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DISTRIBUTION OF SALMON-HABITAT POTENTIAL RELATIVE TO LANDSCAPE CHARACTERISTICS AND IMPLICATIONS FOR CONSERVATION

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Abstract. The geographic distribution of stream reaches with potential to support high-quality habitat for salmonids has bearing on the actual status of habitats and populations over broad spatial extents. As part of the Coastal Landscape Analysis and Modeling Study (CLAMS), we examined how salmon-habitat potential was distributed relative to current and future (+100 years) landscape characteristics in the Coastal Province of Oregon, USA. The intrinsic potential to provide high-quality rearing habitat was modeled for juvenile coho salmon (*Oncorhynchus kisutch*) and juvenile steelhead (*O. mykiss*) based on stream flow, valley constraint, and stream gradient. Land ownership, use, and cover were summarized for 100-m analysis buffers on either side of stream reaches with high intrinsic potential and in the overall area encompassing the buffers. Past management seems to have concentrated nonindustrial private ownership, agriculture, and developed uses adjacent to reaches with high intrinsic potential for coho salmon. Thus, of the area in coho salmon buffers, 45% is either non-forested or recently logged, but only 10% is in larger-diameter forests. For the area in steelhead buffers, 21% is either non-forested or recently logged while 20% is in larger-diameter forests. Older forests are most extensive on federal lands but are rare on private lands, highlighting the critical role for public lands in near-term salmon conservation. Agriculture and development are projected to remain focused near high-intrinsic-potential reaches for coho salmon, increasing the importance of effectively addressing nonpoint source pollution from these uses. Percentages of larger-diameter forests are expected to increase throughout the province, but the increase will be only half as much in coho salmon buffers as in steelhead buffers. Most of the increase is projected for public lands, where policies emphasize biodiversity protection. Results suggest that widespread recovery of coho salmon is unlikely unless habitat can be improved in high-intrinsic-potential reaches on private lands. Knowing where high-intrinsic-potential stream reaches occur relative to landscape characteristics can help in evaluating the current and future condition of freshwater habitat, explaining differences between species in population status and risk, and assessing the need for and feasibility of restoration.

Key words: Coastal Landscape Analysis and Modeling Study; Coastal Province, Oregon (USA); coho salmon; conservation planning; habitat modeling; intrinsic potential; steelhead.

INTRODUCTION

Pacific salmon and trout (*Oncorhynchus* spp.) are integral components of ecosystems in much of western North America (Gende et al. 2002) and are commercially, recreationally, and culturally important (National Resource Council 1996). Given their value, concern has arisen as numerous populations of these fish were placed

at risk (Nehlsen et al. 1991), identified under federal statute (U.S. Endangered Species Act [1973], Canadian Species at Risk Act [2002]), or ultimately extirpated (National Research Council 1996). A variety of anthropogenic factors such as overfishing, artificial propagation in hatcheries, and operation of dams contribute to declining abundances of wild salmonids. Loss and degradation of freshwater habitats are among the most pervasive of these factors (National Research Council 1996). Consequently, salmonid habitat protection and restoration are common objectives of regional conservation strategies (e.g., USDA Forest Service and USDI Bureau of Land Management 1994, State of Oregon 1997).

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Although a broadscale perspective is increasingly recognized as essential when designing, evaluating, and implementing freshwater habitat conservation approaches for salmonids, field data and analytical methods have not kept pace with this need. Comprehensive information on the location of stream reaches with the greatest potential to provide high-quality habitat for salmonids is generally missing for the region. This information can help in evaluating the current condition of freshwater habitat, the potential for future habitat impacts, and the feasibility of proposed restoration when considered relative to land ownership, land use, and land cover. Such landscape characteristics may affect salmonids and their freshwater habitats (Pess et al. 2002, Steel et al. 2004, Van Sickle et al. 2004). For example, timber harvest and the amount of large wood in Pacific northwestern streams are often negatively associated (Murphy and Koski 1989, Bilby and Bisson 1998, Burnett et al. 2006). Large wood is a key element of stream habitat complexity for steelhead and coho salmon (Bustard and Narver 1975, Swales et al. 1986, Reeves et al. 1993). Knowledge about the location and management context of stream reaches with the potential to provide high-quality habitat is vital for prioritizing the limited funds available for salmonid conservation and increasing the likelihood that conservation efforts will succeed.

Through research conducted in the Coastal Landscape Analysis and Modeling Study (CLAMS), we developed spatial models that estimate the potential of streams to provide high-quality rearing habitat for juvenile steelhead (*Onchorynchus mykiss*) and juvenile coho salmon (*O. kisutch*). The calculated metric, termed intrinsic potential, reflects species-specific associations between fish use and persistent stream attributes. The primary objective addressed in this paper is to compare distributions of reaches with high intrinsic potential for steelhead and for coho salmon relative to land ownership, land use, and land cover. Results allowed us to assess likely habitat conditions in, and future effects of forest policies on, reaches with high intrinsic potential using modeled CLAMS outputs for current and projected future land use and land cover (Ohmann and Gregory 2002, Kline et al. 2003, Bettinger et al. 2005, Johnson et al. 2007).

STUDY AREA

The Coastal Province of Oregon encompasses approximately 2.5 million ha (Fig. 1) and is underlain primarily by marine sandstones and shales or basaltic volcanic rocks. Except for interior river valleys and a prominent coastal plain in places, mountains dominate the area. Elevations range from 0 to 1250 m. Montane areas are highly dissected, with drainage densities up to 8.0 km/km². The climate is temperate maritime with mild, wet winters and warm, dry summers. Peak stream flows are flashy following winter rainstorms, and base flows occur between July and October. The Nehalem and Umpqua

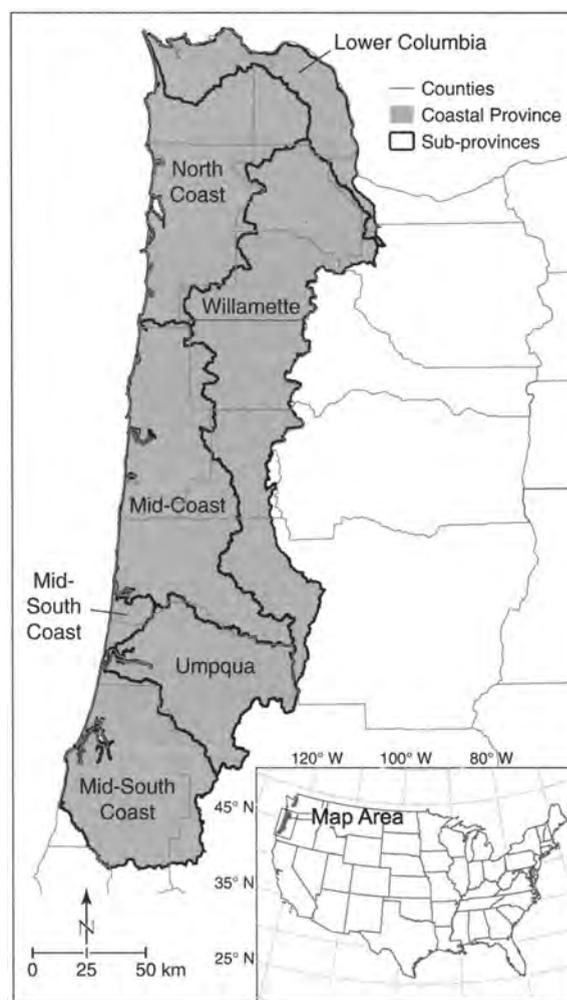


FIG. 1. Location of six sub-provinces and the Coastal Province of Oregon, USA.

Rivers drain the largest areas, with mean annual stream flows in the lower mainstems of 123.7 and 256.1 m³/s, respectively. Although we address only steelhead and coho salmon, the study area supports three other salmonid species: coastal cutthroat trout (*O. clarki*), chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*). Within the study area, steelhead is listed under the U.S. Endangered Species Act (1973) as a Species of Concern in the Oregon Coastal Evolutionarily Significant Unit (ESU) and as a Threatened Species in the Upper Willamette ESU. Coho salmon is a candidate species for listing in the Lower Columbia and Oregon Coastal ESUs; it was recently downgraded from a Threatened species in the Oregon Coastal ESU to not warranted for listing after the role of hatchery fish was evaluated.

METHODS

Intrinsic potential

We modeled intrinsic potential for each stream reach independently for juvenile steelhead and for coho

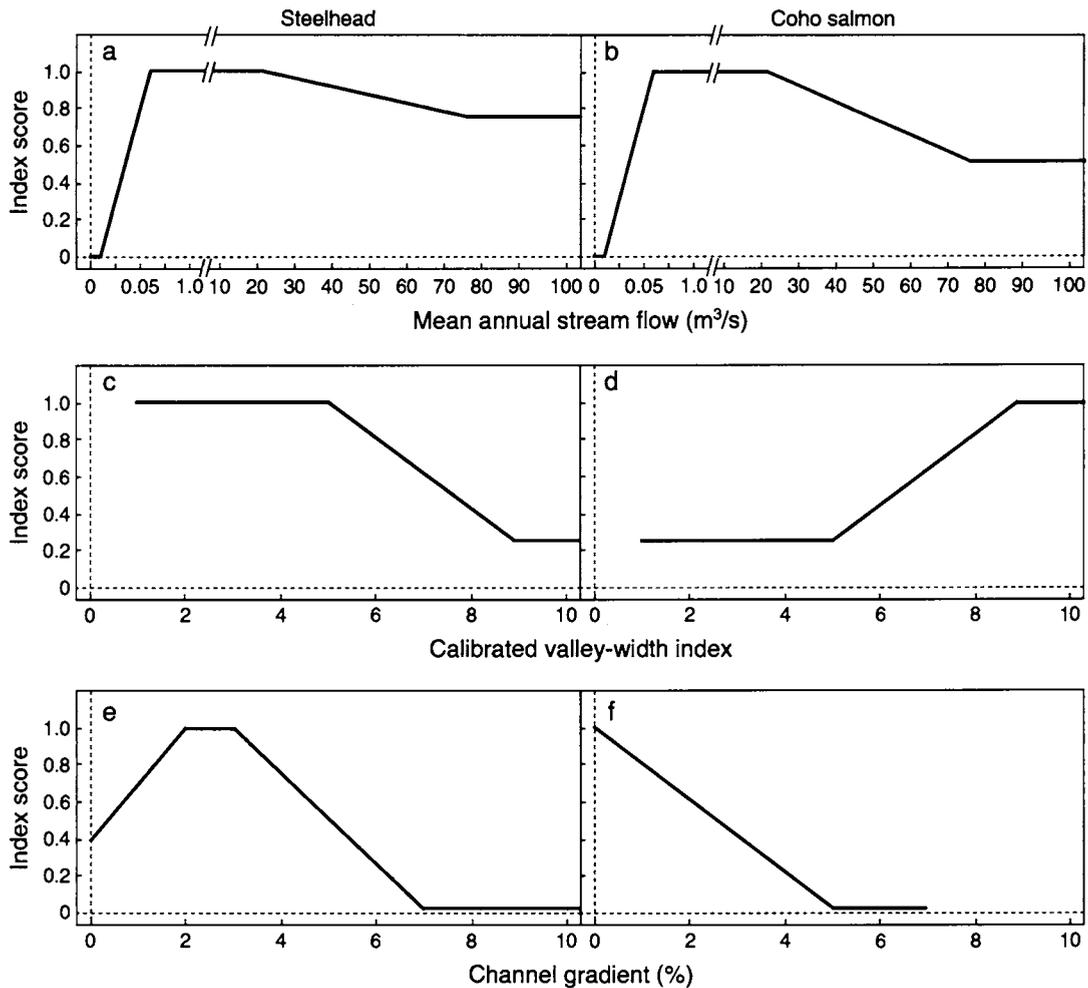


FIG. 2. Relationship between values of the three stream attributes (mean annual stream flow, calibrated valley-width index, and channel gradient) and the index scores that were used to calculate intrinsic potential for steelhead and for coho salmon.

salmon from stream attributes of mean annual stream flow, valley constraint, and channel gradient. These attributes were produced in conjunction with the digital stream network from 10-m digital elevation models (DEMs) (Miller et al. 2003). The stream network was output in an ArcView shape file format and then imported into ArcInfo (version 8.3; ESRI, Redlands, California, USA) for all subsequent processing. Stream attribute values were translated into index scores for each species (Fig. 2). The index scores were based on empirical evidence from published studies regarding the relationship between a stream attribute and juvenile fish use; this evidence is detailed below. Following the most commonly applied approaches for modeling habitat suitability (Morrison et al. 1998, Vadas and Orth 2001), intrinsic potential for each stream reach was calculated by multiplying the un-weighted species-specific index scores together and then taking the geometric mean of the product. This approach reflects the assumption that the three stream attributes are of approximately equal importance and only partially compensatory, and that

the smallest index score has the greatest influence on the intrinsic potential. The index scores and intrinsic potential can range from zero to one; larger values indicate a greater potential for providing high-quality rearing habitat. Stream reaches were classified with a high species-specific intrinsic potential when the calculated value was ≥ 0.75 . Intrinsic potential is reported for a species only below naturally occurring barriers to migrating adults. We identified these barriers based on information from the Oregon Department of Fish and Wildlife that included a field determination of passability, barrier type, barrier height, and 1:100 000-scale maps of fish distribution.

Mean annual stream flow.—Index curves for mean annual stream flow (Fig. 2a, b) were established relative to modeled flows that approximate small (< 0.06 m³/s) streams defined in the water protection rules for the Oregon Forest Practices Act and that approximate gauged flows in streams considered medium (0.06 to 21.24 m³/s), large (21.24 to 76.45 m³/s), and very large (> 76.45 m³/s). The latter corresponds to mainstems of

major rivers in the Coastal Province. Juvenile steelhead occur in streams from small tributaries to large mainstem rivers (Meehan and Bjornn 1991, Behnke 1992), and so index scores for this species are high across a broad range of mean annual stream flows (Fig. 2a). Juvenile coho salmon occur primarily in small tributaries up to mid-sized rivers (Sandercock 1991, Rosenfeld et al. 2000). However, widespread anthropogenic changes to the complex habitats favored by juvenile coho salmon in larger river systems (Sedell and Luchessa 1982, Beechie et al. 1994, Independent Multidisciplinary Science Team 2002) make it difficult to infer the potential for use from the present distribution of coho salmon. Given this uncertainty, the index curve for coho salmon declines at mean annual stream flows exceeding 21.24 m³/s and assigns a score of 0.5 for flows exceeding 76.45 m³/s (Fig. 2b).

Valley constraint.—This reflects the extent to which hill slopes impinge on the channel, and thus the ability of the stream to interact with its floodplain. Valley constraint was characterized for each stream reach by modeling the valley-width index (ratio of valley-floor width to active-channel width) from DEMs and then interpreting the result relative to field-identified geomorphic classes. For a subset of our stream reaches, we evaluated the modeled valley width index against classes of “constrained by hill slopes” ($n = 91$) and “unconstrained” ($n = 33$) as determined in the field by the Oregon Department of Fish and Wildlife (Moore et al. 2002). The difference between the field-determined constrained and unconstrained classes was evaluated with one-way ANOVA on the ranked modeled valley-width index (SAS version 8.2, PROC GLM; SAS 2003). Medians of the modeled valley-width index for the field-determined constrained class (median = 5.06) and unconstrained class (median = 8.87) differed significantly (Kruskal-Wallis test: $\chi^2 = 43.89$; $df = 1$; $P < 0.0001$). Based on the medians, we considered reaches relatively constrained if the modeled valley-width index was ≤ 5.06 and as relatively unconstrained if the modeled valley-width index was ≥ 8.87 . Juvenile steelhead tend to use constrained reaches more than unconstrained reaches (Hicks 1990, Reeves et al. 1998, Burnett 2001). Juvenile coho salmon are typically more abundant and productive in unconstrained than constrained streams (Hicks 1990, Bradford et al. 1997, Reeves et al. 1998, Burnett 2001, Sharma and Hilborn 2001). Therefore, reaches with high values of the valley-width index, those considered unconstrained, are assigned the lowest score in the index curve for steelhead trout but the highest score for coho salmon (Fig. 2c, d).

Channel gradient.—Juvenile steelhead commonly rear in streams with gradients up to 6% in western Oregon (Roper et al. 1994, Scarnecchia and Roper 2000, Burnett 2001) but have been found elsewhere occupying low-gradient areas in steeper stream sections (Engle 2002). Gradient and use by juvenile steelhead appear to be positively related at lower gradients, but the relationship

peaks at intermediate gradients (Roper et al. 1994, Scarnecchia and Roper 2000, Burnett 2001, Hicks and Hall 2003). Thus, the index curve for steelhead assigns the highest score to reaches with channel gradients between 2% and 3% and assumes no use upstream of reaches with gradients exceeding 10% (Fig. 2e). Coho salmon rear typically in low-gradient stream reaches and decrease in density as gradients increase (Schwartz 1990, Nickelson 1998, Rosenfeld et al. 2000). Thus, the index curve for coho salmon declines linearly from 0% channel gradient and assumes no use upstream of reaches with gradients exceeding 7% (Fig. 2f).

Landscape characterization

The location of reaches with high intrinsic potential was analyzed relative to current land ownership, current and future land use, and current and future land cover, as these characteristics are thought to influence stream ecosystems (e.g., Burnett 2001, Wing and Skaugset 2002, Roy et al. 2003). Current refers to the year 1996, and future refers to projections under current policies for the year 100 in CLAMS simulations. Reference to increase or decrease in percentage area occupied by a given class is the absolute and not relative change over the period of simulation.

Current land ownership was compiled from spatial data on private owners (1991) and public owners (1996) (Oregon Department of Forestry 2004). Land ownership was aggregated into six classes: private industrial timberland (PI), nonindustrial private lands (NIP), State of Oregon (state), U.S. Bureau of Land Management (BLM), U.S. Forest Service (USFS), and other public and tribal lands (other). Current land-use data were obtained by combining raster layers of CLAMS current forest cover (Ohmann and Gregory 2002), CLAMS current human development (Kline et al. 2003), and 1998 Oregon generalized zoning. Future land-use data were created by substituting future forest cover (Johnson et al. 2007) and future human development (Kline et al. 2003). Applying the 1998 zoning data to obtain future land use incorrectly assumes no change in zoning, but zoning projections were unavailable. Land use was aggregated into five classes: forestry, agriculture, rural residential (0.25–2.5 structures/ha), urban (>2.5 structures/ha), and other uses (e.g., parks, rural service centers, or 0.06–0.25 structures/ha). Land-cover data for current (Ohmann and Gregory 2002) and future (Bettinger et al. 2005, Johnson et al. 2007) conditions were aggregated into six classes: non-forest; open ($\leq 40\%$ canopy cover as a result of timber harvest), hardwood forest ($\geq 65\%$ of the basal area in hardwood forest), small/medium (quadratic mean diameter [QMD] of dominant trees ≤ 50 cm), large (QMD of dominant trees 50–75 cm), and very large (QMD of dominant trees > 75 cm). Small to very large cover classes contain conifer forests with canopy closure $> 40\%$ and $< 65\%$ of the basal area in hardwoods.

TABLE 1. Summary of lengths of stream modeled to be accessible and to have high (values ≥ 0.75) intrinsic potential for steelhead and coho salmon in the Coastal Province of Oregon, USA.

Location	Total stream length (km)	Steelhead		Coho salmon	
		Length accessible (km)	Length of high intrinsic potential (km) †	Length accessible (km)	Length of high intrinsic potential (km) †
Coastal Province	95 936	25 101	5445 (22)	14 964	5440 (36)
Sub-province					
Lower Columbia	6077	1874	294 (16)	1495	715 (48)
Willamette	18 283	7070	630 (9)	0	0 (0)
North Coast	20 286	4782	1484 (31)	3747	1169 (31)
Mid-Coast	20 503	5386	1588 (30)	4533	1577 (35)
Mid-south Coast	16 950	3410	834 (25)	2993	1201 (40)
Lower Umpqua	13 837	2579	615 (24)	2196	778 (35)

† Values in parentheses are the percentages of accessible stream length that is high potential.

A 100-m analysis buffer was generated on either side of high-intrinsic-potential stream reaches for steelhead (referred to as steelhead buffers) and for coho salmon (referred to as coho salmon buffers). This buffer width was intended to include the streamside zone most likely to influence these reaches (Naiman and Bilby 1998) but was not intended to represent current or proposed riparian management areas. The percentage area of each class of land ownership, use, and cover was summarized within these buffers.

Although a channel-adjacent focus is supported by well-established links between the local riparian area and a stream (Naiman et al. 2000, National Research Council 2002), circumstances further upslope and upstream in a catchment may affect stream ecosystems (Montgomery and Buffington 1997, Burnett 2001, Roy et al. 2003). To provide this context, we summarized land ownership, use, and cover for the entire area encompassing steelhead and coho salmon buffers. Comparisons between buffers and the encompassing unit allowed us also to evaluate whether land management is, or might become, concentrated near high-intrinsic-potential reaches.

To examine issues of spatial scale, the percentage of area in each land-ownership, use, and cover class was summarized for the entire Coastal Province and six sub-provinces. Sub-provinces (Fig. 1) corresponded approximately to the assessment unit boundaries delineated by the Oregon Department of Fish and Wildlife (Jacobs et al. 2001) and contain aggregates of steelhead and coho salmon populations within ESUs determined by the National Marine Fisheries Service.

Evaluating sensitivity of landscape characterization to analysis parameters

We examined the sensitivity of buffer characterizations to the threshold for identifying high intrinsic potential and buffer width. To compare with our results obtained using the threshold value of 0.75, reaches were identified as high intrinsic potential by using threshold values of 0.65 and 0.85. Land use and cover around these reaches were then summarized within a 100-m buffer. The landscape conditions were also summarized

within a 60-m buffer on either side of all reaches identified as high (≥ 0.75) intrinsic potential to compare with results we obtained using 100-m buffers. Land-use and cover data have a 30-m resolution, so we did not examine buffer widths less than 60 m given concerns about spatial accuracy.

RESULTS

Intrinsic potential

Steelhead were estimated to have access to 25 101 km of the modeled stream network in the Coastal Province (Table 1). Reaches with high intrinsic potential for steelhead occupy 22% of this accessible length. Approximately 15 000 km of the modeled stream network were accessible to coho salmon, and 36% of this was classified as high intrinsic potential for the species (Table 1). Although total lengths of high intrinsic potential habitat are nearly equal for steelhead and coho salmon in the Coastal Province, how these lengths are apportioned among sub-provinces generally differs for the two species (Table 1).

Distribution of high intrinsic potential relative to landscape characteristics

Land ownership.—Land ownership in buffers around high-intrinsic-potential reaches differs between steelhead and coho salmon in the Coastal Province (Fig. 3a). The area in steelhead buffers is about evenly distributed between private and public owners. Eighty-one percent of the area in coho salmon buffers is privately owned, with the majority being in nonindustrial private ownership. Steelhead buffers include a smaller percentage of private land but a larger percentage of public land than the province as a whole; the opposite is true for coho salmon buffers, highlighting the concentration of private ownership adjacent to high-intrinsic-potential reaches for coho salmon.

Many ownership patterns observed in the province were observed also in the sub-provinces (Fig. 3). For example, in each sub-province, private lands are held primarily by industrial timber owners in steelhead

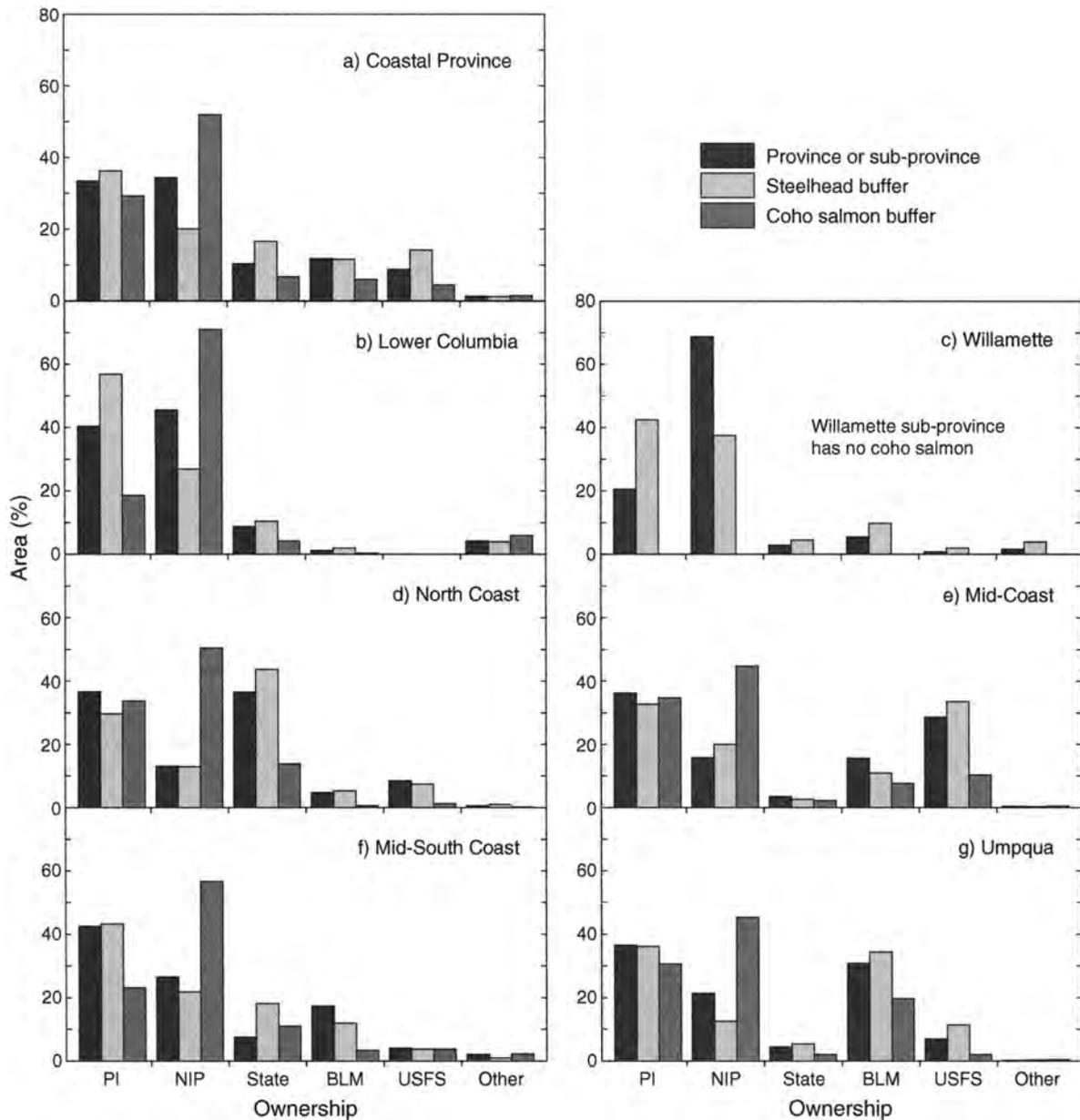


FIG. 3. Distribution of current land ownership in buffers around stream reaches with high intrinsic potential for steelhead and for coho salmon in six sub-provinces and the Coastal Province of Oregon, USA. Analysis buffers are 100 m on either side of high-intrinsic-potential reaches. Abbreviations: PI, private industrial; NIP, nonindustrial private; BLM, Bureau of Land Management; USFS, U.S. Forest Service.

buffers but by nonindustrial owners in coho salmon buffers. Nevertheless, variation exists among sub-provinces. The area of steelhead buffers in private ownership ranged among sub-provinces from 43% to 84%. Additionally, the public landholder with the most direct influence over buffers for each species is the same within a sub-province but different among sub-provinces.

Land use.—Forest uses dominate buffers for each species at the province scale, both now and in the future. Almost all (92%) of the area in steelhead buffers, but only 68% of the area in coho salmon buffers, is currently

being managed for forest uses (Fig. 4a). The percentage of area in forest uses is projected to decrease slightly for buffers of each species (Fig. 4b). Steelhead buffers currently contain a smaller percentage of each non-forest-use class than coho salmon buffers. Although the changes are minimal for buffers of both species, percentages in agriculture and other uses are projected to decrease while percentages in rural residential and urban uses are projected to increase.

As in the province as a whole, forest uses dominate buffers in each sub-province for each species (Fig. 4).

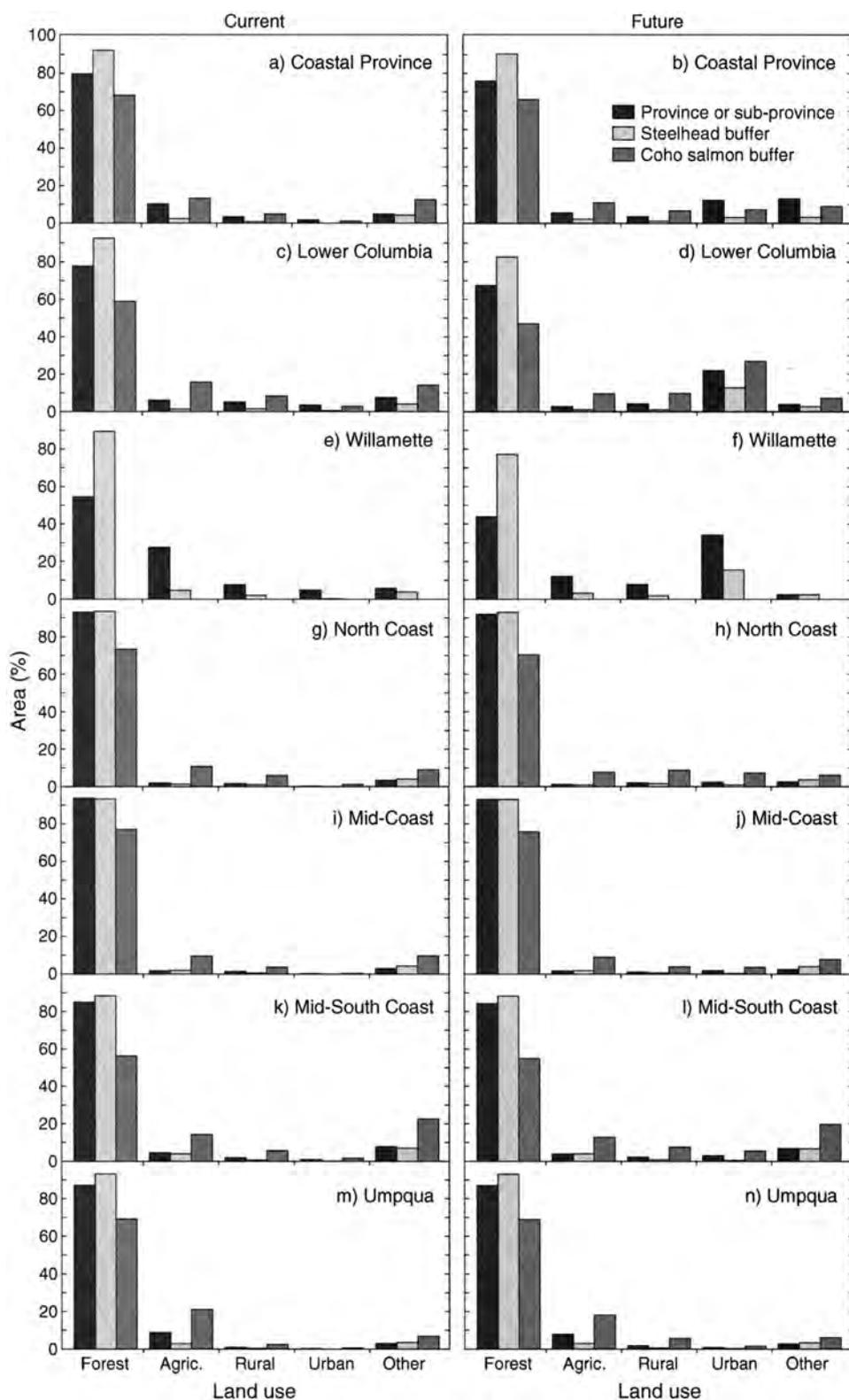


FIG. 4. Distributions of current and future land use in buffers around stream reaches with high intrinsic potential for steelhead and for coho salmon in six sub-provinces and the Coastal Province of Oregon, USA. Analysis buffers are 100 m on either side of high-intrinsic-potential reaches.

Forest uses currently exceed 88% of the area for steelhead buffers in each sub-province and range from 56% to 77% of the area for coho salmon buffers. Developed uses (rural residential and urban) comprise only a small percentage of the area in buffers for each species in each sub-province. However, percentages of developed uses in coho salmon buffers are currently greater, and projected to increase more, than percentages in steelhead buffers or in each encompassing sub-province. The greatest increases in developed uses are expected in the Lower Columbia and Willamette sub-provinces for steelhead buffers and in the Lower Columbia, North Coast, and Mid-south Coast sub-provinces for coho salmon buffers.

Land cover.—At the province scale, steelhead and coho salmon buffers share some land-cover characteristics but not others. Of the forest-cover classes, hardwood forests and small/medium-diameter mixed conifer–hardwood forests comprise the greatest area in both steelhead and coho salmon buffers (Fig. 5b, c). Private owners hold the majority of these forest types, as well as the majority of the open class, in buffers for both species, now and in the future (Fig. 5b, c). Public lands currently contribute most of the large- and very-large-diameter forest classes. When these two classes are combined, the percentage of the larger diameter class in steelhead buffers is 20%, and that in coho salmon buffers is 10%. This relative difference is apt to persist in the future, even though buffers for both species are expected to contain more of the larger diameter classes. Percentages of larger-diameter forests are anticipated to increase more on public lands than on private lands. Almost all of the increase in the percentage of larger-diameter forests on private lands is anticipated in the large- rather than the very-large-diameter class (Fig. 5b, c). The percentage of private lands supporting large-diameter forests is projected to increase more in buffers for both species than in the province as a whole (Fig. 5a–c).

Land-cover characteristics by ownership vary among sub-provinces (see Appendix), but patterns are generally similar to those in the province. Given the relatively high percentage of federal lands, more of the buffered area for steelhead and for coho salmon supports large- and very-large-diameter forests in the Mid-Coast and Umpqua than in other sub-provinces. The percentage of buffers in larger diameter classes is expected to increase for every sub-province, causing these forests to eventually make up at least 75% of buffers on federal lands, at least 60% of buffers on state lands, but no more than 25% of buffers on private lands. The greatest increases are expected for state lands in the North Coast. Increases in larger-diameter forests are projected to range among sub-provinces from 22% to 44% for steelhead buffers and from 11% to 23% for coho salmon buffers. Accompanying decreases are projected in the open and hardwood classes in all sub-provinces.

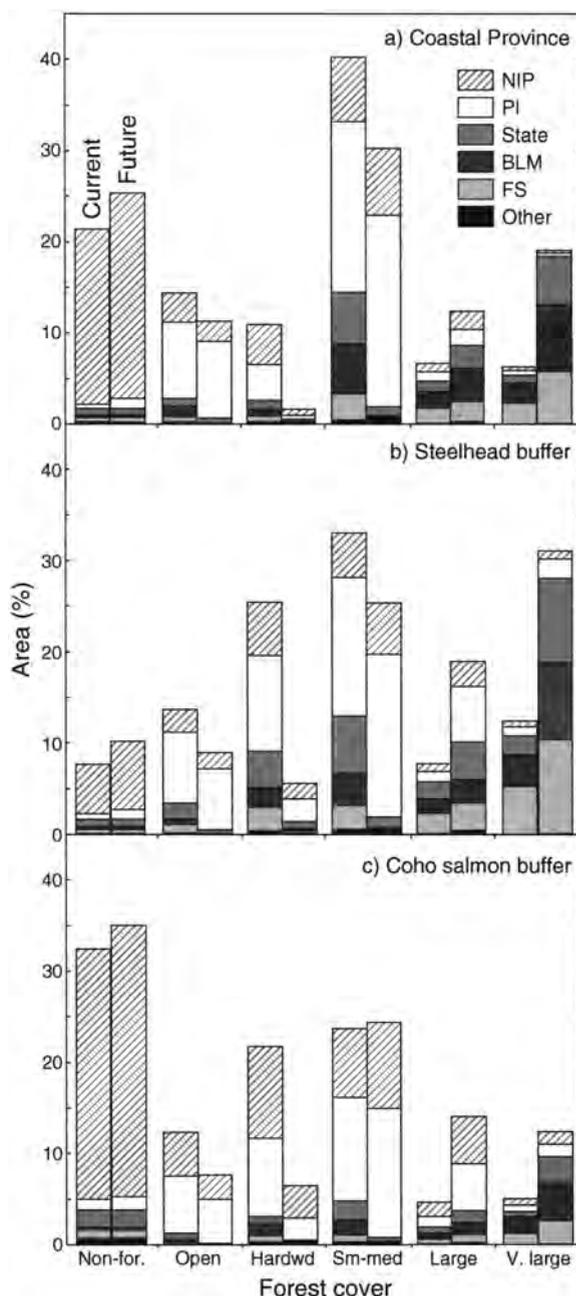


FIG. 5. Distributions of current and future land cover by ownership in buffers around stream reaches with high intrinsic potential for steelhead and for coho salmon in the Coastal Province of Oregon, USA. Land-cover and land-ownership classes are described in the text. Analysis buffers are 100 m on either side of high-intrinsic-potential reaches. In each pair of histograms, the left is current, and the right represents the future.

Sensitivity of landscape characterization to analysis parameters

General patterns of current land use and land cover in buffers around high-intrinsic-potential reaches appeared relatively insensitive to the width of the buffer and to the

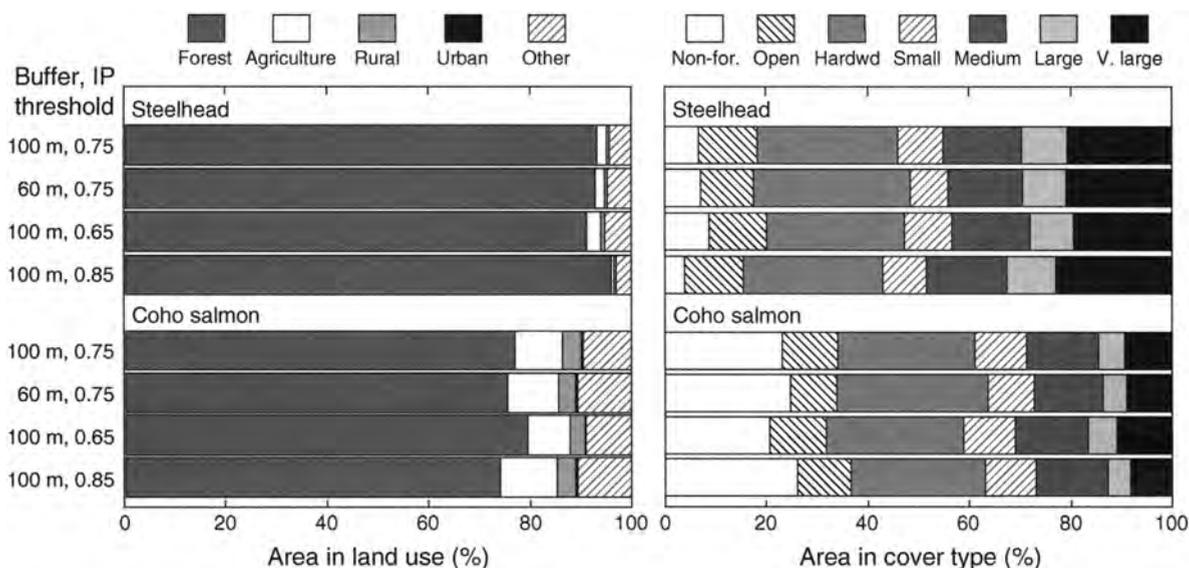


FIG. 6. Effects on landscape characterizations of thresholds for defining high intrinsic potential (IP) and buffer width. Histograms are for steelhead and coho salmon buffers under current land use and land cover in the Mid-Coast sub-province.

values for defining high intrinsic potential over the ranges that we examined. In the Mid-Coast sub-province, for example, percentages of each land-use class were somewhat more sensitive to the threshold for defining high intrinsic potential than to the width of the buffer (Fig. 6). Percentages of each land-cover class differed by $<5\%$ when one or the other analysis parameter was varied (Fig. 6). The largest difference arose for coho salmon buffers in the most abundant cover class (non-forest), when the value for defining high intrinsic potential was changed from 0.65 to 0.85.

DISCUSSION

Implications of landscape characterizations for high-intrinsic-potential habitat

Our approach is consistent with the working hypothesis articulated by Steel et al. (2003) that landscape characteristics can affect stream habitats that can in turn affect salmonid populations. Consequently, the methods we developed build on and complement others applied at broader spatial scales in the Pacific Northwest. Whereas Lunetta et al. (1997) evaluated habitat potential generically for salmonids relative to landscape characteristics, we consider the implications separately for steelhead and coho salmon. Modeling statistical relationships among landscape characteristics, habitat, and indicators of salmonid abundance has also been undertaken (e.g., Pess et al. 2002, Steel 2004, Burnett et al. 2006), but data are rarely available to allow this beyond the subbasin scale. Thus, our examination of the distribution of high-intrinsic-potential reaches relative to land ownership, use, and cover provides a spatially extensive context for steelhead and coho salmon habitat in the Coastal Province of Oregon that was previously unavailable. Actual conditions in high-intrinsic-poten-

tial reaches remain unknown. However, we can infer something about current and future conditions based on knowledge of history, management policies, and relationships between habitat and landscape characteristics. Our conclusions are likely to have relevance outside the Coastal Province because the natural and anthropogenic forces that shape streams are similar throughout much of the Pacific coastal region of North America.

Current land ownership, land use, and land cover.—Streams in montane areas, such as the Coastal Province, are naturally dynamic and can support a shifting mosaic of habitat conditions (Reeves et al. 1995, Montgomery 1999, Benda et al. 2004), therefore we expect that not all reaches with the potential to provide high-quality habitat will do so at any one time. Even so, we surmise based on our results that only a relatively small percentage of reaches for coho salmon may be realizing the potential to provide high-quality habitat in the Coastal Province. Past management appears to have concentrated nonindustrial private ownership, agriculture, and developed uses adjacent to high-intrinsic-potential reaches for coho salmon. Conversion of forested lands to agricultural and developed uses is associated with many negative effects on stream ecosystems (e.g., Independent Multidisciplinary Science Team 2002, Roy et al. 2003, Van Sickle et al. 2004), including lower densities of coho salmon (Beechie et al. 1994, Bradford and Irvine 2000, Pess et al. 2002). By the late 1800s, extensive alteration of channels, floodplains, and forests along most major Pacific coastal rivers (e.g., Lichatowich 1989, Beechie et al. 1994, Independent Multidisciplinary Science Team 2002), may have particularly impacted high-intrinsic-potential habitats for coho salmon on what are today primarily nonindustrial private lands. Congruent with this history, streams on

nonindustrial private lands in western Oregon contain smaller volumes and fewer pieces of large wood than streams on other ownerships (Wing and Skaugset 2002), which implies reduced suitability of rearing habitat for coho salmon.

Land-cover characteristics in buffers suggest anthropogenic impacts in high-intrinsic-potential reaches for both steelhead and coho salmon. Approximately half the area in coho salmon buffers is either non-forested or recently logged. Higher percentages of land cover, indicating intensive forest management, are associated with negative effects on various biotic, water quality, and habitat indicators (e.g., Sutherland et al. 2002, Williams et al. 2002, Weigel et al. 2003), including large wood (Murphy and Koski 1989, Reeves et al. 1993, Burnett et al. 2006). The historical range of variation has been established for forest cover in the Coastal Province (Wimberly et al. 2000, Spies et al. 2007) but not specifically for riparian forest cover. We recognize that disturbance susceptibilities can differ between riparian and upland areas. However, combined percentages of non-forest and open area in steelhead buffers and in coho salmon buffers exceed the historical range of variation in the 0 to 20 year age class generally for the Coastal Province.

Although larger-diameter forests occupy twice the area in steelhead buffers as in coho salmon buffers, recent loading of large wood is probably less than historical loading in high-intrinsic-potential reaches for both species. Large trees are more likely than small trees to supply the most stable, functional pieces of wood to streams (Montgomery et al. 1996, Wing and Skaugset 2002). The percentage of larger-diameter, older forest in buffers for both species is relatively small, and likely below the modeled historical range of variation in the Coastal Province (Wimberly et al. 2000, Spies et al. 2007). Larger-diameter forests in buffers for both species are most extensive on federal lands, rare on private lands, and intermediate on state lands, highlighting the critical role that public lands may have for salmon conservation in the near-term.

Future land ownership.— Unless public landownership increases dramatically, which is doubtful, activities on both public and private lands will determine the future success of salmonid conservation in the Coastal Province. Public lands typically offer the widest range of conservation alternatives, and thus the most comprehensive efforts to protect and restore salmon habitat have been undertaken there (e.g., USDA Forest Service and USDI Bureau of Land Management 1994). Although focusing on public lands has been more socially and politically acceptable, widespread recovery of steelhead or coho salmon is unlikely if habitat is not improved also in high-intrinsic-potential reaches on private lands. Concentration of high-intrinsic-potential reaches for coho salmon in nonindustrial private ownership may complicate conservation efforts for this species. Nonindustrial private owners are numerous,

and hold some of the most intensively managed lands; thus coordinating effective habitat protection and restoration may be more challenging on nonindustrial private lands than on either forest industry or public lands.

Future land use.— Developed uses are projected to increase more in coho salmon buffers than in either steelhead buffers or the Coastal Province as a whole, suggesting that development will accelerate adjacent to high-intrinsic-potential reaches for coho salmon. Thus, the effectiveness of policies addressing nonpoint source pollution from developed uses may reasonably become of greater consequence in coho salmon recovery than in the past. Projections for buffers indicate that habitat impacts from developed uses are likely to be greater for steelhead in the Lower Columbia and Willamette sub-provinces and for coho salmon in the Lower Columbia, North Coast, and Mid-south Coast sub-provinces. Of general concern for all aquatic species, is that overall percentages of the Lower Columbia and Willamette sub-provinces in urban uses are projected to exceed thresholds identified with stream impairment (Beach 2002).

Agriculture is expected to continue in coho salmon buffers. Therefore, incorporating specific measures to protect or restore habitat in reaches with high intrinsic potential for coho salmon on agricultural lands can be valuable in recovery planning (under the Oregon Plan for Salmon and Watersheds and the U.S. Endangered Species Act [1973]), as well as in subsequent revisions of basin plans and rules under Oregon's Agriculture Water Quality Management Act (1993). Providing adequate funding pursuant to this act for technical assistance, education, complaint investigation, and enforcement also will be beneficial.

Forest uses should stay predominant in the Coastal Province, and so the possibility remains high that forest practices will influence habitat in high-intrinsic-potential reaches for steelhead and for coho salmon. Forest practices can be tailored to minimize impacts on or help restore rearing habitat. For example, road construction and timber harvest may be shifted away from areas likely to deliver landslides and debris flows, which can be relatively common natural disturbances in montane areas. Many landslide and debris-flow characteristics, including the probability of initiation, distance traveled, and dimensions and amount of wood delivered to streams can be influenced by forest practices (Naiman and Bilby 1998, Montgomery et al. 2000, May 2002). Overlaying maps of intrinsic potential with probabilities of landslide and debris-flow impacts can identify areas susceptible to the effects of forest management and aid in designing efficient approaches to reduce negative effects on steelhead and coho salmon habitat throughout their range.

Future land cover.— Riparian policies for forested lands of the Coastal Province account for one of the more important projected changes in land cover over the next 100 years: a doubling of the percentage of larger-

diameter trees adjacent to high-intrinsic-potential reaches for both species. Most of this increase is expected on public lands due to policies that emphasize biodiversity protection (Johnson et al. 2007). Nevertheless, CLAMS forest-cover projections suggest that management under the state's riparian rules will increase the percentage of larger-diameter forests along fish-bearing streams on private lands. Increases are anticipated predominantly in the large-diameter class on private lands but in the very-large-diameter class on public lands, reflecting larger initial tree diameters and policies of little or no riparian logging of these large trees on public lands.

The projected increase in the large-diameter class for forested private lands is probably a best-case scenario. This arises from assumptions in CLAMS about how private landowners will manage riparian areas adjacent to fish-bearing streams. For example, it was assumed that private landowners will meet the state's basal area requirements along fish-bearing streams by forest thinning throughout the entire riparian management area (Johnson et al. 2007). Actually, basal area requirements are more apt to be met by leaving trees in a portion of the riparian management area (usually closest to the stream) and clear-cutting the remainder in conjunction with upland harvest. This approach is generally more cost-effective than thinning throughout the riparian management area but less likely to produce the increases in large-diameter trees projected for private forestlands in CLAMS.

Even if the increase in large-diameter trees on private forestlands is less than projected, many riparian functions, such as shade and bank stability, should improve even if others, such as wood recruitment, may not. The adequacy of future wood recruitment under the state's riparian rules has been questioned (Murphy 1995, Independent Multidisciplinary Science Team 1999). Despite findings of similar counts and volumes of large wood in streams on different classes of forest owners (Wing and Skaugset 2002), amounts of wood in fish-bearing streams on private and public timberlands will probably diverge in the future. This is anticipated as existing inchannel wood decays and less new wood is recruited from private than public lands. Wood recruitment is likely to be lower along every stream class on private lands. Policies for private forestlands allow harvest of many riparian trees adjacent to fish-bearing streams and of all riparian trees adjacent to smaller, non-fish-bearing streams that can deliver wood in debris flows.

It is important to note that old-growth conifer forests were not ubiquitous in streamside areas under the natural disturbance regime. Floodplain reconstructions for the Coastal Province indicate that grassy marshes and hardwood forests, in addition to conifer forests, were adjacent to lowland rivers (Nonaka 2004). However, the future percentage of coho salmon buffers in larger-diameter, older forests is projected to remain

below, and the future percentage in non-forest and open areas is projected to remain well above, the historical range of variation for forests generally (Wimberly et al. 2000, Spies et al. 2007). In contrast, the future percentage of larger-diameter, older forests in steelhead buffers is projected to be within the historical range of variation for forests generally. Hardwoods are a substantial component of unmanaged riparian areas along all but the smallest streams in the Coastal Province (Pabst and Spies 1999) and are an important nitrogen source for streams (Compton et al. 2003). Given these considerations, riparian policies aimed at promoting forests of large conifers adjacent to all streams may be neither scientifically supportable nor necessary to protect and restore salmon habitat over the long term.

Scope and limitations

Intrinsic potential models may be limited by incorporating landform controls but not other abiotic or biotic factors. These can affect the suitability of freshwater habitat for salmonids, and thus the accuracy of our landscape characterizations. For example, when our models were adapted and applied by the National Marine Fisheries Service for California, many reaches identified as high intrinsic potential for coho salmon in the southern interior valleys were ultimately eliminated as habitat given concerns about naturally high summer water temperatures (Agrawal et al. 2005). In addition, interspecific competition is well documented between juvenile salmonids at finer spatial scales (e.g., Hearn 1987); thus, suitability of a reach for a particular species may be reduced by the presence of a competitor. Biotic interactions, such as competition, are rarely studied at broader spatial scales (e.g., Fausch 1998), and so how such interactions might affect our sub-province and province results is unknown. Spatial characteristics other than those assessed here may modify the value of high-intrinsic-potential reaches for conservation. High-intrinsic-potential reaches closer to beaver habitat (Pollock et al. 2004), source areas for re-colonization, or other reaches with high intrinsic potential may be of greater conservation value than those farther from these features.

Thresholds within a reasonable range (0.65–0.85) for defining high intrinsic potential had little impact on buffer characterizations or on the relative differences between buffers for the two species. At lower threshold values, however, conditions in steelhead and coho salmon buffers should become more similar because more of the channel network for each species will be identified as high intrinsic potential.

The approach taken in this study is most reliably applied and interpreted at broader spatial scales. The resolution and accuracy of spatial data undoubtedly reduced the accuracy of sub-province- and province-scale characterizations. Even so, results are generally consistent with ecological and policy expectations. To

illustrate, buffers for each species include a larger percentage of broadleaf forest, but a smaller percentage of recently harvested forest, than the overall province. This reflects the greater likelihood of red alder (*Alnus rubra*) occurrence in wetter and more frequently disturbed areas near larger streams (Pabst and Spies 1999) and riparian forest policies that shift timber harvest away from fish-bearing streams (USDA Forest Service and USDI Bureau of Land Management 1994, Young 2000). Accuracies of land use and cover data are influenced by the models from which these were derived and by assumptions about implementation of current policy that are discussed in detail elsewhere (Ohmann and Gregory 2002, Kline et al. 2003, Johnson et al. 2007). These aspects have not been comprehensively evaluated for riparian areas. Preliminary assessment indicates that the accuracies of current forest cover characteristics are generally similar in streamside and upland areas (K. M. Burnett and J. L. Ohmann, unpublished data).

Despite our ability to infer something about actual habitat conditions, we do not know what percentage of high-intrinsic-potential reaches must supply high-quality habitat either to be within the historical range of variation or to support viable populations of steelhead and coho salmon. As a first step in this regard, the intrinsic potential models have been applied to describe historical population structures of steelhead, coho salmon, and chinook salmon for southern Oregon and much of northern California (Bjorkstedt et al. 2005, Lindley et al. 2006). A next logical step is to link models of natural disturbance, habitat, and intrinsic potential to help assess 'how much high-quality habitat is enough?'

CONCLUSIONS

The geographic distribution of high-intrinsic-potential reaches has bearing on the likely status of habitats and populations over broad spatial extents when examined relative to landscape characteristics. By linking intrinsic potential with current and projected-future landscape data, we demonstrate that human activities that reduce the amount and diameter of forest cover have been, and will likely remain, focused adjacent to high-intrinsic-potential habitats for coho salmon. Although policies and ecosystems will change over the next 100 years, landscape projections are valuable for helping decision makers and the public understand how current policies may affect stream habitats and as a baseline for comparing projected effects of alternative policies. The multi-ownership perspective of this research was able to highlight differences between federal and state forest policies for increasing tree diameters adjacent to fish-bearing streams, the importance of public lands in meeting near-term conservation objectives for salmonids, and the need to improve habitat on nonindustrial private lands for long-term coho salmon recovery. Despite our focus on steelhead and coho salmon in the Coastal Province of Oregon, the approach can be

adapted and applied to other areas and to other lotic species with established relationships to landscape characteristics and stream attributes. A key advantage of our approach is that it consistently evaluates each stream reach over a broad area using data (e.g., land use, precipitation, and digital elevation) that are readily available throughout much of the United States and Canada, which will continue to be difficult using field-collected data on habitat or biota.

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⁶ (http://www.fsl.orst.edu/clams/data_index.html)

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APPENDIX

Percentages of current and future land cover by ownership in buffers around stream reaches with high intrinsic potential for steelhead and for coho salmon in six subprovinces of Oregon, USA (*Ecological Archives* A017-004-A1).