Vulnerability to Invasion

The introduction of invasive aquatic species[1] is a major threat to the biodiversity of aquatic ecosystems (Sanderson et al. 2009; Johnson et al. 2008; US EPA NCEA and Britta Bierwagen 2008). Invasive species may compete with, prey upon, or introduce disease to native species. They also disturb aquatic ecosystem function in many ways, including by altering habitat, water chemistry, water quality, hydrology, and trophic dynamics (US EPA NCEA 2008; Pimentel et al. 2005; Hanson and Sytsma 2001; Meacham 2001). Juvenile Pacific salmon in the Columbia River encounter eight nonindigenous predator and competitor fish species in their downstream migration (Sanderson et al. 2009). Grass carp reduce native aquatic vegetation and common carp increase turbidity, thereby reducing water quality. Invasive mussel species decrease oxygen and food resources for native fauna, and in the northwest could dramatically change the food web, greatly affecting rearing salmon (Wells et al. 2010; Pimentel et al. 2005). Additionally, economic losses due to the environmental damages invasive species cause can reach up to $120 billion in the United States alone (Pimentel et al. 2005).

The impacts of aquatic invasive species may compound the effects of climate change on invaded ecosystems, and climate change may in turn exacerbate these impacts (US EPA NCEA 2008). The complex interactions of climate change, invasive species, and other environmental stressors will influence species introduction pathways, establishment, and ecosystem impacts in ways that are not yet fully understood (Rahel et al. 2008; Rahel and Olden 2008; US EPA NCEA 2008). Projected effects of climate change, including warmer water temperatures, altered streamflow patterns, salinization and increased demand for water, may favor the successful introduction of invasive species (Rahel and Olden 2008).

These impacts and complex interactions make an understanding of current and potential invasion essential for conservation planning efforts. To support this understanding, we modeled sub-basin susceptibility to invasion by aquatic non-native species, or invasibility (Davis et al. 2005). This approach avoids the inherent limitations of evaluating vulnerability from a species-by-species perspective, particularly given the inability to predict new invasive species yet to arrive to the region. Many methods of measuring invasibility have been suggested (Guo and Symstad 2008), and practical obstacles can make it difficult to measure at all (Davis et al. 2005). Invasion is highly idiosyncratic and generalities are difficult to make (Marchetti et al. 2004). In our review of the literature it became clear that little precedent had been set for a direct and practical approach to mapping landscape invasibility using widespread, readily-available data.

In light of these obstacles, we developed a practical approach in consultation with state, regional and national aquatic invasive species experts that is supported by literature documenting the introduction and management of specific invasive species. Our approach considers three measurable factors that contribute to the risk of non-native invasive species introduction at the sub-basin level: evidence of current invasion, the distance to common sources of species introduction, and water quality (Table 1).

[1] We refer to "invasive" aquatic species in this document as those whose introduction "causes or will likely cause harm to the economy, environment, or human health" (U.S. Environmental Protection Agency National Center for Environmental Assessment 2008, 1–3). The use of "non-native" indicates any species not native to the area in question, regardless of effect.

Table 1. Factors and data inputs of the invasibility analysis.

Factors	Data Inputs	
Evidence of current invasion	Sub-basin density of non-native species occurrences	
Distance to sources of introduction	Pathways	Roads
		Waterbodies
	Sources	Reservoirs and impoundments
		Recreational areas and boat access
		Hatcheries and fish propagation facilities
		Population density
Water quality	303d streams	
	Mines and mineral processing plants	
	Toxics Release Inventory Program sites	
	Superfund National Priorities List sites	
	National Pollutant Discharge Elimination System Majors	

Evidence of Current Invasion

Many studies have used non-native species richness as a measure of community invasibility (Guo and Symstad 2008). The reasoning is simply that the number of non-native species established in a geographic area indicates the potential for any non-native species to invade (recognizing this is a generalization replete with exceptions). We calculated sub-basin density of non-native species occurrences to measure the magnitude of current invasion. We used data provided by the federal Nonindigenous Aquatic Species (NAS) Database, which collects and distributes spatially-explicit occurrence locations from a variety of sources, including academic researchers and state agencies (USGS 2011)[2]. Though there are some limitations to this dataset, it is the most comprehensive and up-to-date resource available. To address some of these limitations, we solicited feedback from regional, state and local experts on the data distribution. Based on their responses, we removed a single 1975 occurrence of landlocked Atlantic salmon outside of Prineville (Capurso and Rife 2011) and added a known stocking location at Hosmer Lake, Oregon (Capurso and McIntosh 2011; Capurso and Rife 2011). We also removed occurrences of salmonid species native to the region. However, other than these opportunistic cases where corrections were suggested, we did not attempt to mine unpublished datasets to supplement the NAS data.

Distance to Sources of Introduction

Pathways

Aquatic invasive species may disperse naturally or be spread by anthropogenic means through hydrologically-connected stream networks or hauled overland along roads, including on boats, trailers

[2] For more information on all input datasets, please see the bibliography below, or the data dictionary available at http://aquatic-priorities.apps.ecotrust.org/docs.html.

and water-based construction equipment. (Sanderson et al. 2009; IISC Technical Committee 2007; Hanson and Sytsma 2001). We limited our analysis to roads and waterbodies (
Table 1), commonly-cited pathways of invasion, based on expert input and data availability. We used U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) system roads data (U.S. Department of Commerce 2010) and National Hydrography Dataset (NHD) waterbodies and streams (US EPA and USGS 2005) to identify these pathways spatially.

These pathway data were combined into a single, binary raster data layer with a 90-meter resolution identifying pathway presence and absence across the entire analysis area. No weighting was given to overlapping data; e.g., a road crossing a stream counts as only one pathway, not two.

Sources

Invasive species are introduced by three major processes: natural dispersal, accidental introductions by humans, and intentional introduction (Lim et al. 2011). Our approach largely considers accidental introduction, but indirectly measures both intentional introductions and natural dispersal. We selected common sources of introduction supported by spatial data and informed by expert opinion: reservoirs and impoundments, recreation areas and boat access points, hatcheries and fish propagation facilities, and population centers (the latter as a proxy for sources that tend to be correlated with population density, such as aquarium ownership) (Table 1).

Reservoirs and Impoundments

The altered hydrologic regimes created by reservoirs and other impoundments often support the introduction and establishment of non-native species (Havel et al. 2005). They facilitate the introduction of non-native species and increase the invasion risk of natural lakes by their proximity and hydrologic connection (Johnson et al. 2008). The replacement of spatially heterogeneous stream habitats with homogeneous standing water contributes to the displacement of unique, locally endemic communities by widespread, human-disturbance-tolerant species (Havel et al. 2005). Colonization by invasive species is enhanced by reservoirs' large size, public accessibility, hydrologic connectivity and high frequency of disturbance from hydropower and flood control management actions (Johnson et al. 2008; Havel et al. 2005). These characteristics help to make reservoirs popular for recreational use but also support the propagation of aquatic invasive species. The movement of boats between river systems is a key vector of anthropogenic introduction of species; the accessibility and size of reservoirs often result in intensive recreational use by boats traveling from a wide area (Lim et al. 2011; Rahel and Olden 2008; IISC Technical Committee 2007; Havel et al. 2005).

Comprehensive spatial data on reservoirs are difficult to obtain. National hydrography datasets identify only a small portion of reservoirs by designation or name. To identify reservoirs and impoundments, we used National Inventory of Dams (NID) data (U.S. Army Corps of Engineers 2006) from a State of the Salmon assessment of dams and reservoirs (2006). We also collected data on waterbodies using NHD waterbody datasets (US EPA and USGS 2005), Global Lakes and Wetlands Database (GLWD) (Lehner and Doell 2004a; Lehner and Doell 2004b) and U.S. National Atlas water features (ESRI 2006).

First, we selected waterbodies identified as reservoirs by designation or name in all three hydrography datasets. We also selected from the NHD large, known reservoirs on the Snake and Columbia River mainstems not identified as such in the data (Rock Island Pool; Lakes Herbert G. West, Pateros, Sacajawea, Umatilla, Wallula and Wanapum; Franklin D. Roosevelt, Rufus Woods, Banks and Priest

Rapids Lakes). Finally, we selected NHD waterbodies that intersected dam point locations to identify additional reservoirs; these were visually checked for accuracy. We combined these selections into a single dataset of polygonal reservoir and impoundment features. These were ranked based on data accuracy and quality (Table 2). They were then merged based on that ranking and each successive dataset's reservoirs were added only if they didn't intersect any of those previously added, or if they were identified as being a more accurate representation.

Table 2. Waterbody dataset ranking.

Rank	Dataset	Selection Type
1	NHD	designated, named, or otherwise identified as reservoir
2	Ecotrust Reservoir Assessment	
3	U.S. National Atlas data	
4	GLWD data	
5	NHD	intersected with dam point location
6	Ecotrust Reservoir Assessment	
7	U.S. National Atlas data	
8	GLWD data	

Recreational Areas and Boat Access

In addition to reservoirs, recreational areas such as fishing access areas can be a vector for aquatic invasive species (Lim et al. 2011; US EPA NCEA 2008). Aquatic plants and invertebrates are often transported by recreational boaters in carried water, including live wells, bilges, bait buckets, and engines, or attached to boats and anchors directly (Strecker et al. 2011; IISC Technical Committee 2007; Hanson and Sytsma 2001). *Hydrilla*, already present in our focal area, and quagga mussels, a looming threat, are two species commonly spread in this manner (Jacono et al. 2008; Johnson et al. 2008; Drake and Bossenbroek 2004c). Bait bucket releases by recreational fishers can introduce non-native species as well (Strecker et al. 2011). Non-native fish, including Atlantic salmon, have been, and in some cases continue to be, released into new habitats for stocking for recreation (Sanderson et al. 2009; Bisson 2006).

To account for recreation areas, we included a variety of data representing aquatic recreational areas and access points. Using the Protected Areas Database (CBI 2010), we selected protected areas identified or designated for public recreational use. Areas that contained “recreation” in their primary or secondary land management designation were included, as were areas primarily designated as city or county parks, or areas locally designated as boat launch, Fish & Game Access Areas, or reservoirs. From this collection of 528 protected areas, we removed those that were remote, specially protected, or otherwise unlikely to host a large number of recreation vessels. Areas removed included private protected areas, Wild & Scenic Rivers and Areas, Wildlife Refuges, Research Natural Areas and Wilderness Areas. The remaining selections were combined into a single dataset of polygonal recreational areas.

Spatial data on marinas, ports, moorages and other boat facilities data were collected from various state sources (IDPR 2006; Washington State ICOR 2004; ODPR 1989). As these data were often sparsely populated and outdated, we supplemented them with additional location records (Anon. 2012; MarineFuel.com 2012; RANG Ltd. 2012; Manta Media Inc. 2011; Marinas.com 2011; Port of Seattle

2011; Oregon Interactive Corporation 2011a, 2011b; Washington Ports Association 2006; Port of Port Angeles 2004). We included major ports in this category to address ballast water as a vector of aquatic invasives, which has been used to predict the spread of marine invasive species (Adams 2011; Aitkin et al. 2008; Herwig 2007; IISC Technical Committee 2007; Hanson and Sytsma 2001; Moyle and Light 1996). We collected these data into a single point dataset of boat access areas.

Hatcheries and Fish Propagation Facilities

Hatcheries and other fish propagation facilities can also act as vectors of aquatic invasion (IISC Technical Committee 2007). Escape from rearing pens and hatcheries are a long-term introduction risk, particularly with Atlantic salmon (Sanderson et al. 2009; Bisson 2006). Pests and disease may be inadvertently imported with fish to stock hatcheries, and dense concentrations of fish further support infestations of invasive parasites, including whirling disease (US EPA NCEA 2008; IISC Technical Committee 2007; Meacham 2001; Hanson and Sytsma 2001).

Again, due to limited and outdated information, we supplemented existing spatial data (StreamNet 2009; ODFW 2006b) with expert feedback and publicly available location records (IDFG 2011; ODFW 2011a; WDFW 2011; ISDA 2006; ODFW 2006a). These data were aggregated to a single point dataset, with duplicates removed.

Population Density

Many human actions result in accidental introductions of invasive organisms, including those listed above (Hanson and Sytsma 2001). It follows that anthropogenic introduction will occur closer to areas of human inhabitance, and urbanization has been linked to aquatic invasions (US EPA NCEA 2008; Havel et al. 2005). Sanderson et al. (2009) found some of the highest concentrations of non-indigenous species in the Pacific Northwest in areas with high human population density. In addition to the vectors mentioned above, the dumping of unwanted pets and science projects are common vectors of invasion that would presumably create higher propagule pressure around population centers (Strecker et al. 2011; IISC Technical Committee 2007; Hanson and Sytsma 2001). Water gardens, often stocked with non-native species, are also sources of introduction (Rahel and Olden 2008). To further account for these and other human-caused sources of invasion, we included population centers as a source input. Using a simplified adaptation of the U.S. Census Bureau classification of urban areas (2011), we identified regions with a population density greater than 1,000 people per square mile in a single 90-meter raster dataset for our analysis area (Hanser 2000).

Similar to the pathway data, all source inputs – reservoirs, recreation areas and access points, fish propagation facilities and densely populated areas -- were combined into a single, binary raster data layer with a 90-meter resolution identifying source presence and absence across the entire analysis area. No weighting was given to overlapping sources; e.g., a recreational area in an urban area counts as only one source, not two.

Calculating Distance to Sources of Introduction

We then used these two 90m raster datasets of sources and pathways to identify the distance from any point on the landscape to a source via the closest pathway. Figures 1 – 5 illustrate this process. Figure 1 shows an example source, in the upper right, and the surrounding streams, or pathways. We first calculated the distance along pathways to the nearest source (Figure 2). Then each raster cell in the entire focal area was assigned the distance value, calculated in the previous step, of the closest pathway cell (Figure 3). This process identifies the pathway point to which that point on the landscape is closest, and its distance to the closest source (see **Error! Reference source not found.** for an example analysis illustration). We also calculated the direct distance of the landscape to the pathways themselves (Figure 5).

For each point on the landscape, we then summed the value of its distance to a pathway, and the distance along that point on the pathway to a source (Figure 6). In this way, we created a measure of the distance of any point on the landscape along the closest pathway to the closest source. For example, the distance from a point on an undeveloped hillside to a downstream reservoir is the distance from that point directly to the nearest stream reach, and then along that stream's path to the reservoir. Finally, we averaged these values within each sub-basin to calculate sub-basin mean distance to invasion.

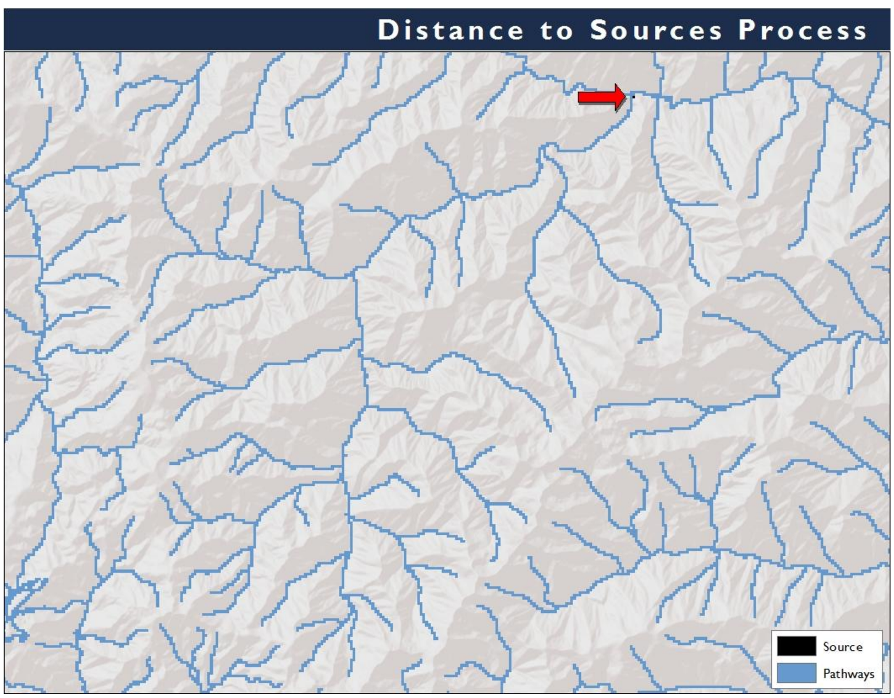

Figure 1. A source, identified with the red arrow, and surrounding pathways.

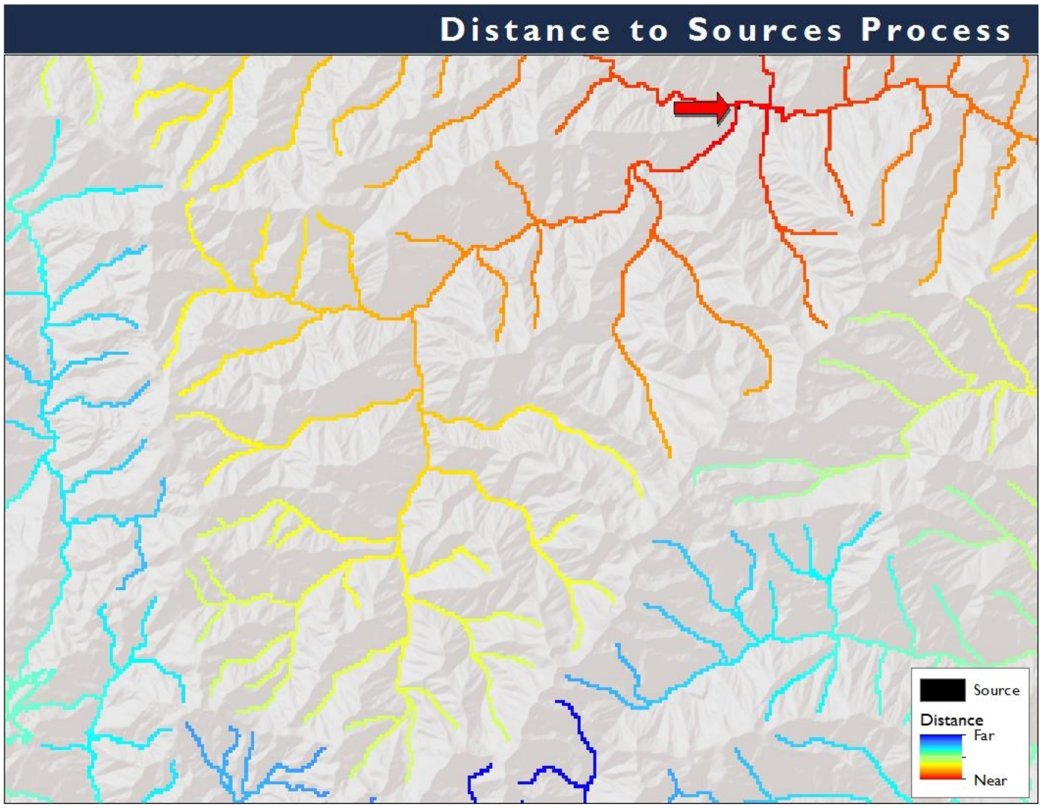

Figure 2. Distance to source along pathways.

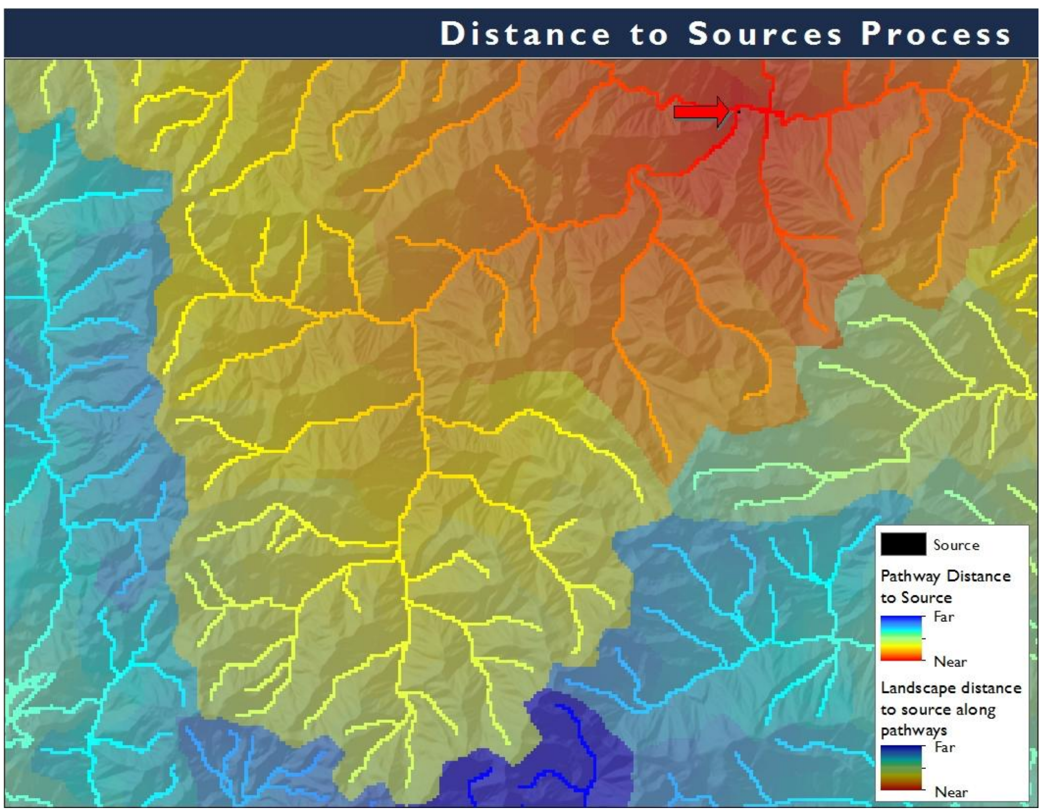

Figure 3. Distance to closest source along pathways and distance of the closest pathway cell to the closest source.

0	0	0	0	1
0	3	2	1	X
0	4	0	0	0
6	5	0	0	0
0	0	0	0	0

3	3	2	1	1
3	3	2	1	X
4	4	2	1	1
6	5	5	1	1
6	5	5	1	1

Figure 4. Example analysis for assigning the distance value of the closest pathway point to the landscape. These two figures represent two small raster datasets similar to those used in our analysis. The values in the figure on the left represent the cell distance along the colored pathway to the black source cell (distance is measured in north, south, east, or west directions only in this simplified example). Cells with values of 0 are not on the pathway. In the figure on the right, the distance values of the closest, lowest valued pathway have been assigned across the landscape.

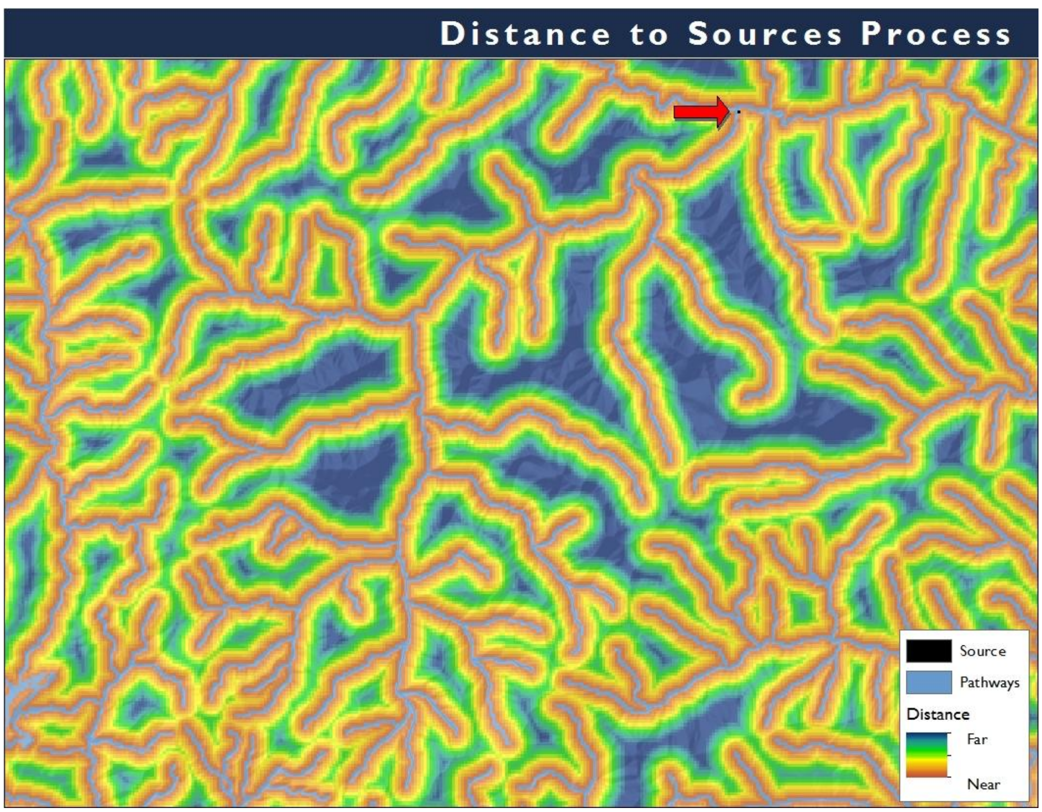

Figure 5. Distance to pathways.

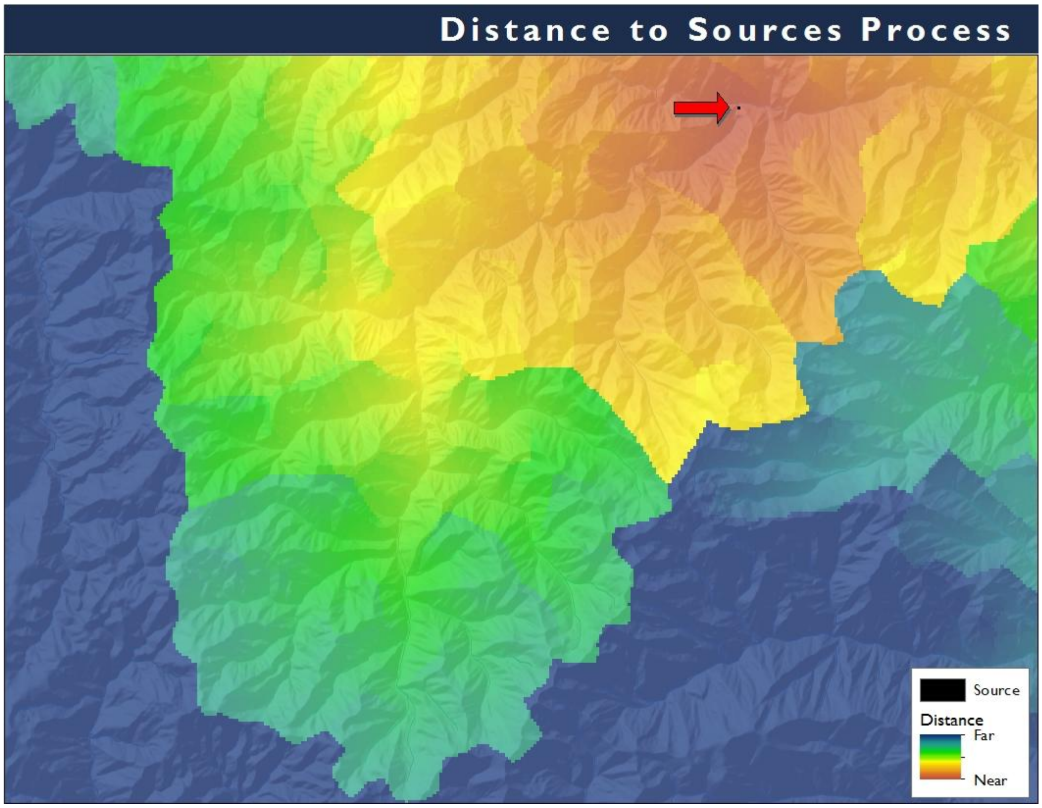

Figure 6. Distance to the nearest source via the nearest pathway.

Water Quality

We included water quality as a measure of human disturbance and an altered environment, which can support the successful establishment of non-native species (Marchetti et al. 2004; Moyle and Light 1996). Degraded habitats have been shown to be more susceptible to invasion than healthy ones, and some invasive species have a higher tolerance to degraded water quality than native species, including the round goby, a regional species of concern (US EPA NCEA 2008). We had initially considered using the watershed condition component of the tool, but limited this analysis to water quality to limit bias in the outputs of the final tool due to counting watershed condition twice, by itself and within the vulnerability to invasion component.

As indicators of degraded water quality we used sub-basin point-source pollution density and an area-weighted index of sub-basin 303(d)-listed stream density, compiled in the watershed condition component of this tool (for more information on how each measure was calculated, please see the watershed condition component document at http://aquatic-priorities.apps.ecotrust.org/docs.html). We then indexed these two measures into a relative ranking of sub-basin water quality.

Invasibility Index

We combined these unweighted inputs – evidence of current invasion, distance to sources of invasion, and water quality – into a single standardized index to create a comprehensive, relative ranking of sub-basins by their vulnerability to invasion by non-native species (Figure 7).

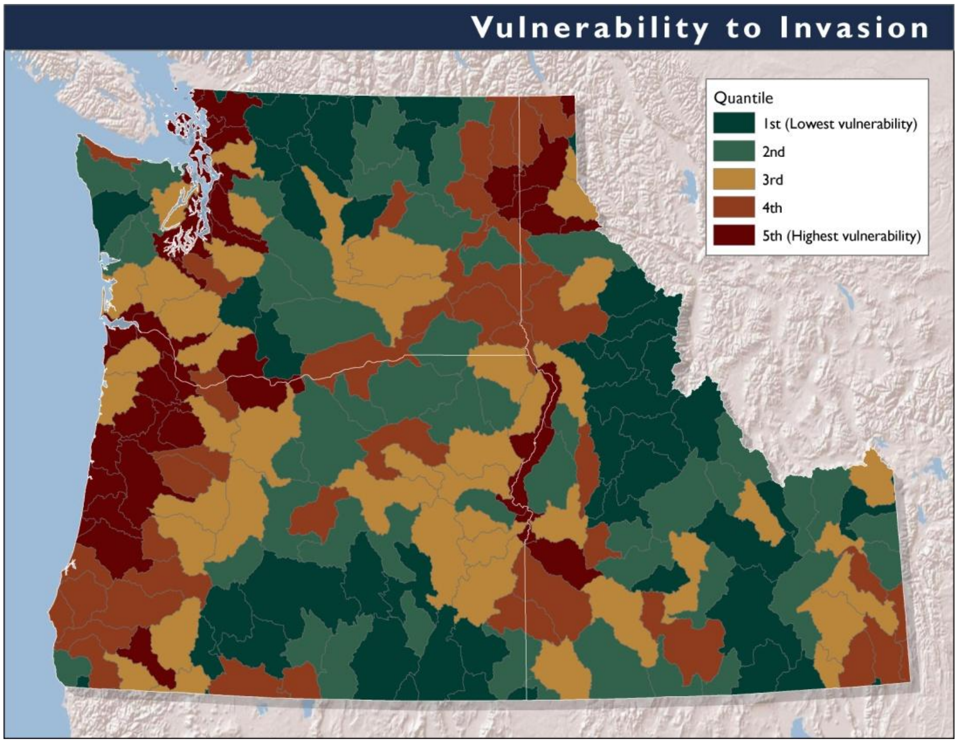

Figure 7. Sub-basin vulnerability to invasion.

Focal Invaders and Potential Invasion

We included supplementary spatial data for visualization in the tool in order to inform the user of additional threats of invasive species. Using expert input and state lists of priority aquatic invasive species, we selected 26 focal invaders for visualization (ODFW 2011b; OISC 2010; WISC, Washington State RCO 2009; IISC 2006). Sixteen of these are currently found in our analysis area, and we mapped these using NAS data (USGS 2011). They are listed in Table 3 and shown in the Focal Invader Documented Occurrences data layer in the tool (http://aquatic-priorities.apps.ecotrust.org/tool/). These 16 species represent plants and animals with demonstrated capacity to harm native Northwest species and/or their habitats. Beyond the general invasibility index, the presence of one or more of these focal invaders may be a significant factor in the success of a particular watershed restoration/conservation action (e.g., presence of brook trout in a stream under consideration for bull trout reintroduction). The remaining 10 species (Table 4) are identified as significant threats to the region, but have yet to invade in significant quantities. To assist users in understanding the future invasion risks of these species, we included available maps of modeled species-specific invasion risk. These included predicted suitable habitat for bighead and silver carp (Herborg et al. 2007a; 2007b; 2007c); potential range of zebra mussels (Drake and Bossenbroek 2004a; 2004b; 2004c); ecoregional *Dreissena* invasion risk classes (Whittier et al. 2008; US EPA 2003); and risk of *Dreissena* establishment and introduction (Wells et al. 2010; Wells unpublished). Modeled, spatial invasion risk was not available for the remaining species, but should be a priority for inclusion in future iterations of this tool.

Table 3. Selected aquatic invasive species threats currently in the Pacific Northwest.

Type	Common Name	Scientific Name
Fish	Smallmouth Bass	*Micropterus dolomieu*
	Carp, Common	*Cyprinus carpio*
	Trout, Brook	*Salvelinus fontinalis*
Herpetofauna	American Bullfrog	*Rana catesbeiana*
Invertebrates	Clam, Asian	*Corbicula fluminea*
	Crayfish, Red Swamp	*Procambarus clarkii*
	Crayfish, Rusty	*Orconectes rusticus*
	New Zealand Mudsnail	*Potamopyrgus antipodarum*
Mammals	Nutria	*Myocaster coypus*
Protazoa	Whirling disease	*Myxobolus cerebralis*
Plants	Brazilian elodea	*Egeria densa*
	Eurasian Watermilfoil	*Myriophyllum spicatum*
	knotweed (Himalayan, Japanese, Giant)	*Polygonum polystachyum, cuspidalum, sachalinense*
	purple loosestrife	*Lythrum salicaria*
	reed canarygrass	*Phalaris arundinacea*

Table 4. Selected aquatic invasive species threats not currently in the Pacific Northwest.

Type	Common Name	Scientific Name
Fish	Atlantic Salmon	*Salmo salar*
	Carp, Bighead	*Hypophthalmichthys nobilis*
	Carp, Silver	*Hypophthalmichthys molitrix*
	Goby, round	*Neogobius melanostomas*
	Northern Snakehead	*Channidae*
Invertebrates	Crab, Chinese Mitten	*Eriocheir sinensis*
	Mussel, Quagga	*Dreissena rostriformis bugensis*
	Mussel, Zebra	*Driessena polymorpha*
	waterflea	*Daphnia lumholtzi*
Plants	hydrilla	*Hydrilla verticillata*

Bibliography

Adams, Nancy. 2011. "Undergraduate Develops Method to Predict Spread of Marine Invasive Species - MIT News Office." *MITnews*, August 19. http://web.mit.edu/newsoffice/2011/marine-species-0819.html

Aitkin, J. Kevin, Sam Lohr, Paul Heimowitz, and Megan Hill. 2008. *Columbia River Basin Asian Carps Risk Evaluation*. U.S. Fish and Wildlife Service. http://www.asiancarp.org/documents/AsianCarp_PNWRiskEvaluation_022208.pdf

Anon. 2012. "List of Deep-water Ports." *Wikipedia, the Free Encyclopedia*. http://en.wikipedia.org/wiki/List_of_deep-water_ports

Bisson, Peter. 2006. *Assessment of the Risk of Invasion of National Forest Streams in the Pacific Northwest by Farmed Atlantic Salmon*. General Technical Report. Portland, OR: USDA Forest Service, Pacific Northwest Region. http://www.fs.fed.us/pnw/pubs/pnw_gtr697.pdf

Capurso, James, and Bruce McIntosh. 2011. "Fw: Distribution Map." Email. April 7.

Capurso, James, and Daniel Rife. 2011. "Fw: Atlantic Salmon Distribution." Email. April 7.

Conservation Biology Institute (CBI). 2010. *Protected Areas Database US 1.1 (CBI Edition) | Data Basin*. Vector digital data. Corvallis, OR: Conservation Biology Institute. http://databasin.org/protected-center/features/PAD-US-CBI

Davis, Mark A., Ken Thompson, and J. Philip Grime. 2005. "Invasibility: The Local Mechanism Driving Community Assembly and Species Diversity." *Ecography* 28 (5) (October): 696–704. doi:10.1111/j.2005.0906-7590.04205.x.

Drake, John M., and Jonathan M. Bossenbroek. 2004a. *Potential Range of Zebra Mussels, Model I*. Spatial ASCII data.

———. 2004b. *Potential Range of Zebra Mussels, Model III*. Spatial ASCII data.

———. 2004c. "The Potential Distribution of Zebra Mussels in the United States." *BioScience* 54 (10) (October): 931–941.

ESRI. 2006. *U.S. National Atlas Water Feature Areas*. Vector digital data. Redlands, CA: ESRI.

Guo, Qinfeng, and Amy Symstad. 2008. "A Two-Part Measure of Degree of Invasion for Cross-Community Comparisons." *Conservation Biology* 22 (3) (June): 666–672. doi:10.1111/j.1523-1739.2008.00915.x.

Hanser, Steve. 2000. *Population Density in the Western United States (Individuals / Ha)*. Raster digital data. Boise, ID: U.S. Geological Survey. http://sagemap.wr.usgs.gov/ftp/regional/usgs/popdens_hf.zip

Hanson, Erik, and Mark Sytsma. 2001. *Oregon Aquatic Nuisance Species Management Plan*. Portland, OR: Portland State University Center for Lakes and Reservoirs. http://www.clr.pdx.edu/publications/files/OR_ANS_Plan.pdf

Havel, John E., Carol Eunmi Lee, and M Jake Vander Zanden. 2005. "Do Reservoirs Facilitate Invasions into Landscapes?" *BioScience* 55 (6) (June): 518 – 525.

Herborg, Leif-Matthias, Nicholas E. Mandrak, Becky C. Cudmore, and Hugh J. MacIsaac. 2007a. "Comparative distribution and invasion risk of snakehead (*Cannidae*) and Asian carp (*Cyprinidae*) species in North America." *Canadian Journal of Fisheries and Aquatic Sciences* 64: 1723 – 1735.

———. 2007b. *Predicted Bighead Carp Habitat*. Spatial ASCII data.

———. 2007c. *Predicted Silver Carp Habitat*. Spatial ASCII data.

Herwig, Russell P. 2007. "Marine Ballast Water - Ocean Technologies - Marine Advisory Services - Washington Sea Grant." *Sea Grant Washington*. http://www.wsg.washington.edu/mas/oceantech/ballast.html

Idaho Department of Parks and Recreation (IDPR). 2006. *Boating Facilities of Idaho*. Vector digital data. Boise, ID: Idaho Department of Parks and Recreation. http://cloud.insideidaho.org/webApps/metadataViewer/default.aspx?path=G%3a\data\anonymous\idpr\boatFac_id_idpr.shp.xml

Idaho Fish and Game (IDFG). 2011. *Fish Hatcheries*. Text location data. Boise, ID: Idaho Fish and Game. http://fishandgame.idaho.gov/cms/fish/hatcheries/

Idaho Invasive Species Council (IISC). 2006. "Idaho Invasive Species List." *State of Idaho Agriculture*. http://www.agri.state.id.us/Categories/Environment/InvasiveSpeciesCouncil/InvSppList.php

Idaho Invasive Species Council (IISC) Technical Committee. 2007. *Idaho Aquatic Nuisance Species Plan*. The Idaho Invasive Species Council Technical Committee. http://www.anstaskforce.gov/State%20Plans/Idaho_ANS_Plan_2007.pdf

Idaho State Department of Agriculture (ISDA). 2006. *Commercial Fish Facilities Mailing List*. Text location data. Boise, ID: Idaho State Department of Agriculture. http://www.agri.idaho.gov/Categories/Animals/fishFarms/fishmailing.php

Jacono, C.C., M.M. Richerson, and V. Howard Morgan. 2008. "Hydrilla (*Hydrilla verticillata*) - FactSheet." *USGS Nonindigenous Aquatic Species Database*. http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=6

Johnson, Pieter TJ, Julian D Olden, and M Jake Vander Zanden. 2008. "Dam Invaders: Impoundments Facilitate Biological Invasions into Freshwaters." *Frontiers in Ecology and the Environment* 6 (7) (September): 357–363. doi:10.1890/070156.

Lehner, Bernhard, and Petra Doell. 2004a. *Global Lakes and Wetlands Database - Level 1 (large Lakes and Reservoirs)*. Vector digital data. Global Lakes and Wetlands Database. Germany: World Wildlife Fund.

http://app.databasin.org/app/pages/datasetPage.jsp?id=d618891c26494d40aa3068aba153dd63

———. 2004b. *Global Lakes and Wetlands Database - Level 2 (small Lakes and Reservoirs, Rivers)*. Vector digital data. Global Lakes and Wetlands Database. Germany: World Wildlife Fund. http://app.databasin.org/app/pages/datasetPage.jsp?id=03cc8ad8d6df453aa641f1730e2bcffc

Lim, Youngah, Munisamy Gopinath, Samuel Chan, and Michael Harte. 2011. “Predicting Potential Invasive Species Distribution: An Application to New Zealand Mudsnails in the Pacific Northwest.” At Agricultural & Applied Economic Association's 2011 AAEA & NAREA Joint Annual Meeting. Pittsburgh, Pennsylvania.

Manta Media Inc. 2011. “Marinas in Idaho.” *www.manta.com*. http://www.manta.com/mb_44_B51ED_13/marinas/idaho

Marchetti, Michael P., Theo Light, Peter B. Moyle, and Joshua H. Viers. 2004. “Fish Invasions in California Watersheds: Testing Hypotheses Using Landscape Patterns.” *Ecological Applications* 14 (5) (October): 1507–1525. doi:10.1890/03-5173.

Marinas.com. 2011. “Washington Marinas - WA Marinas Boat Slips Yacht Slips Washington United States.” *Marinas.com*. http://marinas.com/browse/marina/US/WA/

MarineFuel.com. 2012. “Port of Allyn Dock Marina in BELFAIR.” *Marinefuel.com*. http://marinefuel.com/e-marina/washington/belfair/port-of-allyn-dock/

Meacham, Pamala. 2001. *Washington State Aquatic Nuisance Species Management Plan*. Olympia, WA: Washington Department of Fish and Wildlife Fish Program.

Moyle, Peter B., and Theo Light. 1996. “Biological Invasions of Fresh Water: Empirical Rules and Assembly Theory.” *Biological Conservation* 78 (1-2): 149–161. doi:10.1016/0006-3207(96)00024-9.

Oregon Department of Fish and Wildlife (ODFW). 2006a. *ODFW Visitors Guide Wildlife Areas and Hatcheries*. Text location data. Salem, OR: Oregon Department of Fish and Wildlife. http://www.dfw.state.or.us/resources/visitors/wildlife_areas_hatcheries.asp

———. 2006b. *Hatchery Facilities of Oregon*. Vector digital data. Salem, OR: Oregon Department of Fish and Wildlife. http://nrimp.dfw.state.or.us/nrimp/default.aspx?pn=hatchdata

———. 2011a. *Private Hatchery Locations in Oregon*. Unpublished Excel spreadsheet. Salem, Oregon: Oregon Department of Fish and Wildlife.

———. 2011b. “ODFW Invasive Species - Oregon’s Ten Most Unwanted Invaders - Oregon Conservation Strategy.” *ODFW Invasive Species*. http://www.dfw.state.or.us/conservationstrategy/invasive_species/most_unwanted.asp

Oregon Department of Parks and Recreation (ODPR). 1989. *Inventory of Oregon Coastal Beach Access Sites*. Vector digital data. Salem, OR: Oregon Department of Parks and Recreation. http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml

Oregon Interactive Corporation. 2011a. “Marinas in Oregon.” *Oregon.com*. http://www.oregon.com/recreation/marinas

———. 2011b. “Ports of Oregon.” *Oregon.com*. http://www.oregon.com/recreation/ports

Oregon Invasive Species Council (OISC). 2010. “Oregon Invasive Species Council 100 Most Dangerous Invaders to Keep Out.” *Oregon Invasive Species Council*. http://www.oregon.gov/OISC/most_dangerous.shtml

Pimentel, David, Rodolfo Zuniga, and Doug Morrison. 2005. “Update on the Environmental and Economic Costs Associated with Alien-invasive Species in the United States.” *Ecological Economics* 52 (3) (February 15): 273–288. doi:10.1016/j.ecolecon.2004.10.002.

Port of Port Angeles. 2004. “Port of Port Angeles, Washington State.” *www.portofpa.com*. http://www.portofpa.com/

Port of Seattle. 2011. “Port of Seattle | Maritime Industrial Center.” *www.portseattle100.org*. http://www.portseattle100.org/properties/maritime-industrial-center

Rahel, Frank J., Britta Bierwagen, and Yoshinori Taniguchi. 2008. “Managing Aquatic Species of Conservation Concern in the Face of Climate Change and Invasive Species.” *Conservation Biology* 22 (3) (June): 551–561. doi:10.1111/j.1523-1739.2008.00953.x.

Rahel, Frank J., and Julian D. Olden. 2008. “Assessing the Effects of Climate Change on Aquatic Invasive Species.” *Conservation Biology* 22 (3) (June): 521–533. doi:10.1111/j.1523-1739.2008.00950.x.

RANG Ltd. 2012. “Marinas in Washington (WA) USA.” *PortFocus: Ports Harbours Marinas Worldwide*. http://portfocus.com/united_states_america/zz_marinas_in_wa/

Sanderson, Beth L., Katie A. Barnas, and Michelle Wargo Rub. 2009. “Nonindigenous Species of the Pacific Northwest: An Overlooked Risk to Endangered Salmon?” *BioScience* 59 (3) (March): 245–256. doi:10.1525/bio.2009.59.3.9.

State of the Salmon. 2006. *Assessment of Dams and Reservoirs, Unpublished*. Vector digital data. Portland, OR: Wild Salmon Center.

StreamNet Project, Pacific States Marine Fisheries Commission. 2009. *Hatchery Facilities (StreamNet, August 2009)*. Vector digital data. Portland, OR: StreamNet. ftp://ftp.streamnet.org/pub/streamnet/gisdata/map_data_physical/HatchFacilities_200908.htm

Strecker, Angela L., Philip M. Campbell, and Julian D. Olden. 2011. “The Aquarium Trade as an Invasion Pathway in the Pacific Northwest.” *Fisheries* 36 (2) (February): 74–85. doi:10.1577/03632415.2011.10389070.

U.S. Army Corps of Engineers. 2006. *National Inventory of Dams*. Vector digital data. Alexandria, VA: U.S. Army Corps of Engineers.

U.S. Census Bureau. 2011. “Census 2000 Urban and Rural Classification.” *US Census Bureau*. http://www.census.gov/geo/www/ua/ua_2k.html

U.S. Department of Commerce, U.S. Census Bureau, Geography Division. 2010. *TIGER/Line Shapefile All Roads County-based Shapefiles for Idaho, Oregon and Washington*. Vector digital data. Washington, DC: U.S. Department of Commerce, U.S. Census Bureau, Geography Division. http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html

U.S. Environmental Protection Agency (US EPA). 2003. *U.S. Ecoregions*. Vector digital data. U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (US EPA) National Center for Environmental Assessment (NCEA), Immediate Office. 2008. "Effects of Climate Change on Aquatic Invasive Species and Implications for Management and Research (External Review Draft)". DOCUMENT. *US Environmental Protection Agency*. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=180043

U.S. Environmental Protection Agency (US EPA) National Center for Environmental Assessment (NCEA), Immediate Office, and Britta Bierwagen. 2008. *Climate Change and Aquatic Invasive Species (Final Report)*. Final Report. Washington, D.C.: U.S. Environmental Protection Agency. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=188305#Download

U.S. Environmental Protection Agency (US EPA), and U.S. Geological Survey (USGS). 2005. *National Hydrography Dataset Plus - NHDPlus. Regions 16, 17, 18.* Multiple types of spatial digital data. Washington, DC: U.S. Environmental Protection Agency and U.S. Geological Survey. http://www.horizon-systems.com/nhdplus/data.php

U.S. Geological Survey (USGS). 2011. "Nonindigenous Aquatic Species Database." *USGS*. http://nas.er.usgs.gov.

Washington Department of Fish and Wildlife (WDFG). 2011. *Hatchery Facilities | Washington Department of Fish & Wildlife*. Text location data. Olympia, WA: Idaho Fish and Game. http://wdfw.wa.gov/hatcheries/facilities.php

Washington Invasive Species Council (WISC), Washington State Recreation and Conservation Office (RCO). 2009. "Invasive Species Top Priorities - Invasive Species Council." *Washington Invasive Species Council*. http://www.invasivespecies.wa.gov/priorities.shtml

Washington Ports Association. 2006. "Marinas." *www.washingtonports.org*. http://www.washingtonports.org/issues_areas/marina.asp

Washington State Interagency Committee for Outdoor Recreation (ICOR). 2004. *Motorized Boat Launches and Moorage Facilities of Washington State*. Vector digital data. Olympia, WA: Washington State Interagency Committee for Outdoor Recreation. http://www.rco.wa.gov/maps/boat.shtml

Wells, Steve. unpublished. *Risk of* Dreissena *Establishment and Introduction*. Text location data. Portland, OR: Portland State University Center for Lakes and Reservoirs.

Wells, Steve, Timothy Counihan, Amy Puls, Mark Sytsma, and Brian Adair. 2010. *Prioritizing Zebra and Quagga Mussel Monitoring in the Columbia River Basin*. Portland, OR: Portland State University Center for Lakes and Reservoirs.

Whittier, Thomas R, Paul L Ringold, Alan T Herlihy, and Suzanne M Pierson. 2008. “A Calcium-based Invasion Risk Assessment for Zebra and Quagga Mussels (*Dreissena* spp).” *Frontiers in Ecology and the Environment* 6 (4) (May): 180–184. doi:10.1890/070073.

Document last updated on May 11, 2012