Influence of mapping resolution on assessments of stream and streamside conditions: lessons from coastal Oregon, USA

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ABSTRACT

1. Digital hydrographic data are commonly employed in research, planning, and monitoring for freshwater conservation, but hydrographic data sets differ in spatial resolution and accuracy of spatial representation, possibly leading to inaccurate conclusions or unsuitable policies for streams and streamside areas.

2. To examine and illustrate the potential for different hydrographic datasets to influence in-channel and streamside characterizations, a study area in the US Pacific Northwest was chosen because 1:100 000, 1:24 000, and densified 1:24 000 hydrography are available and widely used in research and management for several species of Pacific salmon and trout at risk. The potential was examined for differences among the digital hydrographic datasets in: (1) spatial extent to influence estimated abundances of fish habitat, streamside buffer conditions, and fish distributions; and (2) spatial position to influence estimated streamside buffer conditions and estimated stream gradient.

3. The analysis of spatial extent found the total stream length represented by the 1:100 000 hydrography was approximately one half that of 1:24 000 hydrography and only one fifth that of densified 1:24 000 hydrography. The 1:100 000 and 1:24 000 networks differed significantly for 13 out of 18 fish habitat attributes, and the three hydrographic datasets differed significantly for many characteristics in streamside buffers; fish distributions mapped at 1:24 000 added 6-14% of stream length to 1:100 000 distributions. The analysis of spatial position found few differences between the 1:100 000 and 1:24 000 hydrography in streamside buffer characteristics but significant differences in channel gradient.

4. Overall, hydrographic datasets differed only slightly in spatial position but differed in spatial extent to the point of representing different populations of streams. If species inhabiting larger streams (greater mean annual discharge) are of interest, then results derived from studies based on 1:100 000 hydrography should prove useful. However, higher-resolution hydrography can be critical when designing and implementing strategies to protect fish and other aquatic species at risk in smaller streams.

INTRODUCTION

Freshwater ecosystems have been severely affected by human activities globally, leading to declining populations or extinctions of numerous aquatic species (Revena et al., 2000). In North America, freshwater fauna are becoming extinct at five times the rate of terrestrial fauna (Ricciardi and Rasmussen, 1999). As human populations grow, water quality declines in many areas of the world due to point-source pollution from municipalities and industry and non-point source pollution from land uses such as agriculture (Cosgrove and Rijssberman, 2000). Increasing water withdrawals for municipal, industrial, and agricultural uses often keep surface flows from reaching the sea in major rivers, including the Yellow River in China, the Colorado River in the USA, and the Indus River between India and Pakistan (Cosgrove...
INFLUENCE OF STREAM MAPPING RESOLUTION

More than half the world's large river systems are affected by dams, resulting in ecosystem fragmentation, habitat loss, modified flow regimes, and reduced sediment flux (Nilsson et al., 2005; Syvitski et al., 2005). Overfishing in inland waters, particularly acute in Asia and Africa, can eliminate top aquatic predators and alter food webs, primary productivity, and nutrient dynamics (Allan et al., 2005). Presence of exotic species also causes major impacts on freshwater systems (Vitousek et al., 1997).

Characterizations of freshwater species and ecosystems over the broader spatial extents necessary to address conservation issues typically rely on maps of streams and lakes (hydrography) in a geographic information system (GIS). Digital hydrographic data are produced from printed maps available at different cartographic scales, for example 1:24,000 (1 cm on map represents 0.24 km on the ground) or 1:500,000 (1 cm on map represents 5 km on the ground). Such data are commonly employed in research and management for conservation (Table 1). For example, the Nature Conservancy has developed an aquatic ecosystem classification method for freshwater conservation planning using digital hydrography at a variety of scales including 1:100,000 for the 31,000 km² Willamette River Basin in Oregon and 1:250,000 for the 600,000 km² Upper Paraguay River Basin in Brazil, Paraguay, and Bolivia (Higgins et al., 2005).

Digital hydrographic data produced from source maps at different cartographic scales differ in spatial resolution, or size of the smallest feature represented (Johnson et al., 1989), and in the accuracy of spatial representation. The Australian GEODATA TOPO 250K hydrographic data, digitized from 1:250,000-scale printed maps, include only streams longer than 2.5 km and water bodies wider than 250 m with areas greater than 62.5 ha (Geoscience Australia, 2003). The 1:100,000-scale National Hydrography Dataset (NHD) for the continental USA includes streams longer than 0.24 km and rivers larger than 2.5 km (USGS, 2005). The locations of stream channels are generally more accurately represented by higher-resolution digital hydrography. For example, the United States Geological Survey (USGS) standard for horizontal positional accuracy in 1:24,000 data is that 90% of mapped streams lie within approximately 12 m of their true positions, but for 1:100,000 data the standard is 50 m (USGS, 2005). Although the 1:100,000 hydrography depicts many fewer streams and depicts streams less accurately than 1:24,000 hydrography (Lunetta et al., 1997; Moglen and Beighley, 2000; Hansen, 2001), the higher-resolution dataset has not yet been completed for the entire USA (Moglen and Beighley, 2000; USGS, 2004). Even 1:24,000 data may not represent all perennial streams in an area and probably represent only a few of the intermittent (wet season flow) or ephemeral (flow during and after precipitation) streams (Hansen, 2001; Meyer and Wallace, 2001).

Where available data are of insufficient resolution to meet research and management needs, several options are possible for developing new digital hydrography. Adding stream lines (densifying) to existing hydrography based on aerial photographs (WDFW, 2006), digital orthophotos (USFS, 2003), or topographic map contour crenulations is one option. These methods are time consuming and costly and so are generally undertaken only for small areas. Another option for representing more of the stream network is to generate hydrography from Digital Elevation Models (DEMs) (Miller, 2003; Burnett et al., 2007; WWF, 2007; Clarke et al., 2008), but results depend upon DEM resolution and quality as well as stream-delineation algorithms. The World Wildlife Fund (WWF) and partners in the HydroSHEDS project have delineated streams for Latin America, Africa, and much of Asia comparable in detail with those represented on 1:250,000-scale printed maps (WWF, 2007). These efforts used digital elevation data from the Shuttle Radar Topography Mission (SRTM) imagery. The SRTM digital elevation data are at 90m resolution and limited to areas between 60° north and 60° south latitude. Other space-borne platforms use a polar orbit to produce digital elevation data at higher resolutions (10m) for non-forested areas over the entire planet (e.g. ALOS, 2007). Airborne laser mapping, such as red waveform light

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>General topic</th>
<th>Source scale</th>
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<tbody>
<tr>
<td>Nel et al., 2007</td>
<td>South Africa</td>
<td>Biodiversity M</td>
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<td>Smith et al., 1997</td>
<td>United States</td>
<td>Water quality R</td>
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<tr>
<td>Wantzen et al., 2006</td>
<td>Brazil</td>
<td>Impact assessment M</td>
<td>1:250,000</td>
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<td>Bolivia, Brazil, Paraguay, US</td>
<td>Conservation M</td>
<td>1:250,000 and 100,000</td>
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<td>Filipe et al., 2004</td>
<td>Portugal</td>
<td>Conservation M</td>
<td>1:100,000</td>
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<td>United States</td>
<td>Ecological condition R</td>
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<td>Conservation M</td>
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<td>Salmon habitat R</td>
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<td>1:50,000</td>
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<td>Burnett et al., 2007</td>
<td>United States</td>
<td>Salmon habitat R</td>
<td>1:24,000</td>
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<td>Clarke and Burnett, 2003</td>
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<td>Aquatic data R</td>
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<td>Lunetta et al., 1997</td>
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<td>Torgersen et al., 2004</td>
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<td>Fish distribution R</td>
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detection and ranging (lidar), can penetrate forest canopies and generate very high-resolution (<1 m) digital elevation data (Lefsky et al., 2001, 2002). Despite key advantages, such data are relatively expensive to obtain, process, and store for large areas.

Because digital hydrographic data for much of the world may be available or developed at different spatial resolutions, conservation workers must choose which of these best meets their needs in each situation. Choice of map scale depends on matching the geographic extent and grain (i.e., fine to coarse) desired for analyses with that of any existing or prospective hydrographic data. Just as for digital road data (Hawbaker and Radeloff, 2004), this choice may affect analytical outcomes, possibly leading to inaccurate conclusions or unsuitable policies for streams and streamside areas (Hansen, 2001; Meyer and Wallace, 2001). How different hydrographic datasets may influence characterizations that are essential to conservation of stream ecosystems has seldom been rigorously evaluated (but see Lunetta et al., 1997; Hansen, 2001; Rosenfeld et al., 2002; Stoddard et al., 2005).

To examine and illustrate the potential for different hydrographic datasets to influence in-channel and streamside characterizations, a study area in the US Pacific Northwest was identified. This area was chosen because 1:100,000, 1:24,000, and densified 1:24,060 hydrography are available and are widely used in research and management for several species of Pacific salmon and trout at risk. The objectives of this study were to compare differences among the hydrographic datasets in: (1) spatial extent to influence estimated stream lengths, streamside buffer conditions, characteristics of fish habitat, and fish distributions; and (2) spatial position to influence streamside buffer conditions and estimated stream gradient. Although analysis targeted streams that provide habitat for Oregon coastal coho salmon Oncorhyncus kisutch (US Endangered Species Act [ESA] threatened species) and steelhead O. mykiss (US ESA species of concern), results that demonstrate the influence of map resolution on stream and streamside assessments should be relevant for informing aquatic conservation beyond the Pacific Northwestern USA.

METHODS

The study area was the 255,000 ha Siuslaw National Forest in the Coastal Province of Oregon, USA. It is underlain by shallow-water marine sedimentary rocks and scattered basaltic volcanics and intrusives (Orr et al., 1992). The resulting landscape is of relatively low relief (elevations range from sea level to >1250 m) but highly dissected, with soil-mantled ridge-and-valley terrain of steep slopes expressing a variety of drainage patterns (Figure 1). The climate is maritime, with wet winters (up to 250 cm precipitation per year), dry summers, and a moderate temperature regime. The natural vegetation is coastal temperate rainforest, with an overstory of conifers that provide habitat for Oregon coastal coho salmon (Chinook salmon) O. tshawytscha, chum salmon O. keta, and coastal cutthroat trout O. clarkii clarkii; none of the latter is ESA listed.

Hydrographic datasets

Three digital hydrographic datasets (Figure 1) that are free and publicly available for the study area were compared: (1) 1:100,000 Pacific Northwest River Reach Files (StreamNet, 2001); (2) 1:24,000 US Forest Service (USFS) Cartographic Feature Files (USFS, 2003b); and (3) 1:24,000 Siuslaw National Forest densified streams (USFS, 2003a). River Reach Files were created by federal, state, and tribal agencies in the early 1990s from streams on 1:100,000 USGS topographic maps, are maintained by the StreamNet program (StreamNet, 2003), and are part of the 1:100,000 National Hydrography Dataset. Cartographic Feature File (CFF) streams were digitized by the USFS Geospatial Service and Technology Center from USFS Primary Base Series maps, which are 1:24,000 USGS topographic maps that have been modified or updated to satisfy Forest Service needs. Most reaches in the 1:100,000 and 1:24,000 hydrographic datasets are coded as having perennial or intermittent flow. The Siuslaw National Forest began to densify their CFF data in 1992 by digitizing streams visible on 1:40000 black-and-white aerial photographs and more recently by digitizing from contour crenulations on 1:24,000 topographic maps and streams visible on 1:24,000 digital orthophotos (USGS, 1996).

Characteristics compared among hydrographic datasets

To evaluate implications for catchment-level and reach-level applications, hydrographic datasets were compared relative to
spatial extent and spatial position (Table 2), using a variety of in-channel (e.g. fish habitat, stream gradient, and fish distribution) and streamside (land cover and topography) characteristics. Reach as used here, generally, is a relatively short section of stream, but has been variously defined, for example, as a stream length that is of fixed distance, 20-times the active channel width, or homogeneous with respect to hydrogeomorphic characteristics (e.g. mean annual flow, gradient, and valley constraint).

**Land cover and topography**

Characteristics of forest cover, hill-slope, and road density were tabulated for buffers created in the GIS for each hydrographic dataset. The characteristics were selected based on the potential to influence freshwater habitat conditions. Buffers incorporated the area within 100m on either side of a mapped channel because this is the distance within which aquatic conservation receives highest priority along fish-bearing streams on federal lands (USDA and USDI, 1994). Also, most functions that riparian forests provide to streams (e.g. large-wood delivery, shade, bank stability) are fully met within 100m of a channel in much of the US Pacific coastal region (FEMAT, 1993).

Forest-cover characteristics were obtained from a classification based on satellite imagery along with topographic, climatic, geologic, and extensive field-plot data (Ohmann and Gregory, 2002). Forest-cover classes were identified based on composition of dominant and co-dominant trees, quadratic mean diameter (QMD), and vegetation density as measured by basal area (BA). Percentage of the buffered area was estimated for six cover classes: non-forest, open (< 0.5m\(^2\)ha\(^{-1}\) BA and QMD < 50cm or < 10m\(^2\)ha\(^{-1}\) BA and QMD > 50cm), hardwood forest (> 1.5m\(^2\)ha\(^{-1}\) BA, > 65% of the BA in hardwood forest), and mixed forests of conifer (BA > 1.5m\(^2\)ha\(^{-1}\)) and hardwood (BA<65%) with a small (2.5-25.4 cm), medium (25.5-50.4cm), or large (> 50.5 cm) QMD. Percentage of streamside buffers in six hill-slope classes was estimated from 10m DEMs. Road densities (km km\(^{-1}\)) were calculated from the US Bureau of Land Management 1:24 000 General Transportation Roads Network (GTRN, BLM,2004).

**Fish habitat**

These data were from an ongoing programme by the Siuslaw National Forest to create an opportunistic inventory of fish habitat (i.e. in non-randomly selected stream reaches). Reaches in the Siuslaw National Forest data were defined to be homogeneous with respect to hydrogeomorphic characteristics (USFS, 1995). Information on a variety of stream attributes (e.g. channel morphology and large wood abundance) that are typical of fish habitat inventories was collected between 1993 and 1995 with standardized protocols (USFS, 1995). The inventory data were attached in a GIS (ESRI, 2000) to the 1:100000 and 1:24000 hydrographic datasets.

**Channel gradient**

Percentage channel gradient was calculated for each reach inventoried by the Siuslaw National Forest through dividing the change in elevation from the upstream to downstream end of the reach by the reach length and multiplying by 100. Elevations were obtained from a 10m DEM (Underwood and Crystal, 2002; Clarke and Burnett, 2003).

**Fish distribution**

The Oregon Department of Fish and Wildlife (ODFW) identified streams on 1:100 000 and 1:24 000 hydrography that were accessible to coho salmon and to winter steelhead (ODFW, 2004). The distribution maps are based on stream surveys and the professional judgement of fish biologists with field knowledge of the mapped area. Distributions of each species are represented as continuous lines at 1:100000 but as isolated points at 1:24000, which denote the most upstream extent of fish use (Figure 2). The total length of fish distribution for each species was estimated at 1:100 000 directly from the hydrography and at 1:24 000 by summing the length determined at 1:100 000 and the distance between the end of distribution at 1:100000 and the point indicating the end of distribution at 1:24 000.

**Comparing hydrographic datasets**

Stream networks were compared in a fixed set of catchments when examining the effects of spatial extent and a fixed set of reaches when examining the effects of spatial position. Consequently, observations were paired by stream networks in all statistical comparisons. Nonparametric Wilcoxon's
signed-rank tests (Sokal and Rohl, 1995) were used because differences between paired observations for most variables were not normally distributed. Densified 1:24 000 streams were compared only for spatial extent and only regarding stream length and streamside buffer characteristics because the added streams were not associated with fish habitat, gradient, fish distribution, or any other attributes.

Spatial extent

The potential for differences in spatial extent among the hydrographic datasets to influence in-channel and streamside characterizations was examined. Analysis was limited to the 34 catchments containing at least 2 km of stream in the Siuslaw National Forest inventories. For each of the three hydrographic datasets in the 34 catchments, the total stream length, stream density, number of stream reaches inventoried, and percentage of stream length inventoried was calculated. For 100 m buffers in the 34 catchments, differences among the three hydrographic datasets were compared pairwise for the percentage area of each forest-cover class, percentage area of each hill-slope class, and road density. The difference between the 1:100 000 and 1:24 000 hydrographic data for the percentage of stream length coded as perennial and the length-weighted average of each attribute in the Siuslaw National Forest fish habitat inventories was also evaluated.

The 1:100 000 and 1:24 000 hydrographic datasets were compared relative to the total length of stream mapped by ODF&W as accessible to coho salmon and to winter steelhead in the 34 catchments. The 1:24 000 fish distribution mapping effort varied greatly among catchments: density of mapped distribution points ranged from one point per 460 ha to one point per 9217 ha. Therefore, comparisons were also made for catchments determined to have more complete mapping efforts at 1:24 000, based on the criterion of at least one mapped distribution point per 1000 ha.

Spatial position

The potential was examined for differences in spatial position between the 1:100 000 and 1:24 000 hydrographic data to influence land-cover and topographic characteristics in and around all 264 reaches in the Siuslaw National Forest fish habitat inventories. Differences in the percentage area of each forest-cover class, the percentage area of each hill-slope class, and road density were compared between the 1:100 000 and 1:24 000 hydrography in 100 m buffers for those reaches. The potential for differences in spatial position between these hydrographic data sets to influence estimated channel gradients for the reaches was also examined.

RESULTS

Spatial extent

For the 34 catchments studied, stream length, stream density, and the proportion of inventoried streams differed significantly (\( \alpha=0.05 \)) among the three hydrographic datasets (Table 3). The total stream length represented by the 1:100 000 hydrography (1758 km) was approximately one-half that of the 1:24 000 hydrography (3517 km) and only one-fifth that of the densified 1:24 000 hydrography (8988 km); stream densities followed the same pattern. Consistent with this, the Siuslaw National Forest field crews inventoried a much greater proportion of the stream network represented at 1:100 000 than at the two higher resolutions. However, one-third of the inventoried reaches were not represented on the 1:100 000 hydrography: of 397 reaches mapped at 1:24 000, only 264 (67%) were shown at 1:100 000. In only seven of the 34 catchments were all inventoried reaches represented at 1:24 000 also represented at 1:100 000.

The three hydrographic datasets differed significantly (\( \alpha=0.05 \)) for many characteristics in streamside buffers (Table 4). Whereas buffers on the lower-resolution hydrography generally contained the greatest percentage of area in non-forested land, broadleaf forests, and lower hill-slope classes, buffers on the higher resolution hydrography contained the greatest percentage of area in open land, in mixed conifer/hardwood forests with small, medium, and large diameter trees, and in higher hill-slope classes (20-40% and 40-65%). The percentage area of the highest hill-slope class was greater, but road densities were less, in buffers on the 1:24 000 than on either of the other hydrographic datasets. The 1:100 000 and 1:24 000 hydrographic datasets differed significantly (\( \alpha=0.05 \)) for 13 out of 18 fish habitat attributes (Table 5). Based on catchment medians, inventoried reaches represented at 1:100 000 had lower gradients, primary channel lengths, pool frequency, and percentage gravel substrate in riffles, but higher flows, active channel depths, active channel widths, width to depth ratios, sinuosity, percentage of reach area in pools, number of deep pools per kilometre, number of complex pools per kilometre, and percentage bedrock substrate than those represented at 1:24 000. Approximately 78% of the total mapped length in the 1:100 000 hydrography and 90% in the 1:24 000 hydrography was coded as perennial stream.
About two-thirds of the 34 catchments contained points representing the upstream distribution of coho salmon and winter steelhead mapped at 1:24 000 (Table 6). In those catchments, the distance from the ends of fish distribution at 1:100 000 to 1:24 000 points added 9% to the distribution for coho salmon and 6% for steelhead. For catchments where the
Table 7. Results of paired signed-rank tests of differences in forest cover, hill-slope, and road density within 100 m buffers around the inventoried reaches in the Siuslaw National Forest data that are represented at both 1:100 000 and 1:24 000, and also of channel gradient

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Signed-rank test P-value (df = 263)</th>
<th>Median difference</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest cover (%)</td>
<td>Non-forest 0.377 0.0, Open 0.453 0.0, Broadleaf 0.522 0.0, Small 0.785 0.0, Medium 0.348 -0.2, Large 0.334 0.0</td>
<td>-6.2-3.3, -9.0-9.4, 29.9-21.0, -9.0-15.7, -14.5-14.7, -28.4-34.6</td>
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<tr>
<td>Hill-slope (%)</td>
<td>0-3% 0.478 0.0, 3-6% 0.160 0.0, 6-20% 0.257 0.1, 20-40% &lt;0.001 0.5, 40-65% 0.293 -0.03, 65% &lt;0.001 -0.1</td>
<td>-9.3-11.5, -8.4-6.0, -20.5-7.8, -19.6-18.4, -11.9-15.9, -21.7-16.0</td>
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<tr>
<td>Road density (km km⁻²)</td>
<td>0.241 -0.01, Channel gradient (%) &lt;0.001 0.14, &lt;0.001 0.14</td>
<td>-4.2-2.6, -6.5-23.8</td>
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The road density comparison was limited to the 131 reaches with roads in the buffers. A negative difference for an attribute indicates the value was greater at 1:24 000 than at 1:100 000.

Spatial position

No significant (p<0.05) differences were found between the 1:100 000 and 1:24 000 hydrographic datasets in the percentage area of any forest-cover class or in road density for buffers on inventoried reaches. For hill-slope classes, significant differences were found between the percentage buffered area in classes of 20-40% and >65% (Table 7). The percentage channel gradient also differed significantly (p<0.001) between the two hydrographic datasets. Paired differences between the 1:100 000 and 1:24 000 hydrography in gradient ranged from -6.5% (3.1% versus 9.6%) to 23.8% (28.2% versus 4.4%), with a median difference of 0.14%. Estimated channel gradients were negative for five reaches at 1:100 000 and for one reach at 1:24 000.

DISCUSSION

Spatial extent

Catchment-level comparisons identified differences among the three hydrographic datasets for length as well as for in-channel and streamside characteristics that were attributable to differences in spatial extent.

Differences in length

Differences were expressed simply in terms of stream length, stream density, and percentage of stream length inventoried for fish habitat. Results for stream length are consistent with those from studies in which topographic maps, ranging from 1:20 000 to 1:100 000, all greatly under-represented field-mapped stream lengths but did so increasingly as map resolution coarsened (Hansen, 2001; Rosenfeld et al., 2002). Identical to the finding from this study for the Oregon Coast Range, Lunetta et al. (1997) determined that a 1:24 000 air-photo densified stream network was five times longer than the 1:100 000 stream network for western Washington, USA. For areas with less topographic relief or precipitation, the 1:100 000 hydrography may more closely represent actual stream lengths. However, coding of perennial and intermittent streams may be less accurate in arid than in humid, montane regions (Stoddard et al., 2005).

Differences in stream length translated into differences in stream density (km km⁻²) that may have implications for freshwater research and conservation. Stream density was an important predictor variable for assessing the status and distribution of several salmonid species in the interior Columbia River basin, USA (Lee et al., 1999). More complete hydrography showing higher stream densities may have greater utility for characterizing aquatic ecosystem heterogeneity and for finding specific sites, such as tributary junctions, that are potential aquatic biodiversity hotspots (Benda et al., 2004; Fernandez et al., 2004; Kiffney et al., 2006; Rice et al., 2006). Thorough mapping of stream density is critical for accurately determining stream order, which reflects the number of tributaries upstream of a point and thus stream size. Streams are often stratified based on order for monitoring, research, and conservation purposes (Filipe et al., 2004; Schmera and Erost, 2004), but digital hydrography that does not represent smaller streams will underestimate true stream order (Wing and Skaugset, 2002). This emphasizes the need to state map scale when giving estimates of stream order.

The percentage of total stream length in this study coded as perennial conflicts with findings in other areas and raises questions about the utility of information on duration of annual flow associated with the 1:100 000 and 1:24 000 hydrographic datasets. At the 1:100 000 scale, Stoddard et al. (2005) identified 28% of mapped stream length for the entire western USA as being perennial versus 78% in the present study for western Oregon. Numerous errors in coding of perennial and intermittent streams in the 1:100 000 hydrography were identified through field evaluation (Stoddard et al., 2005). Drainage areas determined in the field as necessary to sustain perennial flow in western Oregon (Clarke et al., 2008) lead us to conclude that both the 1:100 000 and 1:24 000 hydrography under-represent the extent of the perennial network in the study area. Thus, some of the length added by densification of the 1:24 000 hydrography is in perennial streams, despite the majority being in intermittent streams. Although the true spatial extent of streams can vary seasonally and yearly with discharge, an accurate map of the perennial network is important for broad-scale conservation planning and management of most aquatic species. For other aquatic species, a good approximation of the intermittent network may also be necessary.

Although the additional streams mapped at resolutions higher than 1:100 000 are relatively small, many support fish and may help sustain their populations across large spatial extents. Once the 1:24 000 fish distribution maps are completed for western Oregon, it is expected that the length of the 1:100 000 distributions will be augmented considerably more...
than the 9% and 6% found, respectively, for coho salmon and winter steelhead; this expectation is supported by the finding of greater added distribution length in catchments with more complete 1:24 000 mapping effort. These additional lengths may represent non-trivial amounts of habitat for ESA listed and at-risk fish species. Results of this study agree with those of previous studies quantifying salmonid distributions in small, unmapped streams (Brown et al., 1996; Rosenfeld et al., 2002). These studies indicate that all salmonid-bearing streams are unlikely to be mapped even at 1:24 000. Habitats supplied by small streams may contribute to basin-wide persistence of fish populations. For example, juvenile coho salmon that emigrated from mainstem habitats to rear over winter in small tributaries grew faster, and survived better, possibly contributing more to recruitment, than juveniles that overwintered in the mainstem (Ebersole et al., 2006; Wigington et al., 2006). The importance to stream fish of different habitat types and connectivity among these is increasingly recognized (Kocik and Ferreri, 1998; Pichon et al., 2006; Gresswell and Hendricks, 2007).

Small, headwater streams are unique ecosystems that can sustain numerous species other than fish and are tightly coupled to downstream ecosystems. Headwater riparian areas and streams provide habitat for native amphibians (Sheridan and Olson, 2003; Olson and Weaver, 2002) and macroinvertebrates (Meyer and Wallace, 2001; Progar and Moldenke, 2002), including recently discovered species (Dieterich and Anderson, 2000) and endemics (Adams and Bury, 2002). Storage, processing, and transport in headwater channels influences biophysical conditions onsite (Richardson and Daney, 2007) as well as the delivery of water, wood, sediment, nutrients, and organisms to downstream channels (MacDonald and Coe, 2007). Surface and subsurface hydrologic flows connect headwater and larger streams (Winter et al., 1998, Nadeau and Rains, 2007). Fish habitat in larger rivers can be shaped by sediment (Benda and Dunne, 1997a,b; Zimmerman and Church, 2001; Benda et al., 2005) and wood (Reeves et al., 2003; Hasson et al., 2005; Bingel et al., 2007) transported from small, fishless headwater streams. Such small streams can also affect productivity and biodiversity in fish-bearing streams by supplying nutrients, organic matter, and organisms, including macroinvertebrate prey (Wallace et al., 1995; Webster et al., 1999; Kifney et al., 2000; Wipfli and Gregovich, 2002; Meyer et al., 2007; Wipfli et al., 2007).

Conservation of many aquatic species may depend on the integrity of smaller streams and connections between these and larger rivers. Physical and biological characteristics of small streams warn of ecosystem changes that can eventually affect larger streams, but these small streams are generally the least protected by management regulations and the most sensitive to degradation (Meyer and Wallace, 2001; Rosenfeld et al., 2002). Proper management of small streams and their links to larger rivers can be important in maintaining and restoring downstream ecosystem quality (Gomi et al., 2002; Cummins and Wilzbach, 2005; Meyer et al., 2007).

**Differences in characteristics**

Catchment-level comparisons regarding spatial extent also indicated that the hydrographic datasets differed for in-channel and streamside characteristics and thus represented different populations of streams. Differences between the 1:100 000 and 1:24 000 hydrography in fish-habitat attributes reflected that field-inventoried reaches selected at 1:100 000 regularly excluded smaller streams higher in the channel network. For example, inventoried reaches at 1:100 000 tended to be wider, deeper, and have lower gradients than inventoried reaches at 1:24 000. The 1:100 000 and 1:24 000 data differed in some important measures of habitat complexity (e.g. number of complex pools per kilometre) but not in others (e.g. number of large wood pieces per kilometre).

Because higher-resolution hydrography typically extends streams further up into a catchment’s landscape characteristics at 1:24 000 differed from those adjacent to larger streams represented at 1:100 000. Findings that 1:100 000 streamside buffers contained greater percentages of non-forested area and lower hill-slope classes than 1:24 000 buffers are consistent with the distribution of private non-industrial lands throughout the Oregon Coast Range, including private holdings within the boundary of the Siuslaw National Forest. These private lands occur primarily in low gradient, wide valleys along larger rivers and tend to be in agricultural and rural residential uses (Burnett et al., 2007). The greater percentage of broadleaf forests found along the lower-resolution hydrography reflects a higher likelihood of red alder in wetter and more frequently disturbed areas near larger streams (Pabst and Spies, 1999). In contrast, areas along smaller streams have environmental conditions that foster conifers and greater percentages of recently harvested, open areas generated by federal and private industrial forestry (Young, 2000).

Road density results can be understood in the context of differences in road type and position, and the potential to evaluate effects of roads near the different hydrographic datasets. Road densities were relatively high along the 1:100 000 hydrography because the primary transportation corridors represented were commonly built in valleys parallel to large rivers (Jones et al., 2000). Road densities were also high along the densified 1:24 000 hydrography but for different reasons; roads in these areas include extensive secondary transportation corridors and routes for accessing and hauling timber. Roads can generate a variety of negative effects in both terrestrial and aquatic ecosystems (Trombulak and Frissell, 2000). Effects of non-primary roads may be of particular concern for aquatic ecosystems because these roads often occur in mid-slope locations and regularly cross small streams (Jones et al., 2000), typically were built to lower construction standards than primary roads, and may not be accurately mapped (Hawbaker and Radolli, 2004). The potential to assess many of the aquatic effects (e.g. delivery of road-associated landslides to small streams or blocking of fish passage by culverts on minor roads), depends on the availability of accurate maps across broad spatial extents for both streams and roads.

That different hydrographic datasets may represent different populations of streams can have implications for aquatic conservation beyond western Oregon. For example, in a study of agricultural impacts to streams in the Tenente Amaral River catchment of Brazil, located in the highly threatened Cerrado biome, Wantzen et al. (2006) added numerous streams visible on satellite imagery to the available 1:250 000 hydrography. Field visits indicated that all streams were not resolved in the satellite imagery. The small streams that were added to the available hydrography influenced study findings and potential...
conservation options because unimpaired channels were detected only in headwaters unmapped at 1:250,000. All other channels were either moderately or strongly impaired.

Spatial position

Differences in spatial position between hydrographic datasets had little effect on streamside characteristics examined at the reach scale. Thus, we expect that the publicly available 1:100,000 and 1:24,000 hydrography will yield similar results in future reach-scale characterizations when, as in this study, streamside data are of relatively low resolution and reaches are relatively constrained by adjacent hill-slopes. The choice of hydrography may influence buffer characteristics more when streamside data are at a higher resolution or where channels can meander across a wide floodplain and thus positional differences between the 1:100,000 and 1:24,000 hydrography are likely to be greater. Findings of this study support the first proposition but shed little light on the second. The only significant differences found between hydrographic datasets were with the highest-resolution data (hill-slope classes from 10m DEMs), but these differences were identified with a dataset containing a small proportion of unconstrained reaches. A dataset with more unconstrained reaches than were available for the Siuslaw National Forest is necessary to examine thoroughly how channel constraint may affect reach-scale streamside characterizations.

The differences detected in channel gradient suggest that the choice of hydrography may influence reach-level characterizations of stream channels. The generally higher gradients and more reaches with estimated negative channel gradients at 1:100,000 compared to 1:24,000 indicate the lower-resolution hydrography may present problems when characterizing gradient or other topographic attributes of stream channels. Although a physical impossibility, negative reach gradients can be estimated from DEMs when the elevation at the downstream end exceeds that at the upstream end. This indicates that the digital hydrography is not accurately positioned relative to the DEM (FitzHugh, 2005). Drainage enforcement had been done on the DEM with the 1:24,000 digital hydrography, but not the 1:100,000; this may partly explain differences found in this study. Consistent with these findings, Lunetta et al. (1997) chose to use 1:24,000 rather than 1:100,000 hydrography because the superior ‘absolute stream orientation’ (i.e. positional accuracy) was essential for their analyses. They found 50% greater length of low-gradient reaches (representing potential salmon habitat) in 1:24,000 than in 1:100,000 streams and attributed that difference in part to the poor positional accuracy of 1:10,000 streams relative to the DEM used to measure reach gradients.

CONCLUSIONS

Differences between digital hydrographic datasets in spatial resolution were found to influence in-channel and streamside characterizations at both catchment and reach scales. However, differences in resolution appeared to affect catchment-scale characterizations more than reach-scale characterizations. This is because the hydrographic datasets differed only slightly in the spatial position of examined reaches but differed in spatial extent to the point of representing different populations of streams. Higher resolution hydrography includes more streams, and streams that extend further into a catchment, and thus differs from lower-resolution hydrography in biophysical characteristics.

Whether or not differences in spatial extent among hydrographic datasets produce differences that matter to conservation depends on the particular application. If a species inhabiting larger (greater mean annual discharge), wadeable streams is of interest (Lee et al., 1999; Flitcroft et al., 2002; Wing and Skougset, 2002), then results derived from fish habitat inventories based on a 1:100,000 digital hydrography should prove useful. However, such a dataset can omit up to four-fifths of the stream length in an area and provide little information on one or more categories of stream, including headwater streams that have received much recent attention from researchers and policy makers (Naiman and Larterell, 2005; Danehy and Ice, 2007; Freeman et al., 2007; Nadeau and Rains, 2007). Higher resolution hydrography can be critical when designing and implementing strategies to protect small streams from possible negative effects of common management practices, such as timber harvest or road building, and to restore habitat and functions of small streams for fish and other aquatic species at risk.

It is rare in the freshwater literature to find references to exactly what hydrography was used in studies, and rarer to find discussions of the advantages and disadvantages of hydrographic options that are available for research or management applications. We hope that these findings will motivate others to consider carefully and report the choice of hydrography used. This choice may influence analytical outcomes, the scope of inference for analyses, and the ability to compare results among studies. Consequently, it is critical to report details about the chosen hydrography, including a full citation, so potential implications to study results of mapping attributes such as duration of annual flow, cartographic scale, horizontal accuracy, and method of development can be considered.

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