QUANTIFYING LAND USE DISTURBANCE INTENSITY (LDI) IN THE SKOKOMISH RIVER WATERSHED: SALMONID HABITAT IMPLICATIONS

by

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ABSTRACT

Quantifying Land Use Disturbance Intensity (LDI) in the Skokomish River Watershed: Salmonid Habitat Implications

James W. Harrington

The degradation of in-stream habitat suitable for the spawning and rearing activities of Pacific salmonids, resulting from anthropogenic land-use, has been identified as a potential limiting factor for certain salmonid populations. Quantifying the degree to which individual land-use practices disturb habitats is a challenge to researchers. The research presented here was an attempt to quantify land-use disturbances within a 100-meter riparian buffer on the Skokomish River watershed in Washington State. A Land-Use Disturbance Intensity (LDI) index was employed to classify disturbance by practice and by area of influence. A watershed-scale LDI value was calculated to provide a snapshot of cumulative land-use effects within the entire watershed. The Skokomish River is characterized by a predominance of agricultural practices, forestry and timber harvest-focused practices, low-impact residential areas, and recreational land-use in its lower reaches. A substantial portion of the headwaters contributing to the basin originate in protected areas or areas considered minimally impacted. It was anticipated that a watershed-scale LDI value would be fairly low based on the minimal impacts in the upper reaches of the watershed; however, the watershed showed an LDI-value representing Medium Impact when examined in its entirety. Resulting LDI values based on land-use were also applied to stream reaches exhibiting coho activity in the lower segments of the Skokomish watershed.

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Chapter One: Introduction

Beginning at the turn of the 20th century, anadromous Pacific salmonids have faced continued declines across the majority of their range (Lichatowich, 1999; Montgomery, 2003). The reasons for these declines are multiple, the factors complex, and synergisms among factors powerful. Overarching themes for the declines have emerged within the previous two decades and revolve around what are frequently referred to as the four (or sometimes five) "H's" (Montgomery, 2003). The five H's are comprised of: a) harvest, b) habitat degradation, c) hydroelectric power, d) hatchery issues, and e) history. A tremendous amount of research has been conducted examining these factors and the relationship to salmonid declines at various scales and recent scholarship has indicated that there is a need to study environmental issues at multiple spatial and temporal scales (Lele & Norgaard, 2005; Cresswell, 2013). Furthermore, there is increasing evidence that multidisciplinary, transdisciplinary, and interdisciplinary approaches may prove effective when confronting environmental concerns because of the wide array of factors involved and the complexity of ecological systems (Wells, 2013). The issue of habitat degradation, particularly spawning and rearing habitat in river systems, has been thoroughly researched with great emphasis placed on the effects of timber harvest and the alteration of landscapes for human settlement purposes.

The current study was an examination of human-induced land-use disturbance intensity (LDI) on the Skokomish River in western Washington State and included an assessment of LDI in stream sections exhibiting coho salmon activity. The introductory chapter provides context and rationale for the current research. Subject matter reviewed in Chapter One includes: (a) historical human land-use patterns and the effects on salmonids in the Pacific Northwest in general and the Hood Canal region in particular, from indigenous land-use through Euro-American timber extraction, to current populations, (b) predominant habitat attributes of anadromous salmonid spawning streams in general and biological characteristics of coho salmon and their utilization of habitat, and (c) a review of the habitat characteristics of the Skokomish River basin.

Chapter Two is an assessment of the literature which addresses methodological approaches for quantifying the effects of land-use disturbance intensity (LDI) within watersheds, and the manner in which quantified LDI can be compared to additional ecological circumstances in effort to better model land-use disturbance effects. The basic principles of assessing land-use disturbance within watersheds will be addressed and examples of how researchers utilize this quantified data will be highlighted.

Chapter Three is a detailed account of the LDI quantification methodology employed during the current study. The use of ArcMap software for conducting these quantification procedures is documented and described. Specific procedures developed by Collyard and Von Prause (2009, 2010) and amended during the current research are explained. The integration of existing GIS data regarding salmonid behavior is also addressed.

Chapter Four is a presentation of the analysis of the data examined and the results of the current study. A quantification of human induced land-use disturbance at the watershed-scale of the Skokomish River basin is provided. Additional analysis examines quantified land-use disturbance within reaches of the Skokomish watershed exhibiting coho salmon activity. The intention of Chapter Four is only to deliver results obtained through analysis of gathered data and within the framework of the current study. A discussion of the results and potential implications is undertaken in Chapter Five.

Chapter Five is an expansive discussion of the current study itself, the potential importance and implications of the results, and recommendations for future study. The way in which land-use disturbance affects spawning and rearing habitat, thus potentially affecting salmonid abundance in the Pacific Northwest is addressed. The chapter also explores how future land-use studies may be conducted and how additional factors may confound study efforts.

Chapter Six is a discussion of the interdisciplinary aspects which frame the current study and provide context for developing future research questions. Despite a tremendous body of research, the necessity of studies of Pacific salmonids, and the way in which humans interact with them remains. Focused studies embedded deeply within a particular discipline continue to provide researchers with baseline data and remain practical. However, given the complexity of the factors related to salmonid recovery efforts, interdisciplinary and transdisciplinary approaches should prove germane when addressing environmental concerns in general and may be particularly suited to salmonid recovery.

Human Land-use Patterns and Interactions with Anadromous Salmonids

Indigenous Northwest Populations and Salmonids

Lichatowich (1999), in *Salmon Without Rivers,* utilized multiple anthropological studies in describing the earliest inhabitants (arriving between 15,000 and 13,000 years ago) of the Pacific Northwest and their connections with anadromous fish. One theory presents these earliest populations as unlikely to have utilized salmonids as substantial forage because of the lack of suitable of salmon spawning habitat among the oft-glaciated watersheds these groups inhabited (Matson & Coupland, 1994). Rather, these early populations existed in small groups, exhibiting a migratory lifecycle centered on opportunistic harvest of both terrestrial and aquatic fauna, of which salmonids may have played only a small part. In accordance with this theory, “salmon based economies” (Lichatowich, 1999, p. 27) centered around salmon-bearing watersheds, likely grew as indigenous populations increased and alternative resources became more scarce and less spatially concentrated throughout newly opened post-glacial habitat in the migratory areas the early populations traveled through and inhabited seasonally.

Alternate anthropological studies cited by Lichatowich (1999) suggest that indigenous salmon economies increased and then flourished with shifting postglacial habitats. Improved habitat availability resulted in a robust increase in stable salmon runs, thus decreasing the necessity for excessive migrations of human populations (Faldmark, 1986, in Lichatowich, 1999).

Regardless of whether influenced by the deterioration of alternative forage sources or the increase in harvestable salmon, Lichatowich (1999) and others have extensively chronicled the increasing importance of salmon in the economies of the growing indigenous populations from 9,000 years ago to the peaks of these populations during the 18th and 19th centuries. As climates stabilized and the abundance of salmon increased, indigenous populations began to develop communities at sites where harvestable salmon runs occurred. These sites would include marine shorelines along salmon migratory routes and near the terminal estuaries of rivers as well as streamside locations along larger rivers (Lichatowich, 1999; Mongtomery, 2003). The post-glacial Pacific Northwest during this peak of early human populations has been described as “one of the most densely populated nonagricultural regions of the world” (Boyd, 1990, in Lombard, 2006). Harvest by indigenous populations at the peak may have actually approached numbers similar to commercial harvests seen near the beginning of the twentieth century and this extensive harvest of salmon could have stressed individual runs (Taylor, 1999).

Despite the shift from a migratory lifestyle to settlement based on salmon resource availability, the indigenous inhabitants likely did not impose substantial land-use disturbance in the areas of settlement which would have impacted anadromous fish runs; however, land-use disturbances did occur. In an area of settlement, trees would be felled to utilize for shelters and canoe building (Eells, 1889). Prescriptive fire was utilized as a means to promote new vegetative growth of plant-derived food like camas and to entice megafauna like deer and elk into grazing areas (Robbins, 1997).

Throughout the region, indigenous populations exercised similar lifestyles based on harvesting available resources with minimal disturbance to the landscape. During the 1800's, three tribes inhabited the area of Hood Canal that was addressed in the current study: the Suquamish, the S'Klallam, and the Skokomish. Anecdotal accounts from members of these populations (Kitsap Sun, 1991) suggest that the tribes adhered to the prevailing lifestyles of the region, with the predominant resources utilized being timber, edible plants, salmon and other fish, terrestrial fauna, and marine shellfish. With the influx of Europeans, Euro-Americans, and other immigrant ethnic groups, more substantial land-use disturbances occurred throughout the region and near Hood Canal specifically.

European/Euro-American Settlement and Timber Extraction

The degree of shifting land-use patterns capable of affecting anadromous salmonids intensified in the late nineteenth and twentieth centuries with the large-scale influx of Europeans, Euro-Americans, and other nonindigenous people into the region. In the mid-1800's, the California Gold Rush provided a catalyst for a sharp increase in timber harvest in the Pacific Northwest (Chiang & Reese, 2003). The Puget Sound region was particularly suited for this purpose. Extensive old growth forest in close proximity to protected marine harbors allowed for the efficient harvest of timber, transportation of logs to mills, and the loading of ships bound for San Francisco (Chiang & Reese, 2003.). In 1853, Pope and Talbot established the Puget Sound Mill Company at Port Gamble, WA on the northern end of the Kitsap Peninsula on Hood Canal (Chiang & Reese, 2003).

Mills were often located on streams to utilize hydrological energy (Lichatowich, 1999). The effects of large-scale timber harvest on anadromous salmon streams were substantial as mills created vast amounts of sawdust capable of blanketing river bottoms where incubating salmon eggs were deposited and excessive sawdust could disrupt returning adult fish and outmigrating juveniles by clogging their gills with debris (Lichatowich, 1999). Timber harvesters also utilized the streams for transporting logs and many harvest sites existed near marine shorelines, the mouths of rivers, and within the riparian zone near the banks farther upriver (Committee on the Protection and Management of Anadromous

Salmonids, 1996). Sedell and Luchessa (1981) indicated that trees had been cleared 2 miles inland along Western Puget Sound and Hood Canal shorelines and as many as 7 miles inland near streams and rivers. Harvest efficiency decreased during periods of low river flows therefore, splash dams were created as a means to transport large amounts of timber at a single instance. Splash dams were erected above pool areas between riffles and as water collected, the pools would be filled with logs. At prescribed intervals the dams would be removed (frequently by dynamite) and the presence of large amounts of logs in the streams and increased unnatural flows disbursing sediment and other stream litter disrupted spawning and rearing habitat (Lichatowich, 1999).

In addition to disruptions from splash dams, multiple effects from the close proximity of harvest sites to rivers occurred when riparian timber and vegetation were removed. Forest cover in riparian zones provide shade and keep rivers cool, the root systems of large trees stabilize river banks and mitigate erosion, and naturally fallen trees provide woody debris utilized as cover by juvenile salmonids, as well as introducing nutrients which establish aquatic food chains. Additionally, rivers and streams were often cleared of obstacles, primarily naturally-occurring fallen trees and large woody debris, which would impede the transport of timber, further altering spawning and rearing habitat (Committee on the Protection and Management of Anadromous Salmonids, 1996; Lichatowich, 1999).

In the mid-20th century, technological advancements allowed for the extraction of timber on a greater array of geographic landscapes. Heavy equipment was capable of operating on steeper graded slopes and extensive road systems were developed to provide access for the machines. Salmon streams were now being impacted on greater spatial scales. The construction of roads and clear-cutting of timber on steeper slopes caused soil and sediment destabilization ultimately resulting in potential land-slides, depositing excessive sediment into streams (Committee on the Protection and Management of Anadromous Salmonids, 1996; Lichatowich, 1999). One study indicated that landslides were approximately 25 times more likely to occur in clear-cut areas and areas near roads than in forested areas (Lyons & Beschta, 1983).

Historical Timber Harvest Around Hood Canal

After Pope and Talbot's 1853 establishment of the Port Gamble mill, the succeeding years saw numerous logging camps established along the eastern and southern shores of Hood Canal including present-day Seabeck, Bangor, Nelitta, Holly, Dewatto, Union, and Belfair (Dunagan, 1991, p. 60). In the late 19th century it was anticipated that several railroads would be routed through Union and the cost of land parcels skyrocketed (Dunagan, 1991, p. 61). The town of Clifton (now Belfair) also experienced a boom when roads connected the settlement with Sydney (now Port Orchard). Also, in the late 1800's, the community of Dewatto experienced moderate growth due to its role as a connecting marine landing on the east side of Hood Canal. In 1927, voters approved the formal establishment of a port and subsequent pier and dock expansion but the plans never came to fruition (Buchanan, 1930, as referenced in Dunagan, 1991; "Dewatto Citizens Petition…"

from

http://www.historylink.org/index.cfm?DisplayPage=output.cfm&file_id=9719).

The historical record clearly indicates that timber harvest was the primary driver of land-use disturbance in the Hood Canal region post-settlement and the effects of large-scale timber harvest on salmonid streams is addressed in the previous section. Although timber harvest likely held the predominant role in the degradation of these streams, additional factors including the transformation of cleared land to agricultural use and the harvest of salmon as a food supply for the population of timber workers may have contributed as well (Platts, 1991).

Coho Salmon (*Onchorynchus kisutch*) Characteristics: Understanding Freshwater Spawning and Rearing Habitat Behavior

Anadromous salmonids are those which are born in a freshwater setting, rear in freshwater, begin a migration to marine waters as juveniles, exhibit substantial growth during varying years at sea and return to spawn as sexually-mature adults (Groot et al., 1995). For the purposes of framing the current research, coho salmon are reviewed here; however, individual salmonid species exhibit characteristics which are unique and varied. Currently, the Skokomish River supports coho, chinook, chum, sea-run cutthroat, and steelhead, with additional resident rainbow and coastal cutthroat trout, bull trout, stray pink salmon, and there are current plans to establish a population of sockeye salmon which would utilize the impoundment of Lake Cushman on the Skokomish.

Coho salmon are 1-3 “salt” fish meaning they spend one to three years feeding and growing at sea. Research conducted from 1962 to 1970 indicated that 2-salt fish were the most common at 68.2% of the catch, while 1-salt and 3-salt fish were measured at 22.0% and 7.5% respectively (Higgs et al., 1995). Additionally, certain male individuals of a particular age-class may reach sexual maturity early and return to spawning streams one year earlier than the remaining individuals of the same age-class. These individuals are frequently referred to as “jacks” or “precocious males.” Coho diet preferences in maturing, seagoing fish vary dependent on region, however, larval and adult baitfish (including herring, sand lance, and anchovies), euphausiids, amphipods, and squid constitute the majority of adult coho diet (Higgs et al., 1995).

Populations of coho returning to spawn in Hood Canal typically enter their natal streams in September, October, and November with spawning activities occurring in November and December (Clarke & Hirano, 1995). Entrance to natal streams is influenced by river flows and tidal fluctuations with large precipitation events often prompting stream entry and subsequent upstream migration, as rising water levels allow greater access and in some cases may move impediments such as impassable beaver dams or excessive logjams. Tabor et al. (1995) described this phenomenon occurring on several Hood Canal streams during December 1992 when the city of Bremerton received over 14 cm of rain from Dec. 7-10.

Spawning Habitat Preferences

Coho typically exhibit a preference for smaller streams or the tributaries of larger streams when selecting habitat for spawning. Beds of deposited eggs (redds) are often located in moderately paced sections of rivers between pools and riffles. Moderate stream flow assists the female in removing sediment when digging the redd and provides adequate oxygen to incubating eggs. Additionally, moderate velocity sections are less likely to scour out substrates once eggs are deposited and buried (Bjornn and Reiser, 1991). Gravel and pebble substrates are often preferred for coho egg deposits with larger cobbles being infrequently utilized (Mull, 2005).

Juvenile Rearing

Juvenile coho will typically spend the first year of life after emergence as fry in the natal stream before outmigrating as smolts in late April and May; however, Tschaplinski (1987) found that in some systems, coho fry may outmigtrate with smolts and rear in the estuary before returning to the stream in fall. Tschaplinski also noted that these fry exhibited more rapid growth than those remaining in the streams. Juvenile diets are typified by insects with chironomids comprising a particularly important component of their diet. Yearling smolts continue to feed on insects although other salmonid fry, particularly chum and pink fry, are a substantial component of smolt diet. In estuarine settings, juvenile fry also feed on insects; however, amphipods and copepods also contribute to diet. Smolts in estuaries and marine environments feed primarily on insects and amphipods, but at this life stage, small fish are also a substantial source of forage (Higgs et al., 1995). Additional examinations of coho habitat suitability are addressed in following sections.

Unique Characteristics of the Current Study Site: The Hood Canal Region

The Hood Canal region represents a unique area for watershed land-use disturbance study. Hood Canal is bordered by on the west by the Olympic Peninsula and the Kitsap Peninsula on the east. The canal is a glacially-carved fjord with a general north-south orientation but “hooks” sharply to the east in its southern reaches (Figure 1).

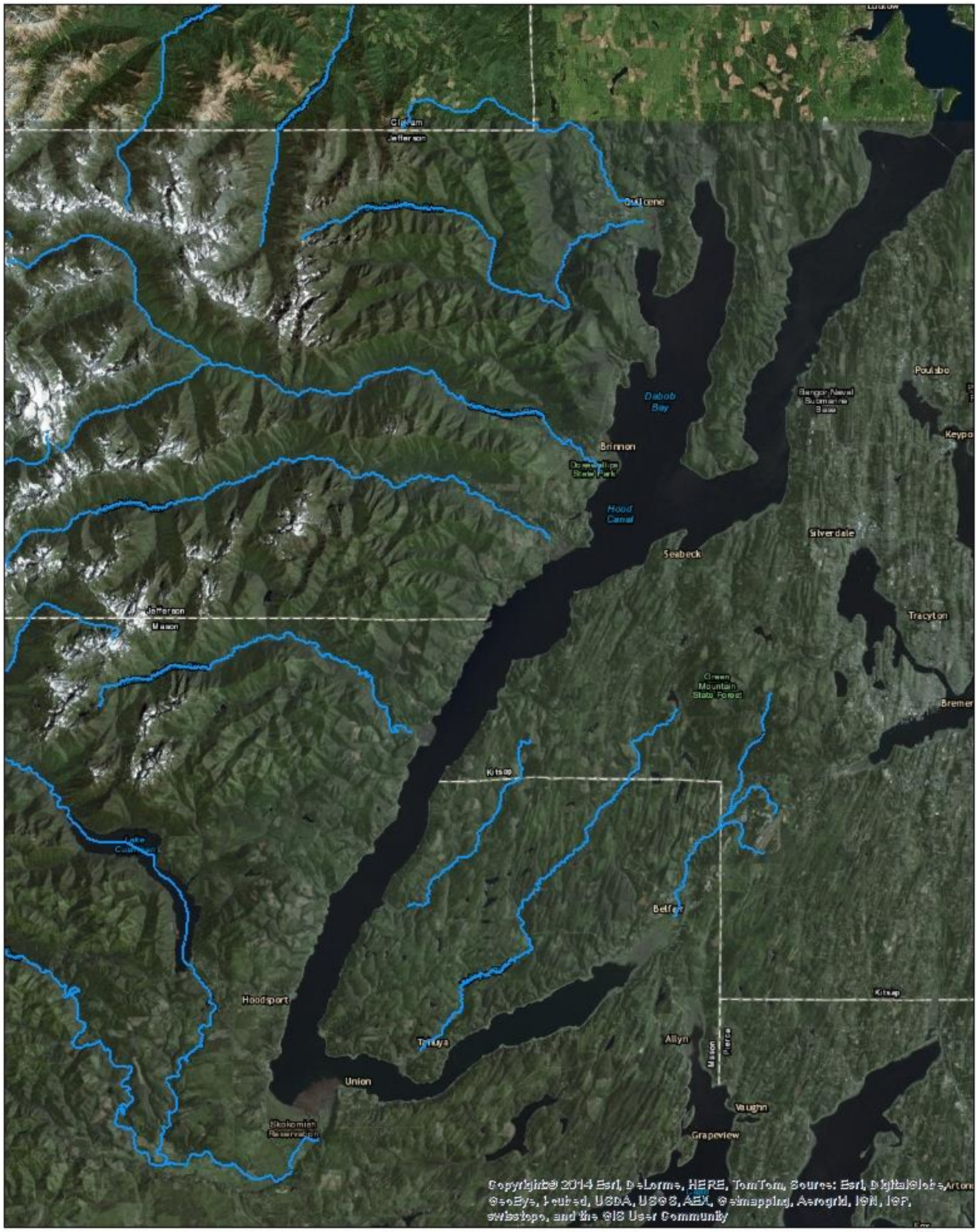

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Figure. 1. Hood Canal Region showing major watershed drainages.

The region differs from other areas of Western Washington with salmonid streams in several regards and in some ways may be represent a transitional area between the highly populated urban areas which cover much of the eastern shore of Puget Sound and the more sparsely populated rural or wilderness areas of the greater Olympic Peninsula to the west. The eastern and northern edges of the Kitsap Peninsula contain the population centers of Belfair, Port Orchard, Bremerton, Silverdale, Poulsbo, Kingston, Seabeck and Port Gamble. West and southwest of Belfair, the southern shore of the "hook" of Hood Canal is far less densely populated although cabins and homes are almost continuous along Highway 106. Interestingly, although in general, the greater Olympic Peninsula has lower population density, the western shore of Hood Canal is paralleled for much of it range by Highway 101 and is far more developed than the eastern shore on the Kitsap Peninsula. The Skokomish River empties into Hood Canal in the southern reaches near the town of Union. Two highways cross the Skokomish, U.S. 101 and state Highway 106. The Skokomish Indian Reservation is situated between the two highway crossings.

Skokomish River Salmonid Habitat

The Skokomish River, examined in the current study, is considered part of Water Resource Area (WRIA) 16 and exhibits characteristics consistent with coho behavior and habitats as explained in this section and the historical record indicates an abundance of coho salmon under relatively undisturbed conditions. Based on the literature, the current study site is representative of prime habitat for coho, provided the river had experienced minimal disturbance. A 2003 report from the Washington State Conservation Commission examined salmon and steelhead habitat limiting factors in WRIA 16 (Correa, 2003). "Stocks were evaluated as to status by the state and tribes in the 1992 Salmon and Steelhead Stock Inventory (SASSI). Washington Department of Fish and Wildlife has updated the report in the 2003 Salmon and Steelhead Inventory (SaSI)" (Correa, 2003). Both the 1992 and 2003 reports determined Skokomish River coho stocks to be rated as "healthy" (Correa, 2003, p. 42).

Watershed Characteristics and Limiting Factors for Skokomish Coho

The Skokomish River drainage is the largest in the Hood Canal region and encompasses 240 square miles with mainstem inputs of 80 miles and tributary inputs of 260 miles (Correa, 2003). Two major forks (the North Fork and South Fork) combine to create the "mainstem" which flows for 9 miles to the terminus in Hood Canal. An extensive report prepared by Mason County characterizes land cover, hazard areas, water quality and priority habitat and species areas by watershed and reach (Mason County Shoreline Inventory and Characterization Report (MCSIC), 2012) and could provide data to be used for comparison with the results of the current research. Land-uses are classified primarily as "agricultural, vacant, forestry, and/or residential." For each stream reach identified in the report, a percentage of land-use type within the reach is provided. Additionally, critical habitat for several salmonid species endemic to the Skokomish are identified at each reach.

Chapter Two: Methodological Literature Review

Land-Use Development Intensity Index

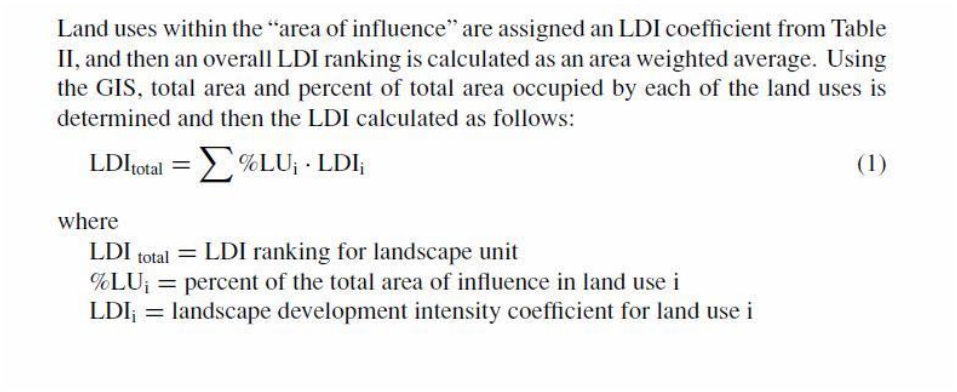
Brown and Vivas (2005) determined that an anthropogenic land-use development intensity index (LDI) could be calculated from land-use data and corresponding energy usage in a measured geographical unit through the utilization of a geographic information system (GIS). Units of geographical scale in which the LDI could be determined include river, stream, or lake watersheds, and even individual wetlands (Brown and Vivas, 2005). The LDI of a particular unit can then be compared against other ecological data to determine land-use relationships with species and habitats.

According to Brown and Vivas (2005), the greater the intensity of human activities, the greater the ecological effects on a given landscape unit, and units exhibiting the highest-energy land-uses may have extremely limited or no natural ecological systems. As the authors indicate, many human populated landscapes exist between the extremes of highly developed human population centers and "wildlands" (Brown & Vivas, 2005). The Hood Canal region seems particularly representative of this assessment based on its geographic position between the highly developed I-5 corridor and largely wild Olympic Peninsula.

Brown and Vivas (2005) define a landscape unit as "the ecological community, drainage feature, or hydrologic system that is being studied. For instance, the study unit could be an individual ecological community such as a wetland, or a stream segment, or a sub-watershed drainage basin" (p. 302). It is important to note that the authors determined a 100 m buffer was adequate to quantify the disturbance surrounding a particular watershed and no significant difference was found between LDIs calculated at 100 m and 200 m. This determination was based on the area the authors examined, which were watersheds in Florida exhibiting low-gradient drainages.

Brown and Vivas (2005), developed LDI coefficients for different land-use classifications based on Emergy Accounting, a system developed by H.T. Odum (1996). Thermodynamic bases of all forms of energy and materials are converted into the equivalent of solar energy. "Emergy is the amount of energy required to make something" (Brown and Vivas, 2005, p. 302). Units of emergy are referred to *emjoules*, and quantify the energy consumed in transformations. Thus, all energy utilized in human development of environments (solar, fuel, electric, and human work) can be defined by the amount of solar energy necessary for the production of each. The unit used for expressing this energy utilization is the *solar emjoule* (sej). The quantification of human-development intensity through land-use can then be calculated from annual usages of non-renewable energies (solar emergy joules [sej]) per unit (sej/ha yr^{-1}). Brown and Vivas (2005) calculate the “LDI coefficient as the normalized natural log of the empower densities (p.292).” Calculating the natural log utilizes a base of “e” or 2.7182818. Brown and Vivas (2005) continue, stating, "first the natural log of the empower densities were calculated and then the resulting values were normalized on a scale from 1 to 10, with the LDI coefficient for natural lands equal to 1.0 and a LDI coefficient of 10.0 for the highest intensity land use, the Central Business District (p. 294)." The use of a natural log transformation and the scaling of values from 1 to 10 indicates that the coefficient values assigned to different land use types represent dramatic increases in land use disturbance as values increase. The methodology used in the current study (see Chapter 3) accounts for this disturbance intensity increase in the models. Furthermore, when analyzing quantifications of LDI, it is imperative to recognize the increasing influence that higher LDI coefficient values will have on area-weighted results for units within the “area of influence.”

Because the LDI is a measure of human alterations, only usage of non-renewable energies were included. Land-use or land-cover categories were then defined and an LDI coefficient assigned to each category (See Appendix). The equation represented in Figure 2 is then used to determine an area-weighted land-use ranking for an individual unit.



Land uses within the "area of influence" are assigned an LDI coefficient from Table II, and then an overall LDI ranking is calculated as an area weighted average. Using the GIS, total area and percent of total area occupied by each of the land uses is determined and then the LDI calculated as follows:

$$\mathrm{LDI}_{\mathrm{total}} = \sum \%\mathrm{LU}_{\mathrm{i}} \cdot \mathrm{LDI}_{\mathrm{i}} \tag{1}$$

where

$\mathrm{LDI}_{\mathrm{total}}$ = LDI ranking for landscape unit
$\%\mathrm{LU}_{\mathrm{i}}$ = percent of the total area of influence in land use i
$\mathrm{LDI}_{\mathrm{i}}$ = landscape development intensity coefficient for land use i

Figure 2. Equation to determine total LDI for a landscape unit (Brown & Vivas, 2005).

Proximity of Land-Use Effects on Stream Fish and Habitats in Great Lakes Tributaries

Stanfield and Kilgour (2012) conducted an extensive seven-year study reviewing LDI relationships to stream fish and their habitats in tributaries to Lake Ontario at 312 individual sites analysis sites. Multiple spatial scales were used in the analysis: catchment, eight varied riparian polygons differing in width and length, upstream polygons of 1.6 and 3.2 km, and residual upland area unaccounted for by the polygons. A covariate analysis was conducted and fish assemblage diversity, habitat suitability, and temperature variation were compared to LDI measurements as well as with each other. The objectives of the data analyses were to "(i) summarize the variations and covariations of the different measures of LDI and template variables against measures of fish community composition and in-stream physical conditions (response variables) and (ii) to determine the magnitude of variation in the response variables that was uniquely explained by LDI measured at different scales" (Stanfield and Kilgour, 2012). Data were analyzed using methods similar to those proposed by Brown and Vivas (2005). LDI values ranging from 0 to 50 were applied to parcels characterized from undisturbed full forests to fully developed urban areas and examined in relation to the response variables.

The results indicated that "sites with high LDI in the whole upstream catchment also generally had high LDI in smaller polygons, regardless of the proximity of the polygon to the stream site" (Stanfield and Kilgour, 2012). Stream temperature was shown to be variable at low levels of LDI and consistently high at LDI levels above 18. Pure fish biomass declined in linear fashion with increased LDI. Additional findings indicated a greater influence of LDI in headwater streams on downstream catchments and fish assemblages. These findings were contrary to a previous study (Frimpong et al., 2006) which determined that upland influence decreases to almost zero beyond 150 m. Stanfield and Kilgour (2012) suggest that:

"…land use in proximity of the headwater streams in these upland areas directly influences the factors that influence both fish biomass and taxa richness of downstream areas, and that future management activities should extend beyond the main river and its valley."

Land-use and Coho in Snohomish River (Pess et al., 2002).

Pess et al. (2002) studied a suite of habitat factors affecting adult coho returns on the Snohomish River system. Pess et al. (2002), utilized a hierarchical linear model (HLM), a method frequently used in social sciences to model nested units, to examine the relationships between habitat characteristics and fish abundance; the HLM was applied to describe spawner counts within years. Single-variable regression analyses were also used to explain the variation in fish density as a function of an individual habitat characteristic, of which, land-cover and land-use was one. Multiple-regression models were used to examine fish densities as a result of a suite of habitat characteristics. Models were applied to both stream-reach and watershed-scale units (Pess et al., 2002).

The HLM indicated a negative correlation over time between spawner abundance and percentage of land in urban or agricultural use, whereas a positive correlation was shown between coho abundance and percent forest cover. Areas designated with more than 50% forest cover showed 1.5-3.5 times greater abundance in coho spawners than areas with less than 50% forested land. The 10 index reaches studied with highest coho spawner abundance exhibited more than 60% forest cover in riparian areas. Additionally, in stream reaches exhibiting less than 10% agriculture, salmon abundance was two to three times greater (Pess et al., 2004).

Allan's (2004) Four Challenges to Understanding Land-Use Change Effects on Watersheds

In a comprehensive analysis of land-use effects on watersheds titled, *Landscapes and Riverscapes: The Influence of Land-use on Stream Ecosystems,* Allan (2004) identified four difficulties for understanding these land-use effects: (a) covariance between anthropogenic and natural gradients, (b) spatial scale issues, (c) nonlinearities, and (d) legacy effects.

Covariation

Covariance often exists between the effects of land-use and natural landscape features. Parent geological material, soil types, and topography will often dictate suitability for anthropological land-uses. Therefore, caution should be exercised to avoid overestimating the contribution of land-use influence on a particular ecological variable (Allan, 2004).

Spatial Scales

Three common designations are frequently used in investigations of stream conditions and land-use relationships. A *local reach* is usually designated as the buffer area 100 m to several hundred meters in width along both banks and some hundreds of meters to one kilometer in length. A *riparian buffer area* is usually described as a similar width as the local reach (100 m or more) but contains a greater length upstream or even an entire upstream distance on smaller waters. A *catchment* is usually designated as the entire drainage upstream from a specific site.

There should be an expectation of variances of responses to large-scale or local-scale factors. Thus the effects of local inputs or influences may be distributed along great distances of the stream. Therefore, the appropriate level of scale for study should be chosen based on the best available literature (Allan, 2004).

Nonlinearities

Allan (2004) pointed to several studies which showed declines in species diversity and the index of biotic integrity (IBI) with increasing urbanization or increasing impervious area (IA). Generally, the evidence suggests that a range between 10%-20% of IA or urban land within the riparian buffer equates to a threshold for stream health; however, some studies indicate that influences of hydrology based on geography and resultant downstream flow are strong indicators and a single threshold should not apply to characterizing an entire watershed. Responses are also likely to vary based on scale and thresholds will shift will based on the area of the catchment examined and resultant thresholds (Allan, 2004).

Legacy Effects

Consequences from disturbances which are still influential long beyond the occurrence of the disturbance are known as legacy effects and may be underemphasized. Wang et al. (2001 as cited in Allan, 2004) reported variations in fish metrics along an urbanization gradient however, habitat quality varied little.

The effect was attributed to a legacy of prior influences of agricultural land-use. Furthermore, previous anthropogenic geomorphological channel changes may have had far reaching effects on physical structure and hydrology, and recovery from these disturbances takes markedly longer than from changes in land-use (Allan, 2004).

LDI Applied Within Washington State Watersheds

Collyard and Von Prause (2009) developed a methodology for the utilization of LDI analyses for watersheds in Washington State using a 1-10 scale with an LDI coefficient of 1 representing undisturbed landscapes and 10 representing the greatest amount of anthropogenic disturbance and (see Chapter Three and Appendix). The researchers determined that a 100 meter riparian buffer was appropriate for an LDI analysis of watersheds in Washington State. Based on the 10-point scale, Collyard and Von Prause (2009) further delineated LDI ratings into three categories represented in Table 1.

Table 1. Low-Medium-High LDI Classifications (*from Collyard and Von Prause, 2009).*

LDI Score	Description
0-2.00	Low Impact Nearly pristine conditions
2.01-5.50	Medium Impact

	Low Intensity Residential/ Agricultural
5.51-10.00	High Impact Urban

Chapter Three: Methods

The current study was an attempt to quantify land-use disturbance in watersheds draining to Hood Canal, based on an index proposed by Brown and Vivas (2005) and adopted by Collyard and Von Prause (2009) of the Washington State Department of Ecology (DOE). Land-use disturbance indices within particular watersheds were calculated at the catchment level (entire system drainage) utilizing a method which allows for more focused analysis of smaller units of the watershed should a researcher desire to do so. Researchers Collyard and Von Prause (2009) indicated the need for a statewide uniform classification of land-use disturbance within all watersheds in Washington State. A complete dataset of quantified land-use disturbance within watersheds would be beneficial for the ease of comparing additional spatial watershed data with adjacent land-use patterns.

LDI Calculation Overview

ArcGIS 10.2 software was the primary tool utilized for quantifying land-use patterns and determining LDI values within a particular watershed. An existing dataset layer produced by the Washington State Department of Ecology and Washington State Department of Revenue (2009), classifies land-use for the entire state based on tax parcel units. LDI coefficients can then be applied to each land-use classification category using the methodology proposed by Brown and Vivas (2005) and refined by Collyard and Von Prause (2009) for Washington State.

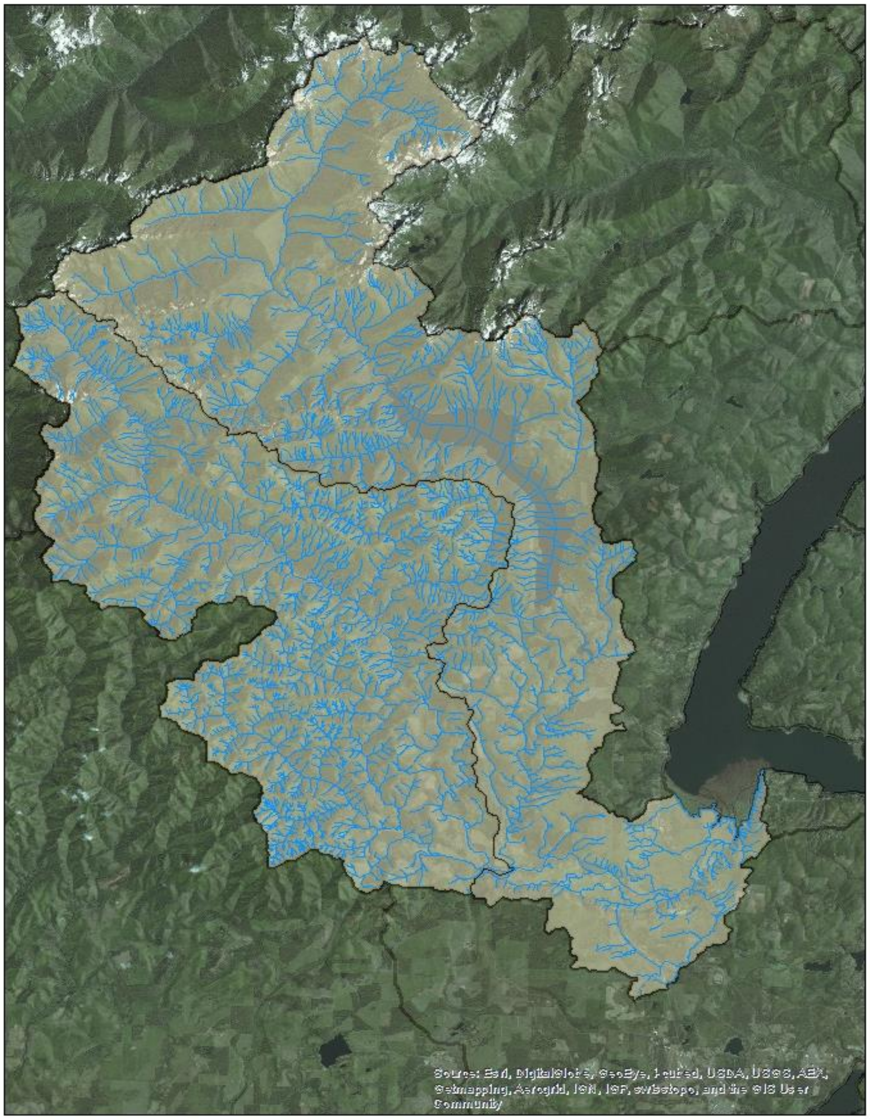
These data, when used in conjunction with GIS layers from the National Hydrology Database (NHD) and scaled to Hydrological Units based on USGS Hydrologic Unit Codes (HUCs), and with the application of a 100 meter riparian buffer in a GIS, allow the user to calculate an area-weighted LDI for a chosen geographic unit at a watershed reach based on the user’s needs.

Primary Study Site: Skokomish Watershed-Land-use Classifications and LDI Coefficients

The primary study site was the Skokomish watershed which drains from the southeast flanks of the Olympic Mountains on the Olympic Peninsula to southern Hood Canal. For the purposes of the current the study (calculating a watershed-scale LDI value), two hydrological units (defined under the USGS NHD classification as South Fork Skokomish River and Skokomish River-Frontal Hood Canal with HUC-10 digit codes of 1711001701 and 1711001702 respectively) were combined and are represented in Figure 3. The NHD flowline data delineates the drainage of tributaries into larger streams allowing for full watershed-scale analyses and is represented in Figure 4.

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3. Combined South Fork Skokomish and Skokomish River-Frontal Hood Canal Watersheds (From HUC-10 layer).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4. Flowline data showing all tributaries contributing to Skokomish River watershed

The DOE and DOR dataset uses a coding system (*see Appendix*) to classify land use for particular parcels (based on tax data from DOR). Table 2 shows land-use classifications and the codes for parcels within the Skokomish Hydrologic Unit. The coded land-use layer for all parcels can then be added to the GIS (shown in Figure 5 at the watershed-scale and in Figure 6 zoomed to the lower-Skokomish reaches for interpretation). Using the “Buffer” and “Clip” tools in ArcMAP, a 100 meter buffer can be applied and the adjacent land-use classifications for each parcel can be clipped to the buffer (Figure 7).

Table 2. *Land-use Classifications of the Skokomish Drainage*

Land-use Code	Description	Land-use Code	Description
11	Household, single family units	68	Educational services
15	Mobile home parks or courts	74	Recreational activities
18	All residential not elsewhere coded	75	Resorts and group camps
19	Vacation Cabin	76	Parks
25	Furniture and fixtures	79	Other cultural, recreational, church, cemetery
45	Highway and street right of way	81	Agriculture (not classified under current use law)
46	Automobile parking	83	Agriculture classified under use Chapter 84.34 RCW
48	Utilities	84	Fishing activities and related services
51	Wholesale trade	87	Public timberland/non-designated forest
53	Retail trade-general merchandise	88	Designated forest land under Chapter 84.33 RCW
54	Retail trade-food	91	Undeveloped land
58	Retail trade-eating and drinking	92	Noncommercial forest
59	Other retail trade	94	Open Space land classified under Chapter 84.34 RCW
63	Business services	95	Timberland classified under Chapter 84.34 RCW
67	Governmental services		

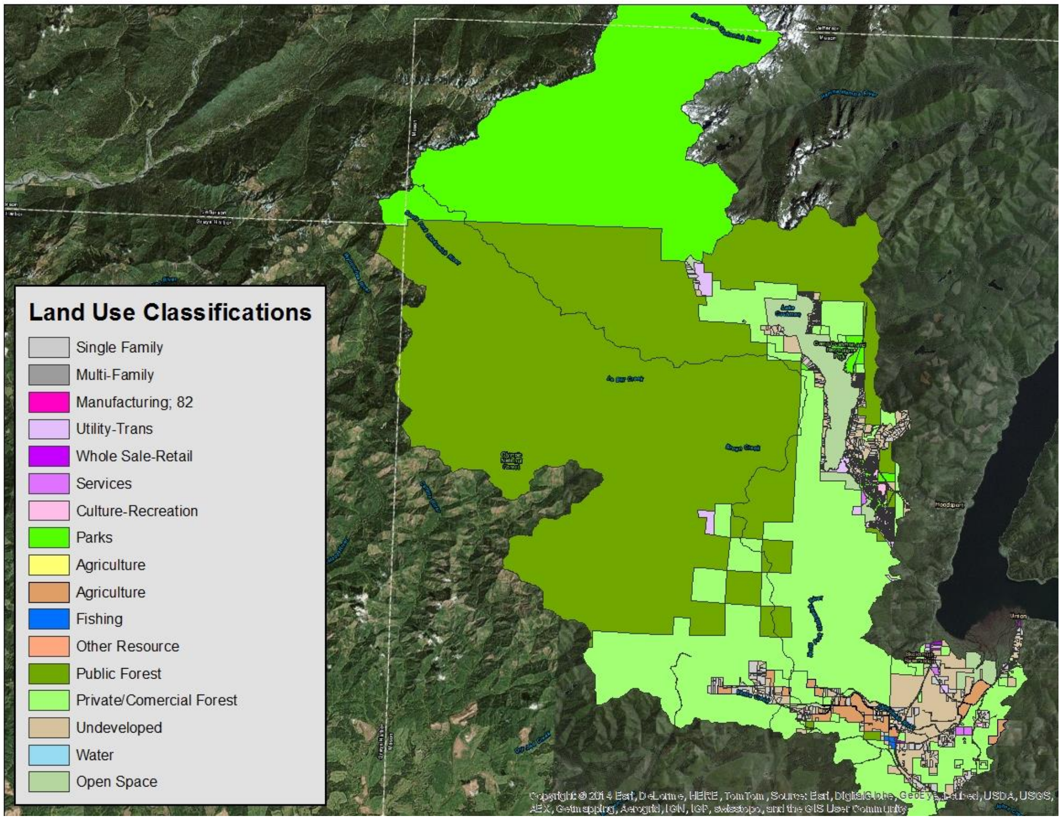


Figure 5. Complete Skokomish watershed and land use classifications.

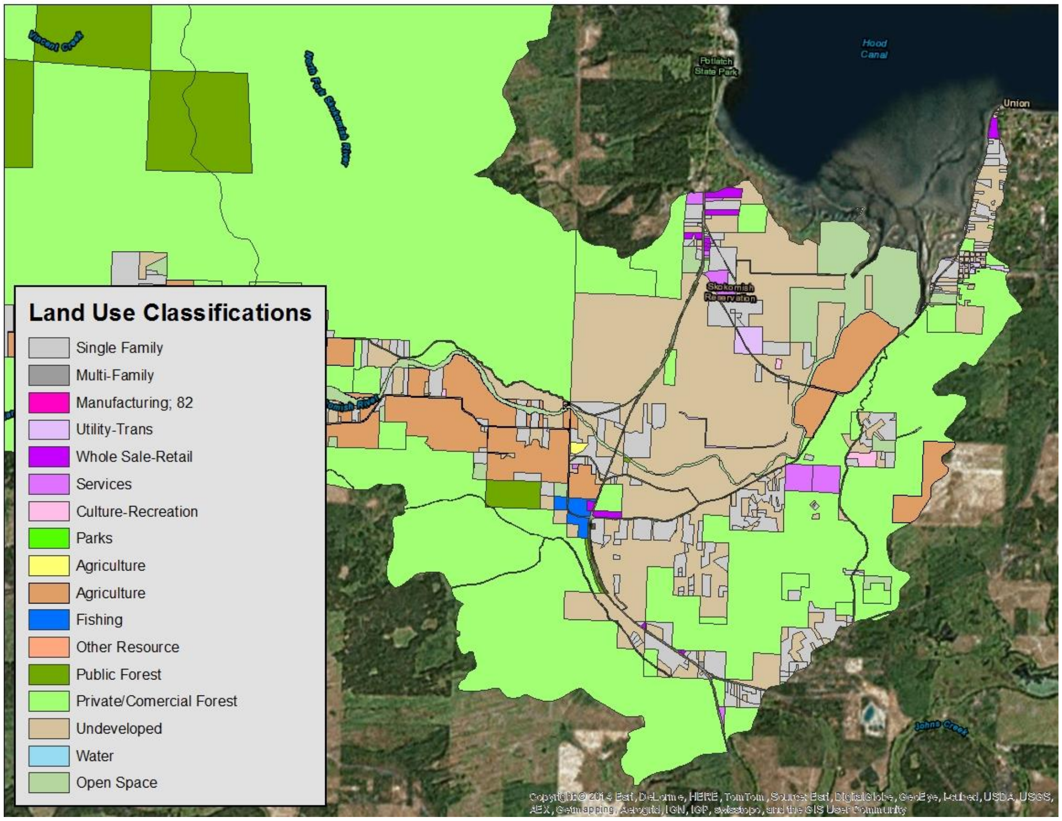


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Figure 6. Lower Skokomish valley land-use classifications. View zoomed and full parcels shown for interpretation purposes.

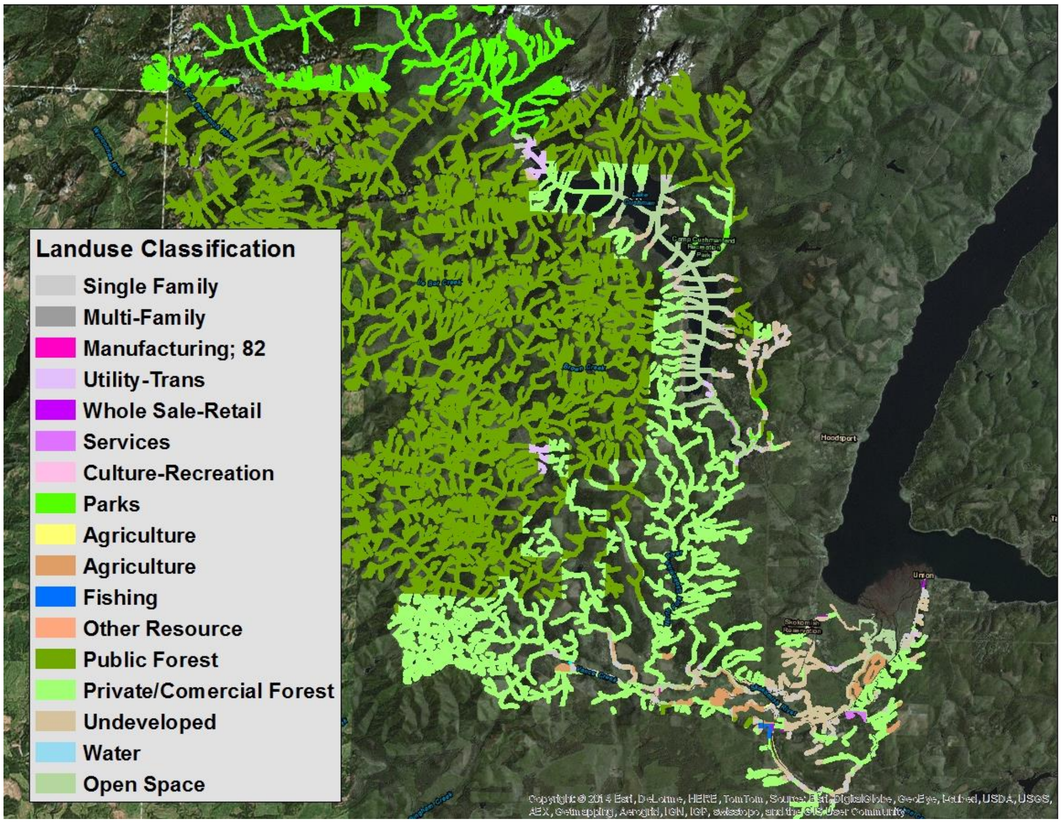

Figure 7. Full Skokomish Watershed with 100 meter buffer applied and adjacent land-use classifications.

Methodological Additions To DOE Framework: Accounting For All Roads in LDI Calculations

A primary addition to the methodology proposed by Collyard and Von Prause (2009) used in the current study, and one which should prove useful in future research, was the integration of accounting for the LDI values of all roads (not only those present in the existing DOR dataset) in the calculation of the LDI indices for watersheds examined in the current study. According to the values from Brown and Vivas (2005), 2-lane highways are given an LDI coefficient of

7.81 and accounting for these roads may result in different LDI scores when examining at various scales.

County road data were added to the GIS (Figure 8); however, because the road data are linear, it was necessary to apply a 35-ft buffer to the linear data line to achieve a polygonal dataset which could be analyzed at intersections with the existing 100 m buffer applied to the stream data. Using ArcMAP, subsequent to the application of the 35-ft buffer to the roads, executing a spatial merge with the existing land-use layer, and clipping areas where the buffered roads intersect with the 100 m riparian buffer, a new GIS layer was created which accounts for the intersection of roads within the riparian buffer zone (Figure 9).

Figure 8. Linear county road data layer applied to the existing map. View is zoomed to show where roads may exist in close proximity to the watershed.

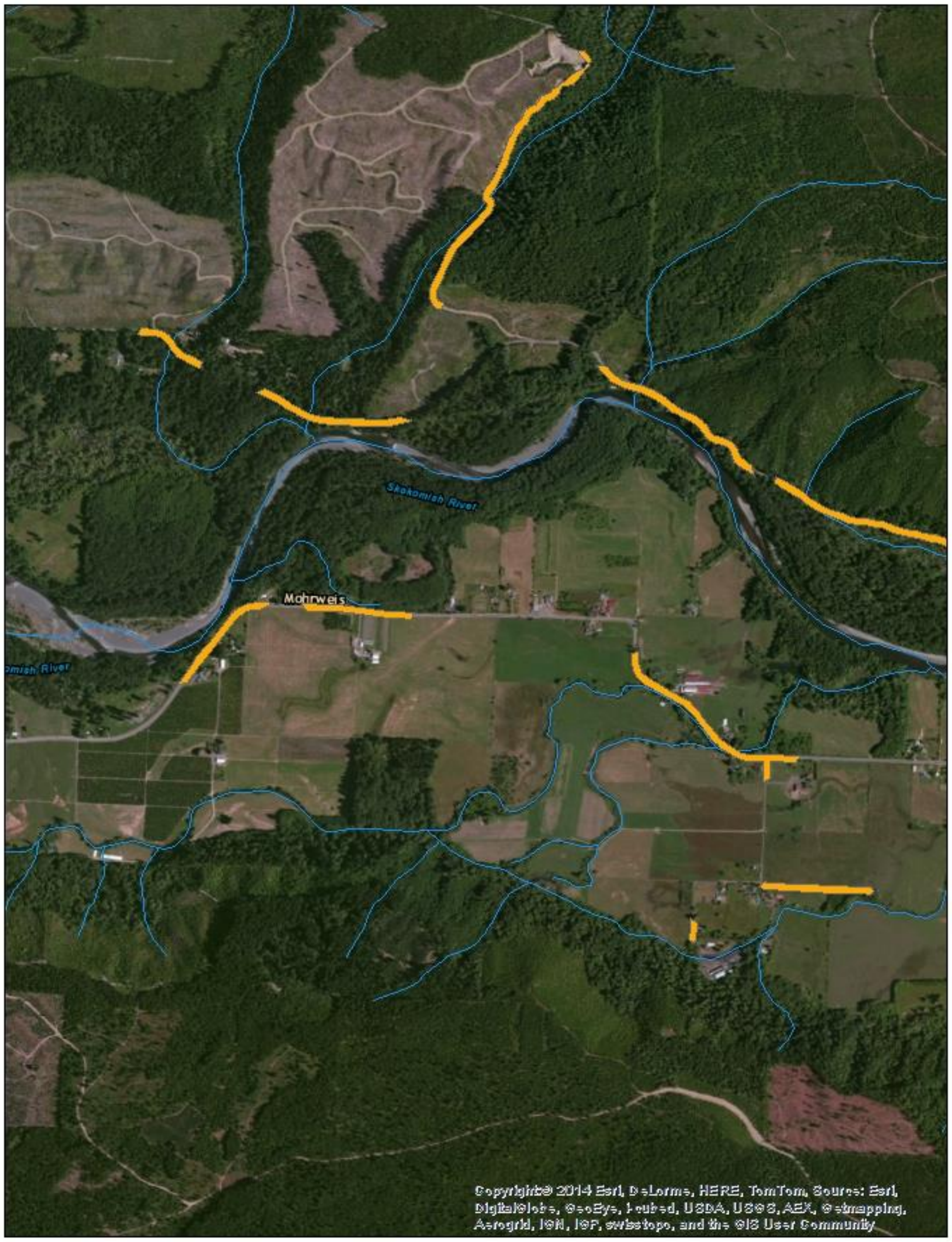

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Figure 9. Road data integrated into the existing GIS map accounting only for spatial area where roads intersect the 100 m riparian buffer used for LDI analysis and allowing for the integration of applied LDI coefficients for roads in the Skokomish watershed. View is zoomed for interpretation purposes.

Calculating Catchment-Scale LDI Values for the Skokomish Watershed

With the land-use classifications clipped to a 100 meter riparian buffer, calculation of an area-weighted LDI becomes possible. ArcMap layers generally have associated data tables providing additional information about the geography being displayed in the GIS. Because each tax parcel is given an identification number (and thus is a distinct unit in the GIS) in the original statewide land-use layer, it was possible to calculate the physical area of each buffered parcel utilizing the X-Tools Pro extension for ArcMap. Working within the layer's data table also allowed for the assignment of the LDI coefficients listed in Table 2 to individual parcels and subsequent calculations, based on the classification system and methodology utilized by Collyard and Von Prause (2009) as adopted from Brown and Vivas (2005). Figure 10 shows an Excel adaptation of the data table for the GIS. The first column (labeled FID) identifies individual parcels, the fourth column (labeled LANDUSE_CD) contains the numerical designations for land-use classification as shown in Table 2, the sixth column lists the area in square meters of each parcel clipped within the 100 meter riparian buffer and the 11th column (labeled LDI_Coef) shows the land-use disturbance coefficient applied to each parcel.

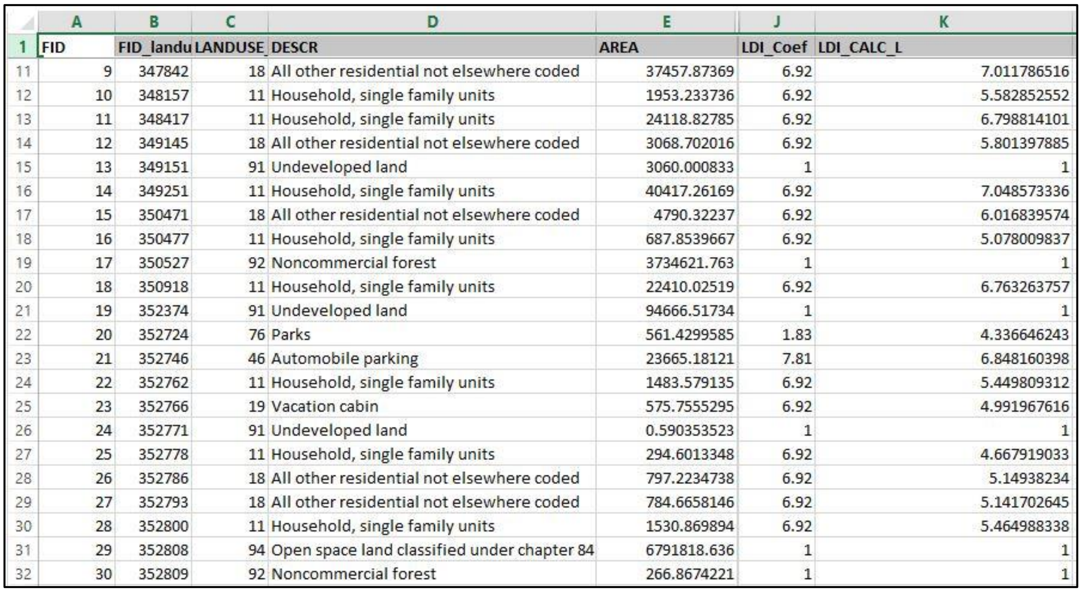
Special Considerations for LDI Value Assignments

A review of the table in the Appendix will show several redundancies among the "Land-use-CD numbers" applied for various land-use types as proposed by DOE (2010). Additionally, several different LDI value coefficients may be applicable to a single “land-use CD number.” During the current research, I used satellite photograph layers, some level of ground truthing, and the existing DOE GIS classifications in an attempt to appropriately classify certain parcels and assign an LDI coefficient for each parcel. For example, a particular parcel with a “land-use CD” classification of “82” in the DOR/DOE dataset (classified as ‘agriculture’) may actually represent one of several different types of agricultural use. Accordingly, LDI values will change based on the intensity of the particular type of agriculture practiced. Because of the nature of the scope of work, time, and financial resources for the current study, I relied best judgment when assigning LDI coefficients to parcels with a “land-use CD” classification which could receive several different LDI coefficients. I am familiar with the study area and with the associated land-use types, so it is my hope that the values are as accurate as possible; however, extensive ground-truthing would likely improve the accuracy of any models derived from the dataset. Furthermore, experts familiar with determining land-use from satellite photography may be able to more accurately determine and assign land-use classifications for future analyses.

Performing The Area-Weighted LDI Calculation for the Skokomish Watershed

Figure 10 depicts the data table associated with the Skokomish River GIS and containing the data required to perform the area-weighted LDI calculation for the

Skokomish watershed. Using the ArcMAP field calculator tools, an additional column (LDI_Calc) was added to the attribute table for the GIS dataset and area-weighted LDI scores were able to be calculated by entering a function which multiplied values in the “Area” column by the associated “LDI_Coef” column and designating the results be returned to the new “LDI_Calc” column. Following the methodology of Collyard and Von Prause (2009), all values in the “LDI_Calc” column were then natural log transformed and finally scaled from 1-10 using the ArcMAP field calculator. The “LDI_CALC_L” column contains final, transformed and scaled LDI values for land-use disturbance intensity within the 100 m riparian buffer.



	A	B	C	D	E	J	K
1	FID	FID_landu	LANDUSE_	DESCR	AREA	LDI_Coef	LDI_CALC_L
11	9	347842	18	All other residential not elsewhere coded	37457.87369	6.92	7.011786516
12	10	348157	11	Household, single family units	1953.233736	6.92	5.582852552
13	11	348417	11	Household, single family units	24118.82785	6.92	6.798814101
14	12	349145	18	All other residential not elsewhere coded	3068.702016	6.92	5.801397885
15	13	349151	91	Undeveloped land	3060.000833	1	1
16	14	349251	11	Household, single family units	40417.26169	6.92	7.048573336
17	15	350471	18	All other residential not elsewhere coded	4790.32237	6.92	6.016839574
18	16	350477	11	Household, single family units	687.8539667	6.92	5.078009837
19	17	350527	92	Noncommercial forest	3734621.763	1	1
20	18	350918	11	Household, single family units	22410.02519	6.92	6.763263757
21	19	352374	91	Undeveloped land	94666.51734	1	1
22	20	352724	76	Parks	561.4299585	1.83	4.336646243
23	21	352746	46	Automobile parking	23665.18121	7.81	6.848160398
24	22	352762	11	Household, single family units	1483.579135	6.92	5.449809312
25	23	352766	19	Vacation cabin	575.7555295	6.92	4.991967616
26	24	352771	91	Undeveloped land	0.590353523	1	1
27	25	352778	11	Household, single family units	294.6013348	6.92	4.667919033
28	26	352786	18	All other residential not elsewhere coded	797.2234738	6.92	5.14938234
29	27	352793	18	All other residential not elsewhere coded	784.6658146	6.92	5.141702645
30	28	352800	11	Household, single family units	1530.869894	6.92	5.464988338
31	29	352808	94	Open space land classified under chapter 84	6791818.636	1	1
32	30	352809	92	Noncommercial forest	266.8674221	1	1

Figure 10. Data table from ArcMap GIS software converted to Microsoft Excel table showing essential data required for an area-weighted LDI calculation of the Skokomish watershed.

Integrating Existing Salmonid-Related GIS Data

The Washington Department of Fish and Wildlife (WDFW) operates an interactive GIS accessible via the web known as SalmonScape. According to the homepage for SalmonScape, "SalmonScape delivers the science that helps recovery planners identify and prioritize the restoration and protection activities that offer the greatest benefit to fish (WDFW, retrieved from http://apps.wdfw.wa.gov/salmonscape/)." Data presented in the mapping system are culled from the research results of state, federal, tribal, and local studies and integrated into a sinuous system which is readily accessed by any interested entity.

A primary feature of the data available in the SalmonScape interface which is pertinent to the current research, is the documentation of salmonid utilization of habitat within specific stream segments. This utilization is classified by species and by type of utilization (spawning, rearing, etc.). Figure 11 shows coho activity in the lower reaches of the Skokomish River watershed as classified within the SalmonScape interface GIS dataset.

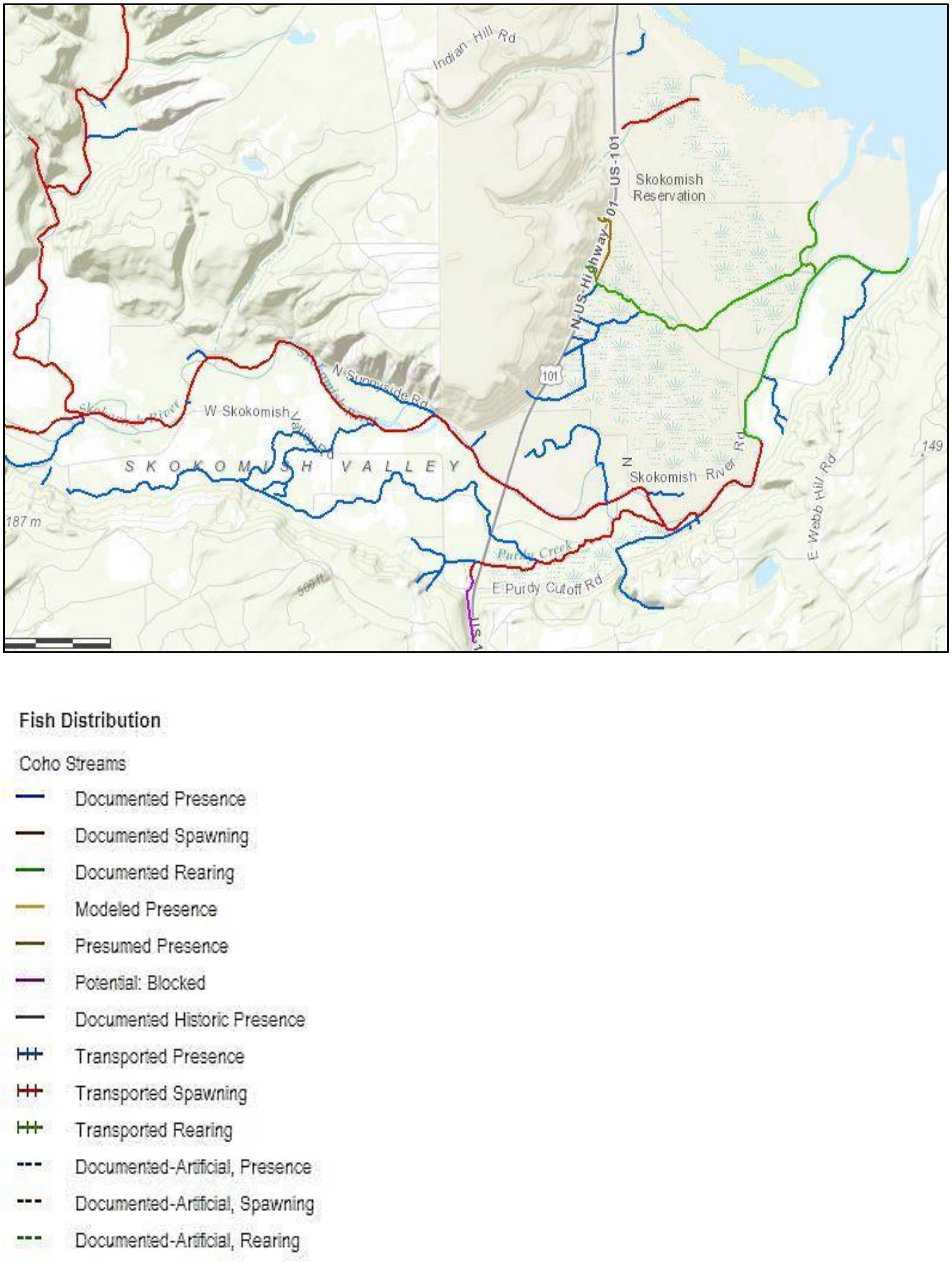


Figure 11. Coho distribution in the lower Skokomish River watershed. Source: http://apps.wdfw.wa.gov/salmonscape/map.html

Using the geoprocessing tools in the ArcMap software, it was possible to integrate SalmonScape data into the LDI dataset for the Skokomish River created during the current study (Figure 12).

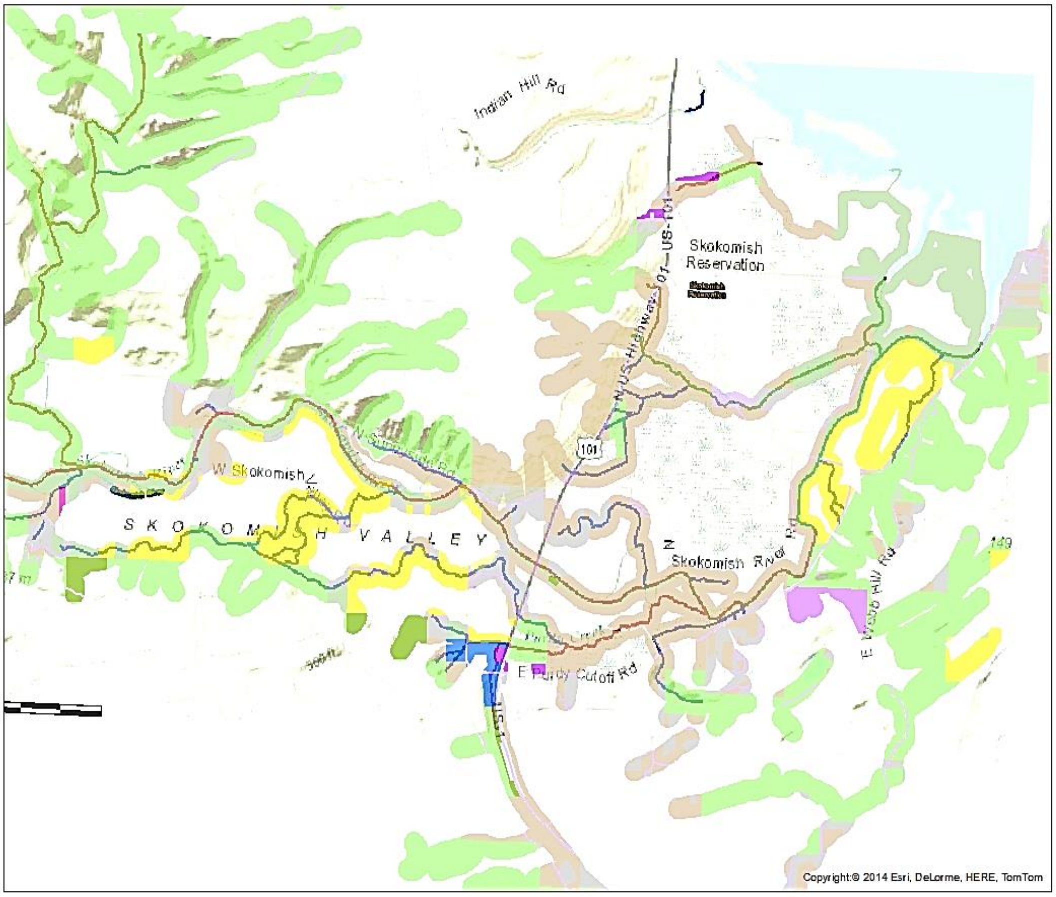


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Figure 12. Integration of coho activity data from SalmonScape with LDI classification data rendered during the current study.

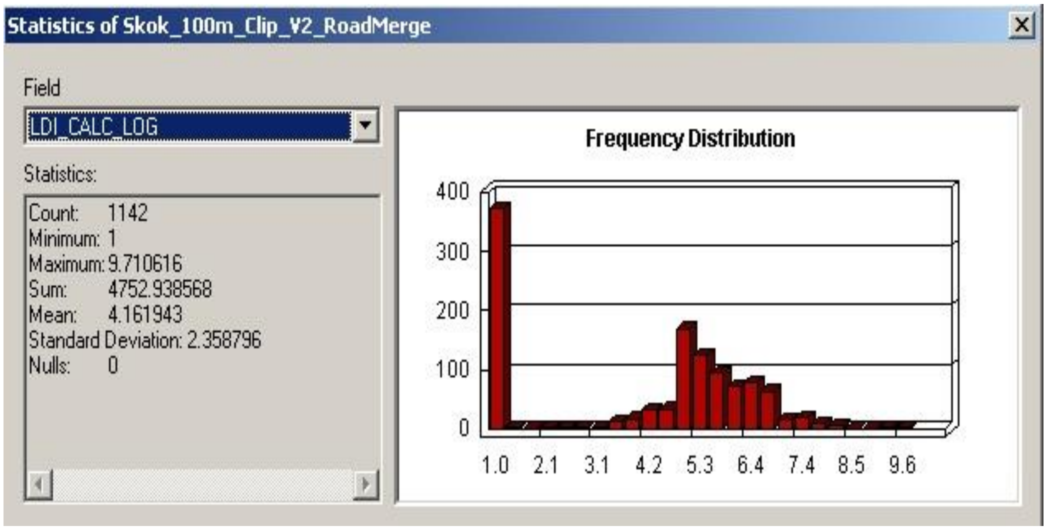
By employing the same procedure used to calculate a watershed-scale LDI value for the entire Skokomish (as described throughout Chapter 3), it was also possible to calculate mean LDI values for individual stream segments exhibiting specific coho activity as classified in the SalmonScape GIS.

Chapter Four: Analysis and Results

A major component of this research involved the effort required to understand, adapt, and apply the methodology for LDI quantification. The methods are GIS-intensive which necessitated that I develop skills using the software and expend the time performing the functions. These efforts constituted a tremendous amount of study and application in and of themselves. A fortunate outcome of the methodological research was the rendering of some interesting and applicable results. This chapter is a review of the results and analysis. Following this chapter is a discussion of the study, limitations and difficulties of the methods and results, contextual information, and recommendations for refinement of the methodology for salmonid habitat assessment and future research opportunities.

Skokomish River: Watershed-scale LDI

After performing the GIS methodology explained in Chapter 3, new data emerged which quantified LDI for the watershed examined and bear further scrutiny. Running a simple statistics summary using ArcMap yielded some compelling results. Figure 13 shows the initial results of the “Statistics” function when isolating the “LDI_CALC_LOG” field from the data table.


Statistics of Skok_100m_Clip_V2_RoadMerge

Field: LDI_CALC_LOG

Statistics:

Count: 1142
Minimum: 1
Maximum: 9.710616
Sum: 4752.938568
Mean: 4.161943
Standard Deviation: 2.358796
Nulls: 0

Figure 13. Results of the basic statistic function from ArcMap using "LDI_CALC_LOG" field for Skokomish watershed LDI values.

Because all LDI values were area-weighted and scaled, the mean value of all values from the "LDI_CALC_LOG" field shows the LDI for the complete watershed catchment within the riparian buffer. Within the Skokomish watershed riparian buffer, the mean LDI was 4.16 (*n=1142, m=4.162, SD=2.36*). Based on Collyard and Von Prause (2009), this value (4.16) indicates that at the watershed scale, the Skokomish River would be classified as "Medium Impact" or exhibiting an LDI-value between 2.00 and 5.50 (see Table 1).

Individual Parcel LDI: Framing Disturbance Impact

The frequency distribution graph in Figure 10 provides a simple visual representation of the distribution of the number of parcels exhibiting various LDI-values within the riparian buffer along the Skokomish. The distribution of the number of parcels exhibiting particular log transformed LDI values as represented in the graph is indicative on one hand *and* potentially misleading when viewed in isolation. The distribution graph shows that the greatest number of parcels within the riparian buffer are classified as a “1” (or “undisturbed” based on the LDI coefficients). The graph also shows a substantial number of parcels are classified by LDI coefficients between “4.2” and “7.4”, which indicates “medium” or “high” impact. However, the frequency distribution does not represent spatial area, only the number of parcels classified by particular LDI values. Therefore, additional analysis was required to more accurately model land-use disturbance within the riparian buffer of the watershed.

When examining the distribution of LDI values by area, an excessive amount of spatial area is classified with an LDI value of “1” and other “low impact” values (Figure 14). It is only when analyzing the area-weighted distribution of LDI values based on the log transformation, that LDI impacts are recognizable.

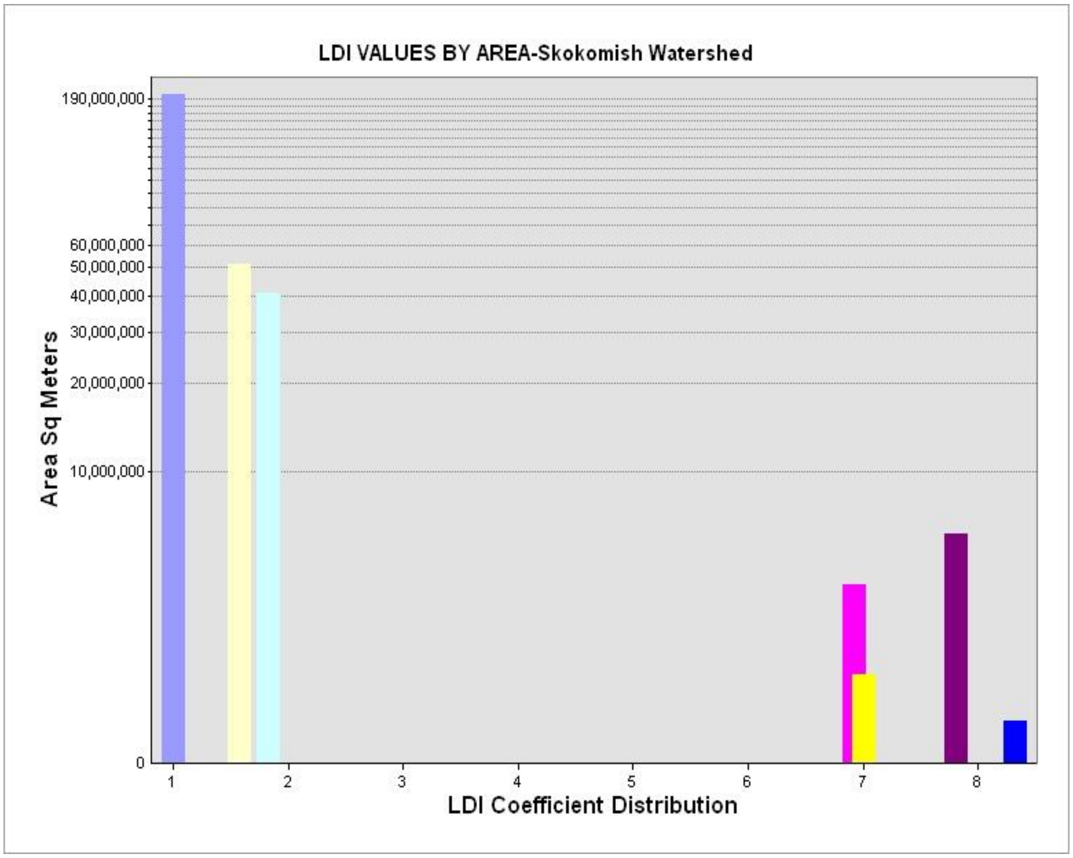


Figure 14. LDI coefficient distribution by area for Skokomish River.

It was hypothesized that the Skokomish watershed would likely show a disturbance index value indicating "low" impact. The rationale for this thinking was based on visual analysis and the perception that watersheds with headwaters within or closely adjacent to protected or managed areas (thus relatively undisturbed) and large segments of riparian area characterized as low impact, would show low impact at the watershed scale. However, based on the methodology for calculating area-weighted LDI values proposed by Brown and Vivas (2005) which utilizes a natural log-transformation for values, the disturbance may be far greater than what a simple visual analysis or count and area analysis would indicate when evaluating based on LDI-coefficient distribution alone.

Figure 15 shows the count distribution of parcels exhibiting log-transformed LDI values. Viewing this distribution shows how the Skokomish River is classified as a system experiencing medium-impact land-use disturbance when analyzed at the watershed-scale.

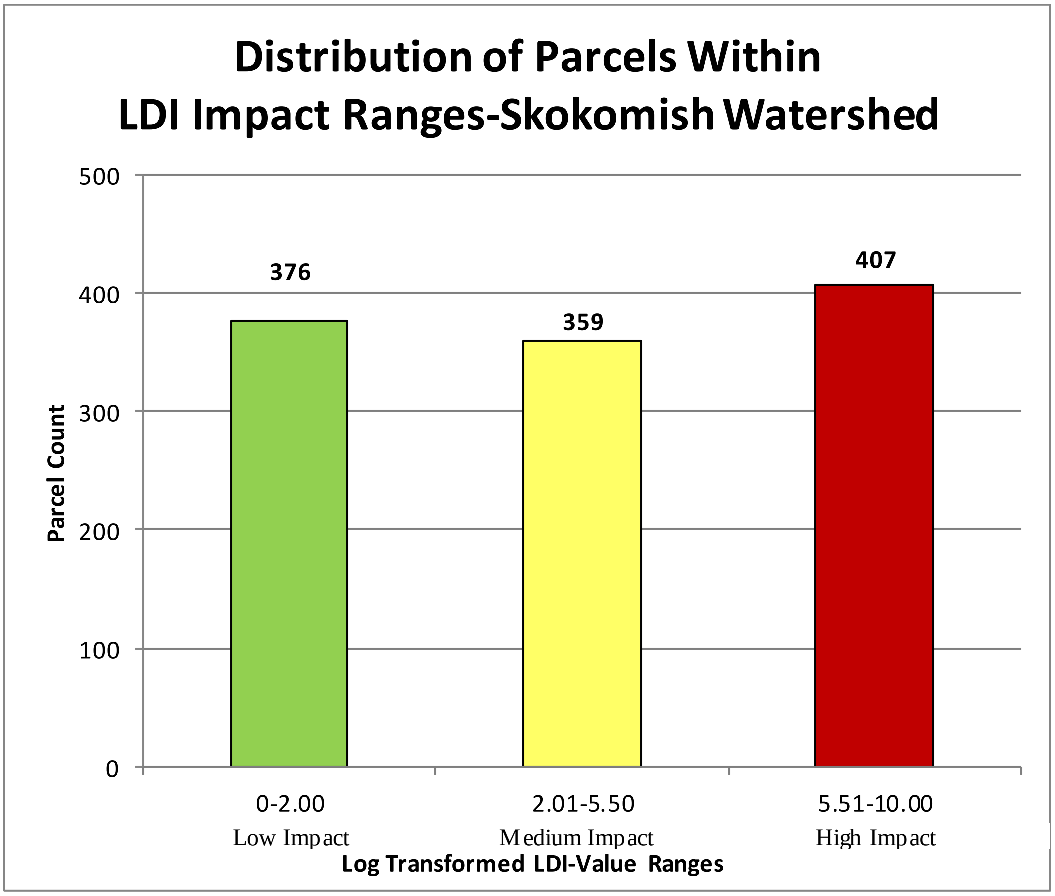


Figure 15. Total number of parcels exhibiting LDI value range by impact type when examining the Skokomish River at the watershed-scale.

LDI-Values at Coho Distribution Sites on the Lower Skokomish River

It was possible to modify the established method for calculating watershed-scale mean LDI values to analyze LDI in individual stream segments. Using the spatial coho distribution data available from SalmonScape, stream segments exhibiting particular coho distribution characteristics could be analyzed for land-use disturbance. Figure 16 shows coho behavior distribution, land-use classification within the riparian buffer, and the area-weighted LDI value for the parcels in the extreme lower Skokomish River.

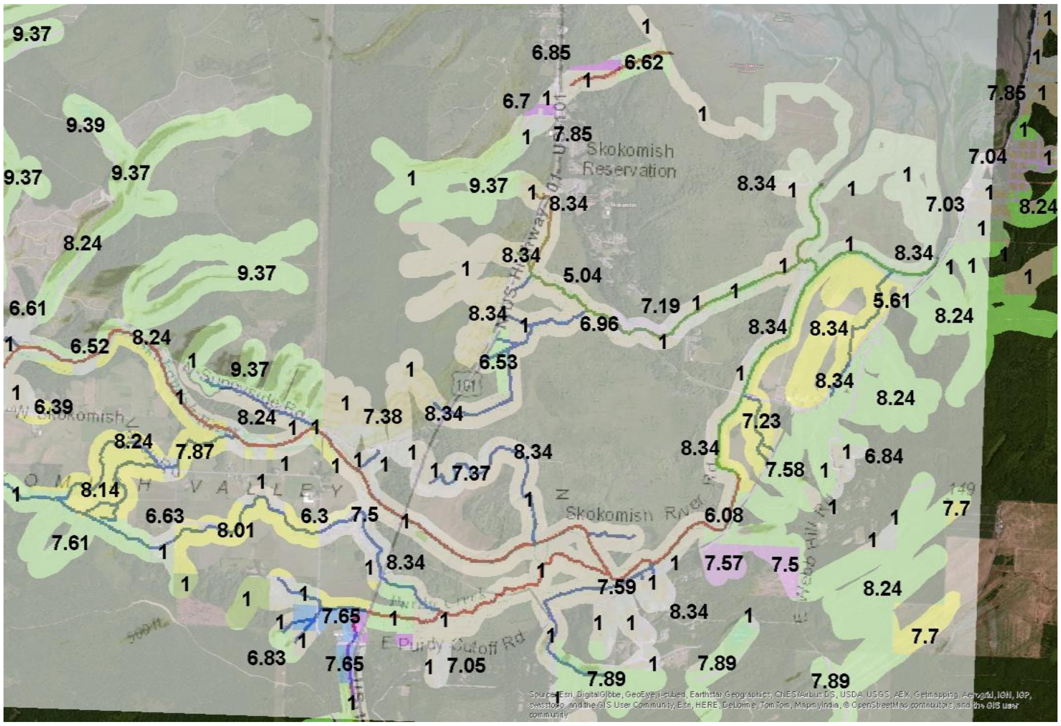
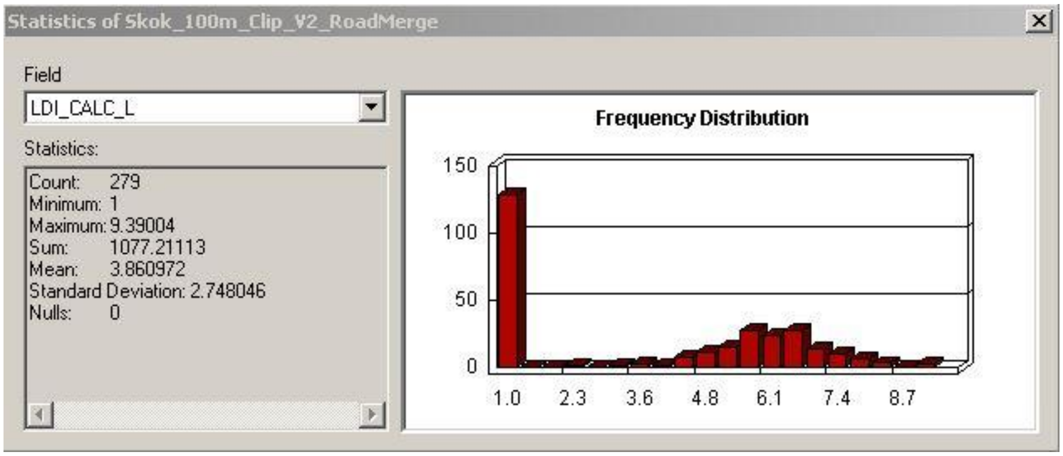


Figure 16. LDI Values for Certain Parcels Intersecting Coho Distribution Sites in the extreme Lower Skokomish River. (*Note: This map does not represent all coho distribution for the Skokomish nor are all parcels labeled with an LDI Value to aid in data interpretation.)*

Reviewing the summary stats provided by ArcMap provided the mean LDI for the extreme Lower Skokomish watershed reach examined in relation to coho activity documentation and the simple frequency distribution of LDI values in the watershed reach. Figure 17 shows the summary data provided by ArcMap.



```
Count:     279
Minimum:   1
Maximum:   9.39004
Sum:       1077.21113
Mean:      3.860972
Standard Deviation: 2.748046
Nulls:     0
```

Figure 17. Results of the basic statistic function from ArcMap using "LDI_CALC_LOG" field for lower Skokomish watershed LDI values in stream reaches exhibiting coho activity.

Within the lower-Skokomish reaches exhibiting coho behavior, the mean LDI was 3.86 (*n=279, m=3.861, SD=2.75*). While this values is somewhat lower than the watershed-scale LDI value for the Skokomish of 4.16, an LDI values of 3.86 is still classified as "medium" impact. Figure 18 shows the parcel distribution of all parcels within the lower Skokomish reaches intersecting with stream reaches exhibiting coho activity.

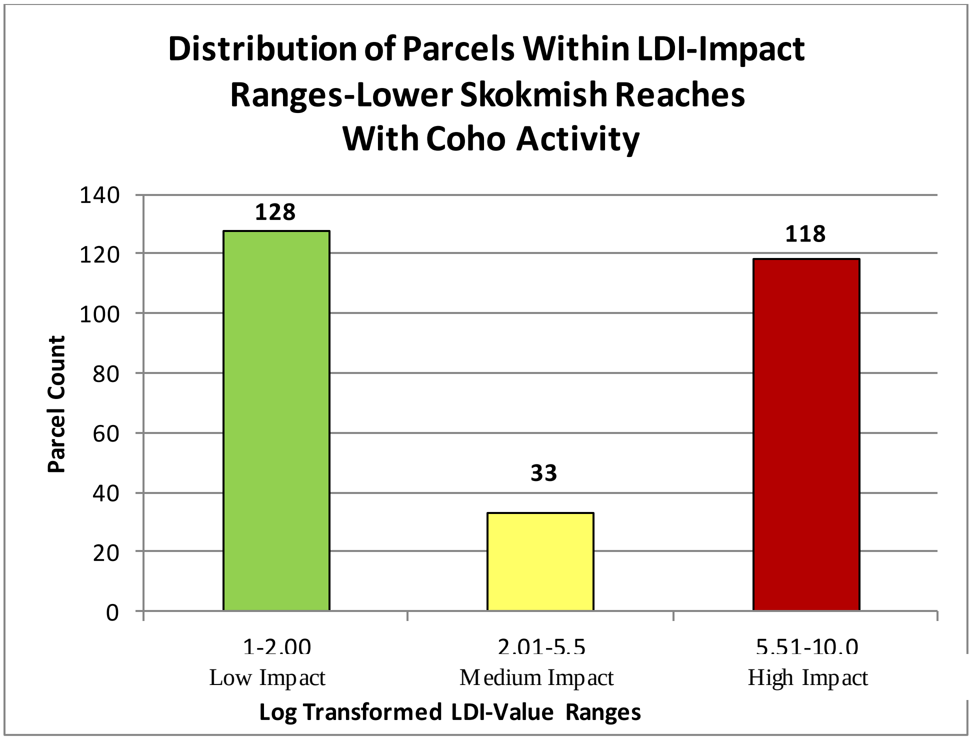


Figure 18. Total number of parcels exhibiting LDI value range by impact type-Lower Skokomish reaches with coho activity.

The parcel LDI-value data indicate that the lower Skokomish reaches with coho activity are characterized by a substantial number of parcels exhibiting low or high impact land-use disturbance. The number of parcels with high LDI-values is clearly influencing the mean LDI within this reach.

LDI-Value By Coho Activity Type-Lower Skokomish River

Figure 11 (presented earlier in the text) showed coho distribution sites as documented by the SalmonScape web interface. Using this spatial distribution data, it was possible to perform some final analyses on LDI impacts at smaller scales of stream reaches with coho activity. There were some limitations to how the LDI quantification methods could be applied at these reaches but a preliminary investigation is presented below. A section in the Discussion chapter will expound on these and other limitations and challenges in the study.

LDI at Coho Spawning and Rearing Reaches

Spawning Reaches

Spawning reaches were isolated (stream segments in red) and mean LDI values were calculated for each reach. Three reaches were identified and are characterized with the associated mean LDI-values in the map in Figure 19.

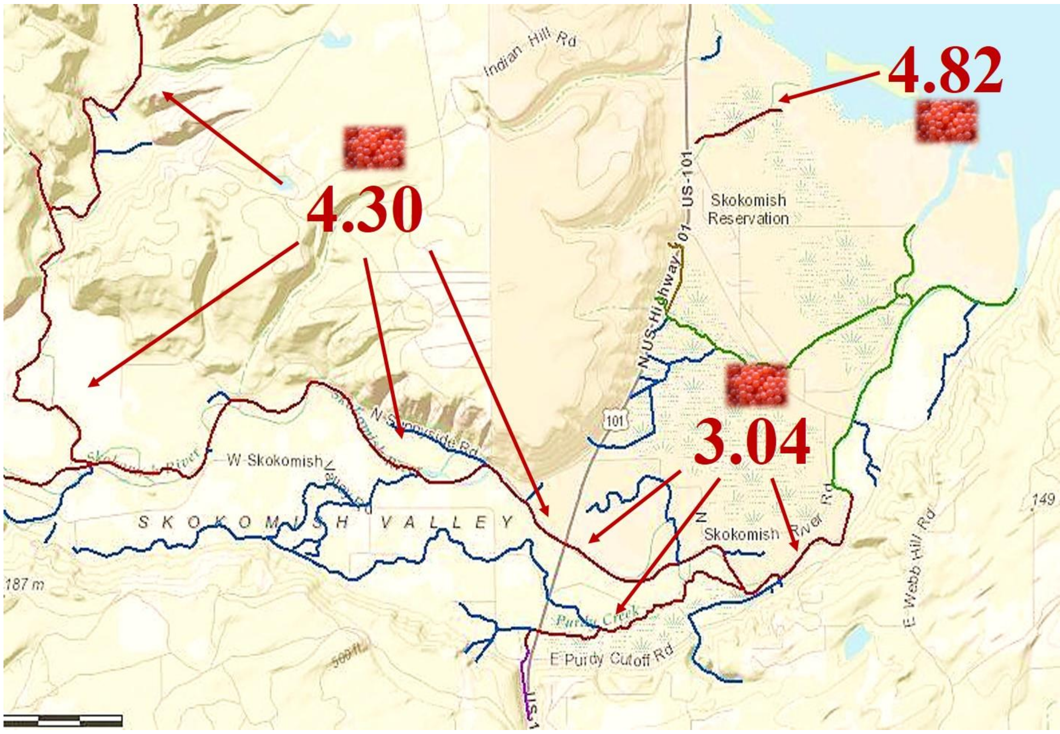


Figure 19. Three reaches of the Lower Skokomish watershed exhibiting coho Spawning Activity and associated mean LDI.

The site showing an LDI of 4.82 is a small drainage basin east of Highway 101 near the Skokomish Indian Reservation. The site showing an LDI of 3.04 encompasses the mainstem of the Skokomish River above the Highway 106 crossing and below the Highway 101 crossing as well as spawning reaches of the tributary Purdy Creek. The site showing an LDI of 4.30 comprised of the remaining drainage above Highway 101. The mean LDIs for each site and associated statistics were: ($n=3$, $m=4.82$, $SD=2.70$), ($n=11$, $m=3.04$, $SD=2.73$) and ($n=30$, $m=4.30$, $SD=2.97$). Based on these analyses, all spawning reaches in the study area would be classified as Medium impact. It should be noted that these reaches do not account for all coho spawning habitat within the Skokomish watershed but simply the area of the lower watershed chosen for this project and as represented by SalmonScape.

Rearing Reaches

A single rearing reach was isolated (Site A) due to the overlapping of LDI parcels (stream segment in green) and the mean LDI values was calculated and is shown in Figure 20.

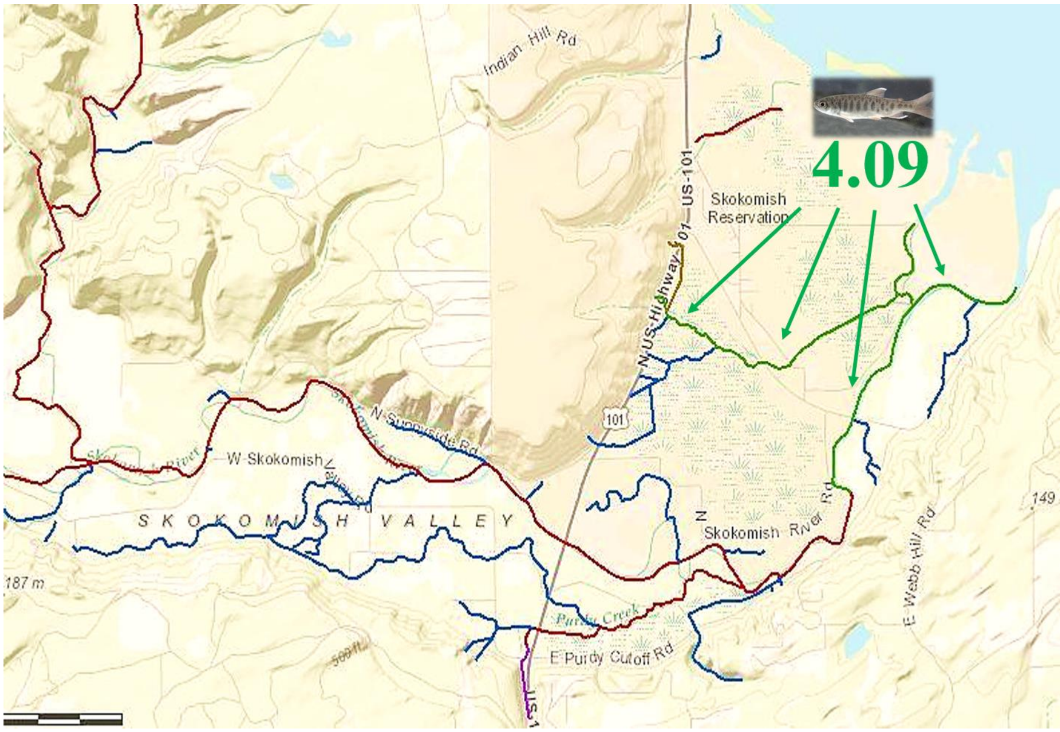


Figure 20. Single reach of the Lower Skokomish watershed exhibiting coho rearing activity and associated LDI.

The mean LDI for the rearing site was 4.09 (*n=14, m=4.09, SD=3.15*). Based on this value, the rearing site identified, like the spawning sites, would be classified as Medium Impact.

It should be noted that similarly to the spawning sites, this site does not account for all coho rearing sites within the Skokomish watershed but simply within the area of the lower watershed chosen for this project. Furthermore, spawning and rearing habitat often overlap. In the current configuration of the SalmonScape web interface, it was not possible to delineate areas of overlap for additional and more robust analysis. Further assessment of these limitations and potential options for addressing these issues is included in the Discussion chapter.

Summary of Analysis and Results

It was anticipated that a quantification of LDI within watersheds would be possible with the utilization of the required data and GIS software to conduct the calculations and analysis and this proved to be true. Collyard and Von Prause (2009) provided a basis for this quantification procedure and subsequent analysis which built upon the work of Brown and Vivas (2005). The current research was an attempt to refine the methods and apply them for the purpose of fisheries habitat assessments. In this regard, the current research appears to be successful in advancing spatial assessments of LDI for watersheds. As with most research, there are certainly areas which can be further refined and improved to yield more powerful and robust results. Chapter Five is an extensive discussion regarding the implications of the current research, challenges and limitations within the current methodology, and recommendations for further refinement of the techniques and avenues for future study implementing LDI analyses within watersheds.

Chapter Five: Discussion

The contents of Chapter Five are intended to provide additional context about the current research, address challenges and limitations encountered, and examine how this research “fits” within the current body of scholarship and may inform future study efforts. Challenges and limitations are discussed along with a framing of the current research and recommendations for future.

Limitations and Challenges Within the Current Study

The current study was limited by multiple constraints including data availability, accuracy, and precision. Additional concerns surrounded the adaptation of the methodology for examining watersheds in the Pacific Northwest. I, as the researcher, was also limited by time and budget constraints which are addressed here. Based on these limitations, the Skokomish River watershed was chosen for the focus of this research.

Determining Scope and Framework

A substantial challenge for researchers interested in examining issues surrounding salmonid fisheries in the Pacific Northwest is the task of determining what aspect is intended to be studied. The body of research on the issue is voluminous and navigating the literature can be difficult. Based on personal experiences, potential researchers must conduct ample “pre-research” to obtain what could be considered even a tenuous grasp on the situation. Beginning with the five “H’s” proposed by

Montgomery (2003), and reviewed in Chapter One should be requisite. Within any of the five “H’s,” there are ever-increasing magnitudes of focus. In the current research, “Habitat” become the focus. For myself, the process of arriving at this focus resulted from my experience in the MES program at Evergreen, two research internships with a local salmon enhancement organization, and finally a personal connection with the issue I intended to focus on.

Focusing on the Skokomish River

Even after determining that ‘habitat’ was the “H” I wanted to examine, what particular aspect of this factor to assess became an additional challenge. Personal experiences combined with graduate internship experiences sharpened my focus. Hood Canal became the initial focal point and several salmonid streams in the area garnered my attention. Initially, I intended to focus on the Dewatto and Tahuya Rivers based on personal interaction with these watersheds and their respective fisheries. However, as I was interested in habitat, and based on data availability and additional constraints, the Skokomish River watershed became the area of focus. I was intrigued by the diversity of land-use adjacent to the riparian zone within the Skokomish watershed (discussed in Chapter One) and personal interactions with the fishery on the Skokomish justified my decision to focus my study here.

Hood Canal Salmonid Recovery and Skokomish River Coho

Several Hood Canal salmonid species have garnered much attention based on their ESA listing status and various recovery efforts. I was involved in two of these efforts as an intern with the Pacific Northwest Salmon Center. Winter steelhead returning to Hood Canal streams, Hood Canal summer chum, and certain populations of chinook salmon returning to Hood Canal streams are considered to be distinct population segments (DPS) or evolutionarily significant units (ESU) and are currently listed as "threatened" under the Endangered Species Act (ESA) (NMFS, 2010). Based on these listings, study efforts and recovery plans under cooperative direction from several agencies have been undertaken. As such, population dynamics of these salmonid species may exhibit greater influence from the supplementation efforts and study protocol which dictate the manner in which these populations are managed.

The winter steelhead project, in which I participated in as an intern, is attempting to evaluate the potential impact of hatchery broodstock supplementation on wild populations as well as the effectiveness of such supplementation as a recovery measure (Hood Canal Winter Steelhead Supplementation HGMP, 2012). Summer chum are considered to be extinct in the Skokomish River but are present in the nearby Tahuya and Union Rivers and are the focus of additional study and recovery efforts.

Chinook salmon spawning in the Skokomish River are considered part of the ESU known as "Puget Sound Chinook" and are included in study and recovery efforts for this population. The Hood Canal Coordinating Council report (2005) characterizes these recovery efforts as "unique and potentially challenging scenarios" and posits "the status of chinook salmon stocks in Hood Canal is confounded by a long history of artificial introduction and production of stocks into Hood Canal systems, severely degraded habitat conditions, and an extremely complex hydroelectric relicensing process" (p. 10).

Based on the status of the species covered above, I chose to focus on Skokomish coho activity for the preliminary LDI analysis conducted in the current research. The rationale for selecting coho habitat for review was rooted in the idea that this particular stock may be under less influence from study and recovery efforts and could potentially provide a clearer assessment of LDI impact on salmonid habitat and fish activity. This is not to suggest that the current findings show any substantial LDI impact on fish behavior but rather present an opportunity for a future study with fewer confounding factors. If LDI impacts on salmonid activity and habitat can be established, the resulting methodology could potentially be used to assess populations of greater concern.

Data Availability, Accuracy/Precision, Integration, Processing and Interpretation

Quantifying land-use disturbance within watersheds using GIS-software is reliant on data availability and/or the opportunity to gather, synthesize, and assess new data. In the case of the current research, the utilization of existing data was imperative based on time and resource constraints. Multiple challenges and limitations were encountered in the process of utilizing data for the purposes of the current research and are examined here.

Available Land-Use Datasets

Determining land-use is a challenging task in itself and quantifying human-induced ecosystem disturbance imposed by land-use is reliant on the land-use classification schema employed by the reporting agencies. The GIS land-use dataset utilized for the current research was the “2010 Statewide Landuse” layer created by the Washington State Department of Ecology (DOE) (http://www.ecy.wa.gov/services/gis/data/planningCadastre/landuse.htm). The GIS layer dataset was derived from digital county tax parcel layers as specified by the Washington State Department of Revenue (DOR). The synthesis of data produced by two separate agencies to create this dataset is telling of the interdisciplinary nature of environmental study and the interconnectedness of ecosystems and human interaction. It is important to acknowledge the fact that land-use classifications were based on an economic framework (tax parcel purposes) and may not be the most accurate representation of land-use disturbance. DOE staff attempted to classify parcels that did not contain DOR coding and were randomly checked for accuracy. Additional effort was made during the current research to validate land-use classification data and was based on my best judgment. There were instances in which I felt it necessary to assign different LDI-coefficients to particular parcels based on orthographic photography or observational ground-truthing. Based on the potential to utilize data derived from the current study and future efforts, it is recommended that consultation with experts from multiple fields be conducted when assigning land-use classifications. DOE technicians echo this sentiment and the following disclaimer and recommendation is offered in the official description of the dataset:

…"The land use coding is only as good as each county was able to provide or as good as we were able to ascertain editing from orthophoto imagery overlay. We welcome and encourage edits, updates and corrections from the GIS user community"…(http://www.ecy.wa.gov/services/gis/data/planningCadastre/landuse.htm).

Additional temporal consideration may also increase the validity of the dataset. For example, a forester may be able to more accurately assign the LDI coefficient for a parcel classified as "Commercial Forest" or "Undeveloped Land" based on assessment of historical timber harvest practices. Furthermore, the inclusion of road data unaccounted for in the existing dataset may also bear additional scrutiny. Experts in erosion effects caused by road construction and subsequent sediment deposition in streams may also choose to reclassify parcels or recommend different LDI coefficients be applied to certain data points.

Methodological Concerns Regarding “Area of Influence”

Brown and Vivas (2005) created the methodology for assessing LDI within watersheds and their research in the state of Florida posited that a 100 meter buffer was sufficient to determine LDI effects. Brown and Vivas (2005) indicated no significant difference between applying a 100 meter or 200 meter buffer when quantifying land-use disturbance influence on watersheds. Given the differences in physical geography between watersheds in Florida and the Pacific Northwest, additional study to determine the appropriate area of influence in Pacific Northwest watersheds may be required. Considerations of slope-gradient and subsequent hydrological influence as contributing factors in land-use disturbance should not be overlooked. It should also be noted that land-use disturbance tends to decrease with elevation gain within the Skokomish River watershed as land adjacent to stream inputs is increasingly unsuitable for development and headwater areas exist within protected lands of Olympic National Park. However, timber extraction has occurred and continues to occur in upstream segments adjacent to streams in areas with slope gradients unsuitable for development but suitable for timber harvest practices. Based on these factors, a sliding scale of increasing riparian buffer for upstream segments at increased elevations when determining the area of influence in Pacific Northwest watersheds may be required.

Integrating LDI with Salmonid Studies

The current research was only capable of examining LDI relationships with salmonid habitat at a finite spatial scale and regarding only a single salmonid species. However, the methodology utilized in the current research may be adapted to conduct more focused research on individual salmonid stocks and salmonid stream habitat.

Utilizing Existing Datasets

During the current research, LDI quantification was conducted in relationship to coho salmon activity in the lower reaches of the Skokomish River. Coho activity data utilized consisted only of "documented" activity at particular stream reach sites and is not indicative of coho activity at the watershed-scale. Furthermore, the current salmonid habitat data utilized for analysis exhibited some deficiencies. The current SalmonScape web interface provides users with an efficient method for reviewing baseline data regarding salmonid activity. It is my opinion that a recent reconfiguration of SalmonScape has made the interface more "user-friendly" for interested citizens and non-experts but has done so at the expense of readily providing more extensive and potentially powerful data. For example, under the current configuration, users are only given the option to select for fish activity based on species. The resulting data displayed indicates documented activity of a particular species at specified spatial scales. There is no indication of overlap among documented activities thus, a particular stream reach may be characterized as exhibiting "documented spawning" and another stream reach characterized as exhibiting "documented rearing." In some cases these stream reaches are connected but only one type of activity per species is assigned to a particular reach making it difficult to determine the variety of manners in which salmonid species are utilizing particular stream habitat. The previous web-based incarnation of SalmonScape, while complicated to use, provided a more robust array of datasets and users could review individual stream reaches for species presence and activity, all which could be displayed separately. I suspect that these data could be obtained by contacting administrators for the SalmonScape site or the individual agencies which contributed the data comprising the dataset but doing so was beyond the scope of the current research given time constraints. Future researchers interested in conducting studies regarding LDI relationships with salmonid activity habitats would be encouraged to seek out more robust datasets to conduct analyses.

Potential for Comparative Studies

Collyard and Von Prause of the Washington Department Ecology indicated that a statewide database of LDI for all Water Resource Inventory Areas (WRIA's) could prove extremely useful for a multitude of studies (personal communication, Spring

2014). With the establishment of a uniform method for classification and reporting of LDI within watersheds, the influence of or relationship of LDI in regard to other ecological factors could be examined. A scenario in which this analysis might prove useful would be a comparative study of LDI, salmonid spawner abundance, and smolt abundance in several watersheds exhibiting varying levels of suitable spawning and rearing habitat availability and currently classified quality. Through such study, it may be possible to quantify the relationship or influence of particular land-use types of parcels adjacent to salmonid streams with fish activity and fish population dynamics or specific habitat characteristics such as water quality, turbidity, stream sediment composition, or forage availability.

Implications for Informing Policy Decisions

The simplicity of the manner in which LDI study results are reported could prove beneficial in informing policy decisions. Most individuals are able to grasp the concept of a “one to ten” scale as a measurement of influence or impact without the requirement of a depth of knowledge regarding the factors which comprise the impact. A simple understanding of land-use disturbance effects may aid in prioritizing fish recovery and management efforts in watersheds, selecting areas for habitat restoration, or in the approval process of development projects.

Chapter Six: Interdisciplinary Aspects and Conclusions

Researchers interested in studying environmental issues are faced with a challenging decision regarding the manner in which to undertake their examinations. Environmental concerns can frequently be approached from multiple disciplinary frameworks and research efforts should attempt to acknowledge the complexity of factors which may be influencing a particular issue. This is not to suggest that tightly focused studies within a specific discipline have diminished value nor to suggest that interdisciplinary efforts are superior. However, the value of interdisciplinary study should not be trivialized and framing a particular study in interdisciplinary terms may improve accessibility to study results and allow for new knowledge to be utilized across disciplines. The interdisciplinary aspects of the current research are presented in this chapter and are followed by a summation of the current research.

Interdisciplinary Nature of Salmonid Studies

Referring back to Montgomery's (2003) five "H's" offers an initiation point for considering salmon studies from a variety of disciplines and are indicative of the interdisciplinarity and transdisciplinarity of the of the issues. The five H's are comprised of: a) harvest, b) habitat degradation, c) hydroelectric power, d) hatchery issues, and e) history. In the particular case of the Skokomish River watershed, all five "H's" have influenced the fishery and offer potential study avenues.

The Intertwined Complexity of History, Habitat, Harvest, Hatcheries and Hydroelectric Issues in the Hood Canal Region

Tribal Communities, Economies, and Land Use

Eells (1887) described extensively the dominant cultural traits of indigenous populations that existed in the Hood Canal region. Additionally, in 1960, Elmendorf produced an extensive volume on the Twana culture which was updated in 1992. Both indicate that the original inhabitants of the Hood Canal region engaged in largely subsistence-foraging lifestyles, similar to other populations in the Northwest (Eels, 1887; Elmendorf, 1992). These populations were therefore engaged in minimal economic exchange with outside communities. Elemendorf (1992) cites an instance of a Hood Canal population "selling" a particular type of clam to a main-body Puget Sound population, whose members eventually would utilize it as a tradable good with inland communities east of the Cascades.

Hood Canal indigenous populations usually utilized two primary community establishment-types: the winter village consisting of plank houses at a single site and summer foraging camps, usually associated with fishing grounds (Elmendorf, 1992). Trees were harvested for plank house building and for the construction of canoes but no additional extensive timber excavation occurred (Eells, 1887; Elemendorf, 1992).

Surplus resources were occasionally gathered but were largely used for community feasting or potlatches involving gathering of multiple communities (Eells, 1887), rather than being harvested and distributed for economic gain. Thus, it could be concluded that these indigenous populations utilized natural resources beyond a deterministic existence and therefore began to shape the landscape in a manner beneficial to the subsistence and growth of populations. However, the rate of resource utilization was minimal compared to the rapid changes which would occur upon European settlement of the region.

Richard White (1980) produced an extensive history of what is currently called Island County, Washington State. As White indicated, the land-use patterns exhibited by indigenous populations on present-day Whidbey Island likely mirrored or at least paralleled those of other indigenous populations in the immediate Puget Sound region. White's assertions support a view of indigenous populations as the original shapers of the landscape in the Puget Sound region, though caution should be taken in generalizing too liberally from the populations on Island County to those of Hood Canal. What is clear, are the rapid alterations in human land-use patterns which occurred after European and Euro-American settlement.

Pope and Talbot Establish Puget Mill Company at Port Gamble

Andrew Jackson Pope and Frederic Talbot were sons of prominent logging families based out of East Machias, Maine. The two made their way to San Franscisco in

1849, and with a third partner, Captain J.P. Keller initiated a transport company. In March of 1850, William C. Talbot, brother of Frederic (who had returned East) arrived from Maine and joined in the business. The California Gold Rush was underway and the city of San Francisco required lumber for the construction of buildings. A.J. Pope and W.C. Talbot had heard from captains who had visited the Puget Sound area, of the vast stands of timber in close proximity to protected inland waters. Pope and Talbot resolved to build a steam-operated sawmill on Puget Sound.

In 1853, the W.C. Talbot and Co. launched their new venture, the Puget Mill Company at present-day Port Gamble. The demand for timber was high with the leading markets in San Francisco and the Far East, and the Puget Mill Company quickly flourished. In addition to the mill operations, the company was possession of a fleet of early shipping freighters. The company shipped not only timber milled at Port Gamble but at others throughout the Puget Sound region and eventually usurped the Usalaty mill on Camano Island and the mill located in Port Ludlow. Additional mills were located at Union and Seabeck and the utilization of timber from the Hood Canal area began in earnest and a striking reshaping of the land was underway. The Puget Mill Company had holdings of up to 170,000 acres at the height of the timber boom.

Effect of Expansion of Timber Harvest on Watersheds

Early logging practices were highly destructive and even wasteful, with clear-cutting the standard mode of practice. Excavation sites were located either near marine areas or within river basins to assist in transport. Marine areas and river basins were often the site of major timber excavation operations because water provided easy transport. Trees felled near marine areas could be deposited into the saltwater then gathered for transport to the mill. Flowing water also assisted in timber harvest further inland. Trees could be fallen and then floated downriver to the marine gathering site. Sedell and Luchessa (1981) indicated that trees had been cleared 2 miles inland along Western Puget Sound and Hood Canal shorelines and as many as 7 miles inland near streams and rivers.

Technological advancements allowed for increasing efficiency and expansion of timber harvest practices. The advent of the automobile and associated mechanized equipment meant the opening of the forests even further inland and at higher elevations. No longer were timber operations limited to close proximity to water. Road systems were developed to facilitate access of the equipment to new logging sites. By the mid-20th century timber excavation had had a tremendous impact on the ecosystems of the forests and the watersheds bore a major brunt of the impact. Roads were often built without culverts or with culverts unsuitable for migratory fish passage. The removal of streamside timber in the riparian zone caused water temperatures to rise during the warm summer months which was at times lethal for salmonids which require cooler water temperatures for survival. Mass excavation of trees also had a major impact on the soil systems as the root systems provide stability, especially on steep hillsides. The newly loosened soil could easily wash off hillsides during major precipitation events and cause a dramatic input of sediment into the river systems.

Analyzing Historical Timber Harvest-Economic Drivers and Lack of Ecosystem Understanding Drive Land Alteration and Degradation

It is easy to take an environmental deterministic view when examining the historical alterations of much of the Puget Sound region's landscape. An environmental deterministic view posits that the surrounding environment dictates the behavior of its human inhabitants. Following this view, one would believe that the harvest of timber was a product of necessity to adapt to the region. In doing so however, one would be remiss in failing to recognize that it was frequently the machinations of the economy that drove the alteration post-European settlement as well as the activities of the indigenous populations prior to that.

As Richard White indicated, "In the northern conifer forests generally, burning has for centuries shaped woodland ecology" and "changes such as these were not readily apparent to the casual observer. Unless the environment bore obvious marks of human handiwork, the first whites dismissed it as wilderness, natural and untouched" (White, 1980, p. 25). It is therefore not unreasonable to conclude that the first Europeans saw a vast, inexhaustible resource in timber. At the time of the initial boom, the philosophies of the likes of John Muir and Gifford Pinchot were still in their infancies and as Richard White states, “waste had little economic meaning” (p. 89). Shipped lumber however, *did* have tremendous economic meaning and wasteful practices continued as White again indicated “waste did have environmental consequences” (p. 89). The reconciliation of the economic gain versus the environmental consequences was decades away.

Furthermore, it is important to recognize that the early utilization of timber by Euro-Americans was undertaken as a means to benefit individuals far from the site of the excavation. San Francisco was a burgeoning city at this time and much of the lumber harvested from Washington State built that city 800 miles to the south. Additional markets existed in Asia, even further removed from the source of the raw materials.

Salmon Harvest in Western Washington and Hood Canal

American and indigenous tribal commercial fisheries have existed in the Puget Sound region for more than a century and provided economic gain for those engaged in the fisheries. Additionally, recreational fishing opportunities serve as an economic driver for the region. Estimates of the economic value of the combined salmon fisheries on Hood Canal ranged from $500,000 to $2.2 million between 1978 and 1988 (Washington Department of Fisheries archival data).

Estimated salmon catch values in 2006 were $3.77 million for the entire South Puget Sound region which includes Hood Canal (TCW Economics, 2008). Throughout Washington State in 2006, recreational angling fisheries for salmon contributed a $128.4 million in net economic gain.

Currently, the Skokomish Tribe operates fisheries on the Skokomish River for commercial, subsistence, and ceremonial purposes and are primarily centered around chinook and chum salmon. Recreational fisheries for both chinook and chum on the Skokomish are also popular among anglers. It is difficult to assess the historical and current impacts these fisheries have had on abundances, but the economic and intrinsic values of these fisheries for individuals utilizing them should be taken into consideration when studying the region.

Hatcheries

The George Adams hatchery is operated on the Skokomish River and contributes to supplementary efforts for restoring salmon and steelhead runs. The impact of hatcheries and the fish produced at these facilities has been the focus of large bodies of research and results show varying degrees of influence from these programs. Currently, the George Adams hatchery is operated under stipulations of the Hatchery Genetics Management Plans (HGMPS) for ESA-listed Puget Sound Chinook and Hood Canal Summer Chum. Multiple state, federal, tribal, and non-governmental organizations are involved with projects that originate from this hatchery facility and are representative of the various interest groups concerned with Hood Canal and Skokomish River fisheries.

Hydroelectric Power

Two hydroelectric dams exist in the Skokomish River watershed: Cushman Dam No. 1 and Cushman Dam No. 2. The dams were erected by Tacoma Power to provide additional electricity to the City of Tacoma. The dams exist in the mid to upper reaches of Skokomish watershed and were presumed to have blocked anadromous fish passage as well as disrupted spawning and rearing habitat for anadromous and non-anadromous fish. According to the Tacoma Public Utilities web page for the Cushman dams, “On Jan. 12, 2009, Tacoma Power, the Skokomish Tribal Nation and state and federal agencies signed a settlement agreement that resolved a $5.8 billion damages claim and long-standing disputes over the terms of a long-term license for Cushman Hydroelectric Project” (https://www.mytpu.org/tacomapower/about-tacoma-power/dams-power-sources/hydro-power/cushman-hydro-project/). Under the new licensure agreements, multiple measures were put in place to place responsibility on the utility provider to address and participate in fish restoration issues (Federal Energy Regulatory Commission, 2010).

Summary of Interdisciplinary Aspects of the Current Study and Conclusions

The interconnectivity of issues surrounding salmonid abundance in the Pacific Northwest is illustrated in brief by the review of the topics discussed in Chapter Six. When examining the Skokomish River, these connections may become apparent when delving into any particular aspect. For example, the current study attempted to quantify land-use disturbance effects within the riparian zone of the watershed. A primary motivation for this research was my desire as a researcher to understand how land-use may affect salmonid stream habitat. This motivation stemmed from my experience with a salmon enhancement group which was involved in a collaborative effort to study and potentially restore diminished stocks of particular salmonid species. Organizations involved in the collaborative efforts of the salmonid studies included federal, state, and tribal agencies, as well as independent non-governmental organizations. The greater motivations for the involvement of these organizations may include economic, biological, ecological, cultural, or climatological concerns among many others.

The data I utilized in the current study included land-use classifications based on a schema utilized for tax assessment purposes and collected by a governmental organization concerned with state revenue. The individual land-use classifications represent the various ways in which humans interact with and utilize landscapes. Reviewing the history of the region indicates the ways in which human populations have interacted with the land over time. Analyzing the geography of the region shows how existing landscapes may have driven the activities of individuals residing here and how previous and current activities continue to alter the landscape and ecosystems.

In summary, the current research assessing the quantification of land-use disturbances in the Skokomish watershed required an interdisciplinary approach in the development, application, and analysis phases of the project. Based on my experience during this research, and in conjunction with the education I received during my involvement with the Graduate Program on the Environment at The Evergreen State College, it is anticipated that research efforts guided by an interdisciplinary approach will become more common and yield increasingly robust results. It is hoped that results derived from such interdisciplinary research projects may aid in improving awareness of environmental issues, help to frame these issues in multiple contexts, and inform policy decisions regarding habitat and species conservation, the management of ecosystems, and developmental planning.

APPENDIX

Land-use	Land-use CD number (Ecology, 2010)	Nonrenewable empower density (E14 sej/ha/yr)	LDI coefficients
Natural system	91,92,93,94,95,96, 97,98,99	0	1.00
Natural open water	93	0	1.00
Pine plantation	88,95	5	1.58
Recreational / open space – low-intensity	71,72,73,74,75,77,78, 79	7	1.83
Woodland pasture (with livestock)	81,82,83	8	2.02
Improved pasture (without livestock)	81,82,83	17	2.77
Improved pasture – low-intensity (with livestock)	81,82,83	33	3.41
Orchard	81,82,83	44	3.68
Improved pasture – high-intensity (with livestock)	81,82,83	47	3.74
Row crops	81,82,83	107	4.54
Recreational / open space – high-intensity	72,73,74,75,77,78,79	1077	6.90
Single family residential – low-density	11,18,19	1230	6.92
Agriculture – high intensity	81,82,83	1349	7.00
Single family residential – medium density)	11,18,19	2175	7.47

Single family residential – high density	11,18,19	2372	7.55
Mobile home (medium density)	15	2748	7.70
Highway (2 lane)	42,45	3080	7.81
Low-intensity commercial	50,51,52,53,54,55,56,57,58,5960,6162,63,64,65,66,67,68,69	3758	8.00
Institutional	67,68,69	4042	8.07
Highway (4 lane)	42,45	5020	8.28
Mobile home (high density)	15	5087	8.29
Industrial	20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,82,85	5211	8.32
Multi-family residential (low rise)	12,13,14,15,16,17	7392	8.66
High-intensity commercial 12	50,51,52,53,54,55,56,57,58,5960,6162,63,64,65,66,67,68,69	661	9.18
Multi-family residential (high rise)	12,13,14,15,16,17	12825	9.19
Central business district (average 2 stories)	50,51,52,53,54,55,56,57,58,5960,6162,63,64,65,66,67,68,69	16150	9.42
Central business district (average 4 stories)	50,51,52,53,54,55,56,57,58,5960,6162,63,64,65,66,67,68,69	29401	10.00

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