EVALUATION OF BUFFER WIDTHS AND ECOLOGICAL FUNCTIONS: A REVIEW TO SUPPORT THE EDMONDS MARSH STUDY

Prepared for

Edmonds City Council
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Acronyms

City	City of Edmonds
FEMAT	Forest Ecosystem Management Assessment Team
LWD	large woody debris
Marsh	Edmonds Marsh
TSS	total suspended solids

1 Introduction

The Edmonds Marsh (Marsh) is a tidally influenced[1] wetland occupying approximately 23 ac in the heart of Edmonds, Washington (Figure 1); it is the remnant of a once much larger (40-ac) estuarine wetland along the shores of Puget Sound Sea-Run Consulting et al. (2007). The western portion of the Marsh supports saltmarsh plants; it is brackish in winter months, when the tide gate downstream of the Marsh typically is closed, and saline in spring and summer months, when the tide gate typically is open (Sea-Run Consulting et al. 2007). The eastern portion of the Marsh is a predominantly freshwater system fed by two tributary creeks—Willow Creek and Shellabarger Creek. The drainage basin of Willow Creek is approximately 393 ac in size, and encompasses residential land to the south and east of Edmonds Marsh (Shannon & Wilson 2015). The drainage basin of Shellabarger Creek is approximately 378 ac in size, and encompasses residential and commercial land to the north, east, and south of Edmonds Marsh. Edmonds Marsh provides valuable habitat to birds and other wildlife, in addition to conveying a large quantity of storm- and surface water.

This report is intended to help the City of Edmonds (City) better understand existing ecological conditions of the Marsh and its buffer areas. Specifically, the report presents findings of a literature review whose purpose was to identify the widths of buffer zones that allow them to provide the following ecological functions:

- Improving water quality (removing sediment, nutrients, and toxic substances)
- Protecting habitat and maintaining habitat connectivity
- Maintaining an appropriate microclimate for Marsh species
- Providing inputs of large woody debris (LWD) to support Marsh functioning
- Preventing disturbance by human activity

It also describes the ways in which wetland and riparian buffers are able to provide the five functions listed above. In combination with a site-specific evaluation of existing Marsh buffers (separate companion report), this information can help guide recommendations for habitat improvements within the buffer zones of Edmonds Marsh and the nearby Shellabarger Marsh.

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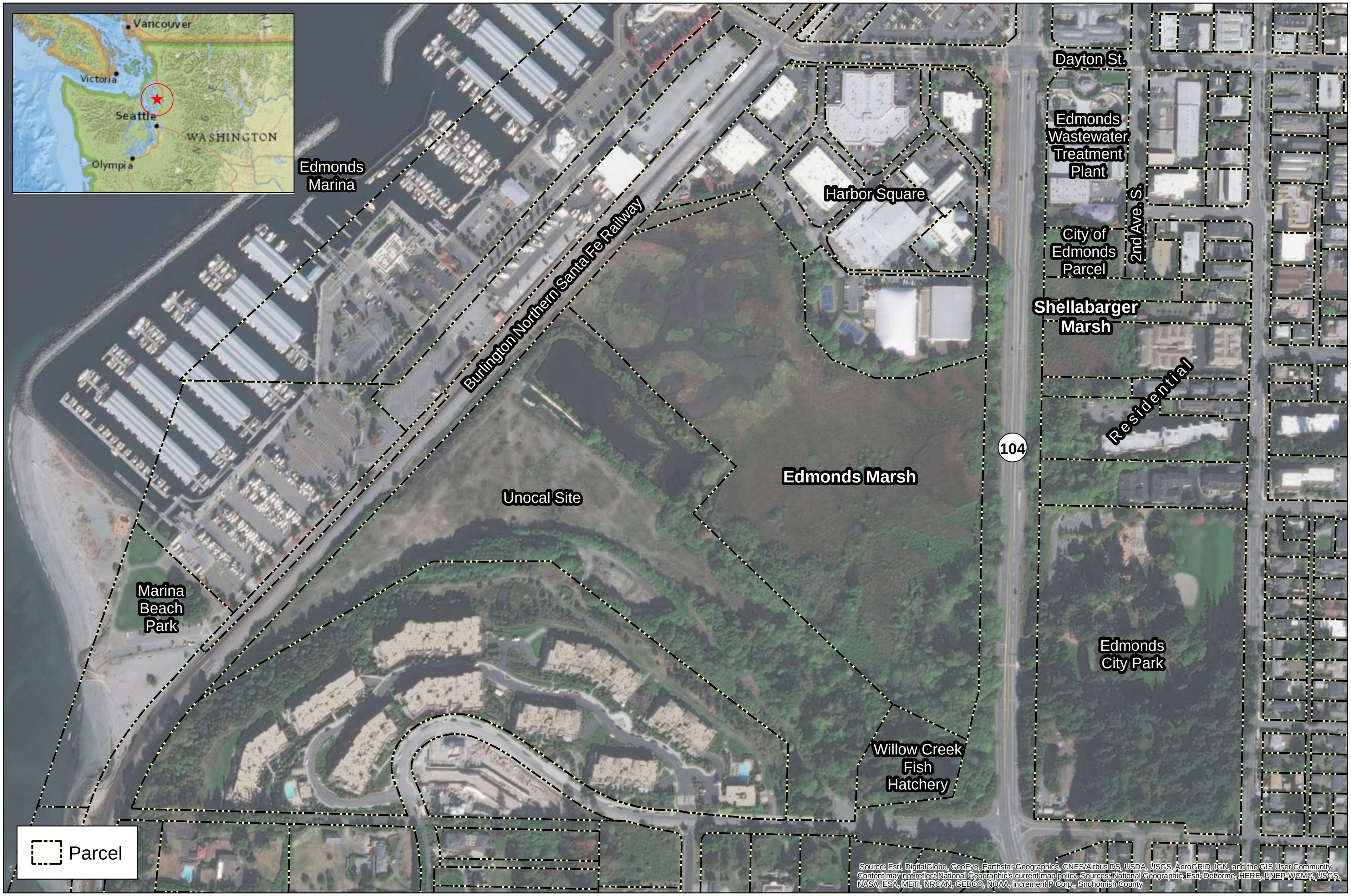
[1] The Marsh is tidally influenced when the tide gate downstream of the marsh is open, typically in spring and summer months from April through September (Sea-Run Consulting et al. 2007).



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Windward environmental LLC

Figure 1. Edmonds and Shellabarger Marsh Vicinity Map

Prepared by mikey, 6/1/2018; W:\Projects\Edmonds Marsh\Data\GIS\Maps and Analyses\Buffer_Zone_Evaluation\Fig 1_6862_Edmonds and Shellabarger Marsh Vicinity Map.mxd

The information in this report was gathered by reviewing scientific literature and guidance documents on wetland and riparian buffers,[2] with a priority on studies of the Pacific Northwest and western United States. Most of the relevant information was found in reports that compiled, thoroughly reviewed, and summarized a substantial subset of the available scientific literature and regulatory guidance. A few studies were included in more than one larger review.

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[2] Information on riparian buffers, buffers along streams and rivers, is considered to be applicable to Edmonds Marsh, particularly since Willow and Shellabarger creeks enter the Marsh within its buffer zones.

2 Ecological Functions Provided by Wetland Buffers

As described in the following subsections, wetland buffers can improve water quality, maintain microclimate conditions for plants and animals, provide inputs of LWD, offer wildlife habitat, and reduce the impact of anthropogenic activities. The functioning of a buffer zone varies with its size, shape, slope, soils, vegetation, and characteristics of its watershed (Sheldon et al. 2005). The multiple ecological functions that buffer zones provide are interrelated.

2.1 WATER QUALITY FUNCTIONS

Wetland buffers can improve water quality by removing sediment, nutrients, and toxic pollutants from surface water inputs (e.g., stormwater runoff), and by moderating water temperatures. In general, the most effective water quality benefits are realized when buffers are wide, gently sloping, and densely vegetated, primarily because these characteristics lengthen the time it takes surface water to flow from the outer edge of the buffer zone to the wetland (Castelle et al. 1992; McMillan 2000; Sheldon et al. 2005).

The shade provided by effective wetland buffers helps maintain cool and consistent water temperatures, fluctuations of which can cause fish eggs to die and invertebrate populations to decline, among other adverse effects (Brennan et al. 2009; Christensen 2000). Additionally, higher water temperatures can accelerate algae growth, increase concentrations of dissolved nutrients, and decrease the solubility of oxygen, in turn creating an oxygen-poor aquatic environment ((Johnson et al. 2000; Castelle et al. 1992; McMillan 2000; Karr and Schlosser 1977).

To protect general water quality and maintain natural water temperatures, a buffer width of approximately 50 to 100 ft was consistently recommended in the literature (Table 1). In one case, however (Brennan et al. 2009), a buffer width of 358 ft (109 m) was recommended. This width represents the average of buffer widths provided in multiple studies that achieved what the author considered “at least 80 percent effectiveness.”[3]

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[3] One of the studies included in Brennan et al. (2009) reported a width of 1,969 ft (600 m), which achieved 99% sediment and pollutant removal efficiency (and provided “excellent” wildlife value).

Table 1. Buffer width recommendations for general water quality protection and maintenance of natural water temperatures

Buffer Width for Level of Ecological Functioning		Notes	Reference
High	Low		
≥100 ft	buffers <50 ft wide not recommended for temperature moderation	A review of buffer effectiveness studies in Washington and other states, as well as a field study of buffers in King and Snohomish counties (Washington). Authors conclude that buffers ≥100 ft wide are generally needed to prevent adverse water quality impacts; review focuses on wetlands.	Castelle et al. (1992)
66–98 ft for moderation of water temperature	nr	A review of studies in Washington and other states focused on wetlands; however, the studies reviewed regarding the ability of buffers to moderate water temperatures were conducted on stream systems	Castelle et al. (1994)
≥49–98 ft (15–30 m) for maintaining general buffer functions, including water quality 98 ft (30 m) for shading and maintenance of natural water temperatures	<33 ft (10m)	A literature review examining effective width of stream buffers based on studies in western Washington and in other states and countries with temperate, humid climates. Authors note consistency of buffer width recommendations despite wide geographic range of study sites.	Johnson and Ryba (1992)
~26–148 ft (8–45 m)	nr	A review of studies throughout the United States.	Desbonnet et al. (1994)
≥49–98 ft (15–30 m) for general water quality improvement and maintaining natural water temperatures	< 49-98 ft (15-30 m) considered to be ineffective for water quality improvement	Master's thesis reviewing studies in Washington and other states; the studies reviewed regarding the ability of buffers to moderate water temperatures were conducted in stream systems.	McMillan (2000)
358 ft (109 m) for water quality benefits 79 ft (24 m) for shade	nr	A review of studies in Washington and other states with the goal of protecting and providing marine riparian functions along Puget Sound shorelines. Buffer widths in "High" column at left represent the average of all literature reviewed on widths that are ≥80% "effective" in removing sediment and other pollutants.	Brennan et al. (2009)
≥ 100 ft for effective shading and maintaining natural water temperatures	nr	A review of studies in Washington, Oregon, California, and elsewhere on riparian buffers for rivers and streams. Widths of 72–150 ft provided shade sufficient to maintain background water temperatures; however, a minimum width of 100 ft was recommended.	Christensen (2000)

Note: All buffer widths are shown in feet; metric equivalents are included only for data originally reported in metric units.

nr – not reported

2.1.1 Sediment removal

Variables that contribute to the sediment removal efficiency of wetland buffers and riparian areas include the width of the buffer area, the velocity of the surface water flowing through the buffer, vegetation type and density, presence of LWD, and the roughness of the ground surface within the buffer[4] (Sheldon et al. 2005; Desbonnet et al. 1994; Polyakov et al. 2005).

Buffers provide the highest water quality function when flow occurs as sheet flow and shallow groundwater (Castelle et al. 1992; McMillan 2000), regimes that require the buffer to resist channelization. In slowing flow rate and providing obstructions to trap particulate material, vegetation and LWD not only help resist channelization (Castelle et al. 1992; Sheldon et al. 2005) but they also allow the settling of sediment and its adsorbed pollutants. Some of the runoff moving slowly through the buffer as sheet flow can seep into the ground, where roots in the buffer zone provide further filtration.

As shown in Table 2, buffers 30 to 100 ft wide were most commonly reported as being able to remove the majority of sediment loads. The greatest benefit in sediment removal occurred at the outer edges of the buffer zone, with less incremental improvement as buffer width increases (McMillan 2000). Only slight increases in removal efficiency with increasing buffer width were reported for buffers wider than 82 ft (25 m) (Desbonnet et al. 1994). Larger buffer widths were required to increase removal when the slope was greater than 5%, to achieve higher removal rates (up to 95%), and when removing very small particles such as clays (McMillan 2000; Sheldon et al. 2005).

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[4] Roughness of the ground surface is the friction or resistance that the buffer surface provides against water flow; it is affected by the presence, amount, and characteristics of downed material; LWD; and vegetation.

Table 2. Buffer width recommendations for sediment removal

Buffer Width for Level of Ecological Functioning[a]			
High Quality	**Low Quality**	**Notes**	**Reference**
50–80 ft	nr	A review of buffer effectiveness studies in Washington and other states, and a field study of buffers in King and Snohomish counties (Washington); 80-ft buffer width removed 92% of sediment in one study cited in reference.	Castelle et al. (1992)
~16–49 ft (5–15 m) for grass buffer to remove all but fine sediment when slope is ≤ 5% ~82–98 ft (25–30 m) capable of sediment reduction by ≥ 7 5% ~197–328 ft (60–100 m) needed for 50% sediment reduction when slope is > 5%	nr	Master's thesis reviewing studies in Washington and other states.	McMillan (2000)
80–200 ft generally able to remove 75–95% of sediment load	nr	*Wetlands in Washington State* Vol. 1, including a literature review of wetland buffer functions. Range in "High" column at left based on five of the eight studies summarized in this reference.	Sheldon et al. (2005)
15–30 ft expected to remove "much of the sediment, depending on site conditions" 30–100 ft "will remove pollutants more consistently"	nr	A review of "several hundred scientific studies and analyses of buffer performance" in Washington and other states to help determine buffer width recommendations.	McElfish et al. (2008)
≥ 33–200 ft (10–61 m)	nr	A review of studies in Washington and other states.	Castelle et al. (1994)
≥ 82 ft (25 m) for ≥ 80% sediment removal[b] ≥ 197 ft (60 m) for ≥ 80% TSS removal	nr	A review of studies in Washington and other states with the goal of protecting and providing marine riparian functions along Puget Sound shorelines. Functional curves (FEMAT curves) plotting "the relationship between the effectiveness of a mature forest buffer at providing an ecosystem function at various buffer widths" were used to derive recommendations in "High" column at left.	Brennan et al. (2009)
100 ft	nr	A review of studies in Washington, Oregon, California, and elsewhere on riparian buffers for rivers and streams. In most studies reviewed, width of 100–300 ft effectively protected receiving waters from sediment inputs; however, a minimum width of 100 ft was recommended to remove the majority of sediment load.	Christensen (2000)

Buffer Width for Level of Ecological Functioning[a]		Notes	Reference
High Quality	Low Quality		
98–125 ft (30–38 m)	nr	A literature review examining effective width of stream buffers based on studies in western Washington and in other states and countries with temperate, humid climates. Authors note consistency of buffer width recommendations despite wide geographic range of study sites. Range in "High" column at left based on range for sediment removal most frequently recommended in the literature reviewed. The 125-ft recommendation was for a sediment removal efficiency of 75%.	Johnson and Ryba (1992)
~82 ft (25 m) expected to achieve 80% sediment reduction	nr	A review of studies throughout the US; buffer effectiveness (primarily grass) modeled by fitting curves to available data on buffer-induced water quality improvements. Studies on forested buffers showed high sediment removal values.	Desbonnet et al. (1994)
~33 ft (10 m) with 9% slope for vegetated buffers (primarily applicable to grass buffers)	nr	A review of studies from the East Coast, the Midwest, southern states, and some European countries examining sediment removal ability of riparian buffer zones, vegetated filter strips, and grassed waterways. Regression models developed from available data were used to recommend optimal buffer width for sediment removal. Primary reliance on studies of grassed buffers/waterways or vegetated filter strips.	Liu et al. (2008)
15-ft buffer reduced TSS by 66%	nr	Effectiveness of vegetated filter strips in agricultural settings on the East Coast.	Magette et al. (1989)

[a] All buffer widths are shown in feet; metric equivalents are included only for data originally reported in metric units.

[b] This buffer width recommendation originated from the study by Desbonnet et al. (1994).

FEMAT – Forest Ecosystem Management Assessment Team (U.S. Departments of Agriculture, Commerce, and Interior)

nr – not reported

TSS – total suspended solids (includes bacteria, algae, and other solids, not only suspended sediment)

Wider buffers are necessary when adjacent land is in high-intensity use or characterized by steep slopes (McElfish et al. 2008). Sediment removal efficiency decreases as buffer slope increases (McMillan 2000), as reflected in Table 2. As the buffer slope increases, water velocity increases and the length of time water spends in contact with the buffer decreases; therefore, the buffer has less opportunity to remove sediments. In addition, channels are more likely to form in buffer zones as water velocity increases. A buffer's ability to remove sediment decreases over time and with more runoff events because the buffer becomes saturated with removed sediments (Sheldon et al. 2005; Magette et al. 1989).

The vegetation and other structures (e.g., LWD) within buffer areas slow the flow of water and help to hold soil in place. By thus reducing the potential for soil erosion, minimizing the development of channelized flow paths, preventing entrainment of solids in runoff, and allowing for more water infiltration into subsurface soils, buffers help maintain bank integrity and provide "stability to streams" (Castelle et al. 1992; McMillan 2000; Christensen 2000).

2.1.2 Nutrient removal

Nutrients like nitrogen and phosphorus occur naturally in soluble (bioavailable) forms and insoluble (non-bioavailable) forms. During the process of eutrophication, excess bioavailable nutrients can cause rapid increases in plant growth (e.g., algae blooms), the eventual decomposition of which can decrease dissolved oxygen concentrations in aquatic systems. Insufficient dissolved oxygen, in turn, can cause plants and animals to die (McMillan 2000; Karr and Schlosser 1977).

Increased water temperatures can also contribute to eutrophication by causing insoluble nutrients bound to sediment to dissolve into the water column and become bioavailable (Karr and Schlosser 1977). In helping to shade streams and wetlands, vegetated buffers reduce solar heating of water and help control input of nutrients to aquatic systems.

Although many of the nutrient removal studies reviewed were conducted in agricultural areas or used grassy filter strips, Edmonds Marsh buffers would be expected to provide some of the same functionality. Overall, nutrients bound to sediments are removed more quickly (i.e., within a shorter buffer width) than dissolved nutrients, whose removal requires longer residence times (Sheldon et al. 2005). As with sediment removal, nutrient removal is enhanced when the buffer contains shallow slopes, is densely vegetated, and otherwise provides conditions in which water is in contact with fine roots in the surface layers of the soil.

As shown in Table 3, buffer widths of 100 ft or less provide at least partial nutrient removal. The variability in the recommended widths has been attributed to a number of factors, including differences in site-specific study setting (field vs. experimental plots), nutrient loading rate, and buffer zone soil and vegetation (Sheldon et al. 2005).

Table 3. Buffer width recommendations for nutrient removal

Buffer Width for Level of Ecological Functioning[a]			
High	**Low**	**Notes**	**Reference**
≥ 20 ft (6 m) for nitrogen removal ≥ 13 ft (4 m) for phosphorus removal[b]	nr	Master's thesis reviewing studies in Washington and other states.	McMillan (2000)
12.5–860 ft	75 ft (23 m)	A review of buffer effectiveness studies in Washington and other states, and a field study of buffers in King and Snohomish counties (Washington). In one study, a buffer 75 ft wide was inadequate for nutrient removal from residential development runoff. Range in "High" column at left represents the range of buffer widths recommended in studies cited in this reference.	Castelle et al. (1992)
15–66 ft (4.6–20 m) for 47–99% removal of nitrogen load 13–279 ft (4–85 m) for 50–90% removal of phosphorus load[b, c]	nr	*Wetlands in Washington State* Vol. 1, including a literature review of wetland buffer functions. The 279-ft value reported in "High" column at left is buffer width for 80% total phosphorus removal.	Sheldon et al. (2005)
100 ft	nr	A review of studies in Washington, Oregon, California, and elsewhere focused on riparian buffers for rivers and streams. Widths of 33–200 ft adequately removed nutrients; however, 100-ft minimum was recommended.	Christensen (2000)
13-141 ft (4-43 m)[b]	nr	A literature review examining effective width of stream buffers in western Washington and in other states and countries with temperate, humid climates. Authors note consistency of buffer width recommendations despite wide geographic range of study sites.	Johnson and Ryba (1992)
30 ft (9.2 m)	15 ft (4.6 m) did not reduce total nitrogen loads but; reduced total phosphorus load by 27%	Effectiveness of vegetated filter strips in agricultural settings on the East Coast.	Magette et al. (1989)

Buffer Width for Level of Ecological Functioning[a]			
High	**Low**	**Notes**	**Reference**
~197 ft (60 m) expected to remove 80% of nitrogen ~279 ft (85 m) expected to remove 80% of phosphorus	nr	A review of studies throughout the US. Buffer effectiveness modeled by fitting curves to available data on water quality improvements.	Desbonnet et al. (1994)
15–30 ft expected to remove “much” of the nutrient load, “depending on site conditions” 30–100 ft “will remove pollutants more consistently”	nr	A review of “several hundred scientific studies and analyses of buffer performance” in Washington and other states to help determine buffer width recommendations.	McElfish et al. (2008)

[a] All buffer widths are shown in feet; metric equivalents are included only for data originally reported in metric units.

[b] The minimum recommended buffer width of 13 ft provided in these 3 studies originated from a study by Doyle et al. (1977).

[c] The recommended buffer width of 279 ft provided in this study originated from the Desbonnet et al. (1994) study, which is also cited in this table.

nr – not reported

2.1.3 Toxic pollutant removal

Toxic pollutants include bacteria, metals, and pesticides (McMillan 2000). Buffers can help remove toxics from water via several processes, including through the removal of sediments (to which toxic pollutants like metals are often adhered), adsorption, chemical precipitation, photochemical oxidation, biodegradation, and plant uptake (McMillan 2000; Sheldon et al. 2005). Buffer width recommendations for removal of toxic pollutants are noted in Table 4. Specific width recommendations generally were found only for fecal coliform bacteria and other microorganisms, although one study from the southeastern US recommended buffer widths for the removal of pesticide residues.

Table 4. Buffer width recommendations for toxic pollutant removal

Buffer Width for Level of Ecological Functioning[a]			
High	**Low**	**Notes**	**Reference**
≥115 ft (35 m) to remove microorganisms sufficient for primary contact recreational use	< 115 ft (35m)	A review of studies in Washington state, in one of which Young et al. (1980) buffer width of ~115 ft was necessary to reduce total coliform levels to "acceptable levels."	McMillan (2000)
98-ft grass buffer reduces fecal coliform by 60%[b]	nr	A review of buffer effectiveness studies in Washington and other states, and a field study of buffers in King and Snohomish counties (Washington). Two studies examined fecal coliform removal in buffers. Value in "High" column at left is from one study cited in reference.	Castelle et al. (1992)
12.5–98+ ft for fecal coliform removal (98 ft reduced fecal coliform by 60%)[b] ~49 ft for pesticide residue removal	nr	*Wetlands in Washington State* Vol. 1, including a literature review of wetland buffer functions. Width range reported in "High" column as left is based on two of the three studies summarized; the third (Young et al. 1980) is included separately above. Width for pesticide residue removal is from a study in the southeastern US.	Sheldon et al. (2005)
~75–300 ft (23–92 m) to reduce fecal coliforms	< 33ft (10 m)	A literature review examining effective width of stream buffers based on studies in western Washington and in other states and countries with temperate, humid climates. Authors note consistency of buffer width recommendations despite wide geographic range of study sites. Range in "High" column at left is based on two studies.	Johnson and Ryba (1992)

[a] All buffer widths are shown in feet; metric equivalents are included only for data originally reported in metric units.

[b] The information provided in both of these studies indicating that a 98-ft grass buffer reduces fecal coliform by 60% originated from a study by Grismer (1981).

nr – not reported

2.2 MAINTAINING AN APPROPRIATE MICROCLIMATE

Microclimates can be defined as small areas created by vegetation and other habitat structures (e.g., large rocks or pieces of LWD) that help regulate the temperature of air, soil, and water; the moisture content of air, soil, and or sediment; and degree of exposure to wind. Buffers can produce valuable microclimates in a wetland environment. For example, buffer vegetation can reduce the extreme temperatures of peak summer and winter seasons, which benefits species whose tolerance for temperature or moisture fluctuation is narrow (Brennan et al. 2009). Air and soil temperature and humidity can also be moderated by the shading and wind-blocking functions of buffer vegetation and other habitat structures (Christensen 2000). These protections support semi-aquatic species by creating consistent, habitable temperatures as well as physical shelter (Christensen 2000). Specific buffer width recommendations found with respect to microclimate were related to providing shade and maintaining natural water temperatures. These recommendations are summarized in Table 1.

2.3 INPUTS OF LARGE WOODY DEBRIS

LWD is the term commonly used to describe large pieces of dead wood present in a natural area. Generally, LWD can include standing snags (as when a tree or portion of a tree dies but remains standing) and pieces that have fallen or otherwise remain on the ground (such as a large log laying on the ground, or a trunk remaining where a large tree was felled). LWD provides complex habitat features for invertebrates and wildlife, and can also serve as "nurse logs," providing habitat for native plants (Sheldon et al. 2005).

Insects and other invertebrates feed off the detritus produced by LWD, and many species live within or beneath pieces of LWD (Sheldon et al. 2005; Brennan et al. 2009). Avian species utilize both standing snags and fallen wood for roosting, nesting, and foraging (Sheldon et al. 2005; Bottorff 2009). LWD also provides refuge and denning habitat for many native mammal species (Bottorff 2009), and the species richness (diversity) of small mammals in wetlands of the Puget Sound region was found to be closely related to the quantity of LWD within the buffer areas (Sheldon et al. 2005). LWD provides important habitat structure and cover for fish, and in streams it contributes to the formation of pool habitat (Sheldon et al. 2005; Christensen 2000; Gurnell et al. 2002). LWD also provides organic matter inputs to streams and other water bodies (Christensen 2000).

In buffer zones, LWD helps to maintain water temperature, trap sediment, and control bank erosion (as discussed in Section 2.1) (Sheldon et al. 2005; Brennan et al. 2009). LWD is also able to moderate soil temperatures and moisture conditions (Brennan et al. 2009).

As shown in Table 5, a buffer width of 100 to 200 ft is typically recommended for provision of LWD to adjacent aquatic systems. Most of the research on this topic has been conducted on stream and river systems. Factors affecting the variability in the buffer width recommendations include the types of vegetation growing in the buffer, the heights of mature trees present, and the slope of the buffer zone (Brennan et al. 2009).

Table 5. Buffer width recommendations for providing large woody debris inputs

Buffer Width for Level of Ecological Functioning			
High	**Low**	**Notes**	**Reference**
56-125 ft (17-38 m) (based on literature review findings) ≥131 ft (40 m) (based on FEMAT curve model)	nr	A review of studies in Washington and other states with the goal of protecting and providing marine riparian functions along Puget Sound shorelines. Minimum buffer widths of 147-164 ft (45-50 m) are recommended in individual studies. Functional curves (FEMAT curves) plotting "the relationship between the effectiveness of mature forest buffers at providing an ecosystem function at various buffer widths" were used to derive recommendations in "High" column at left; values represent minimum width for ≥80% "effectiveness" at providing LWD.	Brennan et al. (2009)
100-180 ft (based on literature review findings) ≥150 ft (based on recommendations of Christensen (2000))	nr	A review of studies in Washington, Oregon, California, and elsewhere focused on riparian buffers for rivers and streams. Although widths of 100-180 ft provided 80-90% of the LWD in the stream and river systems studied, author recommended a minimum width of 150 ft.	Christensen (2000)
102 ft (31 m)	nr	A literature review examining effective width of stream buffers based on studies in western Washington and in other states and countries with temperate, humid climates. Authors note consistency of buffer width recommendations despite wide geographic range of study sites. Value in "High" column at left is for recruitment of woody debris in one study cited in the literature review.	Johnson and Ryba (1992)
105-250 ft	nr	Buffer widths for streams near logging areas in Washington. Instream LWD (and small woody debris) levels that approximate natural conditions require a buffer width of ~105-250 ft (equivalent to one "300 year site potential tree height" ($SPTH_{300}$), which, in western Washington, is approximately 105-250 ft).	Pollock and Kennard (1998)
33-200 ft	nr	A review of the best available science. Range in "High" column at left is based on multiple studies.	The Watershed Company (2007)

Note: All buffer widths are shown in feet; metric equivalents are included only for data originally reported in metric units.

FEMAT – Forest Ecosystem Management Assessment Team (U.S. Departments of Agriculture, Commerce and Interior)

LWD – large woody debris

nr – not reported

2.4 PROTECTING WILDLIFE HABITAT

There are many ways in which buffer zones protect the quality of their interior aquatic habitats (e.g., providing water quality improvements, shade, and LWD inputs, and reducing disturbance to wildlife from upland anthropogenic activities). In addition, wetland and riparian buffers themselves are important transitional habitat areas, providing important connections between aquatic wetland and upland terrestrial habitats (Semlitsch and Jensen 2001; McMillan 2000). The number of species tends to increase in such transitional, or edge, habitat as its inherent diversity can support both terrestrial and aquatic needs of semi-aquatic species.

Semi-aquatic species like frogs, turtles, many species of invertebrates, and even some mammals (like mink and otters) rely on both terrestrial and aquatic habitats. For example, multiple studies have shown that salamanders spent 86 to 99% of the year in upland habitats, after breeding in the wetland (Semlitsch and Jensen 2001). And while many frog species depend on a wetland environment for part of their life cycle, upland habitat is critical for feeing and nesting (Semlitsch and Bodie 2003). Mammals and birds also use wetland and riparian buffer habitats for foraging, access to water sources, nesting/denning, and rearing young (Castelle et al. 1992).

Urbanization creates isolated habitat patches and breaks connections between upland and wetland habitats. In an urban setting, wetland and riparian buffers provide protected travel corridors for invertebrates, amphibians, reptiles, mammals, and avian species as they move through a developed urban landscape (Castelle et al. 1992).

Vegetation quality and composition play an important role in the ability of a buffer to provide habitat and travel corridors. A grass buffer may filter pollutants from stormwater, but may not provide habitat structure or refuge for many species (Desbonnet et al. 1994). A diverse native plant population, vegetation within different layers (e.g., overstory tree canopy, sub-canopy shrubbery and young trees, and herbaceous groundcover), and LWD (both on the ground and as standing snags) all contribute to high-quality buffer habitat for many species native to the Pacific Northwest (McMillan 2000; Desbonnet et al. 1994; Sheldon et al. 2005). The species using a particular buffer is determined by site-specific vegetation and other conditions

As noted in Table 6, literature-based recommendations for buffer width to support habitat vary greatly. This variability is due to several factors, including the specific habitat needs and life histories of the species using the buffer habitat, the type of vegetation within the buffer, the presence of other habitat structures like LWD, and the land uses around the wetland and its buffer zone (McMillan 2000; McElfish et al. 2008).

Table 6. Buffer width recommendations for providing wildlife habitat

Specific Habitat-related Function	Buffer Width for Level of Ecological Functioning		Notes	Reference
	High	Low		
General wildlife habitat	100–328 ft (30 -100 m)	nr	Master's thesis reviewing studies performed in Washington and other states. Travel corridor value based on one study cited in the reference. Mammal habitat value provided in the "High" column at left is based on the furthest extent of mink home range, which was determined to be 590 ft (180 m), although mink spent most of their time in the forested areas within 328 ft (100 m) of the water. Amphibian habitat buffer widths are also recommended as "two to three tree heights".	McMillan (2000)
Bird habitat	328 ft (100 m)	50 ft (15 m)		
Amphibian habitat	328 ft (100 m)	100 ft (30 m)		
Mammal habitat	590 ft (180 m)	nr		
Travel corridor	490 ft (150 m)	nr		
General wildlife habitat	150–300 ft	75-150 ft	*Wetlands in Washington State* Vol. 1, including a literature review of wetland buffer functions. Review summarizes many studies presenting various ranges based on specific species and habitat functions.	Sheldon et al. (2005)
General wildlife habitat	300 ft	200 ft	Value in "High" column at left is from Appendix C ("Buffer Needs of Wetland Wildlife") to provide "important wildlife functions" for wetlands in a western Washington urban setting.	Castelle et al. (1992)
Bird habitat	200 ft	50 ft	In one study reviewed, increasing width corresponded to increasing bird species diversity at buffers widths greater than 50 ft.	
Small mammal habitat	305 ft (93 m)	220 ft (67 m)	A literature review examining effective width of stream buffers based on studies in western Washington and in other states and countries with temperate, humid climates.	Johnson and Ryba (1992)
Large mammal habitat	nr	330 ft (100 m)	Minimum buffer width based on a literature review.	
Bird habitat	655 ft (200 m)	250 ft (75 m)	Bird habitat ranges based on literature review; range can vary with breeding season.	
Salmonid habitat	nr	100 ft (30 m)	Minimum buffer width based on a literature review.	
Benthic habitat	≥100 ft (30 m)	nr	Value in "High" column at left necessary to support benthic communities similar to those in undisturbed stream habitats.	

Specific Habitat-related Function	Buffer Width for Level of Ecological Functioning		Notes	Reference
	High	Low		
Travel corridor	100 ft (30 m)	50 ft (15 m)	A review of studies throughout the US; buffer effectiveness modeled by fitting curves to available data on wildlife habitat. Buffers of 50 ft or, in certain circumstances even less, were reported to provide some habitat for temporary activities.	Desbonnet et al. (1994)
General wildlife habitat	650 ft (200 m)	50 ft (15 m)	Ranges determined by literature review.	
Bird habitat	650 ft (200 m)	50 ft (15 m)	Ranges determined by literature review.	
General wildlife habitat	> 660 ft	nr	A literature review, in which 660 ft “protected some wildlife habitat functions,” widths being highly dependent on species present.	Brennan et al. (2009)
Small mammal habitat	230 ft (70 m)	100 ft (30 m)	Literature review of stream- riparian buffers	May (2003)
Bird habitat	410 ft (125 m)	165 ft (50 m)		
Amphibian and reptile habitat	950 ft (290 m)	520 ft (159 m)	Literature review focused on determining core terrestrial habitat widths of wetland amphibians and reptiles from across the U.S. After habitat was determined an additional 50ft buffer was added to protect habitat from edge effects.	Semlitsch and Bodie (2003)
Turtle habitat	240 ft (73 m)	nr	Literature review focused on determining core terrestrial habitat widths of wetland salamanders and turtles from across the U.S. After habitat was determined an additional 50ft buffer was added to protect habitat from edge effects.	Semlitsch and Jensen (2001)
Salamander habitat	540 ft (164 m)	nr		

nr – not reported

The buffer width necessary to support different animal species depends on the species present, their respective life histories, and their sensitivity to disturbance. Specific habitat needs of various bird species (from Castelle et al. 1994; Castelle et al. 1992) known to be present in Edmonds Marsh provided below illustrate the difficulty of establishing a minimum buffer width that satisfies habitat needs of all species:

- Red-winged Blackbird (*Agelaius phoeniceus)* – For blackbirds nesting with a wetland, the only foraging sites assumed to be useful are those within 656 feet of the wetland.
- Lesser Scaup (*Aythya affinis*) – The nesting habitat of highest value for Lesser Scaup is assumed to occur within a 164-ft zone surrounding permanently flooded, intermittently exposed, and semi-permanent wooded wetlands with 30 to 75% canopy cover of herbaceous vegetation. Most Lesser Scaup can be found nesting within 33 ft of the water's edge.
- Gadwall *(Mareca strepera)* – Gadwalls typically nest in the tallest, densest, herbaceous or shrubby suitable vegetation available. In several studies of gadwall, the average distance from nest site to water was less than 150 ft.
- Great Blue Heron (*Ardea herodias*) – Great Blue Herons can generally tolerate human habitation and activities about 328 ft from a foraging area, although approaching humans have been noted to flush them at distances of 200 ft. They also generally tolerate occasional, slow moving vehicular traffic about 164 feet from a foraging area.

A general rule about the value of vegetated buffers to wildlife, however, is "bigger is better, and some is better than none" (Desbonnet et al. 1994).

2.5 PROTECTION FROM DISTURBANCE

Wetland buffers surrounding urbanized wetlands serve the important role of reducing the disturbance to wildlife caused by surrounding land uses and daily human activity. Human disturbances include noise and light pollution, startling/flushing wildlife, physical damage to vegetation and other habitat structures, dumping of refuse, and introduction of invasive species and pets that prey on native species (Castelle et al. 1992; Sheldon et al. 2005; McMillan 2000). Buffers create a physical barrier between human activity and interior wetland habitats.

The ability of a buffer to protect a wetland from intrusion increases with increased width, plant density, and slope, as people and domesticated animals are typically deterred from traversing large, densely vegetated, or steep areas. Buffers under 50 ft are easily degraded by human intrusion; in King and Snohomish counties, human impact (i.e., disturbance of nesting ground and foraging area, noise pollution, and the dumping of refuse) affected 95% of buffers narrower than 50 ft but only 35% of buffers wider than 50 ft (Appendix A ofCastelle et al. 1992). These impacts can reduce the overall buffer width over time as humans and domesticated animals continue encroaching on the buffer.

Noise in urban areas has been shown to create stress, cause hypertension, mask auditory signals, and disrupt wildlife sleeping, feeding and breeding (McMillan 2000; Sheldon et al. 2005). The degree of disruption varies, depending, for example, on sensitivity to certain frequencies and the experience of an individual animal (Sheldon et al. 2005).

As shown in Table 7, the buffer width recommended to protect wetlands from disturbance ranges from 20 ft to more than 300 ft. In one study, a 20-ft, well-vegetated evergreen buffer reduced noise by approximate 4–6 decibels (Castelle et al. 1992).[5] In another, a heavily forested buffer 100 ft wide was recommended to reduce commercial noise to background levels (Castelle et al. 1994).

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[5] While this difference would likely not be very noticeable to humans (a decibel level of 10 is described as being barely audible), "a loss of 3 to 4.5 decibels(A) corresponds to approximately tripling the distance between the source of noise and the receptor" (Castelle et al. 1992)

Table 7. Buffer width recommendations for protecting wetlands from disturbance

Specific Habitat-related Function	Buffer Width for Level of Ecological Functioning		Notes	Reference
	High	Low		
Protection from general human disturbance	150 ft	< 50 ft	General human disturbance includes trampling, dumping of debris, etc.; recommendations are based on a field study in King and Snohomish counties.	Castelle et al. (1992)
Protection of birds from general human disturbance	≥ 200–300 ft	nr	Minimum distance needed to prevent disturbance to (flushing of) Great Blue Heron and waterfowl, according to Appendix C of reference).	
Protection from noise pollution	nr	20 ft	Value at left based on one study cited in reference.	
Protection of birds from general human disturbance	46–164 ft (14–50 m) to screen birds from directly observing humans 328 ft (100 m) to prevent disturbance of nesting Great Blue Herons	nr	*Wetlands in Washington State* Vol. 1, including a literature review of wetland buffer functions.	Sheldon et al. (2005)
Protection from noise pollution	nr	105 ft	Width to reduce noise from commercial areas to background levels, per one study cited in reference. Buffer contained dense forest vegetation.	McMillan (2000)
Protection from general human disturbance	100–150 ft	≤ 50 ft	Study of wetlands in New Jersey, based on three classifications of buffer (salt, fresh, and hardwood); widths in columns at left are recommended for wetlands near industrial, commercial, and/or high-density residential land uses.	Shisler et al. (1987)

nr – not reported

Semlitsch and Bodie (2003) propose a three-zone buffer system:

- A primary terrestrial zone immediately adjacent to the aquatic wetland habitat that "is restricted from use and designed to buffer the core aquatic habitat and protect water resources"
- A secondary terrestrial zone (no access restrictions specified) encompassing the primary terrestrial zone and extending beyond it to include core terrestrial habitat for selected semi-aquatic species (e.g., amphibians or small mammals)
- A tertiary terrestrial zone (no access restrictions specified) beyond the secondary zone intended to buffer the first two zones from surrounding land use activities.

3 Conclusions

The minimum buffer width recommended in the literature varies with the ecological function of primary concern. For a relatively high level of water quality improvement (e.g., shade to maintain natural water temperature, removal of sediment, at least partial removal of nutrients), the literature generally supports a buffer width of 100 ft. For delivery of LWD to adjacent aquatic systems, a buffer width of 100 to 200 ft is typically recommended.

Buffer width recommendations to support habitat and minimize disturbance vary greatly, depending upon the habitat needs and life histories of the species using the buffer and wetland habitat, the type of vegetation within the buffer, the presence of other habitat structures like LWD, land uses around the wetland and its buffer zone, and other factors. When determining appropriate buffer widths for the provision of suitable habitat and prevention of disturbance, it is generally recommended that primary consideration be given to species known to use a specific buffer area or are otherwise of concern at that location.

Perhaps one of the most useful buffer width recommendation identified in this review was the following: "with regard to value of vegetated buffers to wildlife, bigger is better and some is better than none" (Desbonnet et al. 1994). In many developed urban areas, wetland buffers wide enough for full ecosystem function are unlikely to remain in place, or even to be available for restoration. However, smaller buffers still provide ecological value, and opportunities are usually available to enhance their quality, if not quantity. The site-specific evaluation of existing Marsh buffers (separate companion report) deals further with this topic.

In addition to the ecological functions discussed in this review, buffers surrounding aquatic systems provide protection against predicted sea level rise, because undeveloped shoreline/buffer zones can accept some inundation increases before infrastructure is affected and must be relocated. Furthermore, prior to the actual occurrence of any predicted sea level rise, "soft shore protection" (e.g., placement of log cribs or other types of LWD, gravel, or additional sand along beaches; installation of native vegetation tolerant of wet site conditions) (Gianou 2014) can be installed within buffer zones (and have the opportunity to reach maturity), making the shoreline more resilient to wave energy and erosion.

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