemented. Avoidance of harvest on sensitive slopes, the use of partial harvest, and retention of woody debris were found to be common prescriptions in Watershed Administrative Units, according to a review of several completed Watershed Assessments (Washington Department of Natural Resources 2008). Additionally, a number of sensitive sites on slopes are protected, as discussed in the section on riparian protections. All of these measures result in the mandatory retention of carbon in managed landscapes.

In California, certain riparian areas with high slope angles are subject to enhancements of the Watercourse and Lake Protection Zone. The state of Oregon has implemented a very thorough set of restrictions on timber harvest and road construction on unstable slopes. These include a limit on the amount of recently harvested land on a given slope (only 50% of an unstable slope in a single ownership may be in a stand age class of 0-9 years) and retention of large (>20" dbh) trees along small stream channels capable of generating debris torrents. British Columbia has no specific regulations *per se*, but does require analysis of slope stability as part of its management plan. Similar to Washington, this may result in administrative reduction of the harvestable land base, with corresponding enhancement of carbon storage in the landscape.

Regeneration Requirements

Minimum standards for regeneration of harvest units were present in all of the regulations reviewed. Prompt regeneration of harvest units is critical to maximizing carbon storage under any system of forest management. For even-aged management, California requires 300 trees per acre to be established on more productive sites, and 150 per acre on less productive sites. These trees must be selected from a list of approved commercial tree species. Reforestation requirements in Oregon are based on site class and whether seedlings, saplings, or sawtimber are used to meet the requirements. On productive sites, the requirements may be met by 200 seedlings, 125 saplings, or sawtimber comprising 80 ft^2 of basal area. These requirements are reduced for less productive sites. Washington requires 190 seedlings or 100 saplings per acre in western Washington, and 150 seedlings or 100 saplings per acre in eastern Washington. British Columbia has specified regeneration requirements according to a system of biogeoclimatic zones. In each vegetation association within a biogeoclimatic zone, the following regeneration characteristics are specified: acceptable conifer and broadleaf tree species, stocking standards, the length of the regeneration period, acceptable ratios of tree cover to brush cover, and the height at which trees are considered "free to grow". Minimum stocking standards are equivalent to those in Washington and Oregon (e.g., ~165 trees per acre for the Vancouver forest region).

All of the regeneration regulations encountered are designed to promote the establishment of well-distributed, productive stands of commercial tree species. As such, they greatly enhance the sequestration of carbon in forest biomass, especially as contrasted with the frequent occurrence of long-lasting early-successional communities on forest sites following natural disturbance in western North America (Franklin and Dyrness 1973, Franklin et al. 2002). However, they do not differ sufficiently between the four entities in their influence on normal stand development and carbon sequestration and storage.

Retention in Harvest Units

All of the states and the province examined have requirements for retention of habitat elements in harvest units. Washington, Oregon, and British Columbia have remarkably similar requirements with respect to green leave trees (2-3 per acre for Washington and Oregon, and 2 per ha for British Columbia) and coarse woody debris (2 pieces per acre for Washington and Oregon, and 1.6 per acre for British Columbia). Washington additionally requires two "green recruitment trees" with a live crown ratio of 1/3 or greater. In British Columbia, at least 3.5% of the total area of the harvest unit must be covered by wildlife tree retention. Under the assumption that the reserved area is representative of the unit, this amounts to a corresponding reservation of carbon. However, foresters may allocate this requirement to less productive areas of the unit, thus avoiding the maximum possible takings of carbon. California requires that all snags be retained in the harvest area, but there are numerous allowable exceptions to this rule (safety, merchantability as described in the management plan and fire hazard). In the case of safety or fire hazard, snags may be felled, retaining carbon in the unit.

Special Wildlife Habitat Retention Requirements

The structural habitat needs of a number of species of wildlife, endangered or not, are recognized in the FPAs of California, Oregon, Washington, and British Columbia.

Birds of Riparian Habitats

All four entities have requirements protecting nest trees of great blue herons (*Ardea herodias*), bald eagles (*Halieaeetus leucocephalus*), and osprey (*Pandion haliaetus*). California has the most stringent requirements, with 5-40 acre buffers around the nests of these species and others (e.g., great egret). Within these buffers, clearcutting is not allowed, and only silvicultural prescriptions that leave a significant protective overstory are permitted, such as shelterwood without a removal step.

In Oregon, active nesting sites are termed 'resource sites', which include nesting trees, perching trees, staging trees, and replacement trees, plus any additional timber as a safeguard against windthrow. Great blue heron resource sites receive a 300' buffer (at least 6.5 acres) in which active management is allowed to improve habitat utility. Osprey resource sites have no buffer, but a significant retention requirement of nesting, perching, and replacement trees. A minimum 330' buffer (at least 7.86 acres) must be maintained around bald eagle resource sites.

Washington State governs protection of eagle sites through rules outside of the Forest Practices Act, as contained in WAC 232-12-292. Site management plans are agreed upon by the landowner and the state, which would contain provisions for retention and replacement of nest trees and perch trees.

British Columbia also has regulatory authority over the nest trees of bald eagle, osprey, great blue herons, and other bird species of concern. These may be designated Wildlife Habitat Features, and accorded site protection via modification of forest management activities and silvicultural prescriptions in a specified area. Most of these areas are less than 200 ha in size.

Marbled Murrelet

The marbled murrelet (*Brachyramphus marmoratus*) has the most specific habitat-related regulations in Washington State. No harvesting is permitted within the nesting site, or within suitable habitat containing 7 or more platform structures (large-diameter, mossy branches or witches'-brooms) per acre. Occupied sites are protected with a 300' managed buffer where silvicultural activities cannot reduce the density of trees > 6" diameter to less than 75 trees per acre (with additional restrictions). California's FPA contains language leaving marbled murrelet protections to the discretion of the state. Oregon does not have specific language in its FPA related to the marbled murrelet. British Columbia's National

Marbled Murrelet Recovery Plan specifies that timber harvest may not be reduced by greater than 1% in designated timber production zones, but a large amount of habitat will be protected in non-production zones.

Northern Spotted Owl

The northern spotted owl (*Strix caurina caurina*) receives specific protection of nest sites in Washington, Oregon, and California, and forest practices may fall under the provisions of the Endangered Species Act. The state of California requires that the area within 500' (18 acres) of the nest site be maintained in a late-successional structure, and that within the next 500'-1000' of the nest site, late-successional characteristics be maintained. There are further requirements involving maintaining significant proportions of 0.7 mile circles (500 acres of 985) and 1.3 mile circles (1336 acres of 3398) beyond these initial core elements in late-successional habitat. Oregon requires a 70-acre core nest site with suitable spotted owl habitat as indicated by sufficient canopy closure (60-80%), a multilayered canopy, the presence of large trees with structural decadence and large snags, and other characteristics of late-successional habitat. On private lands in the state of Washington, a 70-acre core site "of the highest quality habitat" will be off-limits to timber harvest, road construction, or aerial application of pesticides. These same restrictions are further applied to 1.8 mile radius median home range circles (6500 acres) located in special management areas (Spotted Owl Special Emphasis Areas, or SOSEAs). Landowners with fewer than 500 acres receive an exemption. Dispersal habitat may receive protection, and since this habitat may consist of quickly-growing younger stands, a significant amount of carbon sequestration and storage potential may fall under regulation.

There are insufficient numbers of northern spotted owls in British Columbia to have a province-wide effect through implementation of forest practices regulations. Selected watersheds may be conserved under the Species at Risk Act, the Wildlife Act, and the Government Actions Regulation, so this may reduce harvestable timber, especially old growth, in some portions of the province.

Other species

The gray wolf (*Canis lupus*) and grizzly bear (*Ursus arctos* ssp. *horribilis*) represent significant management concerns in Washington and British Columbia. In Washington, wolf den sites have an equipment operation exclusion buffer of 0.25 miles (125 acres). If grizzly bears recolonize Washington in the future, then specific regulations are likely to be enacted. Landscape-level planning for the grizzly bear on Crown lands in British Columbia are likely to result in the removal of mid- to high-elevation stands from the timber producing base, with consequences for management of the carbon resource.

Road Construction and Maintenance

Both California and British Columbia have specific regulations that influence the area that may be incorporated into access structures or roads. In California, this consists of restrictions on road width and the angle of slopes on which roads may be constructed. Both of these restrictions serve to reduce the amount of area in roads, thus enhancing the amount of forest area where carbon continues to be fixed and stored. In British Columbia, a maximum of 7% of the surface area in a harvest unit may be in roads or landings. This also limits the loss of forestland, thus influencing operation-level carbon balances.

In Washington, roads may not be constructed in certain types of wildlife leave areas, wetlands, and other sensitive areas. Road construction may also be curtailed as a result of Watershed Assessments. In Oregon, roads may not be constructed on slopes where substantial downslope safety risk exists due to the possibility of mass movement. These regulations result in both direct and indirect impacts on landscape-scale carbon balance due to avoidance of direct loss of forestland to the road right-of-way and reduced timber harvest due to decreased accessibility of harvestable forestland.

All entities have enacted FPAs that limit road construction on unstable slopes. The FPAs of California and Washington, however, are noted as being somewhat more stringent than the others. They contain more specific direction on situations in which to avoid or constrain road construction than the FPAs of Oregon or British Columbia.

Restrictions on Rotation Length

California is the only entity in this study to place a restriction on minimum stand age at harvest. This minimum stand age varies from 50 years on Site I lands to 80 years for Site V lands. This type of requirement is consistent with application of principles of maximum sustained yield, which is codified in California's FPA. Since longer intervals between even-aged harvests result in greater carbon storage over time (Curtis 1997, Harmon and Marks 2002), this constitutes a takings of tradable carbon.

Adjacency ("green-up") requirements may have an impact on the rate of forest harvest, fundamentally operating as a constraint on frequency of harvest. This is especially true on poorer sites where growth rates are slower and seedling mortality is higher due to frost pockets, nutrient deficiencies, and other site-specific conditions. All four entities have adjacency requirements, typically consisting of height, age, or "free to grow" criteria. California requires that regeneration in an adjacent unit either be five feet in mean height or five years of age. Oregon requires, for a Type 3 harvest (traditional clearcut), that regeneration in an adjacent unit must have reached at least four feet in height and 4 years of age. Washington requires that one of the following conditions be met: 30% of the perimeter of an even-aged unit must be occupied by a stand 30 years of age or greater, 60% of the perimeter must be occupied by a stand 15 years of age or greater, or 90% of the perimeter must be occupied by a stand five years of age or greater, or at least four feet in height. In British Columbia, the tallest 10% of the trees in an adjacent unit must be 10' in height, and on the coast, the stand must be at least 4.3' in height.

In general, the regulations do not functionally differ between the entities. All four entities require a well-distributed stand of desired commercial species to be established within a reasonable period in harvested units, or, in the case of seed-tree or shelterwood silvicultural systems, to create the conditions necessary for these methods to succeed.

Special scenic area legislation

In areas where land use is partially governed by the California Coastal Area Commission, there are additional restrictions on the intensity of timber harvest (14 CCR, Article 11). These include a general prohibition on clearcutting, restrictions on removal of overstory conifers in various diameter

classes, buffers around Scenic Corridors (main highways with high volumes of tourist traffic) and parks/reserves, and a widening of the WLPZs in certain cases for Class I and II waters.

In Oregon and Washington, the 292,000-acre Columbia River Gorge National Scenic Area provides for enhanced scenic and cultural values in an area of exceptional natural beauty and touristic importance. The enabling legislation, the Columbia River Gorge National Scenic Area Act, has restrictions on timber harvest that are additive to those encountered in state-level FPAs. For the moister forests in the west end of the Gorge, required green tree retention is 15-40% of pre-harvest canopy cover. There is a substantial requirement for snag and down wood retention (about 2-5 times the amount required under the FPA), as well as any remnant trees greater than 180 years of age (Commission Rule 350-81-020, definition 125, and Commission Rule 350-81-270). Additionally, 200' no-touch buffers are prescribed for many riparian features (Commission Rule 350-81-600), which represents a greater takings of carbon sequestration and storage than that in the state-mandated buffers for either Washington or Oregon. Forest landowners in Washington will be disproportionately impacted by the National Scenic Area guidelines, since much of the land in that state within the National Scenic Area is privately owned. Much of the National Scenic Area in Oregon, however, is owned by either the Forest Service or the Oregon Parks and Recreation Department.

Oregon requires retention of 50 trees 11" or greater dbh, or 40 ft^2 of basal area, for aesthetic and visual purposes along scenic highways (as defined in the FPA). The retention requirements are temporary, however, since this overstory may be removed when the regeneration reaches 10' in height. This regulation results in a temporary enhancement of carbon storage.

British Columbia has established a program of Special Management Zones, in which forest management practices will be altered. The extent to which these practices will enhance carbon storage and sequestration remains to be seen, but it is certain that higher levels of structural retention will be an integral part of the altered management regime.

Table 2

Brief summary of principle forest practices regulations that impact carbon sequestration and storage

	California	**Oregon**	**Washington**	**British Columbia**
Riparian buffers	50-150', or smaller. Operable, but silviculture favors conifers, large trees, and intact understories.	20' core no-harvest buffer. RMA widths 20-100', in which basal area targets apply (40-270 ft^2 per 1000' of stream).	Three-zone riparian buffers. 30' or 50' core no-harvest zone. Inner zone: 10-100', in which 57 tpa must be left. Outer zone: 0-67', in which at least 20 tpa must be left. Buffers on non-fish bearing waters may be required.	Core no-harvest zone (RRZ) 66-164' for most waters larger than 5' width. Riparian Management Zones 66-328', in which 10 or 20% of basal area must be retained.
Wetland protections	Except for Coastal Commission Special Treatment areas, no specific mandates.	"Significant wetlands" receive 50-200' buffer with 50% retention for several diameter classes, and retention of snags/downed woody debris.	75 tpa must be retained in a Wetland Management Zone averaging 50-100' around non-forested wetlands.	33' no-harvest reserve for large wetlands, none for small. 66'-131' management zone adjacent to reserve for large wetlands, and 98' management zone only for small wetlands.
Unstable Slope Protections	Restrictions on high angle slopes in certain riparian areas	Limit on amount of land in 0-9 year age class on a slope. Retention of large trees in debris torrent-prone terrain.	50-56' buffer on certain slope features (side-slope seeps, headwall seeps). Additional SEPA requirements; case-by-case mitigation, usually partial harvest or harvest avoidance.	Analysis required on case-by-case basis; specific mitigation.
Upland retention (per acre requirements)	Snags must be retained (with exceptions). Highly variable.	2 snags or green trees ≥ 30' ht. and ≥11" dbh. Two logs (DWD), ≥ 6' length and ≥ 10 ft^3 gross vol.	2-3 wildlife reserve trees (≥ 12" dbh, ≥10' ht.). 2 green recruitment trees (≥10" dbh, ≥30' ht., crown ratio ≥ 1/3). 2 pieces of DWD, ≥ 12" diameter at large end, ≥ 20' length.	3.5% of the total area of the cutblock must be covered by wildlife retention trees. 1.6 pieces of DWD per acre (≥12" diameter at one end, ≥ 26.4' length, for coast).
Active Wildlife Use	5-40 acre buffers around nest sites where only certain silvicultural prescriptions allowed.	Nest sites protected with buffers, resulting in 6.5 acre+ buffers/	Nest sites of eagle, marbled murrelet, and others protected.	"Wildlife Habitat Features" protected. Variable size.
Restrictions on rotation length	50+ years, depending on site class	None.	None.	None.

Analysis

The diversity of forest practices regulations across California, Oregon, Washington and British Columbia is summarized in Table 2. It is apparent that while similar approaches have been adopted in form, the regulations differ in both extent (e.g., width of riparian management areas) and effect (management requirements within riparian management areas). Stand-level and landscape-level impacts are addressed in the following sections.

Stand-level regulations and requirements

Washington State is primarily disadvantaged by its substantial riparian management areas. The extent of watercourses in the state that must be protected with a no-harvest core zone and an operationally restricted inner zone suggests that significant amounts of carbon will be unavailable for either timber harvest or generation of ERUs. The timber harvest practices that are permitted in the inner zone are designed to concentrate growth on large, vigorous conifers, thus sequestering carbon in long- lived structures. Washington State does allow alternative management plans that may allow different treatments within buffer zones. It is conceivable that such plans could be used to enhance the capture of carbon otherwise restricted by regulation. The similarity in wetland area and protection measures in Washington and Oregon suggest that impacts will be fairly equitable between these states. British Columbia may be disproportionately impacted by wetland protections due to its greater area of wetlands, and the buffers on those wetlands.

Requirements concerning retention of specific structures at the stand level (nest sites, snags, downed woody debris) are fairly similar among all four entities. British Columbia's requirement that 3.5% of the area of the harvest unit should be kept in wildlife reserve trees may constitute the largest takings, but is subject to considerable variability in impact given differences between and within harvest units. The impact of California's requirement to retain all snags is similarly difficult to predict, due to high variability in snag size and variability, and also given the many allowable snag harvest exceptions

for fire hazard, safety, marketability, and other conditions. California's Special Treatment Areas and other areas in California with special silvicultural regulations (e.g., Marin County) fundamentally have long-term silvicultural prescriptions determined for them, which means that a substantial takings of carbon sequestration potential may occur. Many of these areas have percent retention requirements for one or more diameter classes, meaning that long-term stand dynamics is constrained by regulation.

Wetland protections have different impacts among the entities. Oregon's requirements for "significant wetlands" may result in substantial takings of carbon, due to both the width of the buffers and the prescription across diameter classes for retention of 50% of the live trees. Washington's 75 tpa requirement in Wetland Management Zones mandates what essentially is a heavy thinning, potentially enhancing long-term carbon sequestration in long-lived, large-diameter structures. The clustering of 30-70% of upland retention structures into forested wetlands in Washington may also enhance carbon sequestration in some cases, since trees adjacent or in forested wetlands may have higher growth rates due to a lack of moisture limitations.

Protection of unstable slopes in Oregon and Washington has the potential to reduce the amount of area available to timber harvest, resulting in greater carbon storage that is not eligible for the generation of ERUs. These two states have more specific direction in their FPAs for protection of steep or unstable slopes than either California or British Columbia. Certain portions of Oregon and Washington are most vulnerable to restriction of road construction and timber harvest due to erodible or unstable lithologies (Swanson *et al.* 1987). This will result in regional inequities in the ability of landowners to generate emission reduction units. A final consideration on unstable slopes is that trees or woody debris left in unstable areas may sequester carbon for hundreds or thousands of years if they are incorporated into the hyporheic zone of a watercourse by slope failure processes, since decomposition is inhibited by freshwater saturation (Harmon *et al.* 1986).

Landscape-level regulations and requirements

Adjacency or "green-up" requirements for harvest units may be considered a landscape-level restriction, since they constrain the age pattern of the patch mosaic created by harvesting activity.

Adjacency requirements have an impact on the amount of harvesting that may occur in a landscape (Nalle *et al.* 2005). The green-up requirements are very similar for all four of the entities in this analysis.

British Columbia's efforts to conserve old growth via region-specific orders have the potential to remove a very large amount of potentially tradable forest carbon from the available pool. Since late-successional forests tend to have higher carbon stocks, conserving them in particular will influence the amount of carbon available under the principle of additionality.

California's FPA is certain to increase the amount of carbon stored in forestlands through riparian regulations, restrictions on clearcut harvesting, and wildlife-related regulations. The added costs of administrative compliance with the California FPA may also result in the completion of fewer timber harvests. Oregon seems to have, in comparison to the other three entities, a fairly liberal FPA. This may facilitate entry of landowners in this state into emerging carbon markets.

Road construction is a landscape-level concern, since roads are necessarily constrained by transportation needs in a spatial sense as well as limitations imposed by topography. California and Washington appeared to have the greatest amount of specific direction contained in their FPAs regarding situations in which road construction must be limited or avoided. This impacts carbon stores by reducing the amount of forestland accessible to timber harvest or directly lost to the area occupied by the road prism.

Regional differences

Regional differences in tree species composition, upper bounds of carbon storage, decay rates, and net primary productivity will interact with differences in forest practices regulations to influence the ability of landowners to participate in the carbon mitigation market. The region of California dominated by California redwoods (*Sequoia sempervirens*) has the ability to store higher amounts of carbon in biomass than any other forest type, but the rest of the state is characterized by relatively xeric forest types with lower upper bounds of carbon storage. Oregon and Washington can achieve very high aboveground carbon density (mass of carbon per unit area). British Columbia's geographic location is relatively high-latitude, with corresponding decreases in productivity and the associated opportunity for carbon

sequestration and storage. Table 3 gives a sample of aboveground carbon densities for mature forest types across the four entities.

The density of stream channels also varies at numerous scales, from region to the area covered by all four entities. Within regions, landscape position as well as differences in geology and precipitation may result in large portions of some forest properties falling under riparian regulation, while other properties are only minimally affected. There may also be a considerably higher density of perennial, fish-bearing streams in northern Oregon, Washington and British Columbia due to continental and latitudinal patterns of precipitation. This means that progressively more land will be impacted by riparian protections with increasing latitude.

Uncertainties associated with regulation-enhanced carbon storage

A major source of uncertainty is the high variability in net primary productivity and upper carbon bounds of riparian areas. Many riparian areas in the Pacific Northwest have been converted in the past to hardwoods through harvesting activity (Berg 1995), which limits the amount of carbon stored in these systems. The extent to which landowners take advantage of the hardwood conversion clauses in the laws of Oregon and Washington will directly influence the amount of carbon stored over time in these states. In California, the leave requirements in the WLPZs favor conifers of large diameter, which will have a similar effect. Finally, some riparian areas are not naturally dominated by large-diameter conifers, but by broadleaf trees such as Oregon ash (*Fraxinus latifolia*) (Franklin and Dyrness 1973), meaning that riparian buffers in these systems will have less impact on overall carbon stores.

Table 3

Forest Type	Aboveground C density (Mg ha^{-1})	Source
California		
Mid-montane conifer	118	Fellows and Goulden, 2008
Upper-montane conifer	172	Fellows and Goulden, 2008
Northern CA/Sierra	100	Fellows and Goulden, 2008
Southern conifer	99	Fellows and Goulden, 2008
Coast redwood	2094.6	Busing and Fujimori, 2005

Oregon			
Coastal conifer	464.7		Smithwick et al. 2002
Cascades conifer		431.7	Smithwick et al. 2002
Eastern Cascades conifer		85.3	Smithwick et al. 2002
Washington			
Coastal conifer	363.5		Smithwick et al. 2002
Cascades conifer		380.2	Smithwick et al. 2002
British Columbia			
Pacific cordilleran forest		115.5	Kurz and Apps, 1999

Where riparian regulations require the protection of perennial streams, there is often some difficulty associated with identifying the extent of these streams and the resultant impacts on landscape carbon balance. Water flow from springs is influenced by a number of geophysical variables, and may vary from year to year. This may affect the ability of operators to identify and protect springs where such features require protection buffers.

Where regulations require that individual live trees or a portion of the pre-harvest basal area be retained, there is a great amount of variability associated with the ability of retained trees to respond to changes in the growing environment associated with the harvest operation. Suppressed or intermediate retention trees frequently do not respond as well to release as dominant or co-dominant trees (Nyland 2002, Emmingham et al. 2007). Therefore, if trees of suppressed or intermediate form are selected as leave trees, as sometimes occurs on private timberlands, carbon sequestration and storage over time will be substantially less than if co-dominant or dominant trees are retained. A similar uncertainty relates to the decay rates of coarse woody debris as a function of size or species wood chemistry. Larger pieces of coarse woody debris tend to decay more slowly than small pieces, and decay rates vary by species due to differing wood chemistry (Harmon et al. 1986). Finally, where discretion is granted to the operator to retain some proportion of basal area (as in British Columbia's RMZ or Washington's "outer zone"), the spatial arrangement of the retention will influence the amount of carbon stored. Trees left in aggregates (groups) may experience less growth than dominant trees left dispersed across a unit. However, this may need to be balanced with the risk of windthrow associated with dispersed retention.

Limitations

The many differences between regulations and forest conditions across the states make precise comparisons difficult. Furthermore, the scope of this work is forest carbon at the scale of the forested property or landscape, thus not considering how regulations might enhance or constrain credits that may be available for carbon generated in the forest but stored in products or derived by displacing fossil intensive emissions through the use of wood as a biofuel or substitute for fossil intensive products. If a regulation constrains harvest volume it essentially reduces the eligibility of forest carbon for credits while also reducing the potential volume that might be processed and eligible for credits outside of the forest. Even if credits are made available for green buildings that use more wood to displace fossil intensive products, the price increase required to induce increased supply will only be available to the forest owners that have the flexibility to respond within the range permitted by regulations.

Overall Comparison

The state of Oregon appears to have the greatest potential to participate in emerging carbon markets based on the greater flexibility inherent in its forest practice regulations. It is also important to note that Oregon has some of the most productive forest lands among the entities in this analysis (Smithwick *et al.* 2002), further enhancing its advantage in carbon markets. At the other end of the spectrum is the state of California, where limitations on harvest size, the outright prescription of silvicultural methods, landscape-level requirements for endangered species conservation, and other restrictions create relatively little flexibility for forest landowners to modify the amount of forest carbon on their lands. Washington and British Columbia fall into the middle of the spectrum in this analysis, with Washington's riparian rules accounting for the greatest proportion of the carbon excluded from tradability by regulatory status. Washington has additional limitations imposed by other regulations, including the spatially variable effects of the Watershed Assessment process. The effects of British Columbia's regional old-growth rules remain to be seen, but are bound to be substantial.

In terms of a highly qualitative ranking, this analysis suggests that the four entities are limited in the following order: California, Washington, British Columbia, and Oregon.

Conclusion

In general, carbon storage on forestlands in California, Oregon, Washington and British Columbia can be expected to be increased by the FPAs enacted in those entities, reducing their potential for obtaining credits through additionality from longer rotations. It is especially significant that these three states and province are home to very productive temperate coniferous forests that are capable of achieving some of the highest known standing carbon stocks in the world. Existing regulations reduce the potential credits that might be eligible for increasing carbon in the forest as well as through restricted harvests limiting access to credits for other services provided by forest ecosystems. Whatever the future role of forest carbon in the mitigation of climate change, mechanisms need to be created to harness this tremendous potential without imperiling the environmental values that forests provide and that forest practice regulations are designed to protect.

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Appendix I

Subject	Code
Riparian Management Areas (RMAs)	
California	14 CCR §§ 916
Oregon	OAR 629-635, OAR 629-640, OAR 629-645, OAR 629-650, OAR 629-650
Washington	WAC 222-22
British Columbia	FRPA 150.5, FPPR 47, 51-52
Wetland Protections	
California	14 CCR §§ 916
Oregon	OAR 629-645, OAR 629-645
Washington	WAC 222-16-030, WAC 222-16-035, WAC 222-24-015, WAC 222-30-020, WAC 222-30-070
British Columbia	FPPR 48-52
Unstable Slope Protections	
California	14 CCR §§ 914.2
Oregon	OAR 629-623, OAR 629-630-0150, OAR 629-640-0210
Washington	WAC 222-30-021, WAC 222-22
British Columbia	FRPA 159, FPPR 37-39, 54
Regeneration Requirements	
California	14 CCR §§ 913.1, 14 CCR §§ 913.2
Oregon	OAR 629-610, OAR 629-611, ORS 527.740, ORS 527.745
Washington	WAC 222-34
British Columbia	FRPA 157, FPPR 44, 46
Retention in Harvest Units	
California	14 CCR §§ 913
Oregon	ORS 527.676, ORS 527.755,
Washington	WAC 222-30
British Columbia	FPPR 66-68
Special Wildlife Habitat Retention Requirements	
California	14 CCR §§ 919.1
Oregon	OAR 629-665
Washington	WAC 222-16-080
British Columbia	FRPA 149.1, Wildlife Act

Road Construction and Maintenance	
California	14 CCR §§ 916.3, 14 CCR §§ 916.9, 14 CCR §§ 961.5
Oregon	OAR 629-623-0450, OAR 629-625
Washington	WAC 222-24
British Columbia	FPA 22-24, FPPR 35-36, 50, 70-84
Restrictions on Rotation Length/Adjacency	
California	14 CCR §§ 913
Oregon	ORS 527.740
Washington	WAC 222-30-025
British Columbia	FRPA 157, FRPA 160, FPPR 64-65
Special scenic area legislation	
California	California Coastal Act of 1976 14 CCR 11
Oregon	ORS 527.755, 16 USC 544
Washington	16 USC 544
British Columbia	FRPA 150.3, FPPR 9.2