WETLAND RATIOS, SOIL TYPES AND GEOLOGIC HISTORY

AT OREGON SPOTTED FROG

WETLANDS IN THURSTON COUNTY

by

Bonnie J. Blessing

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by

Bonnie J. Blessing

has been approved for

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Member of the Faculty

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ABSTRACT

Wetlands, Soils and Geologic History at Oregon Spotted Frog Wetlands in Thurston County, Washington

Bonnie Blessing

Conservation of rare species is contingent on understanding their habitat and potential distribution. Wetland vegetation, soils and geology underpin the distribution of most flora and fauna. First, I used a species distribution model called MaxEnt to identify potential suitable habitat on 4 USGS 7.5' quadrangles. From environmental conditions occurring at egg deposition sites on one quadrangle, MaxEnt calculated the importance of the 3 environmental variables to species suitable habitat using jacknife statistics. MaxEnt results suggest that soils and geology layers contributed more than the wetland layer to suitability of habitat. Because the OSF is a highly aquatic species, wetlands should contribute highly to their distribution. The unexpected MaxEnt outcome may be due to a small sample size, the existence of wetlands on only a portion of the assessed area, or to the presence of eggs on wetland margins or flooded fields that may not have been identified as wetlands on the NWI wetlands coverage I used. To reduce this potential error, the NWI coverage was discarded and I digitized areas within approximately 200 meters of egg mass deposition sites at the occupied wetlands, focusing on habitat in and near oviposition sites. I then used various GIS tools to calculate the average number of egg masses per cluster on different soils, the ratios of wetland vegetation, soil types used for oviposition vs. availability. Results were tested with the Chi-squared statistic. Also the number of records per geologic type was calculated. In breeding wetlands, habitat averaged 56% emergent or flooded, 37% shrub, and 7% aquatic cover. Since detection in the early 1990s, 15 soils were used for oviposition but only 9 were used in 2013. The number of egg masses within each soil type was not proportional to the extent of the soil type; A significant difference between proportion of specific soils and proportion of eggs occurred in 4 wetlands. Most OSF wetlands in Thurston County occur in Holocene alluvium, with fewer egg masses in Holocene peat, Vashon recessional outwash from Tanwax-Ohop glacial flood and Vashon outwash. While surveying portions of 17 wetlands, I found no previously unknown OSF populations. However, while asking permission of landowners, I discovered landowner values such as aesthetics, privacy, valuing agriculture, way of life and nature, all of which influence property management.

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INTRODUCTION

Conservation of a rare species depends on understanding its distribution and habitat associations in local areas. The distribution of any species is underpinned by vegetation, soils, geology and climatic history (Baselga 2012). Wildlife species with a discontinuous distribution may be difficult to find. Unearthing vegetation, soils and geology underlying the distribution of a rare species may generate a greater understanding of their habitat associations and potential occurrences. One local rare species, the Oregon spotted frog (OSF), *Rana pretiosa*, is proposed for Federal listing under the Endangered Species Act (1973) (USFWS 2013). Habitat characteristics contributing to its persistence in wetlands should be ascertained, especially as new locales are found. This project focuses on characterizing wetland vegetation, soils and geology underlying egg deposition sites used by OSF in Thurston County, Washington.

1. LITERATURE REVIEW

Section 1.1 focuses on factors of decline in OSF. Section 1.2 discusses how wetland character, soils, and geologic history influence amphibian species and the OSF in particular. Section 1.3 reviews recent survey efforts, and other models to identify habitat are reviewed in Section 1.4. Section 1.5 presents justification for this research.

OREGON SPOTTED FROG: STATUS, BIOLOGY AND FACTORS OF DECLINE

The OSF, a denizen of wetlands in the Pacific Northwest, is a medium size frog with highly webbed feet and upward pointing eyes. Historically, OSF laid eggs in wetlands from British Columbia and Puget Trough south through the Willamette valley, extending into the Cascades in Oregon and Northern California (McAllister and Leonard 1997). Eggs are laid in shallow water in large clusters during early spring (Licht 1971). After metamorphosis, juveniles and adults remain aquatic (Watson 2003). Current OSF extent is considered much reduced, and former populations from over 70% of its former range are now thought extinct (Cushman and Pearl 2007). Their current distribution includes Thurston County (Figure 1).

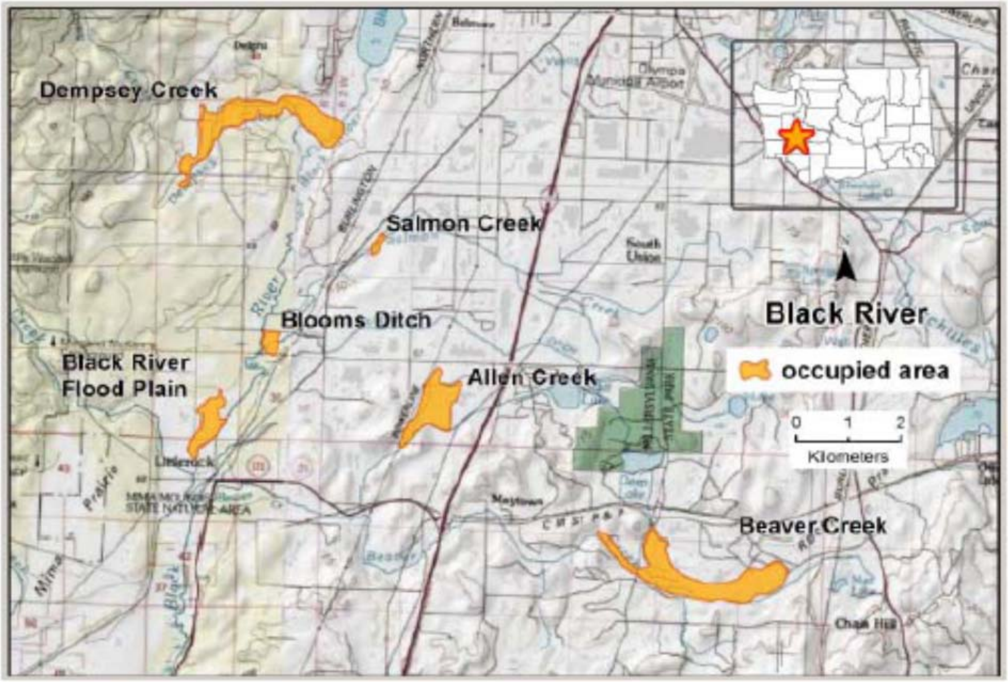


Figure 1. General distribution of Oregon Spotted Frogs in the southern Black River.

Declines of this species are attributed to wetland loss or alteration, predation by native and non-native organisms, urbanization, disease and riparian management practices (Cushman and Pearl 2007). Of these, wetland alteration and vegetation succession are ranked among the most significant factors of decline (Cushman and Pearl 2007, Pearl and Hayes 2005). For instance, in the Willamette Valley, the decline is partially attributed to conversion of large expanses of seasonal wetlands into smaller area of permanent wetlands (Pearl and Hayes 2005, Hulse et al. 2002, Holland et al. 1995, Cushman and Pearl 2007) as well as succession to shrubby habitats. Due to historical declines and habitat loss and remaining threats to populations, OSF is now a State Endangered species and a candidate for Federal ESA protection (USFWS 2013). Unearthing environmental parameters underlying wildlife habitat suitability is important for conservation of all species. How wetlands, soils and geology partly underlie distribution of all amphibians, including OSF, are discussed below.

WETLAND VEGETATION, SOILS AND GEOLOGY UNDERLYING DISTRIBUTION OF POND-BREEDING AMPHIBIANS AND OSF

Wetland size and vegetation

As wetlands increase in size, the number of wetland categories tends to increase, possibly resulting in greater amphibian richness (Hamer and Mahony 2010, Vos and Chardon 1998). The relationship between wetland size and amphibian richness is unresolved however (Snodgrass 2000). In a study of 103 wetlands in New Hampshire, species richness was greatest in wetlands larger than 0.25 hectare (Babbitt 2005) but richness was contingent on hydroperiod. Richness increased in wetlands with short to intermediate hydroperiods (inundated less than one year) (Babbitt 2005). In another study, no relationship between wetland size and species richness was confirmed (Snodgrass 2000). In the Pacific Northwest, criteria for wetland size sufficient to meet the breeding requirements of most species of amphibians' remain unresolved. A minimum breeding area criterion of .02 hectare for the red-legged frog (*Rana aurora*) was based on a study of 18 wetlands in King County (Richter et al. 2008). However, in the same geographic region, Azous (1991) found no significant correlation between wetland size and amphibian species richness (based on wetland sizes ranging from 1 to 30 acres). Small wetlands may support breeding for some species capable of upland dispersal if juxtaposed to larger forested habitats.

The minimum size wetland required to support a population of OSF is unknown. However, all OSF tend to occur in large wetlands with a permanent body of water juxtaposed to shallower areas (Watson 2003). Hayes (1994) hypothesized that most OSF occur in wetlands larger than 4 hectares but may occur in sites as small as 2.5 hectare, if near aquatic corridors (Pearl and Hayes 2004). The relative ratios of various vegetation types may inform habitat suitability.

For most amphibians, vegetation influences habitat suitability. Specifically, four primary wetland types (Cowardin 1979) influence amphibian species' occurrence and richness: emergent, palustrine scrub-shrub, forested and floating or submerged vegetation.

Abundance of herbaceous and submerged aquatic vegetation predicted occurrence of the green frog *Rana clamitans* (Mazerolle 2005). Similarly, emergent vegetation in wetland margins predicted amphibian occurrence and richness (Hazell et al. 2004). In the Pacific Northwest, emergent vegetation increased amphibian richness (Richter and Azous 1995). The abundance of Pacific treefrog (*Hyla regilla*) and red-legged frogs (*Rana aurora*) increased in ponds with a high ratio of emergent to open water (Richter and Ostergaard 2002). Not only vegetation ratios, but vegetation structure influences suitability of habitat. For instance, Northwestern salamanders (*Ambystoma gracile*) deposit eggs on vegetation with a stem diameter of 3 millimeters (Richter 1997).

For most pond-breeding amphibians, composition of upland vegetation may be as important as wetland vegetation. Many anurans in Europe remain within 200 to 300 meters of the wetland (Semlitsch et al. 2002, Sinsch 1990). However in western North America pond breeding frogs and toads may disperse as far as 4.8 kilometers or more (Hayes et al. 2007). The red-legged frog (*Rana aurora*) increased in abundance as the size of the upland forest patch increased (Holcomb 2012, Martin and McComb 2003, Gomez and Anthony 1996). Fewer red-legged frogs were found in clearcuts (Chan-McLeod 2003). Because this frog can travel through upland habitats or aquatic areas, connectivity between natal ponds is facilitated via aquatic habitats, meadow or woodland forests.

Like other amphibians in the Pacific Northwest, OSF exhibits a relationship with vegetation composition. OSF wetlands are characterized by emergent vegetation adjoining permanent aquatic water (Watson 2003, Hayes and Pearl 2005, Cushman and Pearl 2007). In 5 wetlands where breeding occurred, the average extent of palustrine emergent was 82% (Pearl and Hayes 2004). But, vegetation associated with OSF may depend on life stage and season (Watson et al 2003). For instance, breeding adults often deposit egg masses in oviposition sites dominated by emergent, herbaceous or short vegetation that does not protrude above the water (Hallock 2013, Pearl 1999, Pearl and Hayes 2004, Licht 1986). After metamorphosis, juveniles and adults may move to deeper water with floating aquatic plants interspersed with shrubs (Watson 2003, Popescu 2013).

Habitat models for OSF emphasize the importance of large emergent wetlands juxtaposed to aquatic habitat (Germaine and Cosentino 2004, Groff 2011, Bohannon 2012). However, the relative size, proportion and connectivity of all habitat types needed to maintain populations are less studied and needs to be reanalyzed, especially as new sites are discovered.

Notwithstanding the use of shrubs outside of breeding season (Popescu 2013, Watson 2003), invasion of shrubs into oviposition areas is a significant factor of decline (Cushman and Pearl 2007, USFWS 2013). Vegetation succession from short emergent plants to either *Phalaris arundinaceae* or dense shrub has occurred in some locales where this species is considered extirpated, but the extent to which it is a primary factor is unknown (Hallock 2013, M. Hayes personal communication 2013).

Habitat enhancement has consisted primarily of maximizing breeding habitat by minimizing vegetation height and creating openings in dense thatch or shrubs (Kapust et al 2012, White 2002). Most sites occupied by OSF in Washington have agricultural or enhancement activity that reverses vegetation (Hallock 2013).

Perhaps because of the OSF association with large emergent wetlands, National Wetlands Inventory maps have guided successful OSF habitat surveys and predictive models (Groff 2011, Bohannon 2012). But the proportion of vegetation and other environmental components and connectivity to sustain populations is important to understanding the conservation of this species.

While extant vegetation composition informs amphibian habitat suitability, formerly live vegetation still plays a role in shaping habitat by influencing water quality and quantity.

Soils

Frogs are highly connected to soils. Some sympatric frogs change color to match the soil or vegetation (Stegen et al 2004). Tadpoles may incidentally consume soil. (Echeverria et al.

2007). The body composition of tadpoles may reflect soil metal composition (Sparling 1996). Most frogs burrow into mud (Pinder 1992). Specific properties of soil types such as position in landscape, water table and fluctuations, percent organic or mineral matter may directly influence survival or ability to disperse. All wetlands are nested into a soil (Vepraskas 2000), which have been mapped and characterized by the soil conservation services (Pringle 1990). Hence, soil maps may be useful tools for amphibian ecologists.

***Soil position in landscape*.** Soil Position in landscape underlies soil and wetland development as well as amphibian communities. Upland soils may harbor terrestrial breeding amphibians or dispersing pond-breeding amphibians. Soils occurring in upland depressional, terrace or floodplain/high groundwater areas may have wetlands capable of hosting pond-breeding amphibians. Of these 3, connectivity may vary due to the inherent position in landscape. Geographically isolated wetlands tend to occur in upland depressional and terrace soils whereas floodplain/high groundwater wetlands may have hydrologically-connected wetlands (Tiner 2003).

Geographically isolated wetlands host species that can disperse between populations over upland habitats and include the carpenter frog (*Rana virgatipes*), marbled salamander (*Ambystoma opacum*), spotted salamander (*Ambystoma maculatum*), Jefferson salamander (*Ambystoma jeffersoniana*), wood frog (*Lithobates sylvaticus*), gray treefrog (*Hyla versicolor*) and spring peeper (*Pseudacris crucifer*) (Semlitsch, 2000, Tiner 2003). Species breeding in isolated seasonal wetlands use the wetlands for reproduction and larval growth, but may disperse through upland woodlands. Amphibian biomass in geographically isolated wetlands can be large (Gibbs 1993, Gibbons 2006, Calhoun et al 2003), perhaps due to lack of fish, bullfrogs and dragonfly larvae if the pond is seasonal. Other species may be more adapted to floodplain wetlands. For instance, Northern leopard frogs (*Lithobates pipiens*), green frog, (*Rana clamitans*) and Northern Cricket Frog (*Acris crepitans*) are associated with floodplains (Stockwell and Hunger 1989, Messina and Conner 1998).

Floodplain wetlands with a high groundwater table may support genetic exchange by facilitating movement through moist habitat.

Species corridors between breeding populations maintain populations and genetic exchange (Kauffman et al 2001, Haila 2002, Fahrig 2003, Hecnar and McCloskey 1996). Metapopulation theory suggests that wetlands close enough and connected by permeable habitats prevent population crashes (Trenham et al 2003). For the red-legged frog *Rana aurora*, permeable habitat may consist of moist woodlands. For the OSF, permeable habitat consists of moist wetland margins or aquatic habitats.

Unlike sympatric ranids that disperse through upland woodlands, OSF are aquatic (Watson 2003, Forbes and Pederson 1999, personal communication Monica Pearson, personal communication M. Hayes). Ergo, movement between geographically isolated wetlands is highly unlikely, possibly only occurring during high water or through streams or ditches. Movement through dry upland habitat would be precluded but movement along moist wetland margins that extend into riparian woodlands has been reported (Richardson 2011). Most radiotelemetry studies suggest dominant use of aquatic habitats with relatively short movements within their ranges. Within their aquatic habitats, daily and annual home range may be relatively small, up to 37 square meters (Watson 2003) and 2.2 hectares, respectfully, notwithstanding being situated within a larger complex of 30 ha (Watson 2003). However, long-range movements have been documented along aquatic corridors (Pearl and Hayes 2004, Watson 2003), where most movement occurred within 800 meters of their capture locations (Watson 2003). The furthest reported distance by adult OSF was 2.4 kilometers (McAllister and Walker 2003).

However, the ability of OSF to persist in wetlands may depend on the suitability of dispersal and breeding habitat (Pearl and Hayes 2004), so characterization of habitat elements at newly discovered sites is important. Moreover, hydrology, another soil property identified in soil surveys, informs habitat suitability. Conservation measures to maintain connectivity between populations may maintain diversity (Blouin 2010), but connective corridors have to be defined.

Soil water table. Hydrology shapes soil and biological communities (Mitsch and Gosselink 2007) as well as human activities (Pringle 1990). More specifically, water capacity and water table, which influences soil decomposition rates and chemistry, also strongly influence amphibian communities (Snodgrass 2000, Hruby 1995, Semlitsch 2002, Richter 1997). Habitat suitability for both desert and temperate amphibians is shaped by water capacity of soils. Abundance of four species of desert amphibians, Couch's Spadefoot (*Scaphiopus couchii*), Red-spotted Toads (*Bufo punctatus*), Texas Toads (*Bufo speciosus*) and Western Green Toads (*Bufo debilis*) was higher in clay soils due to higher water capacity (Dayton et al 2004). Similarly, in temperate areas, the Northern Cricket Frog (*Acris crepitans*) overwinter in soils with high but stable water content perhaps because this frog has low tolerance of desiccation and freezing (Ralin and Rogers 1972, reviewed in Lannoo 2005). In the Pacific Northwest, duration and timing of surface water influence pond-breeding amphibians. Inundation must persist from egg deposition to metamorphosis for all native pond-breeding amphibians. For instance, the red-legged frog (*Rana aurora*) breeds in wetlands with adequate surface water from February through August. Water level fluctuations influence richness of amphibian communities. Wetlands with greater water level fluctuations (>24 cm) had lower amphibian species richness (Richter and Azous 2005).

Hydrology also affects wetland plant communities, which in turn shpaes habitat quality for amphibians. For instance, richness of palustrine emergent plant communities was greater in wetlands with low water level fluctuations (Azous and Cooke 2001). However, invasive plants such as Douglas spirea (*Spirea douglasii*) and Reed Canary Grass (*Phalaris arundinaceae*, that deprecate amphibian habitat, tolerate greater water level fluctuations than most wetland emergent plants (Azous and Cooke 2001).

Hydrology also influences habitat suitability for all OSF life stages. Specifically, timing and depth of inundation in and between their breeding and overwintering habitats influence use and survival. This is due to key life history, morphological and behavioral characteristics that shape habitat use. First, OSF is a highly aquatic frog, feeding, moving and avoiding predators in moist to aquatic environments year round. (Watson 2003, Licht 1986, Hallock and Pearson 2001). On land, OSF is a weak mover, jumping in circles at a 10- degree angle to the ground (Licht 1971).

Like most sympatric frogs, OSF lays eggs during early spring in ponds. However, unlike local frogs, it oviposits in shallow water up to about 35 centimeters deep (Licht 1971, Cushman and Pearl 2007, Nussbaum 1983). After egg deposition, water must persist in these shallow areas until embryos hatch and tadpoles metamorphose (Hayes 2000, Licht 1974, Hallock 2001, cited in Hallock 2013). High egg mortality was attributed to declines in water levels after deposition that stranded eggs (Hayes 2000, Licht 1974, Hallock cited in Hallock 2013). After metamorphosis, juveniles and adults remain in wetland margins, moving to deeper areas through moist habitats as the water retreats. OSF breeding area and overwintering area must be juxtaposed with minimal intervening upland habitats (Hayes 2001), especially during migration between these habitats in March and October (Chelgren 2008, Hayes et al 2001). Water persistence facilitating movement between breeding and overwintering wetlands is instrumental, especially in drought years (Hayes 2001). In fact, hydrological changes that reduce connectivity between the breeding and nonbreeding habitats may explain some declines in some regions. For instance, retreat of water stranded OSF at a wetland in the Black River watershed (Watson 2000) and egg losses have been attributed to the retreat of water at several locations (Licht 1971, Hayes 2004). Effects of retreat of water in early winter on juvenile and adult life stages have not been fully explored yet but drought may both limit movements between habitats and bring them closer to aquatic predators (Hallock 2013).

Maintenance of connections between breeding and overwintering habitat depends partially on water tables, which was considered in site selection for habitat creation in Oregon, where ponds excavated in soils with peat, silt and clay with a high water table have had successful breeding (Biebighauser 2007). Evidence of stable water tables includes gleyed soils or accumulation of peat (Mulamoottil 1996). In summary, soils characterized by a stable high water tables may benefit species with high aquatic habitat requirements.

Soil parent material. Parent material, the organic and mineral unconsolidated matter in which the soil forms, includes vegetation, diatoms, and mineral matter, all of which influence habitat suitability for amphibians. Soil 'parent materials' provide a snapshot in time, shedding light on historical vegetation, climatic or aquatic conditions.

Vegetation as soil 'parent material'. Organic soils form in depressions or as a consequence of high groundwater that accumulates decaying vegetation. Organic soils influence habitat suitability for amphibians in many ways: Organic soils may hold more water than many mineral soils, release it during drought, are less likely to compact (Wortman and Jasa 2003), may form a complex with metals (Gambrell 1994, Adamus et al 1991, Mitsch and Gosselink 2007), may decompose and lower dissolved oxygen (Minaya et al 2006), but also may provide food resources for amphibians (Solomon et al 2004). Vegetation composition in and adjoining the wetland may influence soil properties. For instance, vegetation adjoining wetlands such as bracken fern, (common on some soils in south Puget Sound) may increase the availability of aluminum in the soil (Sommer 1990) and reduce conifer regeneration (Ferguson 1988 Watt 1953). Wetland soil chemistry was not the focus of this study, but all other things being equal soil with high aluminum and iron have an affinity for phosphorus (Mitsch and Gosselink 2007) that may influence vegetation communities.

However, accumulation of fibrous organic matter may be attributed to lack of decomposition from cold temperatures, low oxygen environments or presence of aluminum-humus complexes in low pH environments (Shindo 2002, Eswaran 1993, Tokashiki and Wada 1975). One type of organic soil, andisols occur in the PNW (McDaniel 2007) and form inorganic matter and volcanic ejecta (Nanzyo 1994, Shoji et al 1985a, Shoji 1985b, Takahashi 2010). Aquic andisols may be prevalent in depositional floodplains (Buol 2011). Ergo, aquatic organisms benefiting from the water holding capacity of organic soils in the Pacific Northwest may also then be subject to environmental factors maintaining organic conditions, such as cooler, anoxic climes or aluminum-humus complexes. When subject to lower pH, these aluminum-humus complexes may release aluminum into the water (Nanzyo 1994). However, I could find minimal literature regarding the occurrence of aquic andisols in wetlands or their effects on amphibians, but these soils are relatively common in Washington State as a result of deposition of volcanic ash on organic matter (McDaniel 2007, 2005).

In some cases, vegetation accumulation forms peat. While peat bogs do not always support a diverse amphibian community (Freda and Dunson 1986), this may depend on the parent material, be species or amphibian life-stage specific. For instance, peat soils form from either 1) sedges, rushes and grasses, 2) woody material or 3) mosses (Rydin 2013). Each of these parent materials influence chemical and physical properties of the peat soils and water. For instance, peat formed from sedges and rushes is more euic (pH > 4.5) with higher concentration of cations (Rydin 2013) important for amphibians (Tietge 2000) than peat soils formed from woody materials or sphagnum mosses (Rippy and Nelson 2007).

Peats derived from woody materials (Rifle peat soil) release humic and fulvic substances (Rydin 2013), which reduce survival of both tadpole embryos and larvae especially if complexed with aluminum (Freda et al. 1990). However, the effect of natural organic acids on amphibians is unresolved. For instance, the detrimental effects of low pH may be ameliorated by organic acids (Barth 2010). Peat formed from mosses (Greenwood peat soil) is lower in pH than peat derived from grasses or sedges (Rydin 2013). It is generally agreed that amphibian survival is greater in water with pH greater than 5.0 (Sparling 1995). However, the use of peat by amphibians may be species or life-stage specific. Some amphibians find sphagnum peat hospitable. For instance, the Corroborree Frog (*Pseudophryne corroboree*) of Australia deposits eggs deep in Sphagnum moss, a highly acidic substrate (Campbell 1983). Alternately, use of peat may depend on life stage. Peat with low pH rarely supports oviposition by green frogs, but these same peatlands were important for rehydration of adult green frogs (Mazerolle 2005).

Diatoms as 'parent material: Another 'parent' material is diatoms, which bloom in marine or freshwater in response to inputs of volcanic ash, silica and phosphorus or runoff from phosphorus-rich basalt or andesite (Wallace et al 2006). Diatomaceous earth (DE) is produced by the deposition of these diatoms in aquatic environments. Diatoms that occupied the wetland in the past may have augmented the diet of amphibians: Organic sediment with abundant diatoms resulted in increased growth of *Rana palmipes*, a detritivorous tadpole (Solomon et al 2004). Diatoms were used as an index of habitat quality for the Hewitts ghost frog (*Heleophryne hewitti*) (Botha 2012). Perhaps this is because some tadpoles preferentially consume diatoms rather than algae such as *Oedogonium* (Rossa-Feres 2004). In other studies, tadpoles that consumed diatoms had increased growth, survival and size at metamorphosis (Kupferberg et al 1994). Locally, diatoms accumulated in Tisch soils (Pringle 1990).

Soils in Thurston County include not only organic soils composed of the three types of organic materials and diatomaceous earth, but also inorganic mineral soils.

Mineral parent material. 'Mineral' parent materials consist of either consolidated material such as igneous, sedimentary or metamorphic rock, or, unconsolidated rock formerly transported by air, water or glaciers. 'Rock' transported by 'air' consists primarily of volcanic ash that may be subsequently transported by water, eventually depositing as alluvium. Mineral soils include clay, silt, sand, volcanic ash and gravels. Some consider biogenic material such as diatomaceous earth a mineral soil.

Certain properties of mineral soil influence frog occupancy or tadpole growth and survival. The Striped Burrowing Frog, *Cyclorana alboguttata* occupied clay more frequently than sand. Authors attributed this to higher water content in clay than in sand (Booth 2006). Northern Cricket Frogs (*Acris crepitans*) were more abundant in clay than in loam when exposed to low pH (Sparling 1995). Bentonite clay-lined stormwater ponds were used by pond-breeding amphibians in Western Washington (Ostergaard 2001). Clays, which may be deposited in lakes or form from weathering of rocks in place (Shedd 1910), influence water quality and quantity in many ways.

For instance, clay soils exhibit higher water holding capacity and cation-exchange-capacity (CEC) than sandy soils, which has been shown to be important to amphibians. Secondly, soils high in clay (Velde 1995) adsorb metals (Gambrell 1994).

Mineral soil underlying wetlands may be consumed by the larval stages of amphibians. Most frog tadpoles are detritivores, feeding by scraping detritus, algae and diatoms from surfaces (Sanderson and Kupferburg 1999). Incidental consumption of mineral soil by tadpoles (Ranvestel et al 2004), may result in accumulation of mineral sediment in their guts. For instance, mineral sediment in the guts of 9 Rococo Toads (*Chaunus Schneideri*) tadpoles was 55% (Echeverria et al. 2007).

Metals occurring in soils underlying wetlands may be incidentally ingested during feeding or expose hibernating frogs to metals but the exact mechanisms and potential of toxicity of many metals depends on speciation and pH and presence of organics in the water.

As a consequence of ingestion or absorption, the body burden of metal may increase and reflect soil composition. For instance, metal content of northern cricket frogs (*Acris crepitans*), gray treefrogs (*Hyla versicolor*) and green frogs (*Lithobates clamitans*) was attributed to soil ingestion (Sparling 1996). Body concentrations of Ba, Be, Fe, Mg, Mn, Ni, Pb, and Sr increased with soil concentrations of these elements (Sparling 1996). Concentrations of metals in tadpoles may reflect background conditions (Karasov 2005). Similarly, the bioaccumulation of heavy metals such as copper, lead and zinc by tadpoles increased with stream sediment concentrations near a mine in Greece (Kelepertzis et al. 2012). Metal ingestion can have mixed effects however. The metals in the bodies of these tadpoles could reduce tadpole growth or survival (Freda 1986) or could be potentially toxic to predators (Sparling 1996).

Iron and aluminum, two common metals in soils, may affect tadpoles in many ways: For instance, tadpoles raised on iron substrates had increased body size, whereas tadpoles raised on lead substrates smaller body sizes (Severtsova et al. 2013). Iron, ubiquitous in the geologic strata and some wetlands in Western Washington, is released in the water column in the ferrous state, producing gleyed soils when water tables are stable (Mitsch and Gosselink 2007). Another common metal, aluminum, depending on pH, adversely affects tadpole growth (Cummins 1988). However, I could not locate research on aluminum concentrations in wetlands or soils in Western Washington, nor is aluminum regularly tested for in standard or advanced soil tests. However, aluminum is a relatively high component (~15%) in basalt, and volcanic ejecta, both of which are common in soils underlying Thurston County.

Not only are tadpoles barometers of wetland health, they are also engineers, shaping micro-topography and amount of organic matter. ‘Tadpole holes’ form when when tadpoles create circular micro-depressions in the soft layers of silt and fine sand in shallow ponds (Dionne 1969). Western toad tadpoles, which actively ingest organic rich sediments as a food resource (Wood and Richardson 2009) may alter organic content of underlying sediments in enclosures. As a consequence of tadpole grazing, 37 times more inorganic sediment developed in mesocosms (Wood 2010).

Very little research has been conducted on soil parent material and OSF. However, perhaps more than other frogs, OSF are in contact with soils in aquatic habitat their entire life rather than on land. OSF were observed using organic soil even though mineral soil was available (Hallock and Pearson 2001). However, USFWS attributed part of the decline of OSF to the loss of natural wetland and riverine disturbance processes such as beaver, fire and meanders that removed shrubs and created ‘bare patches of mineral soil’ (USFWS 2013). Diatomaceous earth, formed via biotic processes, underlies a population of OSF at Conboy Lake (USFWS/ICF 2014). Due to the fact OSF overwinter in aquatic habitats overlying soils over the winter, they are integrally connected to soil/water chemistry. Like other ranids, OSF tadpoles may be adversely affected by water with low pH, low dissolved oxygen or high amount of humic substances. Organic matter decomposition that lowers dissolved oxygen may reduce survival rates because OSF do not tolerate anoxic water (Hayes 2001) but do bury themselves in mud for perhaps up to 2 days (Tattersall and Ultsch 2008 as cited in USFWS 2013). Soil ingestion is relatively unknown by OSF but they may feed on detritus (Watson 2003). However, a related species, the Columbia spotted frog (*Rana luteiventris*) fed more frequently on detritus above contaminated sediments when predators were present. Conversely, when predators were absent, Columbia spotted frog larvae fed more frequently in the vegetated matter and did not consume as much cadmium, lead and zinc in the sediments (Lefcort et al. 1998). Metamorphosis and predator response were impaired as a consequence of increased exposure to these metals (Lefcort et al 1998).

Soil parent material, as identified in the soil surveys, may indicate historical wetland vegetation. For instance, peat soils formed in either woody materials, sedges and grasses, mosses. Because most oviposition occurs in sedges and grasses, soils formed in sedges and grasses may have hosted better historical oviposition habitat than soils formed from woody materials. Similarly, other soils formed with diatoms may have provided a food resource in the past

Parent materials influence cations that characterize the soil type. Diatomaceous, organic and clay have a high cation exchange capacity (CEC). Higher CEC was correlated with higher OSF embryonic survivorship (McKibbin et al. 2008). In Alaska, wetlands in relict glacial drainage-ways that support the Columbia spotted frog exhibit higher pH and conductivity than depressional, lakebed, spring fen or kettle wetlands (Gracz 2011).

Because all amphibians are so integrally connected to soil properties, soils are one factor used in habitat suitability models designed to predict suitable habitat for amphibians. (Mazerolle and Villard 1999, Frisbie and Wyman 1992, Groff 2011). Soil surveys identify soil properties relevant to amphibians and thus, may be a valuable tool for ecologists.

Geology and amphibians

The study of the distribution of species is called biogeography. Phylogeography, a subset of biogeography, is the study of the patterns of species distributions and is strongly influenced by geologic history and climate. Geologic and climatic history may lead to isolation of species (Avise 2000), shaping the distribution and gene flow of amphibians (Baselga 2012). Geologic history resulted in topographic influences on the permeability of the landscape to migrating amphibians. Mountain ridges may act as barriers for some amphibians (Lougheed 1999). For instance, the distribution of the salamanders of the genus *Eurycea* in the Appalachians is more influenced by geologic history than contemporary conditions (Kozak et al. 2006). The gene flow of a Chinese mountain frog was shaped by geologic events that separated groups of organisms (Yan 2013). Climate, specifically de-glaciation, inundation of the Mississippi embayment and formation of rivers rather than uplift of mountains, influenced genetic variation in the trilling frog *Pseudacris* in the Mississippi basin (Lemmon 2007).

It is clear that geology and climate, in concert, exerted strong influence on flora and fauna of the northwestern United States (Kruckeberg 1991). In Alaska, geology and climatic events produced wetlands in relict glacial drainage-ways now occupied by the Columbia spotted frog. These relict drainageways, dominated by emergent vegetation with a stable high water table also have high concentrations of minerals in the groundwater (Gracz 2011, personal communication M. Gracz 2014). Other species associated with former floodplains include the pond-breeding amphibians *Rana clamitans* and *Acris crepitans*, which occur in alluvial floodplains (Messina and Conner 1998) whereas the Wood frog and spotted salamander were associated with “glaciofluvial” deposits and not with alluvium (Skidds et al. 2007). Alluvial floodplains, (which are considered one type of geologic strata) facilitated dispersal between frog populations of southeastern Australia (Hazell et al. 2003).

Geologic and climatic history also influenced speciation of the OSF (Green 1996, 1997, Funk 2005) and strongly shaped current Thurston County topography (Kruckeberg 1991).

At the regional scale, geologic and glacial expansion and contraction resulted in two distinct species, OSF and *Rana luteiventris* that eventually exhibited differences in life history patterns, morphology and genetic composition (Green 1996 Green 1997, Funk 2005). However, its range was highly fragmented due to isolation of springs and rivers approximately 6000 to 8000 years ago (reviewed in Green 1996). This resulted in relatively permanent disconnects between many populations. Secondly, geologic history formed large oversized valleys and pothole lakes in Thurston County (Kruckeberg 1991) in which wetlands such as Pleistocene peat, pothole lakes, Holocene peat and Holocene alluvium mapped in detail by geologists. However the relationship between distribution of amphibians and these geologic features has not been characterized locally.

Overview of recent surveys for Oregon Spotted Frogs

Results of surveys for OFS, which have occurred in portions of most of its range suggest a reduction in OSF populations. In the Willamette river floodplains of Oregon, the OSF once was common (Graf 1939, Nussbaum 1983). Subsequent surveys failed to yield any additional detections in 10 historical locales (Hayes 1997). Surveys of 85 wetlands by Pearl (2005) failed to yield any new detections but OSF was not a targeted species (Rosenberg 2013). Surveys conducted between 1993 and 1997 by trained volunteers and staff in King County, Washington yielded no new locales (Richter and Ostergaard 1999), but surveys were not specifically focused on OSF habitat (personal communication K. Richter 2005). Surveys conducted near 2 historical locales in eastern Pierce County, Washington yielded no detections (Blessing, unpublished report on-file with WDFW/NWT). However, surveys conducted in wetlands with suitable NWI categories yielded additional OSF detections in Whatcom and Skagit County, Washington (Bohannon unpublished report 2012). Surveys conducted in 60 locations in Pierce and Thurston County, Washington, in 1989-1991 resulted in the detection of OSF at one location in the Black River watershed (McAllister 1993). Subsequent surveys in Thurston County occurred in the next few years, generating 3 locales within several miles of existing locations. However, as of 1997, only 4 wetlands were known to be occupied by OSF in Thurston County.

Since 2010, serendipitous detections by naturalists as well as detections during focused surveys conducted within the Black River watershed yielded new locales in the Black River Watershed.

The fact that new locations have been found recently due to increased survey efforts by biologists and educated naturalists suggests that a few remnant populations remain undetected. A systematic approach may yield more fruitful searches or identify potential habitat. Species distribution models have proven useful in locating rare species and several models have been developed for OSF.

Species Distribution Models for the Oregon Spotted Frog

Species distribution models integrate species occurrence data with environmental layers to predict species occurrence or suitability over a larger landscape. For instance, model predictions were used to facilitate detection of rare plant species (Poon and Margules 2004, Williams et al 2009) and rare aquatic snakes (Durso 2011). Habitat suitability relationships that are used to inform models (Pauley 1993, Odom 2001, Klute 2002, Hinsley 1995, MacKenzie 2004, Manly et al 2010, McDonald 2004 (Gogol-Prokurat 2011) encourage conservation by contributing to the generation of maps depicting likelihood of occurrence as well as informing habitat associations and potential sites for conservation measures.

Several models to identify potential habitat for OSF and its relative, the Columbia Spotted Frog have been developed. Criteria for these models were informed by literature reviews and professional input. In one model, two levels of analysis were performed to assess whether a wetland may provide suitable habitat for OSF (Germaine and Cosentino (2004). Tier 1 criteria had to be met for the wetland to be considered for Tier 2 criteria. Specifically Wetlands meeting Tier 1 criteria were at least 4 hectares and less than 9.8% of the area within a 1.6 km mile radius developed for residential or urban uses. Wetlands smaller than 4 hectares were considered suitable if connected by surface water and less than 1 km from another wetland. Wetlands meeting Tier 2 criteria exhibit a diversity of habitat types including 1) shallow water 5 – 30 cm in depth dominated by native submerged and emergent vegetation, 2) summer habitat with lentic pools within 1 km of breeding area, 3) less than one km to winter habitat. In Skagit and Whatcom counties, NWI (National Wetland Inventory) categories were used to find previously undetected occupied OSF locales (Bohannon 2012).

NWI classification helped identify Columbia spotted frog potential habitat (Munger et al 1998); flatness, solar insolation, presence of tree-frogs and percent development in adjoining uplands predicted potential Columbia frog presence (Goldberg and Waits 2009, Golderberg and Waits 2010). Flatness, or low topographic relief, may occur from alluvial deposition, lahars, proglacial lakes or aeolian deposition (Cameron and Pringle 1986).

A predictive model called MaxEnt was used to predict the likelihood of occurrence of OSF in southern Oregon and California (Groff 2011). Of 27 variables used, hydric soils, open water and emergent vegetation contributed the most to the potential distribution of OSF, and were mapped to find 2 more OSF locales in Oregon. Groff (personal communication 2014) suggested that geologic history could be employed.

These models illustrate approaches developed to identify habitat for OSF. The authors suggested refinement and adjustment of these models for local areas. Cosentino's model could not, at the time, consider habitat variables at sites detected since his model was developed. Germaine and Cosentino (2004) did list the full suite of hydric soils that occur in the larger wetland that encompasses OSF locales but did not identify specific soil type preferences. Moreover, maps depicting the potential distribution of predictive soil and wetland types were neither produced nor were the number of oviposition sites on these soils counted. Nor have any previous models incorporated the newer geology maps recently produced by the Washington State Department of Natural Resources Geology Division. Finally, the use of topographic relief as a predictor of OSF habitat has not been conducted, despite its use as a predictor of Columbia spotted frog breeding areas and anecdotal observations that OSF occur in 'very flat places'.

Models, once built, could be tested or modified for local regions. In my project, I research and investigate characteristics of several variables underlying models already built for OSF. I also explore the importance of another variable, geology.

Justification for this project

The collective literature suggests that a certain set of habitat attributes contribute to its persistence. Specifically, habitat complexity to support an OSF population even when isolated, wetland habitat characteristics and types of corridors that reduce isolation between OSF breeding sites (Pearl and Hayes 2004). The ratios of vegetation types, as well as soils and geology have not been assessed for all the wetlands now occupied in Thurston County. Potential avenues of connectivity between populations should be mapped to guide conservation.

To help answer these questions, GIS analysis complemented with surveys of wetland sites within 2 to 3 km of known or suspected breeding sites were recommended with attention paid to increasing potential habitat for OSF (Pearl and Hayes 2004).

In this project, I focus on wetland character, soils and geology in one small portion of their range. Finally, while public perceptions of wildlife were not the focus of this research project, I gleaned values from these stakeholders for conservation owners that may influence sustainable species conservation.

As part of this project, the following hypothesis is tested:

Ho: Null hypothesis: There is no statistical difference in soil type between soils in occupied wetlands and the soils underlying the specific oviposition sites.

Ha: Alternative hypothesis: There is a difference between in soil type between soils in occupied wetlands and the soils underlying the specific oviposition sites.

2. METHODS

Study area.

The study area lies in Thurston County, which is in the Puget Trough at the southern end of Puget Sound. The County is bounded on the east by the Nisqually River, extending south to Grays Harbor county and Lewis County, where it shares portions of the Chehalis River Basin. The western portion in the Black Hills extends to Mason County. The total area of the county is 717 square miles or 458,880 acres. Land use includes urban, rural, industrial, residential and agricultural. Several wide valleys with relatively small streams were formed from postglacial runoff such as overflow from glacial lakes (Bretz 1913) with hydrology influenced by landform, climate and anthropogenic activities. Vegetation ranges from upland forest with Douglas fir (*Pseudotsuga menzeisii*) to prairies.

Goal and Data Sources

The goal of this study was to identify potential suitable habitat and characterize wetlands, soils and geology at occupied sites in Thurston County. I used occupancy data from Washington Department of Fish and Wildlife (WDFW) Priority Habitats and Species (PHS) program, wetland maps developed by Ecology, soil types from maps produced by Natural Resource Conservation Service (NRCS), geology map (Logan and Walsh 2009) from Washington Department of Natural Resources (WA DNR). Later I chose to digitize wetlands occupied by OSF to calculate wetland types. Tools I used to assess environmental variables consisted of a gradient of complexity from basic GIS analysis of environmental parameters occurring at species locations to a software program that employs a modified Bayesian approach to predict likelihood of suitable habitat and the relative importance of environmental variables.

Wetland vegetation analysis.

After viewing egg mass deposition locations in air photos, I decided to divide a few wetlands in two because either the wetland was bisected by a road or groups of egg masses were separated by over a quarter mile. I digitized and calculated areas of aquatic, palustrine emergent and scrub-shrub (Cowardin 1979) at 12 occupied wetlands using online aerial imagery and GIS software (Arcmap Version 10.2 software from Environmental Systems Research Institute, Redlands, California).

While digitizing I included wetland type within about 200 meters of the egg deposition sites, ensuring the nearest aquatic habitat, a key habitat requirement was digitized but excluded unsuitable habitat. I excluded areas of unsuitable habitat by excluding uplands, areas where the wetland narrowed to a narrow forested stream or dense shrub/forest adjoining breeding areas. A few outlying egg masses were excluded from this basic digitization of wetland type (Cowardin 1979), but all eggs were included in the soils and geology analysis. Each of these digitized wetlands occurred in much larger extensive wetlands. Size of some of the larger wetlands these wetlands occurred in were calculated by Germaine and Cosentino (2004) and not the focus of this study.

Soils and geology characteristics

I identified the soils, geology and wetland type used by OSF for oviposition using the Intersect tool on ARCMap. I then compared the proportion of egg deposition on the soil types with the proportion of the soil types occurring in the wetland, and calculated whether the difference was statistically significant using the Chi-squared statistic. I also calculated the average and range number of eggs per cluster by soil type. I calculated the number of records of OSF occurrence records by geologic type. I also qualitatively reviewed several soil properties and LIDAR imagery at the oviposition wetlands. Finally I reviewed geologic history of Thurston County.

Surveys

I conducted wetland surveys in potential habitat. In order to select wetlands I stratified wetlands in Thurston County to generate a ‘population’ of wetlands meeting Tier 1 criteria for

OSF (Germaine and Cosentino 2004). From this ‘population’ of wetlands, I randomly selected 30 wetlands to survey. Of these, I was able to survey portions of 17 wetlands. Most of these wetlands were on private property.

Permission from property owners associations was acquired by phone calls, attending community meetings or knocking on doors.

Search methods consisted of modified area-constrained searches with an endpoint. I looked in suitable habitat during the breeding season of OSF until I detected red-legged frog (*Rana aurora*) then attempted to search in shallower water within 200 meters of these locations. Most sites were surveyed twice. In most cases, this was the first survey in these wetlands, so a second survey should be conducted.

MaxEnt analysis of wetlands

In order to predict the likelihood of suitable habitat and assess the relative contribution of wetlands, soils or geology type to the likelihood of suitable habitat for OSF, I used Maximum Entropy Modeling (MaxEnt). This software program is a relatively new software program that employs occurrence data and environmental parameters occurring at occupied sites to attempt to predict the likelihood of suitable habitat and the relative contribution of environmental parameters to the observed occupancy distribution (Phillips 2006). MaxEnt 3.3.3k can be downloaded from http://www.cs.princeton.edu/~schapire/maxent/ and is free for academic use. If properly conducted, habitat models can be used to predict the relative probability that a given habitat unit is suitable (Manly et al 2010).

In order to predict likelihood of occurrence of OSF in wetlands on 4 quadrangles entitled Tumwater, East Olympia, Maytown and Lacey, I used occupancy data supplied by WDFW PHS, soil maps from NRCS, geology maps from WADNR and NWI wetland maps.

The following protocol was used for MaxEnt analysis:

1. Acquired species occurrence data points from the Washington Department of Fish and Wildlife

2. Acquired the following maps:

    a. Geology 24K from Washington Department of Natural Resources

    b. Thurston County soils from Natural Resource Conservation Service

    c. NWI wetland maps

3. Prepared an Excel spreadsheet from species occurrence data, selected only egg mass locations, converted the file to an .csv, then to an ASCII file for use in MaxEnt.

4. Ensured extent and cell size were identical. Adjusted cell size to 30 m.

5. Converted soils, wetlands and geology maps to raster format for MaxEnt

6. Entered species data and 3 environmental categorical layers into MaxEnt for analysis.

7. Entered species data (as training data) and 3 environmental layers (as categorical data) into MaxEnt for analysis. Training locations overlapped the environmental layers.

3. RESULTS

Results of this project should be useful for resource agencies tasked with identifying historical or potential habitat.

Wetland Survey results

Surveys were conducted in 17 wetlands meeting the Tier 1 criteria (Germaine and Cosentino 2004), i.e., within emergent wetlands of adequate size with hydric soils near aquatic permanent water. These surveys in 2014 did not generate any additional geographic locations for OSF within the wetlands surveyed for this project. Besides surveying for presence of OSF oviposition, I also observed a range of private landowner activities that could influence habitat for OSF. Five of the 17 wetlands were ditched historically but had not been maintained and beaver activity was creating a diversity of habitats. At 7 wetlands, most grazing had terminated and a mosaic of native wetland plant communities, invasive canary grass and shrubs occurred. However, native emergent wetland communities persisted near reed canary grass in wetlands adjoining both the unmaintained North Pitman Ditches and the maintained Spurgeon Creek ditch. Four wetlands were lightly grazed, and two hayed or mowed.

Three previously reported occupied wetlands I visited this year had active beaver activity unimpaired by anthropogenic activities. Specifically, Fishpond North wetland and Salmon Creek wetlands have beaver dams downstream of oviposition locations and egg deposition areas are maintained as short grass by pruning shrubs and brush-cutting in late summer. Abandoned gravel roads adjoin breeding areas, and egg masses have been detected on these abandoned gravel roads when water levels were adequate. Salmon Creek wetlands was formerly grazed, Fishpond was a former active blueberry farm. Fishpond South wetland has beaver activity but a dam was not observed. Both Salmon Creek and Fishpond North have unmaintained ditches and excavated ponds.

Environmental parameters at occupied sites.

Environmental parameters occurring at occupied wetlands and oviposition locations within these wetlands were identified and characterized using GIS tools, MaxEnt, literature reviews and basic statistical analysis.

Vegetation at oviposition sites

The average ratios of wetland categories at 12 occupied wetlands was 7% aquatic, 56% shallow palustrine emergent and 37% palustrine scrub-shrub (Figure 2).

In 2013, most egg mass deposition occurred on emergent wetlands with the next highest number of eggs occurring on ‘disturbed’ (Figure 3). In 2 wetlands most eggs were deposited in what appeared to be scrub-shrub in aerial photos. The ‘disturbed wetland’ category suggests agriculture or other anthropogenic activities.

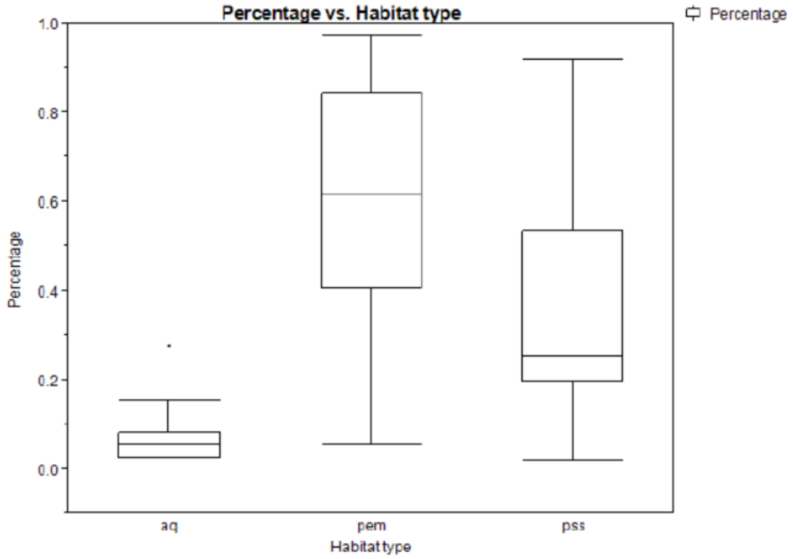


Figure 2. Ratios of wetland NWI categories at occupied wetlands.

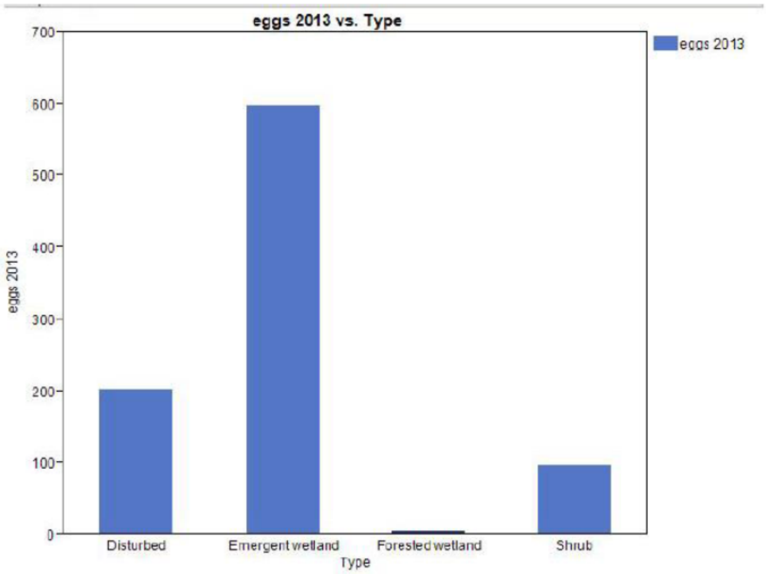


Figure 3. OSF egg mass deposition primarily occurred in emergent wetlands.

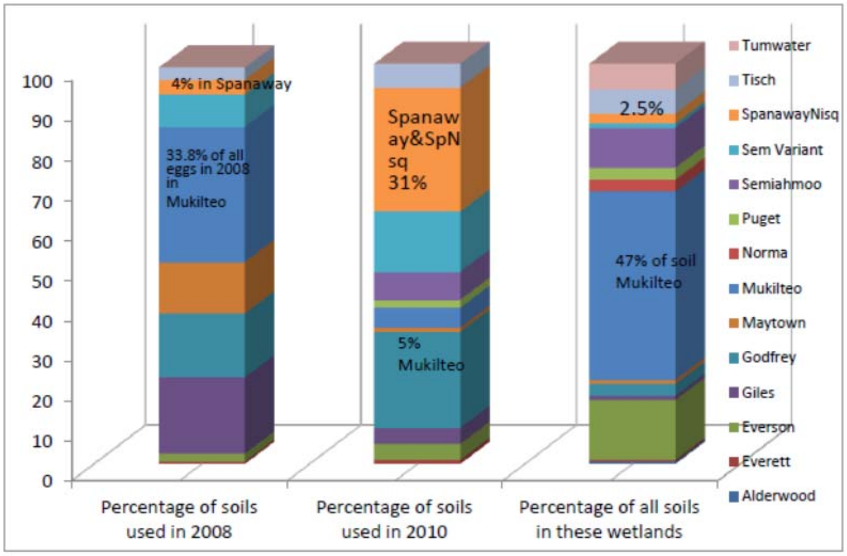


Figure 4. Soils use in proportion to availability.

Soils at oviposition sites

I first screened the data for egg masses. Then GIS tools were used to intersect the egg mass deposition locations by soil type. I calculated the number of egg masses on each soil type by year (Table 1 in Appendix). Of 507 records of egg mass occurrences from 1994 to 2013, a total of 8057 masses were documented on 15 soil types over the years of surveys. Eggs were deposited in clumps with an average of 15.41/cluster (standard deviation 24.9, range of 1 to 304 per cluster) that varied by soil type (Table 1).

I was able to acquire data for most sites since they were surveyed. Because some sites had no data available from 2011 to 2013, I was unable to assess soils used by OSF at these sites between 2011 and 2013. However, prior to 2011, egg mass deposition documented on other sites was used to assess use v. availability.

My hypothesis that the egg deposition sites are not equally distributed among soil types on several wetlands (Figures 6-9, Table 2 in Appendices) was accepted for some years in some wetlands. For instance, in 2010, frogs appeared to be using certain soils for egg mass deposition (Tables 1, 2, 3, Figure 4). Significant differences exist between the expected and observed number of eggs per unit area of wetland soil type at most wetlands where the sample size is high enough (Table 2 in Appendix).

For instance, while Mukilteo soils appeared to comprise a large proportion of the wetlands, in 2010, only 5% of eggs were deposited on Mukilteo Muck in that year. This contrasts with 2008, when almost 34% of eggs were deposited on this soil type (Figure 4). These results contrast with Spanaway/Spanaway-Nisqually soils, that represented only 2.5% of the surface area of the wetlands I digitized, but in a few years had high egg mass deposition. (For purposes of this analysis I combined egg masses on Spanaway and Spanaway-Nisqually).

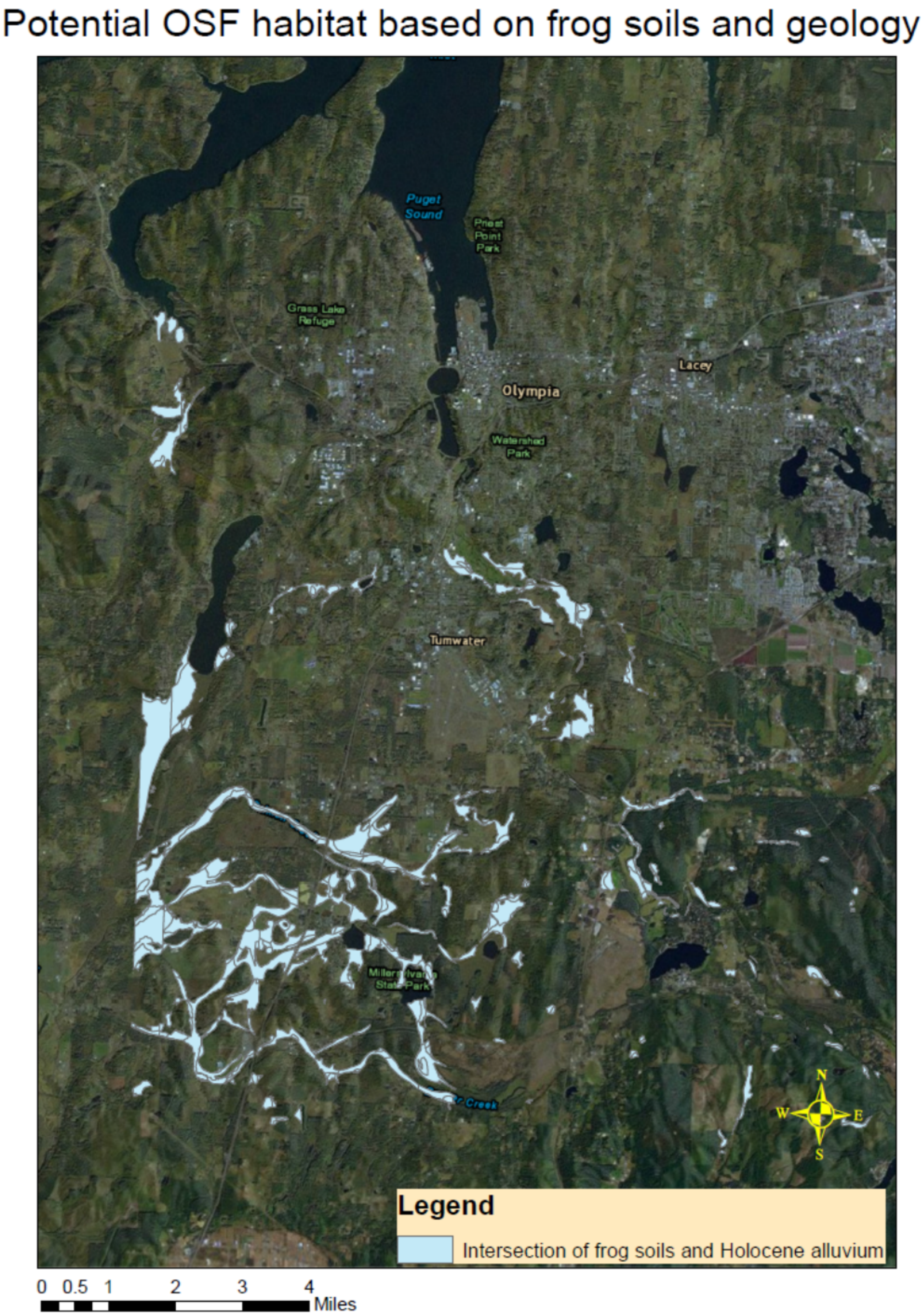


Figure 5. Potential OSF habitat based on Holocene alluvium and 15 used soils.

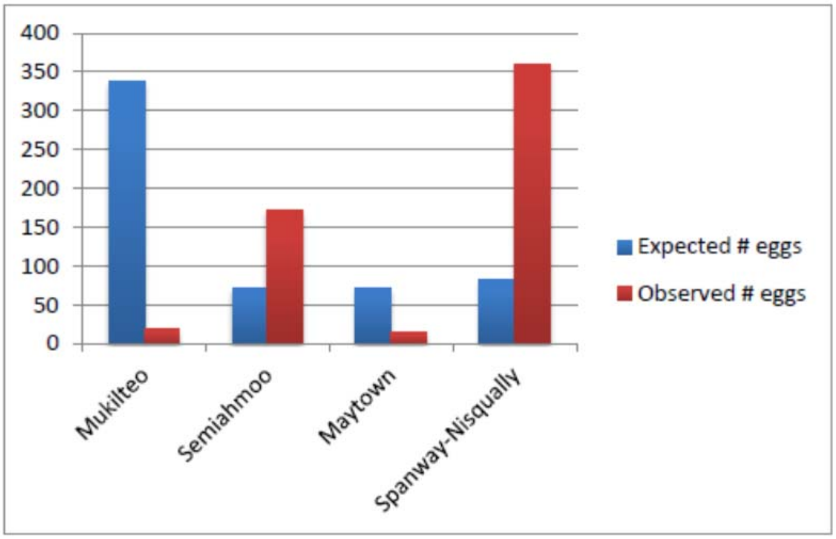


Figure 6. Soils not used in proportion to their availability at Site 1. Chi-Squared = 1431, d.f.= 4, p < 0.001

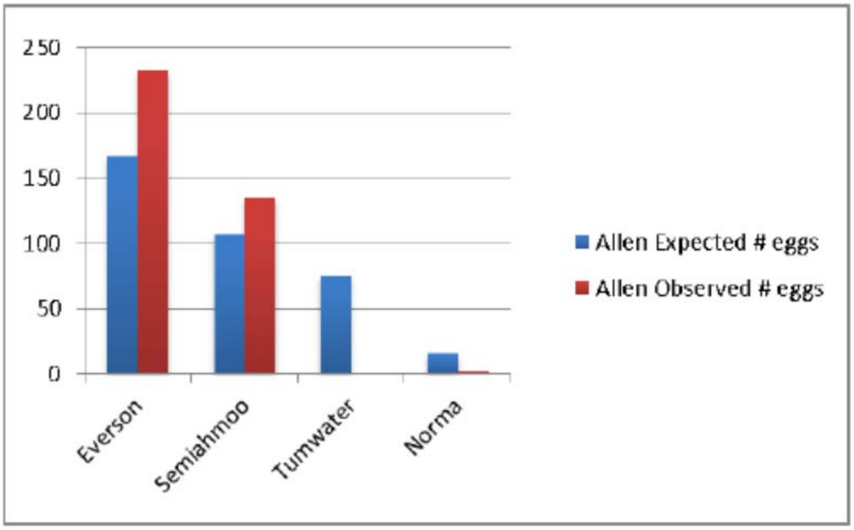


Figure 7. Soils were not used in proportion to their availability at Allen site. Chi-squared = 123.88, d.f.= 4, p < 0.001.

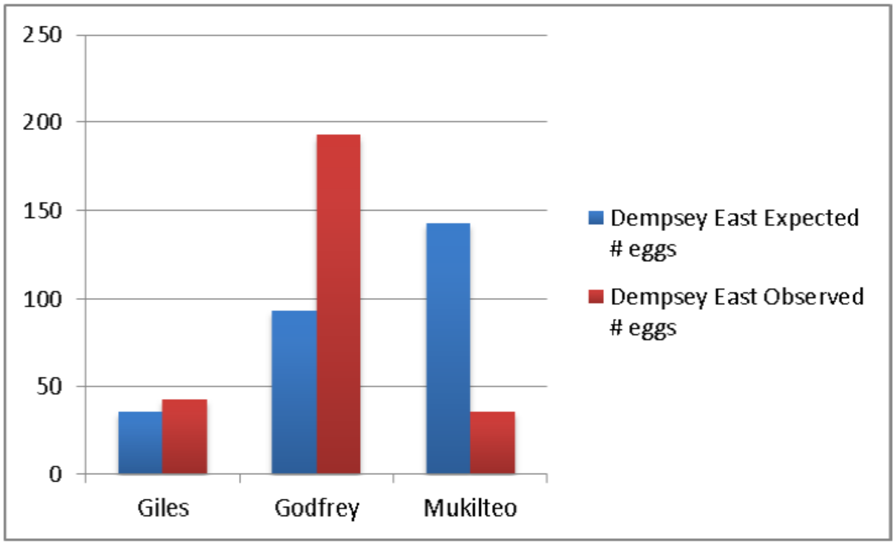


Figure 8. Soils were not used in proportion to their availability at Site 9. Chi-squared = 189, d.f.= 2. p < 0.001.

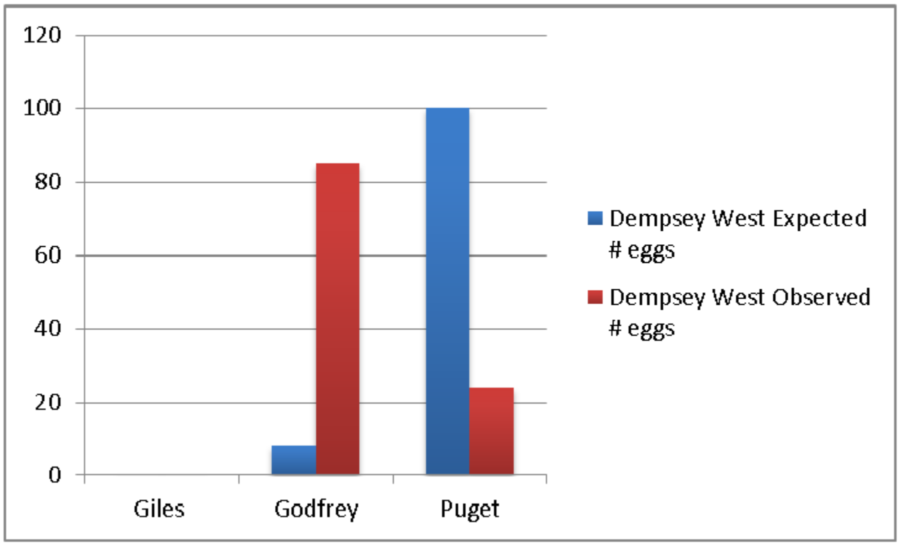


Figure 9. Soils were not used in proportion to their availability in 2010. Chi-squared = 799, d.f.= 2, p < 0.001

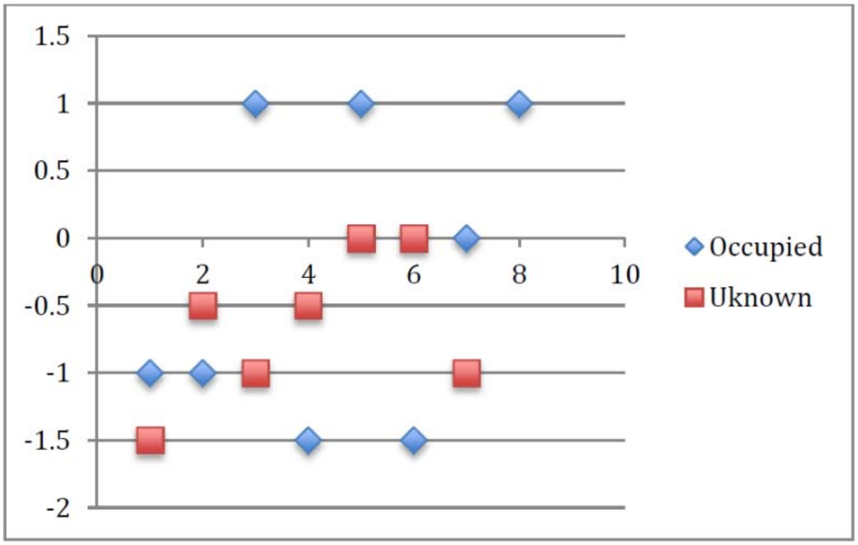


Figure 10. Water tables at most occupied wetlands higher than other hydric soils.

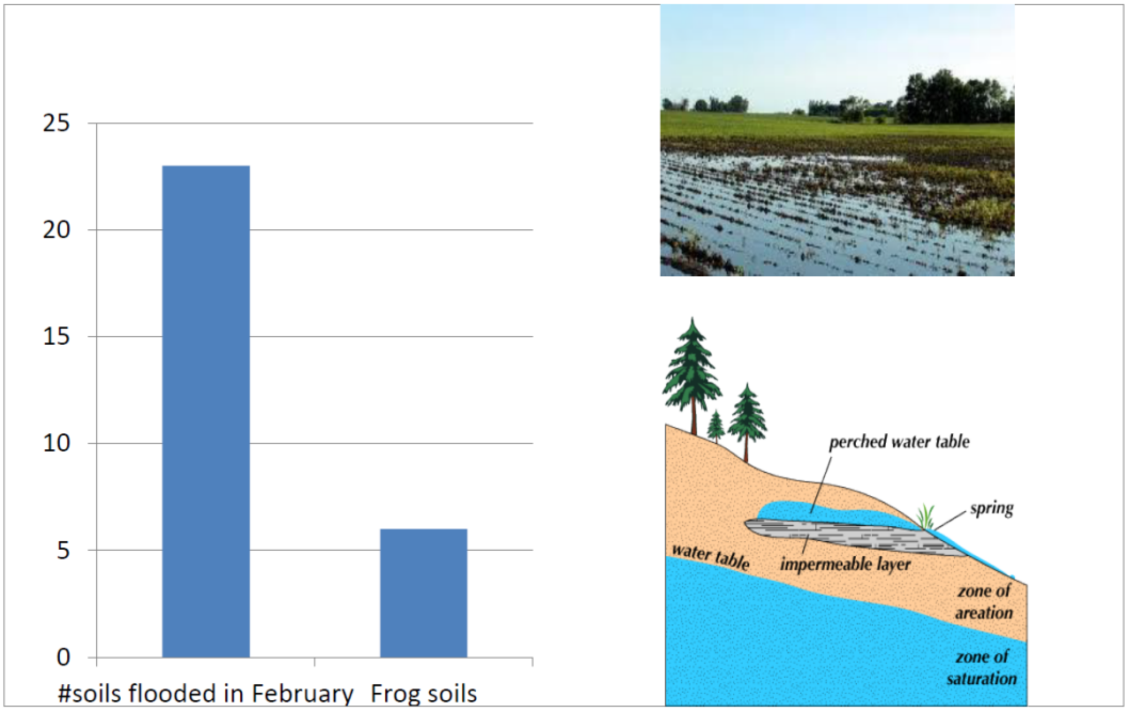


Figure 11. 23 soils in Thurston county are characterized by temporary flooding in February, possibly attracting egg deposition.

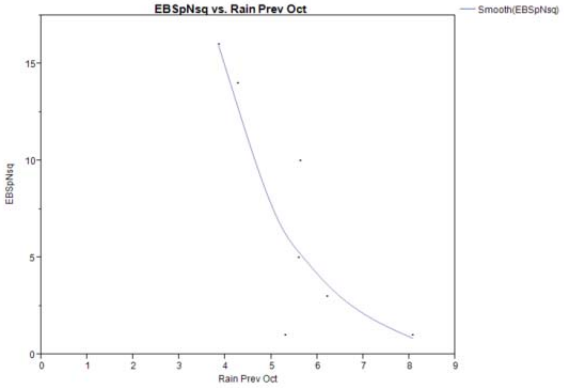


Figure 12. Egg mass deposition on combined Spanaway-Spanaway-Nisqually soils at one site.

In 2013 (from data available in 2013), 9 soils occurred under the oviposition sites (Table 3) of which 5 were most common, consisting of Tisch, Everson, Mukilteo, Semiahmoo and Godfrey (Table 3 in Appendix).

Geology at oviposition sites

Of 248 total records of OSF on the Maytown and East Olympia quad, 212 occur on Holocene alluvium. The remaining records occur in Vashon Outwash (5), Vashon recessional outwash from the Tanwax-Ohop flood and Holocene peat (8) (Figure 13, Figure 14) ahd Holocene peat (10). Intersecting the 15 soils used for oviposition by the Holocene alluvium (Figure 5) generates a map depicting most the areas known to be occupied by OSF.

MaxEnt predictive model results

MaxEnt generated a map predicting potential suitable habitat on the Maytown, Lacey, Tumwater and East Olympia quadrangles based on environmental categories occurring at egg deposition sites on the Maytown quadrangle (Figure 18). Both soils and geology contributed more than wetlands to the distribution of OSF (Figure 18, 19, Table 4 in Appendix).

Breeding locations on Holocene Alluvium

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

Map by Nathan Nadaniceck and Bonnie Blessing

Figure 13. Most oviposition wetlands occurred in or near Holocene alluvium.

4. DISCUSSION

Wetland characteristics

Wetlands used for egg mass deposition exhibit a high ratio of emergent and shrub wetland to aquatic permanent water, with an average of 56% palustrine emergent, 37 % palustrine scrub-shrub and 7% aquatic habitat (Figure 2). Persistence of OSF in Thurston County may be partially attributed to extensive shallow wetlands. In the Willamette Valley, where the OSF was once considered abundant, the historically high ratio of shallow wetlands to permanent wetlands (Hulse et al 2002) has changed to a high ratio of permanent to shallow. Decline of OSF was partially attributed to the extensive conversion of shallow wetlands to permanent wetlands as well as vegetation succession to scrub-shrub (Cushman and Pearl 2007, Pearl and Hayes 2005).

Vegetation

As predicted, most vegetation occurring at oviposition wetlands was palustrine emergent in 2013 (Figure 2). This is consistent with literature (Cushman and Pearl 2007, Watson 2003, Licht 1971). However, not all oviposition occurred in open palustrine emergent wetlands (Figure 3). Some egg deposition occurring in or near shrub. Use of shrub outside of breeding season is reported (Popescu et al 2013 Watson 2003). The canopy cover and water temperature of the scrub-shrub wetlands these organisms deposited eggs in should be measured in the field.

Soils

Over the years of surveys, 15 soils were used for oviposition in the occupied wetlands (Table 3 in Appendix). In the oviposition wetlands, the soils were not used in proportion to their availability in most wetlands, with a statistically significant relationship observed in 4 wetlands in several years (Figures 4, 6-9, Table 2). This may be partially attributed to water depth, habitat enhancement, vegetation composition or proximity to aquatic habitats.

Variation in egg deposition may be attributed to selection but also possibly to habitat enhancement or intrusions of unmapped Norma soils into Spanaway-Nisqually soils (personal communication Dahlke 2014), or higher than average water tables in some years. At one site with Spanaway-Spanaway-Nisqually soils, egg masses were only reported on years with greater than average rainfall the previous year, but as rainfall increased the number of egg masses declined (Figure 12).

Notwithstanding oviposition on specific soils, these results should not preclude the occurrence of OSF on other soils. However, certain characteristics of the highly occupied soils may contribute to species persistence. All occupied soils occur in alluvial valleys in aquatic corridors and most soils were characterized in the soil surveys by a high water tables. But not all.

I had expected all soils used for oviposition to be characterized by a relatively stable water table and an apparent rather than perched water table (Figure 10 and Figure 11). For instance, when I excluded the specific soils with a low water table, average depth to water table decreased with increased egg deposition, but the results were not significant (r-squared = 0.017).

However review of other egg deposition from data from before 2011 suggest oviposition on several soil types characterized as well draining with a water table lower than 6 feet (Figure 12). In fact, egg deposition was greater than expected based on area of the soil (Table 2) at two locales. However, in all cases, these soils adjoined soils with a high water table.

Limitations of this analysis may include variable survey effort but eggs were deposited on these soil types and variation existed between the use and availability.

Use of soils may vary by life stage but that was not the focus of this study. This frog deposits eggs in shallow portions of wetlands, moving to deeper portions as water levels decline. Soils would be expected to differ between shallow and deep water. Some combination of soil types may then be ideal to ensure adequate habitat for all life stages.

Position in landscape of occupied soils

Most soils occurred in riverine depressions or glacial uplands. Godfrey soils consist of deep poorly drained soils formed in recent alluvium on floodplains. Everson, Spanaway, Spanaway-Nisqually, Everett and Tisch occur in level depressional areas or terraces in glaciated uplands (Ness 1958, Pringle 1990). Giles soils develop on young terraces in sandy soil under forests. Spanaway, Spanaway-Nisqually and Everett soils develop on young terraces under grasses, consist of black loam and glacial deposited gravel, but are considered well drained. Ditch excavation to lower water table was recommended in order to undertake agricultural activities in many of these soils (Ness 1958).

Parent material of occupied soils

Soil parent material was highly variable, ranging from mineral to organic and consist of diatomaceous earth, clay, glacial deposits, alluvium, volcanic ash or sedges and grasses. Parent material included:

1) grasses and sedges (Mukilteo and Semiahmoo)

2) Diatomaceous earth, (Tisch soils)

3) Mineral matter such as alluvium, sand and volcanic glass, silt and clay (Everson, Norma, Giles, Godfrey) under forest or grasses

4) Mineral matter such as gravel and sand underneath organic black soil (Spanaway, Everett, Spanaway-Nisqually)

Organic soils in occupied wetlands include Mukilteo, SemiahmooVariant, Semiahmoo and Tisch soils, which are derived from sedges and grasses or diatoms, respectively. Mukilteo Muck tends to develop in low spots in the landscape, is acidic, with surface layer of muck and various layers of clay and sand underlain by undecomposed grass/sedge material. Semiahmoo is more decomposed than Mukilteo but is euic. The high water tables of Mukilteo and Semiahmoo soils facilitate organic matter accumulation. These soils form in frost pockets (Ness 1958). The 1958 soil survey indicates that frost occurs almost every month of the year in most Mukilteo soils, affecting agricultural activities (Ness 1958). These cold conditions may contribute to the preservation of the fibrous nature of the peat. Whether frost pockets still occur is unknown and how they affect the organism in this region is relatively unstudied. However, *Rana pretiosa* move around under ice in winter, possibly to locate dissolved oxygen (Hayes et al 2001), but OSF embryos from Central Oregon tolerate low temperatures (Bowerman and Pearl 2010).

Mineral soils include Spanaway, Spanaway-Nisqually, Godfrey, Norma, Everson, Maytown, Giles, Everett, Tumwater and Yelm, and are derived from alluvial or glacial deposits. Tisch soils, high in both volcanic ash and diatomaceous earth, occurred at one wetland that has had recent habitat enhancement. Everett and Giles soils are considered andic (Pringle 1990). Spanaway soils were once considered andic (Pringle 1990, NRCS 2012).

One soil property that influences the growth of canary grass is soil consolidation. Soils under glaciers became consolidated (Boulton 2006). In one study, areas without *Phalaris arundinaceae* had consolidated subsoil, while *Phalaris arundinaceae* exhibited >50% cover in loose soil (Foster 2003). Recently deposited alluvium is usually not consolidated until it has been compacted. Most of the egg mass deposition locations are in recently deposited alluvium.

Water table of soils in occupied wetlands

In 2013, most OSF oviposition occurred on soils characterized by a relatively high stable water table relative to other hydric soils (Figure 10, Figure 11). However, my expectation that all soils used for oviposition would be characterized in the soil surveys (Pringle 1990) as having a high water table in all cases was not met.

However in all cases, these soils characterized in the soil surveys as having a low water table (specifically Spanaway-Nisqually, Spanaway and Everett) adjoined larger wetlands with soils characterized in soil surveys by high water table. Unmapped Norma soils may intrude into the Spanaway complex soils (personal communication E. Dahlke 2014). However, at one location, oviposition on Spanaway and Spanaway-Nisqually soils occurred in years that followed years with greater than average rainfall (Figure 12). However, this evidence of egg deposition on non-hydric soils such as Spanaway-Nisqually and others strongly suggest that soils occurring near deeper wetlands may be used for egg mass deposition and hence, important to the persistence of the organism.

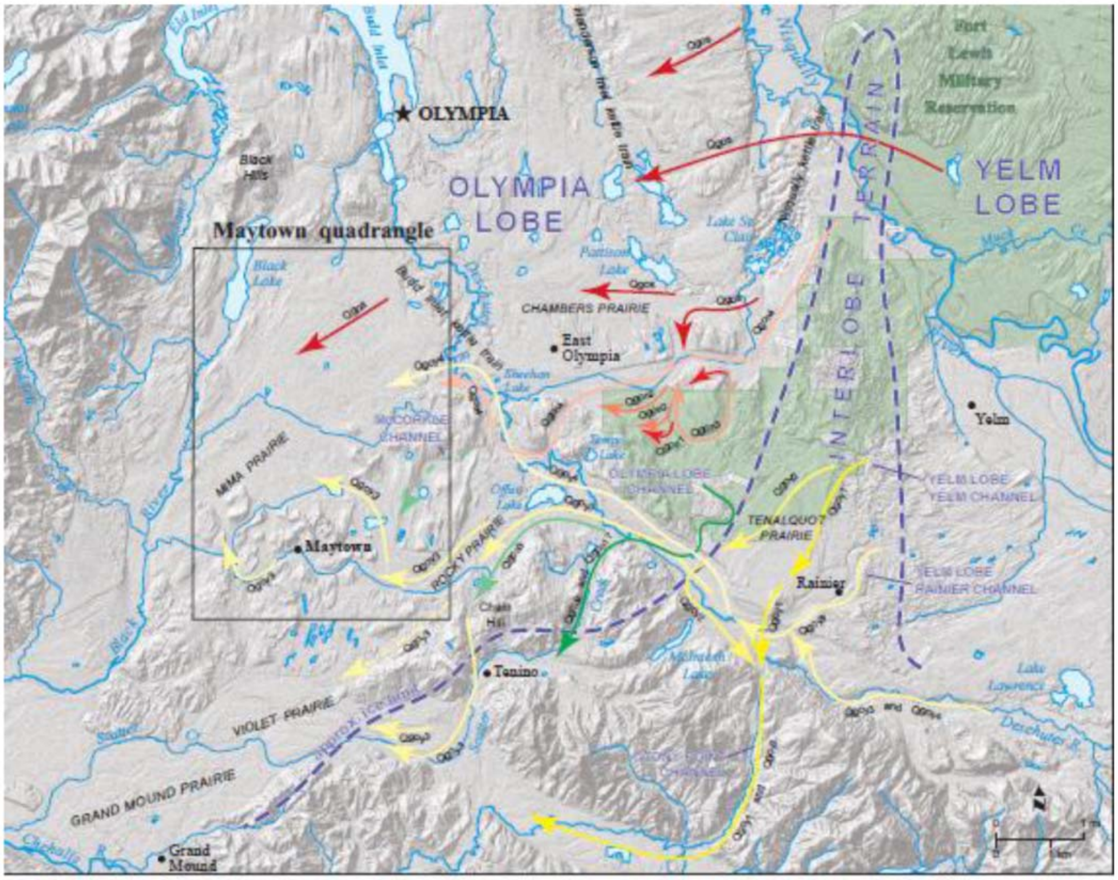
Geology

Most OSF oviposition occurred in Holocene alluvium (212 of 248 records), other oviposition occurred in Holocene peat (Qp), Vashon recessional outwash sand and silt (Qgos) and Vashon recessional outwash from the Tanwax-Ohop glacial flood (Qgoy3) (Figure 13). The prevalence of OSF on Holocene alluvium or low terraces is consistent with their current association with long aquatic corridors in flat terrain where dispersal through moist habitats is facilitated. However, alluvium is often unconsolidated, facilitating growth of reed canary grass. Use of Holocene peat, and Vashon outwash geology only occurred when proximal to Holocene alluvium. Some Holocene alluvium appeared to occur in extant or previous aquatic corridors that were oversized valleys formed from Pleistocene glaciation and subsequent deposition in the post-glacial Holocene era. Tools used to identify Holocene alluvium include LIDAR (Figure 15 and 16) and maps depicting post-glacial outburst floods from Glacial Lake Carbon and Glacial Lake Russell (Figure 14).

LIDAR imagery emphasizes the topographic flatness that characterizes Columbia Spotted Frog habitats in Idaho. In Thurston County, LIDAR images (Figures 15-17) depict flat topography at occupied wetlands.

Much of the OSF known extant occurrences in Thurston County lie along the margins of the former Puget lobe of the Vashon Glaciation. As the glaciers advanced and retreated, a series of pro-glacial lakes developed (Booth 1987) which occasionally spilled out through various drainageways (Bretz 1913). Field investigations of sediment characteristics suggested deposition of sediment through an area (Goldstein 2010) bounded by the distribution of OSF in Thurston

County (Figure 14) by a post glacial flows from Glacial Lake Russell and Glacial Lake Carbon. The extent to which this disturbance affected OSF in post-glacial or more recent times is unknown. However, MaxEnt results suggest geologic history contributes to likelihood of suitable habitat for this species (Figures 18 and 19).



re 7. Lidar shaded-relief image showing progressive meltwater paths during ice withdrawal from the southern Puget Lowland. Modified from Walsh and Logan (2005). Not all of the outwash units in the East pia quadrangle (Walsh and Logan, 2005) are present in the Maytown quadrangle.

Figure 14. Post glacial flooding from the Tanwax-Ohop flood overlapped the Maytown quad.

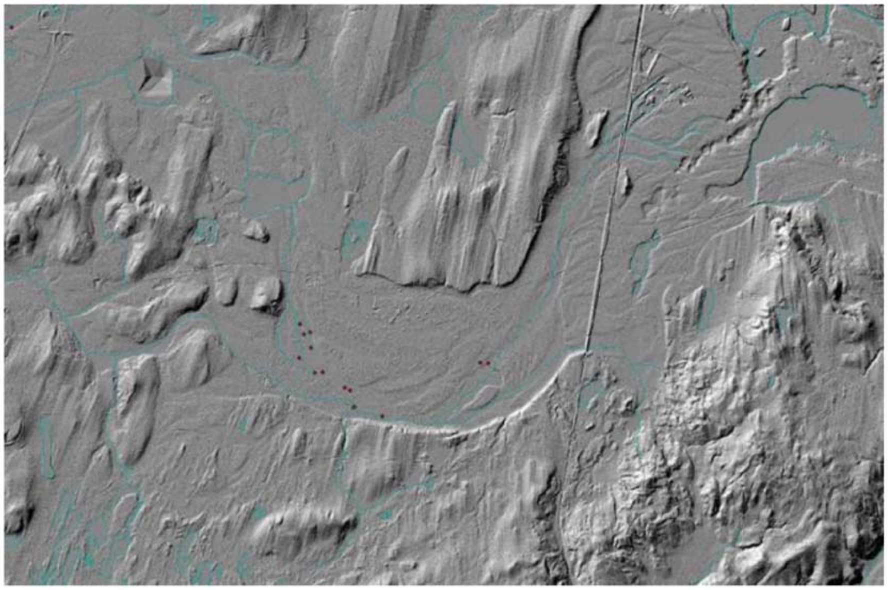


Figure 15. Egg mass deposition locations on LIDAR.

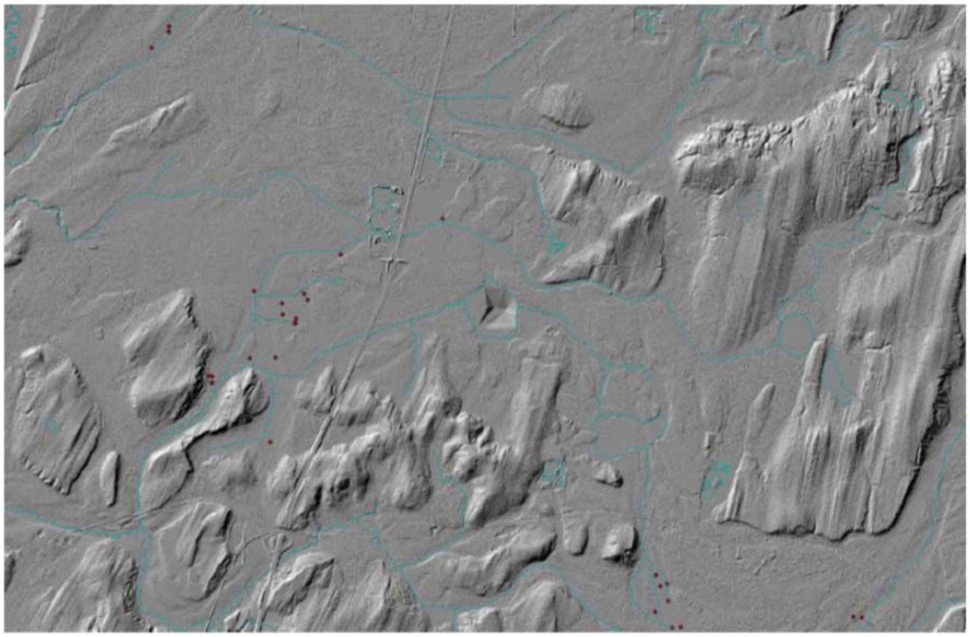


Figure 16. Egg mass deposition on streams on LIDAR image.

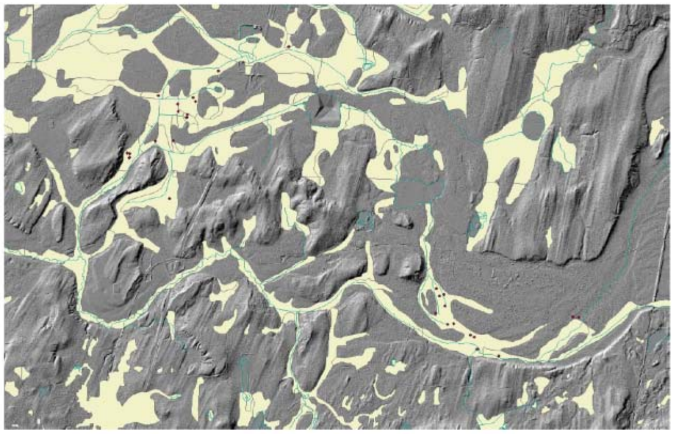


Figure 17. Egg mass deposition on soils overlaying LIDAR imagery.

While most OSF were detected on Holocene alluvium, my methods did not test for differences in abundance due to geology. To confirm this association with Holocene alluvium, surveys should be conducted in other suitable habitat on other geologic strata such as Holocene peat, Vashon outwash, Pleistocene wetlands. Water quality parameters that may also differ between Holocene alluvium and Holocene peat include pH and organic acids.

Because the distribution of OSF may be partially attributed to geologic and climatic history, a review of geologic history of Thurston County is provided below:

The history of the geology underlying OSF locations in Thurston County begins with the deposition of igneous or marine sediments during the Eocene epoch (Drost 1993). These geologic strata underlie most wetlands, in some cases influencing water tables underlying OSF wetlands. For instance, the high water table at one locale was attributed to Eocene igneous deposits underlying Holocene alluvium (Pacific Groundwater Group 2001) but the Eocene deposits in this area have relatively high levels of aluminum oxide (16%)(Logan and Walsh 2005) . These marine sediments may be responsible for high salt levels in groundwater in some parts of Thurston County, including near Offutt Lake (Drost 1993). Specifically, high chloride in groundwater near Offut Lake is attributed to connate seawater trapped in Marine tertiary marine rocks such as the McIntosh formation of Eocene age (Drost 1993). Seawater was presumably trapped in the sediments as they were deposited (Drost 1993). The extent to which this groundwater influences wetland quality in OSF habitat several miles away is unknown. Anurans do not deposit eggs in saltwater. However, high chloride (and high conductivity) reportedly improved OSF tadpole survival by increasing conductivity (McKibbin et al 2008). Others have reported a positive association between high conductivity water and western toad abundance and survival (Hawk 2000, Hecnar and McCloskey 1996, Klaver et al 2013, Loman and Lardner 2006). The extent to which the high chloride in groundwater near Offutt Lake could affect amphibians is unknown.

While the Eocene deposition of igneous material and marine sediments underlies most of Thurston County, most surficial topography was subsequently shaped by the glacial advances and retreats (Booth 1987), followed by alluvial or ash deposition, which overlay the Eocene deposits. (Bretz 1913, Logan and Walsh 2009). Glacial advance and retreat resulted in redeposition of gravel and sediments, formation of existing lakes, formation of freshwater lakes that no longer exist, kettle pothole lakes that can still be seen today, and oversize valleys (Bretz 1913). These landforms shape the biogeography of the region, possibly contributing to the distribution of species in Thurston County. In Thurston County, no OSF are known to occur in extant kettle lakes entirely bounded by uplands, but these have perhaps not been surveyed. But extinct lakes shaped habitat that persist to this day.

As the Vashon glacier receded, Glacial Lake Russell, Waddell Creek Lake, and Glacial Lake Carbon formed near the terminus of the glacier (Crandell 1965, Bretz 1913) eventually overflowing (Goldstein 2010, Bretz 1913) through the extant distribution of OSF in Thurston County (Figure 14). Glacial Lake Russell drained through the Black river-Chehalis Basin. Glacial Lake Carbon mobilized the Lily Creek formation near Mount Rainier depositing andesite-rich sediment in a large swath through Tanwax and Ohop Creek, crossing the extant Deschutes past West Rocky prairie, finally terminating west of the range of OSF in Thurston County (Figure 14) (Goldstein 2010, Logan and Walsh 2009). Chemical analysis of Lily Creek formation near

Mt. Rainier reveals it is similar to andesite found at the West Rocky Prairie Mima mounds in Thurston County (Goldstein 2010). Finally, a glacial lake near the mouth of Waddell Creek spilled out temporarily west then eventually drained through the Black River system (Bretz 1913).

Not just glacial activity, but volcanic activity contributed to distribution of flora. However, the extent to which volcanic ejecta influence extant distribution of fauna seems enigmatic. Volcanic ejecta have been deposited in both pre and post-glacial times in Western Washington. Mt. St Helens has had 19 eruptions in the past 13000 years, Glacier Peak 8 eruptions in the last 13000 years, Mt. Rainier 14 eruptions and 4 large lahars in the last 9000 years, Mount Adams has had 3 in the last 10,000 years with the most recent between 1000 and 2000 years ago. Volcanic ash from Mount Mazama deposited in a wide range (Williams and Goles 1968) and includes the entire range of OSF in Western Washington as well as Oregon. After the retreat of the glacier and its associated glacial lakes, deposition of volcanic ash in Thurston County is attributed to volcanic eruptions by Mt. Mazama, Glacier Peak, Mt Rainier and Mt. St. Helens (Wilcox 1965, Fryxell 1965) and is found in layers in bogs (Rigg and Gould 1957). Depending on composition of ash, soils formed in volcanic ash may store calcium magnesium and potassium, possibly beneficial to frogs, but may also have andic properties due to presence of volcanic glass, aluminum, high surface reactivity and low bulk density. Volcanic ash influences vegetation communities in the Pacific Northwest (Kimsey et al 2007), possibly due to aluminum toxicity during low pH (Dahlgren 2004, Takahashi et al 1995, Takahashi et al 2010). The extent to which aluminum-humus complexes occur in wetlands in Western Washington is unknown but due to the prevalence of volcanic deposition and organic matter, may occur in wetlands in Thurston County. Aluminum often occurs in andic soils. At least 13 soils in Thurston County are categorized as andic soils, which form in volcanic ash (Pringle 1990) and include Everett and Giles soils (Pringle 1990).

Wetland survey results

Surveys were conducted in potential wetlands for occupancy. Surveys were conducted because understanding the numbers of wetlands occupied as well as dispersal and rates of extinction are key for understanding metapopulations (Levins 1970). I found no additional populations within wetlands surveyed for this thesis. However, one year of surveys are not generally considered sufficient to confirm occupancy. Moreover, not every wetland identified as high quality habitat could be surveyed either due to landowner resistance or lack of resources. But, in order to establish the distribution of any rare species, a large number of units would need to be surveyed (McDonald 2004). Success in the study of rare populations may require (1) the sampling procedure be spread out over the entire area and 2) survey methods must be developed to achieve some level of minimum probability of detection (McDonald 2004). I only sampled in one portion of the organisms range and could not assess probability of detection, which may vary by habitat type.

I focused my searches in palustrine emergent habitat because most literature and anecdotal observations supported evidence of egg oviposition locations in emergent open wetland areas. However, to confirm the dominant use of one habitat type, surveys of ‘unsuitable’ habitat, either atypical or distant from occupied sites (McDonald 2004) are needed confirm habitat associations. Similarly, for rare species, Poon and Margules (2004) recommended the following approach: 1) map existing records, 2) identify survey gaps in environmental space, 3) conduct field surveys to fill those gaps, 4) construct spatial models to predict likely locations and 5) conduct field surveys to test predictions.

Because existing records are mapped, most local naturalists attempt to fill in survey gaps, but because of limited resources to conduct surveys across all wetlands, my thesis focused on habitat relationships at occupied wetlands.

But, even if strong spatial models are developed from habitat relationships, the likelihood of both maintaining habitat and understanding the distribution of a rare species is determined by values held all the stakeholders of conservation efforts, including private landowners.

On privately owned lands, management of rare species occurs as a result of management activities. Landowners I spoke with valued privacy, preferred views of meadows rather than shrubs, valued sustaining a ‘way of life’ and connections with nature, all of which may support management for wildlife.

Other research conducted on landowner responses to the Endangered Species Act (1973) provided further evidence of the importance of landowner values:

Aesthetic preferences, recreational activities, social factors, personal values, being allowed responsibility for restoration of the species, and residence status (i.e. living on the land) influenced landowner responses to species listing and management practices affecting the Preble’s meadow jumping mouse (*Zapus hudsonius preblei*) (Brook 2003). Specifically, these factors strongly influenced whether surveys would be allowed and whether they would participate in management to maintain the organism.

MaxEnt Results

MaxEnt results suggested that soils and geology contributed to the suitability of habitat for Oregon Spotted Frogs. This may be partially attributed to the fact I used egg mass deposition locations, which may be deposited in wetland margins not identified as wetlands in the electronic predigitized maps I used. Moreover, I had a small sample size, consisting of oviposition sites on one quadrangle. Finally, the statistical rigor underlying MaxEnt is scrutinized, especially when environmental categories are correlated, such as soils and geology. Nonetheless, MaxEnt predictions may be a valuable tool to identify suitable habitat.

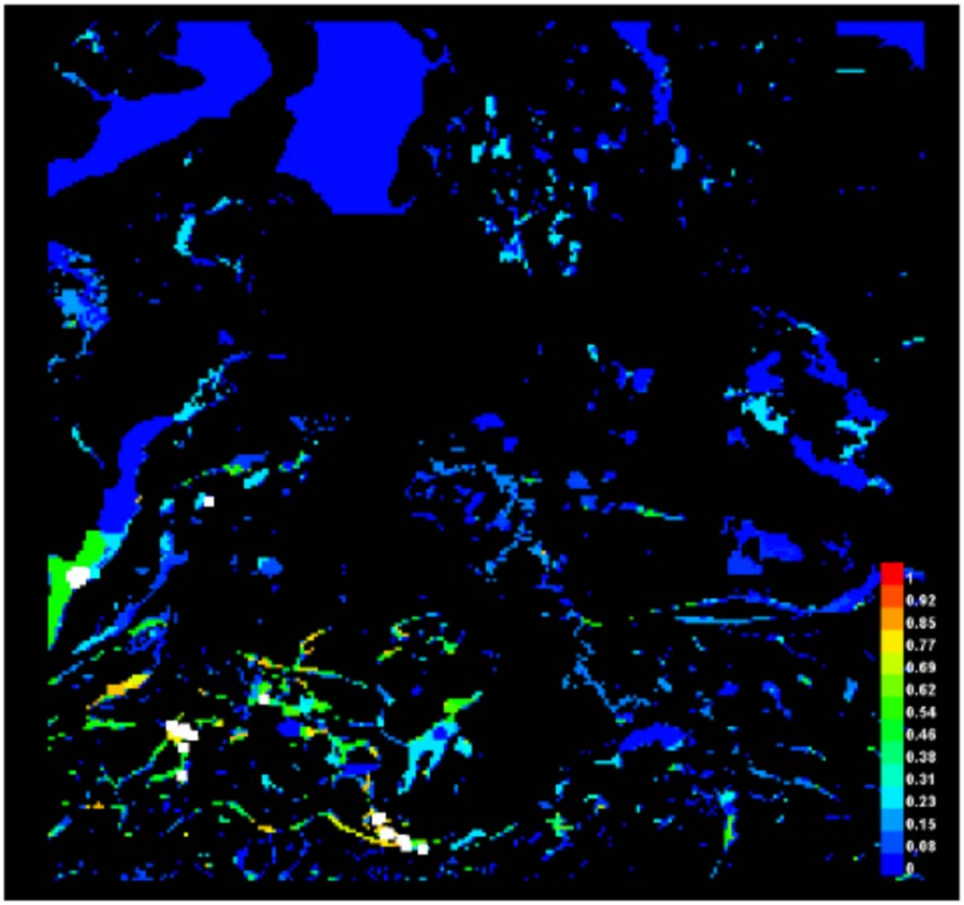


Figure 18. Maximum Entropy Modeling Imagery depicting habitat suitability.

Figure 19. Jacknife of regularized training gain for OSF suitable habitat.

5 CONCLUSIONS

My research provides a preliminary assessment of the factors underlying OSF local distribution. However, my results suggest ratios of wetland vegetation, soils and geologic history underlie distribution of OSF in Thurston County. An assessment of specific soil properties, wetland complexity and geologic parameters at OSF locales should be conducted across the range of the species, especially as new sites are found. An assessment of soil use and availability should be conducted with adequate sample size and survey effort. I could rule out no hydric soils due to my small sample size. The effect of soil consolidation (by compaction from vehicle, solarization plastic, grazing, or addition of dolomitic lime) on growth of an invasive weed, *Phalaris arundinaceae* should be ascertained. Restoration ecologists should consider soil properties and wetland character that contributes to species persistence, as well as avenues of connectivity. Topographic flatness, which identified Columbia Spotted Frog habitat, should be compared between Columbia Spotted Frog locales and OSF locales. The effect of urbanization on wetland character, soil quality and connectivity should be ascertained. The extent to which connectivity between extant populations in Thurston County is facilitated by soils or geology could be tested with genetic methods. MaxEnt predictions of suitable habitat should be calculated or ascertained with field surveys. Finally, surveys should be conducted of all land stakeholders to assess conservation values, barriers to conservation measures and find creative means to manage working lands for wildlife.

Interdisciplinary nature and philosophical approach to this project

The study of habitat relationships is often interdisciplinary. This project is highly interdisciplinary because I used maps generated by other disciplines, such as botany, soils and geology to learn about factors underlying the distribution of a wildlife species.

My philosophical approach to this project is pragmatic, i.e., we should use whatever tools we have to explore natural relationships.

Many searches for this organism in suitable habitat have been unsuccessful. So I was wondering if there are explanations for the given distribution in Thurston County, other than surficial wetland vegetation characteristics and lack of urbanization in certain watersheds. Perhaps there are glasses that allow us to see historical or underlying conditions imperceptible to the naked eye. We use telescopes to see the moon and microscopes to view bacteria. Whether LIDAR, soils, geologic history reflects a previous habitat condition is enigmatic, but they are tools that can be employed to identify landforms. So I employed these tools to try to understand the distribution of habitat for this organism in Thurston County. I incorporated another novel tool called MaxEnt, which uses Bayesian methods to predict likelihood of occurrence of a species. MaxEnt sort of ‘eliminates’ unlikely habitat and informs us of the likelihood that an organism would ‘completely fill’ the remaining habitat, given the elimination of unlikely habitat.

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Appendix

Table 1. Mean number, standard deviation and range of eggs per cluster by soil type.

Soil Type	# Clusters over the years	Mean # eggs	Standard Deviation	Range
Everett	6	7.83	5.98	1 -15
Everson	71	12.18	13.59	1-56
Giles	39	17.82	23.4	1-110
Godfrey	87	25.2	26.23	1-100
Maytown	12	14	16.8	1-50
Mukiilteo	124	9.4	10.3	1-70
Norma	8	2.5	2	1-6
Puget	15	10.2	9.7	1-32
Semiahmoo	22	17	19	1-65
Semiahmoo Variant	24	26.7	43.98	1-181
Spanaway	24	30	64	1-304
Spanaway-Nisqually	19	6.7	4.9	1-17
Tisch	55	12.5	17.96	1-106
Tumwater	1	2		2
Yelm	1	1		1

Table 2. The difference between observed and expected number of eggs between soils by area in oviposition wetlands was statistically significant in 4 wetlands.

Site/Year	Soils (used soils bolded)	Expected # Eggs	Observed # eggs	Chi-squared, d.f. p-value. Discussion

		based on areal extent of soil in wetland		
Site 9	SPANAWAY	0.5	10	Chi-squared= 190. d.f.4, low sample size unreliable p-value
	Spana-Nisqually	0.5	0	
	Mukilteo	9	0	
	Norma	0	0	
	Alderwood	0	0	
Site 8	Mukilteo	1	1	Historical site
Site 1 Year 2010	Spanaway-Nisq	82	360	Chi-squared = 1431, d.f.4, p<0.0001
	Everett	10	10	
	Maytown	72	14	
	Mukilteo	338	18	
	Semiahmoo Variant	72	172	
Site 2 Year 2013	Everson	167	232	Chi-squared= 123.877, d.f=4, two-tailed p<0.0001
	Norma	16	2	
	Semiahmoo	107	135	
	Everett	4	0	
	Tumwater	75	0	

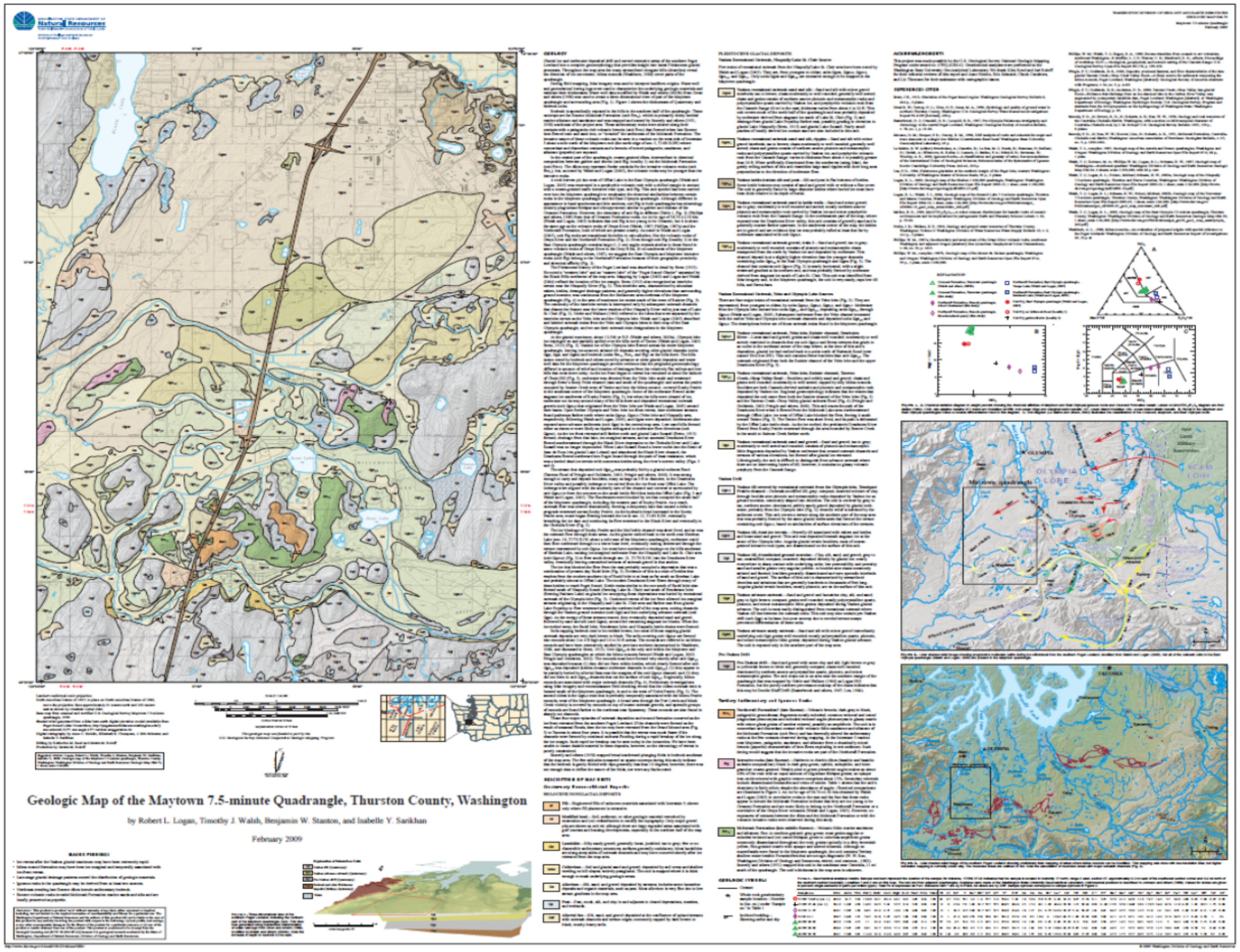
WRP-West	Everett	0	0	Expected = Observed.
	Tisch	66	66	
Site 6	Everson	24	25	Chi-squared=2.174 w/ 2 d.f. p=.3372
	Mukilteo	21	0	
	Everett	2	0	
Site 5	Mukilteo	21	24	Chi-squared= 3.429 w/ 2 d.f. p=.1801
	Norma	1	0	
	Tumwater	2	0	
Site 4 in 2010	Giles	1	0	Chi-squared=799.885, d.f.=2, p<0.0001
	Godfrey	8	85	
	Puget	100	24	
Site 3 in 2010	Giles	36	43	Chi-squared=188.951, 2 d.f. p<0.0001.
	Godfrey	93	193	
	Mukilteo	143	36	

Year	Godfrey	Giles	Puget	SpNsq	Mukilteo	Tisch	Spanaway	Yelm	Norma	Everson	Everett	Semiahmoo	Sem Var	Maytown	Tumwat
1996	49	116													
1997	82	43													
1998	80	2	37	5											
1999	173	9		28	1										
2000	183	39		16		107									
2001	19	67			77	59	13						28		
2002	93	22			11										
2003	109	40			236			1							
2004	110	6			187		7		1				117		
2005	127	27	20		5				1						
2005	127	27	20		5				1						
2006	65	48			35	36	1								
2007	142	50		11			81			30	15		2		
2008	122	127	17	10	285	20	17		1		4		58		
2009	202	56	23	16	90	29	291					1	241	73	
2010	278	43	28	19	54	63	322			66		76	198	14	
2011	143			3	56	42			15	182		111			
2012	111			14	35	63				30		54			
2013	107			10	99	266			2	437	14	135			

Table 3. Raw data with number of egg masses per soil type per year. Data was not available for all sites for all years.

Table 4. MaxEnt model results indicate that geologic type and soil type contribute to the occurrence. This is based on a small sample size and employed previously digitized wetland data. Strong spatial correlations occur between soils and geology.

Variable	Percent Contribution
Geology	49
Wetlands	7.3
Soils	44.7



Geologic Map of the Maytown 7.5-minute Quadrangle, Thurston County, Washington

by Robert L. Logan, Timothy J. Walsh, Benjamin W. Stanton, and Isabelle Y. Sarikhan

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Figure 20. Geologic map employed.