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A FIRST STEP TOWARD BROAD-SCALE IDENTIFICATION OF FRESHWATER PROTECTED AREAS FOR PACIFIC SALMON AND TROUT IN OREGON, USA

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Abstract

Decision makers, concerned with Pacific salmon and trout, must often select freshwater areas to protect or restore based on only site-scale information. In response, the Coastal Landscape Analysis and Modeling Study (CLAMS) has developed broad-scale models based on topographic features of watersheds to assess potential use by steelhead (*Oncorhynchus mykiss*) or by coho salmon (*O. kisutch*). The modeled attribute, termed intrinsic potential, was expressed for each species as the geometric mean of classified channel gradient, valley constraint, and mean annual discharge. These components were derived from 10-m Digital Elevation Models (DEMs) for all streams in two large basins in the Coastal Province of Oregon, USA. Because the types of topographic features associated with steelhead and coho salmon differ, stream reaches with high intrinsic potential (values ≥ 0.8) for these two species generally did not overlap. Streamside areas adjacent to reaches with high intrinsic potential were characterized relative to land ownership and use. High-intrinsic-potential reaches typically occurred on publicly owned forestlands for steelhead and on privately owned lands with various uses for coho salmon.

Results are relevant in describing the likelihood of finding unimpaired habitat in high-intrinsic-potential reaches for these species and in assessing the feasibility of conservation options, thus in identifying freshwater protected areas. Findings for steelhead and coho salmon in the study basins suggest how the approach and developed models might be applied to other aquatic species for which links to topographic features are known or scaled-up to aid in regional prioritization of reaches or watersheds as protected areas. Tailoring actions to the intrinsic potential of an area should enhance the efficacy and efficiency of broad-scale freshwater conservation strategies so may improve their societal support.

Keywords: coastal landscape analysis and modeling study; freshwater protected areas; coho salmon; steelhead; channel gradient.

INTRODUCTION

Salmon and trout (*Oncorhynchus* spp.) are integral components of ecosystems in the Pacific northwestern United States of America (Willson and Halupka 1995). Adults of the anadromous forms link the marine and terrestrial environments by returning essential resources to the relatively nutrient-poor streams in which they spawn. Juveniles complete the freshwater phase of their life history in rivers, rearing in all parts of the network from headwaters to estuaries. Salmon and trout in this region are also commercially, recreationally, and culturally important.

Many populations of Pacific salmonids are considered at risk (Nehlsen *et al.* 1991), and some of these have been listed under the United States *Endangered Species Act 1973*. A variety of factors may contribute to declining fish abundances (National Resource Council 1996). Regularly included among these are loss and degradation of freshwater habitats from human activities. Consequently, habitat protection and restoration are common objectives of salmonid conservation strategies (e.g. USDA and USDI 1994; State of Oregon 1997). Measures to protect and restore freshwater habitats are often perceived to conflict with the goal of maximizing profits from land-use. Thus, tools that can focus salmonid recovery efforts by identifying locations with the greatest potential to yield conservation benefits should hold value for policy makers, regulators, and land managers.

Stream reaches with significance to salmonid conservation can be distinguished, in part, by their topographic characteristics. Specific landforms may affect the capacity of reaches to develop high-quality habitat (Frissell 1992;

Montgomery and Buffington 1997) and, ultimately, to support salmonids. Different species of salmonids have been associated with particular landform types. For example, in coastal Oregon, USA, juvenile steelhead (*O. mykiss*) dominated high-gradient stream reaches constrained by adjacent hill slopes (Burnett 2001). However, juvenile chinook salmon (*O. tschawytscha*) and coho salmon (*O. kisutch*) in these same streams were observed primarily in unconstrained reaches (Burnett 2001). In western Washington, USA, channels with lower gradients contained greater numbers of coho salmon adults returning to spawn (Pess *et al.* 2002) and of coho salmon smolts migrating to the ocean (Sharma and Hilborn 2001). Consequently, a regional conservation strategy aimed at protecting and restoring the most topographically favorable stream reaches for a particular salmon or trout population can logically prioritize limited funds and improve the likelihood of success.

This research is intended to develop and demonstrate tools for identifying topographic characteristics associated with use by aquatic species. Specifically, the potential of all stream reaches to support steelhead or coho salmon was characterized and mapped in two major coastal Oregon drainages, the Tillamook Bay and Nestucca River basins. Additionally, the distribution of stream reaches with the highest potentials for each species was examined relative to land ownership and use. As is true throughout the region, many coastal Oregon salmonid populations have decreased in number, with freshwater habitat loss and degradation being suggested as important causes (Nehlsen *et al.* 1991; Nickelson *et al.* 1992). Much historical evidence indicates that large salmon runs (e.g. coho salmon, Lichatowich 1989) were maintained in coastal Oregon streams. However, neither these streams, generally, nor those in the Tillamook Bay and Nestucca River basins, specifically, have been comprehensively evaluated for the potential to support salmonids.

STUDY AREA

The Tillamook Bay and Nestucca River basins drain westward and comprise approximately 2300 km^2 of the Coastal Province of Oregon (Fig. 1).

These basins support five of the seven species of anadromous trout and salmon occurring in the Pacific Northwest (steelhead, cutthroat trout (*O. clarki*), chinook salmon, coho salmon, and chum salmon (*O. keta*)). The climate is temperate maritime with restricted diurnal and seasonal temperature fluctuations; mean annual temperatures range from approximately 1°C in January to 15°C in August (Daly *et al.* 1994). Most of the 300 cm of annual precipitation arrives between September and May, principally as rainfall. Peak stream flows are flashy following winter rainstorms rather than associated with spring snow melt, and base flows occur between July and October.

Fig. 1. Location of the Tillamook Bay and Nestucca River basins in the Coastal Landscape Analysis and Modeling Study (CLAMS) area of western Oregon, USA.

The study area is underlain primarily by sandstone and basalt formations, and except for a few interior river valleys and a prominent coastal plain, is dominated by mountains (Orr *et al.* 1992). Elevations range from sea level to approximately 1100 m. Uplands are highly dissected with drainage densities up to 5.0 km/km^2 (FEMAT 1993). Montane areas are predominately in conifer and broadleaf forests that include tree species of Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and red alder (*Alnus rubra*). Western red cedar (*Thuja plicata*) and big leaf maple (*Acer macrophyllum*) are typical additions in riparian areas. Forests span early successional to old-growth seral stages as a result of a disturbance regime driven by timber harvest and by infrequent, intense wild fires and windstorms (Franklin and Dyrness 1988). Using data from Ohmann and Gregory (2002), we determined that approximately 7% of the original coastal temperate rainforest remains in these basins.

METHODS

Unless otherwise noted, digital data layers were developed for the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies *et al.* 2002). Each data layer was clipped to the drainage boundaries of the Tillamook Bay and Nestucca River basins.

Streams

From 10 m digital topographic data (i.e. drainage-enforced digital elevation models (DEMs) (Underwood and Crystal 2002)), a high-resolution stream network was developed for the study area. Algorithms used to model streams allow flow dispersion over topographically divergent areas until a channel is initiated, regulate the degree of topographic convergence permitted at channel heads, and vary the approach by which channels are initiated based on underlying processes (Miller 2002). To minimize extensions of the derived network into planar areas, channels were initiated for the Tillamook Bay and Nestucca River basins from a slope/drainage-area relationship where fluvial processes dominate at gradients less than 25%, and from a single 0.75 ha drainage-area threshold where mass-wasting processes dominate at gradients greater than or equal to 25%. The channel network was divided into reaches by aggregating contiguous pixels with uniform DEM-derived geomorphic and hydrologic characteristics. Endpoints of reaches were placed at tributary junctions except where distances between tributary junctions exceeded the allowable length for a particular drainage area (i.e. 50 to 200 m for drainage areas between 0.04 and 50 km^2, 50m for drainage areas less than 0.04 km^2, and 200 m for drainage areas greater than 50 km^2).

Intrinsic potential

Intrinsic potential to support steelhead or coho salmon was expressed as the geometric mean (Van Horne and Wiens 1991) of classified channel gradient, valley constraint, and mean annual discharge (Table 1), an approach similar to that taken by Gregory et al. (2001).

Classes of the attributes reflecting strength of association with steelhead or coho salmon were based on available literature and field observations. The approach assumed that the three attributes were partially compensatory but weights the calculated intrinsic potential by the classified attribute with the smallest value. Calculated intrinsic potential values ranged from zero to one. Intrinsic potential was determined for each reach in perennially flowing streams (drainage area exceeding 0.04 km^2) (Clarke *et al.* 2002) below known barriers to migrating adult salmon (Brodeur and Bowers 2000; Gresswell *et al.* 2000).

Channel gradient

Channel gradient was obtained from the 10 m DEM by fitting a second-order polynomial to stream pixel elevations in a variable-length moving window (Miller 2002). The length of the window was 300 m for channel gradients less than 0.1%, was 30 m for channel gradients greater than 20%, but varied linearly for channel gradients between 0.1% and 20%.

Table 1. Attributes and classified values used to calculate intrinsic potential of streams to support steelhead and coho salmon.

Channel gradient (%)	Classified Value	Valley constraint	Classified Value	Mean annual flow (m^3/s)	Classified value
		Steelhead			
0.00 - 2.00	0.80	Low	0.5	$\leq$ 0.06	0.75
2.01 - 3.00	1.00	Medium	1.00	0.07 - 2.10	1.00
3.01 - 5.00	0.75	High	1.00	2.11 - 21.23	0.75
5.01 - 6.00	0.75			> 21.23	0.25
6.01 - 8.00	0.50				
8.01 - 10.00	0.25				
10.01 -15.00	0.10				
> 15	0.00				
		Coho salmon			
0.00 - 2.00	1.00	Low	1.00	$\leq$ 0.06	0.75
2.01 - 3.00	0.50	Medium	0.50	0.07 - 21.23	1.00
3.01 - 5.00	0.25	High	0.25	0.07 - 21.23	1.00
5.01 - 10.00	0.10			> 21.23	0.25
> 10.00	0.00				

Juvenile steelhead in Oregon coastal streams are commonly found in gradients up to about 6% (Dambacher 1991; Roper *et al.* 1994; Burnett 2001) but have been observed to use low-gradient areas in steeper reaches. Roper *et al.* (1994) determined that densities (number/100m^2) of one-year-old steelhead were positively related to reach gradient for gradients between 0.7% and 2.9% and that one of the lowest observed densities was in the single examined reach where gradient exceeded 6%. Steelhead in this same age class were found predominantly in streams with gradients between 2% and 3% (Hicks 1989). Consequently for steelhead, we assigned the highest value to channel gradients between 2% and 3% and assumed no use upstream of reaches with gradients exceeding 15% (Table 1).

Coho salmon in the Coastal Province of Oregon rear typically in low-gradient stream reaches and decrease in density as gradients increase to about 10% (Nickelson 1998). For example, Schwartz (1990) found a negative relationship between the density (number/100m) of juvenile coho salmon and channel gradient for gradients between 0.5% to 7% and the greatest densities of coho salmon in gradients below 2–3%. Similarly, Hicks (1989) observed juvenile coho salmon predominately in streams with gradients less than 2%. Thus for coho salmon, we assigned the highest value to channel gradients less than or equal to 2% and lower values to gradients exceeding this (Table 1). We assumed that coho salmon did not use areas upstream of reaches with gradients greater than 10%.

Valley constraint

Valley constraint was determined for each stream reach through a generalized linear model between DEM-derived valley width index (VWI) and four classes of field-assigned channel form (Clarke *et al.* 2002; Moore *et al.* 1997; Firman and Jacobs 2001). Valley width index is the ratio of valley-floor width to active-channel width. The valley-floor width for each stream reach was estimated from the 10-m DEMs (Miller 2002). The active-channel width for each stream reach was predicted from DEM-derived watershed area using a regression model developed with field-measured active-channel widths for 264 reaches of stream (Moore *et al.* 1997; Firman and Jacobs 2001; Clarke *et al.* 2002). Values of the DEM-derived valley-width index corresponding to field-assigned channel-form classes were aggregated into three classes of valley constraint (i.e. low: VWI > 8.0; medium: 5.0 < VWI ≤ 8.0; high: 0.0 < VWI ≤ 5.0).

Densities of juvenile coho salmon tend to be greater in unconstrained than constrained reaches (Hicks 1989). Juvenile coho salmon selected unconstrained reaches over other reach types in multiple years, but one-year-old steelhead often avoided unconstrained reaches (Burnett 2001). Reaches with low valley constraint were assigned the highest value for coho salmon but the lowest value for steelhead trout (Table 1).

MEAN ANNUAL DISCHARGE

Mean annual discharge for each stream reach was predicted as a function of drainage area and mean annual precipitation (Lorensen *et al.* 1994). Drainage area to each pixel was calculated from the 10-m DEMs (Tarboton 1997). Each reach was assigned the drainage area of the furthest downstream pixel in that reach (Miller 2002) and the weighted average over that drainage area (Miller 2002) of mean annual precipitation (from PRISM data; Daly *et al.* 1994).

Steelhead occur in a range of stream sizes from upper mainstem rivers to small tributaries (Meehan and Bjornn 1991; Benke 1992). Coho salmon are thought to occur primarily in mid-sized mainstem rivers to small tributaries (Sandercock 1991; Rosenfeld *et al.* 2000). One-year-old steelhead in a coastal Oregon basin selected tributaries over the mainstem in some years but used both stream-system types with equal probability in other years (Burnett 2001). Juvenile coho salmon in this same basin selected for the mainstem in some years but for mid-sized tributaries in others (Burnett 2001). Thus, we assigned a similar range of values to mean annual discharge for each species, but streams with a mean annual discharge between 2.10 and 21.23 m^3/s were assigned a slightly lower value for steelhead than coho salmon (Table 1).

Land ownership and land use

Land-ownership data (Fig. 2 *left*) were derived from the Western Oregon Industrial Forest Land Ownership digital coverage. Data were aggregated into six classes: United States Forest Service, United States Bureau of Land Management, State of Oregon, miscellaneous public, private industrial, and private non-industrial. The miscellaneous-public class included various developed and less-developed lands such as cities, road right-of-ways, and county parks. The private-industrial class included owners with at least 20 km^2 of timberland and/or a log processing facility (Gedney *et al.* 1986). The private-non-industrial class included owners of timberlands not meeting these criteria or of lands managed for purposes other than timber production.

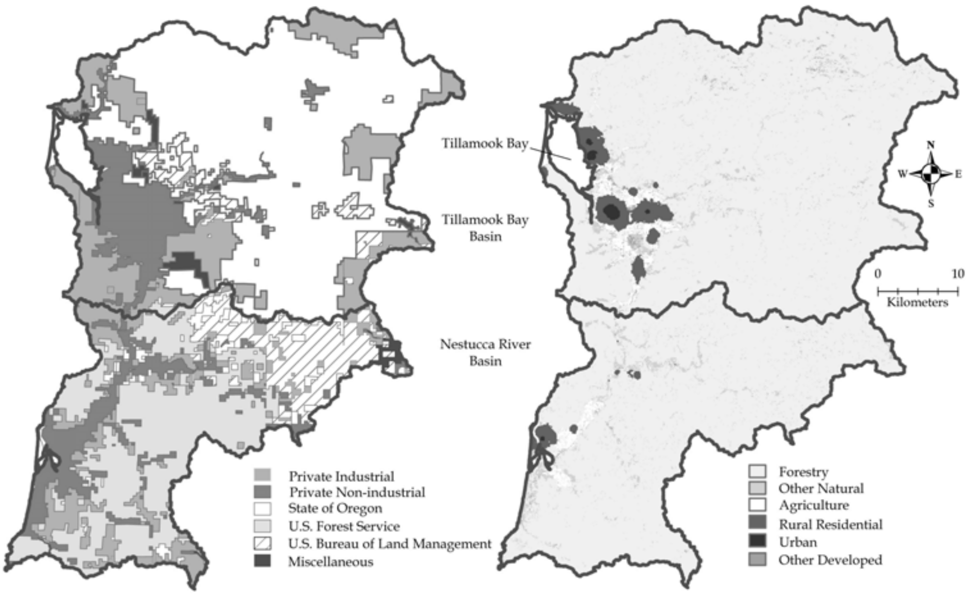

Fig. 2. Landownership (*left*) and land use (*right*) in the Tillamook Bay and Nestucca River basins, Oregon, USA.

Land-use data (Fig. 2 *right*) were obtained by combining raster layers of human development, forest cover, and the 1992 National Land Cover Data (Vogelman *et al.* 2000). Six land-use classes were identified: rural, urban, forestry, agriculture, other natural areas, and other developed areas. The human-development layer was derived by interpolating structure densities (number of structures in a 32 ha circle around a photo point) among a grid of regularly spaced photo points from 1995 (Kline *et al. in press*). Lands classed as rural had 0.25–2.5 structures/ha, and those classed as urban had more than 2.5 structures/ha. Where structure densities were less than 0.25/ha, forest-cover data at 25-m resolution were modeled by integrating vegetation measurements from field plots, mapped environmental data, and Landsat Thematic Mapper imagery from 1996 (Ohmann and Gregory 2002). The forestry class contained open areas resulting from timber harvest, semi-closed canopy forest on private industrial timberlands, semi-closed canopy forest that resulted from timber harvest on other land ownerships, and closed-canopy forest. Forest cover data consisting of open areas not due to timber harvest, water, and woodlands/other vegetation were considered non-forested (K.N. Johnson *pers. comm.*). Land uses for these non-forested areas were determined from the 30-m resolution National Land Cover Data (NLCD). Lands classed as: (*1*) 'agriculture' included orchards, vineyards, pasture/hay/grains, row crops, and fallow areas on the NLCD; (*2*) 'other natural areas' included water, bare rock/sand/clay, perennial ice/snow, and all other natural vegetation (e.g. grasslands, wetlands, and shrub lands) on the NLCD; and (*3*) 'other developed areas' included transportation corridors, quarries/strip mines/gravel pits, urban recreational grasses, and any other developed land use on the NLCD.

Characterizing reaches with high intrinsic potential

Reaches were classified as having a high species-specific intrinsic potential when the calculated value was at least 0.8. Such reaches were assumed to be the most capable of supporting the species. A buffer was generated that extended 60 m on either side of these stream reaches with high intrinsic potential. The buffer width was intended to encompass the zone most likely to directly influence these reaches, so approximated the expected height of old-growth conifer trees in the study area. Buffers surrounding high-intrinsic-potential reaches were characterized relative to the percent area in each land ownership and land-use class.

RESULTS

On the basis of the 10-m DEMs, 10,421 km of streams were delineated for the Tillamook Bay and Nestucca River basins. Approximately 2160 stream kilometers were believed to be accessible by steelhead because none of these were upstream of known barriers or of reaches with a gradient exceeding 15% (Fig. 3 *left*). Of this accessible stream length, 545 km were classed as high intrinsic potential to support steelhead (Fig. 3 *left*). Coho salmon were assumed to have access to 1479 km of the modeled stream network that were not upstream of mapped barriers or of reaches with gradients exceeding 10% (Fig. 3 *right*). Reaches with high intrinsic potential to support coho salmon constituted 268 km of this accessible length (Fig. 3 *right*). Reaches with high intrinsic potential for steelhead and coho salmon occupied 5.2% and 2.5%, respectively, of the total modeled stream length.

Land in the Tillamook Bay and Nestucca River basins is distributed among six ownership classes, but the State of Oregon owns the largest percentage of the area (Fig. 4 *upper*). For steelhead, land ownership in the buffers adjacent to reaches with high intrinsic potential reflected overall land ownership in the two basins with a few minor exceptions (Figs 4 *upper* and 4 *lower*). As an example, the State of Oregon owns 38% of the basin area but 44% of the buffered area adjacent to high-intrinsic-potential reaches for steelhead. For coho salmon, the distribution of land ownership in the buffer adjacent to the high-intrinsic-potential reaches differed from overall land ownership (Figs 4 *upper* and 4 *lower*). Approximately 95% of the buffered area adjacent to the reaches with high intrinsic potential for coho salmon was privately owned, with the majority of this being held by non-industrial owners.

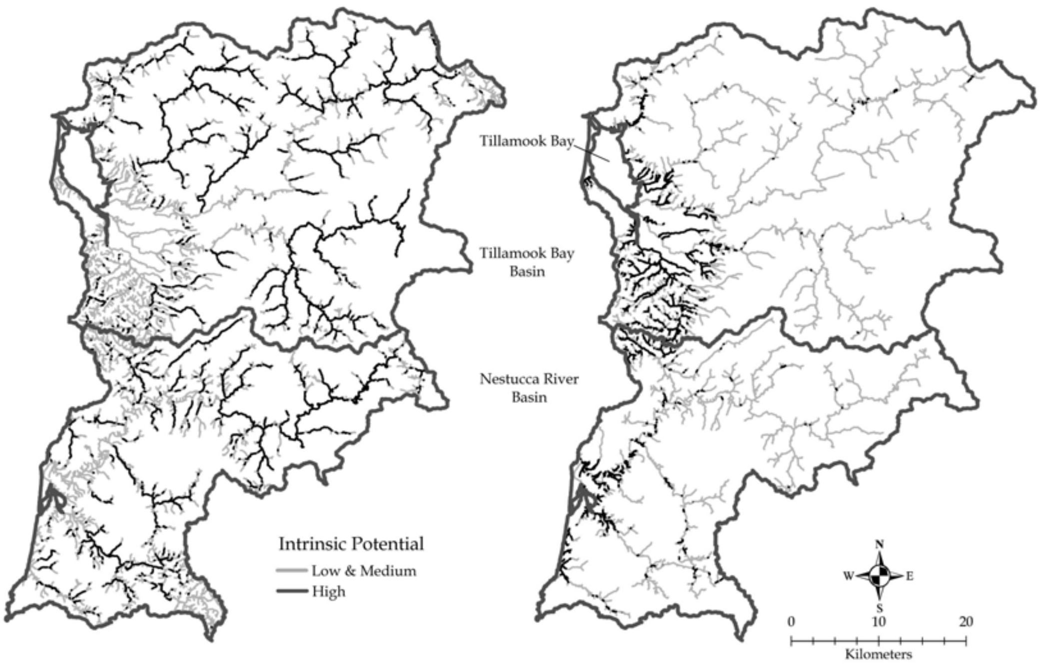

Fig. 3. Intrinsic potential of stream reaches assumed accessible in the Tillamook Bay and Nestucca River basins, Oregon, USA, by: (*left*) steelhead and (*right*) coho salmon. Areas upstream of reaches with gradients exceeding 15% were assumed inaccessible by steelhead and exceeding 10% were assumed inaccessible by coho salmon. Values of intrinsic potential ≤ 0.8 were classified as high.

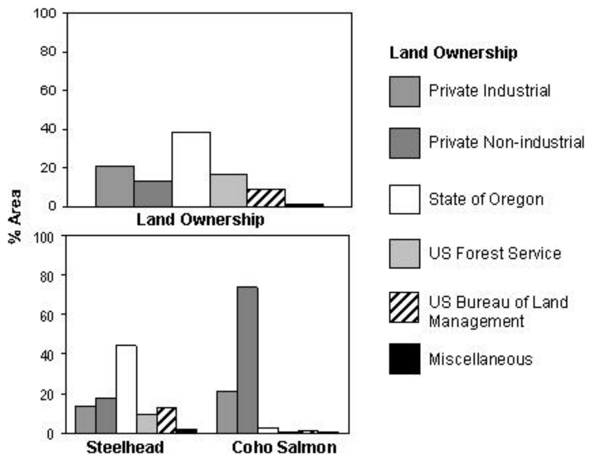

Fig. 4. Percent area by landownership classes (*upper*) in the Tillamook Bay and Nestucca River basins, Oregon, USA, and adjacent to reaches in these basins with high intrinsic potential (≤0.8) for (*lower*) steelhead and coho salmon.

Although forestry is the dominant land use in the Tillamook Bay and Nestucca River basins, more intensive uses such as agriculture, rural residential, and urban are also present (Fig. 5 *upper*). The percentages of area are almost identically distributed among land-use classes in these basins and in the buffers adjacent to reaches with high intrinsic potential for steelhead (Figs 5 *upper* and 5 *lower*). This is not true for the buffers adjacent to reaches with high intrinsic potential for coho salmon (Figs 5 *upper* and **5c**). Forestry constitutes approximately 46% of this buffered area as contrasted with 91% of the basin area. Analogously, more intensive land uses occupy 34% of buffered area adjacent to the reaches with high intrinsic potential for coho salmon but only 5% of the basin area.

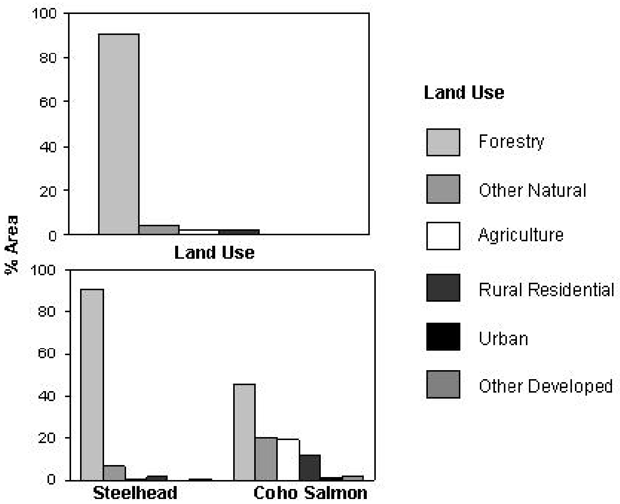

Fig. 5. Percent area by land-use classes (*upper*) in the Tillamook Bay and Nestucca River basins, Oregon, USA, and adjacent to reaches in these basins with high intrinsic potential (≥0.8) for (*lower*) steelhead and coho salmon.

DISCUSSION

The intrinsic potential of streams to support steelhead and coho salmon was modeled from digital topographic data. Because types of landforms associated with steelhead and coho salmon differ, stream reaches identified with high intrinsic potential for these two species generally did not overlap. Reaches with high intrinsic potential typically occurred on publicly owned forestlands for steelhead but on privately owned lands with various uses for coho salmon. These results are relevant in describing the likelihood of finding unimpaired habitat in reaches with high intrinsic potential for these species and in assessing the feasibility of conservation options, thus in identifying freshwater protected areas. Additionally, findings for the Tillamook Bay and Nestucca River basins demonstrate that the models and approach may be readily used over broad spatial extents. Although this study focused on steelhead and coho salmon, the developed tools may be adapted and applied to help identify protected areas for other freshwater species with distributions that are influenced by topographic features.

Stream reaches with high intrinsic potential on public lands may contain less impaired habitat than those on private lands because private lands have been intensively and consistently managed for much longer than public lands. Settlement in the Coastal Province of Oregon began in the mid 1800s and gradually progressed upslope and upstream from the easiest locations in low gradient, unconstrained valley bottoms around river mouths (Sedell and Luchessa 1982). By the 1880s, forests were cleared along main tributaries of most major rivers in western Oregon, and activities associated with development greatly reduced habitat quantity and quality (Sedell and Luchessa 1982). Logging on most private industrial timberlands has continued under a relatively short rotation interval (40–60 years). The majority of the land in the study area owned by the State of Oregon had been logged or recently burned when the State began acquiring it the 1920s and 1930s; thus, timber harvest on these lands has been limited while forests have been allowed to grow. Timber was rarely harvested from federal lands until private lands were unable to meet demands generated by World War II and post-war economic expansion (Wilkinson 1992). Logging accelerated on federal lands in the study area until the late 1980s then declined precipitously. Although histories of State of Oregon and USA government lands are different, net results are similar – fish habitats have been exposed to less management activity on public than on private lands during the past 150 years, probably leaving more unimpaired habitats on public lands.

High-intrinsic-potential reaches occurring on lands governed by relatively permissive land-use policies are more likely to contain impaired aquatic habitats. With laws passed in the 1970s, forestry became and remains the most regulated land use in Oregon regarding non-point-source water pollution. However, policies differ among forest ownership classes; regulations are more restrictive on federal lands (USDA and USDI 1994), intermediate for State lands (Oregon Department of Forestry 2001), and least restrictive on private lands (see Young 2000 for summary). Aquatic-related measures regulating urban and rural land uses in the study area, though mandatory, are less stringent than those for forestry, and aquatic-related measures for agriculture are largely voluntary. Because more of the area surrounding reaches with high intrinsic potential for steelhead was on public lands, subjected to less-intensive uses and managed under more protective policies, less impairment is expected in key habitats for steelhead than for coho salmon.

Probable locations of future freshwater protected areas may be influenced by land ownership and use because these can affect degree of habitat impairment and dictate applicable land-use policies. Given differences in land-use history and governing policies, reaches with high intrinsic potential may have fewer impaired habitats on public lands than on private lands, especially those managed for intensive uses. Thus, high-intrinsic-potential reaches on public forestlands are anticipated to supply some of the best-quality habitats remaining in the study area for both steelhead and coho salmon. Once this is corroborated directly from in-channel conditions (e.g. pool density or large wood volume) or indirectly from management indicators (e.g. forest stand age or road density), these reaches and encompassing watersheds [catchments] may contribute substantially to conservation if protected. When ancillary data suggest impairment, habitat restoration is likely to yield positive biological results in reaches with higher than lower intrinsic potentials. High-intrinsic-potential reaches on public lands can be easily incorporated into watershed protection frameworks. Watersheds have been identified as logical conservation units for aquatic systems because habitat conditions may be largely determined by upslope and upstream influences (Reeves *et al.* 1995; Moyle and Randall 1998). Specific watersheds, in which stream protection and restoration are emphasized, were identified on federal forestlands (Key Watersheds) (USDA and USDI 1994) and are proposed for State forestlands (Salmonid Emphasis Watersheds) (Oregon Department of Forestry 1999) in the study basins. Areas where reaches with high intrinsic potential are concentrated for steelhead, for coho salmon, or for both species, can help decision makers select watersheds to include in these protection frameworks.

Although directing conservation activities toward reaches with high intrinsic potential on public lands may be necessary and garner less societal resistance, this may be insufficient for conserving all species of salmonids. Private forested, agricultural, rural, and urban lands in the study basins represent a substantial percentage of areas adjacent to reaches with high intrinsic potential for coho salmon. Thus, widespread recovery for coho salmon is doubtful unless private land owners can be encouraged to protect and restore habitat in high-intrinsic-potential reaches through education, incentives, or stricter regulations. Additionally, State and federal forests, despite encompassing a large percentage of the Tillamook Bay and Nestucca River basins, do not occupy as much area for every basin in the Coastal Province of Oregon. Consequently, a narrower range of conservation options will be available for steelhead in basins with less public land unless current policies governing other ownerships are expanded and strengthened.

By identifying the most topographically favorable stream reaches for salmonids, this research provides tools that help focus broad-scale programs on areas most likely to deliver conservation benefits. Targeting activities may increase opportunities for success and is more efficient so may decrease economic costs. These outcomes should improve societal support of efforts to protect and restore habitats for Pacific salmon and trout. We think these results are important first steps in providing a basin-scale context for numerous pending site-scale habitat protection and restoration decisions in the Tillamook Bay and Nestucca River basins. Our next steps include incorporating models for cutthroat trout and chinook salmon and evaluating variation among land ownership and use classes in habitat impairment for reaches with high intrinsic potential. Although work remains, this study demonstrates how the approach and developed models might be applied to other species associated with topographic features or scaled-up to aid in regional prioritization of reaches or watersheds as protected areas.

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