

The Effect of Agricultural Riparian Buffer Width  
on Generalist Natural Enemy Diversity

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**Abstract**

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Wooded stream buffers support food production, from fish to farms. While wider buffers of conservation woodlands do improve salmon habitat (Beechie & Sibley 1997), they decrease arable cropland. Riparian buffers do, however, benefit agriculture through erosion control, wind protection and habitat for beneficial species. Some of these beneficial species are termed “natural enemies,” as they are the traditional biological control, or predators, of herbivorous crop pests. Many beetles and spiders are prime examples of natural enemies because of their generalist feeding on several families of crop pests (Landis et al. 2000, Landis & Wratten 2002). There is growing support that greater natural enemy diversity correlates to a greater control of crop pests (Lehman & Tilman 2000, Gardiner et al. 2009) Using the Shannon-Wiener diversity index I measured the diversity as well as the abundance of generalist natural enemies moving between fields and riparian buffers at different spatial scales (5’, 15’, 35’, and 180’ wide buffers from the stream) during a corn growing season. The 180 foot buffer exhibited significantly greater natural enemy diversity during early corn growth suggesting that larger buffers can provide greater biological control when crops are most susceptible to pest outbreak.

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## Chapter 1: Introduction

Farmlands around the world are encircled by field margins that, depending on their size, structure and species composition, can benefit both crop production and the natural environment (Marshall & Moonen 2002). For centuries field margins have incorporated strips of trees and shrubs, often called hedgerows or vegetative buffers. With the progression of industrialized agriculture, woody field margins have obstructed machinery and seen greater fragmentation and removal globally (Petit & Burel 1998). The effects of these woody buffers on agricultural production and ecosystem health have received increased scrutiny in the past few decades, particularly in the wake of greater environmental consciousness and the rapid degradation of farmland soils (Lovell & Sullivan 2006, Marshall 2004). Buffers have been shown to reduce soil erosion (Deasy et al. 2009), improve water quality (B-M Vought et al. 1995, Dosskey 2001), increase biodiversity (Kleijn et al. 2006, Merckx et al. 2009), and reduce wind related evaporation (Burt et al. 2005) and the drift of agricultural pollution (Merrington et al. 2004). The direct benefits of buffers to agriculture are variable, with compounding effects that are difficult to value, which has led many farmers to choose to plant all available land in crops and minimize field margins.

Field margins along streams are of particular importance to the environment as they have greater potential to improve water quality and increase biodiversity (Jose 2009). Streams also play critical roles in supporting irrigation to farmlands. As streams are dynamic and under constant change, evaluating the benefits of vegetated field margins along streams adds additional levels of variability.

## **Riparian Buffers**

Riparian buffers, or corridors, consist of biotic communities growing along the shores of streams and other bodies of water (Naiman & Decamps 1997). These buffers are diverse, both in species composition and structure, because they are subject to frequent disturbance and interface between different ecosystems. Streams, or alluvial systems, are subjected to periodic flooding at varying levels throughout a century long cycle. This variable flooding, or mixed disturbance regime, results in the associated riparian buffer organisms being more resilient with more diverse adaptations than organisms in more static environments (Naiman & Decamps 1997). Streams also undergo a relatively rapid cycling of organic and inorganic material through channel processes of erosion and the deposition of those materials on the shore from upstream (Nilsson & Svedmark 2002). Additionally, a great number of terrestrial and aquatic organisms utilize streams and riparian corridors for food, water and shelter (Naiman et al. 1993). This fluctuation of disturbance along with diverse species and material composition lend to a dynamic and highly studied ecosystem.

Riparian buffers are particularly well studied in the Pacific Northwest because of the hydric environment and the presence of federally listed Salmonid species that utilize these buffered streams for spawning (Gregory & Bisson 1997, Bayley 2002). This area of study is complicated by the fact that many of the streams flow through both intensive agricultural, and highly urbanized lands. Pacific Northwest riparian buffers generally consist of woody vegetation and the resulting large woody debris that falls into streams, increasing the shifting sinusoidal, or meandering, dynamic of the river channel (Latterell 2006), and providing spawning habitat for Salmon and other aquatic organisms (Murphy

et al. 1984). The development of lands for agriculture, residential, commercial, and industrial purposes often leads to the removal of riparian vegetation, clearing of aquatic debris, and the straightening and dredging of streams, reducing spawning habitat (Pess et al. 2002).

The protection of Salmon species that are endangered or threatened and serve as an important food source has largely influenced riparian buffer conservation and restoration in the Pacific Northwest, particularly for levied farmland that was historically wetland salmon habitat. Government agencies are working together to determine optimal buffer widths for salmon habitat in Washington State (Cramer et al. 2002).

Recommendations vary for riparian buffer width in accordance with management goals, such as erosion control, water quality, and the provision of both aquatic and terrestrial habitat. Other factors can influence the effects of riparian buffer width including, slope, soil type, vegetation mix, and buffer type (Lee et al. 2004, Wenger 1999). Recommended buffer widths range from 10 to over 1000 feet wide and are made by academics and public institutions like the Army Corps of Engineers, the U.S. Environmental Protection Agency, and the U.S. Department of Agriculture (USDA). (Mayer 2005). One of the primary programs for developing riparian buffers in the United States is the USDA Farm Service Agency's Conservation Reserve Enhancement Program (CREP), which rents sensitive lands from farmers to take them out of production and conserve. The regional interest in determining optimal riparian buffer width for salmon habitat led to the funding of a complementary study in the Puget Sound measuring the effect of CREP riparian buffers of varying widths on stream temperature, with lower temperatures generally benefiting salmon. The study was supported by the King County Water and Land

Resources Division, King County Conservation District, Whatcom Conservation District, and Washington State University Extension. The study concluded that smaller buffers (5' and 15') were as effective at reducing maximum air temperatures as larger (35' and 180') buffers (Benedict et al. 2012).

The spatial scale of riparian buffers at both local and system wide levels are a common variable to measure the effects on environmental (Roth et al. 1996) and agricultural systems (Schultz et al. 1995).

## **Riparian Buffers and Agriculture**

Farmers incorporate riparian buffers into their agricultural landscape for a variety of reasons: some are required through governmental regulation, some volunteer to restore the landscape, and others utilize programs that pay to protect streams through a conservation easement. Many farmers and land managers are actively adopting buffer restoration onto their lands, particularly along streams, to shade out invasive grasses that increase evapotranspiration and reduce the farmer's access to water (Schilling & Kiniry 2007, Cavaleri & Sack 2010). The width of riparian woodlands along streams can be optimized to provide multiple ecological benefits to food production (Bottrell 1979). Agriculture benefits from some degree of woodland riparian buffer through erosion control, wind protection, and filtration of contaminants, as well as offering protection and food to beneficial species such as pollinators and natural enemies (Landis & Wratten 2002, Wilkinson & Landis 2005).

## **Integrated Pest Management**

Herbivorous insects that are pests to agricultural crops are influenced by both the availability of plant resources and the level of biological control from predation (Hunter & Price 1992). In homogeneous agricultural systems, or monocultures, plant resources are uniform, allowing for periods of explosive pest population growth because herbivorous pests can easily find and exploit crops (Root 1973). At the same time monocultures do not provide the protective habitat and stable food resources to support a robust population of predators to control the crop pests (Hunter & Price 1992).

In most farming systems pest control action is necessary in protecting crops, and integrated pest management, or IPM, is a method to control pest populations, pathogens and weeds holistically through a combination of best available practices. In IPM a series of steps are taken, first of which is to determine a threshold of damage that is allowable before the farming becomes economically unviable. This threshold, or economic injury level, varies depending on the species of pest and the environmental characteristics of the site. It is accepted that some population of pests will persist in an agricultural system and that efforts to completely eradicate the pest would be cost prohibitive, in addition to causing unnecessary damage to the environment, due to excessive chemical use, and expediting resistance to pesticide treatments (Andow et al. 1990).

Additional steps in IPM include the selection of varieties best suited to the environment, mechanical controls, biological controls and finally pesticide application. Pesticides are costly to purchase and apply so careful monitoring and record keeping are essential to create an effective and economic IPM regiment (Andow et al. 1990). In allowing herbivorous insect crop pests to persist at low levels in agricultural systems,

farmers also facilitate the consistent presence of the natural enemies (i.e. biological control) of those pestiferous insects (Hajek 2004).

IPM is contrasted by traditional industrial agriculture, which has relied increasingly on chemical pesticides as a primary step to control pest outbreak (Fernandez-Cornejo et al. 1998). Rachel Carson's novel *Silent Spring* (1962) was the bellwether to increased understanding of the impacts of pesticides like DDT on humans and the natural environment. Additional studies have shown the negative impacts of unconstrained pesticide use including increased pest resistance (Denholm & Rowland 1992, Tabashnik 1994) and the negative impacts to human health (Margni et al. 2002).

## **Natural Enemies**

Riparian buffers provide ideal habitat for many insect-eating (entomophagous) Arthropods (insects and spiders) by providing ecological stability through stable food sources and shelter (Wilby & Thomas 2002). A diverse and consistent food supply supports many orders of insects, including beneficial families of Hymenoptera (ants and bees) that utilize vegetation, nectar and pollen (Fiedler & Landis 2007). Buffers also support organisms at multiple levels of the food chain, including herbivorous and carnivorous arthropods, which are preyed on by families in the orders Araneae (spiders) and Coleoptera (beetles). A diversely vegetated riparian forest provides shelter in various forms, from the canopy down to the soil. The fact that this protection pertains to all arthropods including agricultural pests as well as natural enemies helps to maintain diversity across the food chain. The diverse environment, instead of allowing any one species to dominate, limits species success through predation allowing for more species

to utilize the available resources. Larger predators, such as birds and reptiles, within the buffer, maintain natural enemy diversity. In open fields, with less habitat protection, some natural enemies would be eliminated from the system by large predators, reducing diversity instead of maintaining it. (Naiman et al. 1993, Levin 2000, Landis et al. 2000). Wooded riparian buffers also create climate stability, allowing nesting and overwintering for natural enemies (Dennis & Fry 1992). A riparian buffer stands in sharp contrast to adjacent agricultural lands, generalized as a large homogeneous and vibrant vegetative food source that is vulnerable to pest outbreak. Additionally, agricultural land is often warmer and dryer than woodlands and has a disturbed soil profile from plowing. These implications result in a landscape that is less hospitable to both pestiferous and beneficial arthropods that benefit from shade during hot periods to conserve moisture and utilize undisturbed soil for overwintering and nesting (Daly et al. 1998, Hajek 2004).

Natural enemies can be categorized as specialist or generalist based off of their feeding preference, though they fall within a range of having one or few food sources (monophagous or stenophagous) to having several or many food sources (oligophagous or polyphagous).

## **Biodiversity and Scale**

Two driving forces maintain biological diversity. First, competitive exclusion theory explains that complete competitors cannot coexist, which leads to adaptation by the less fit species to exploit different resources and not directly compete with the more fit species (Gause 1964). This speciation increases biodiversity as species adapt to utilize more diverse niches (MacArthur 1958, Hardin 1960). Second, as a species becomes more

successful and populous it becomes more vulnerable to predation or disturbance; whether it is a city full of people spreading a virus, a cornfield hosting an exploding aphid population, or a dry pine forest swept by fire, the environment impacts species' success and maintains biological diversity (Levin 2000). This maintenance of diversity operates at different scales of time, space and organizational complexity, making a species', or community's, level of success difficult to measure because of various interactions and positive and negative feedbacks (Levin 2000).

Biological diversity, particularly for arthropods, can vary greatly in an ecosystem over different scales of time. Organisms both make resources available seasonally and utilize resources differently during various life phases (Daly et al. 1998). Pest populations fluctuate over time in response to these cycles, such as seasonal temperature changes and plant growth, with field crop pests and their associated natural enemies reaching peak abundance during the rapid crop growth phase in early summer (Bardner & Fletcher 1974). Additionally, arthropods are active during different times of day with many natural enemies, including beetle and spider species, predating nocturnally to conserve moisture (Daly et al. 1998).

Different species of arthropods function at different spatial scales in their activities. One example is in regard to generalist natural enemies that have a broad array of food sources, contrasted by specialist natural enemies that prey on a specific host organism (Gurr et al. 2012). Many generalist natural enemies, such as spiders, have a smaller geographical range of predation, particularly when moving into crop monocultures from field edges (Sunderland & Samu 2000). This is contrasted by many

specialists, such as parasitic wasps, that prey across acres of land to find their specific feeding source (Hubbard & Cook 1978).

In addition to the variable range of predation and dispersal, many natural enemy species simply rely on a larger contiguous habitat type. This is attributed to the fact that greater species diversity is reached through greater connectivity of habitats (Simberloff 1994). A buffer corridor facilitates the dispersion of various species, with greater corridor length correlating to higher diversity (Haddad 2003). Corridors can also create a negative feedback on diversity by facilitating the movement of pathogens and invasive species. The spatial scale of habitat size and fragmentation, as well as the scale of feeding and dispersion range of individual species, therefore affect the measure of species diversity.

Compounding the variance of diversity at different scales of space and time is the abundance and proportion of species interacting, or the scale of organizational complexity of an ecosystem. Predator-prey interactions are dependent on time and space as well as the diversity and abundance of plants, herbivores and predators in the system (Hassell & May 1986). Relationships occur within a diverse assemblage of natural enemies that alter the pest control dynamic, including cooperative predation, competition, and predation of other natural enemies. Foliar foraging lady beetles (*Coccinella septempunctata*) cooperate with ground foraging predators to have a greater synergistic effect on aphids because during feeding lady beetles will knock some aphids to the ground (Losey & Denno 1998). Natural enemy dynamics can also reduce pest control, for example intra-guild predation of wolf spiders preying on planthopper-eating mirid bugs (Finke & Denno 2003) or carabid beetles predating parasitoid wasps, which reduces long-term pea aphid population control (Snyder & Ives 2001).

Another example of organizational complexity is the enemies hypothesis, which states that natural enemies are better suited to control crop pests in systems with more diverse vegetation as compared to monocultures (Root 1973, Andow 1990 & 1991, Russell 1989). Monocultures also support more dense populations of fewer species of herbivores as explained by the resource concentration hypothesis (Root 1973). There is some evidence that the effect of crop heterogeneity on herbivore populations is scale dependent, with large heterogeneous plots having negligible impacts on herbivore and predator abundance (Bommarco & Banks 2003). The responses of different predator and prey species are not uniform across varying distributions of plants. In diverse vegetative systems, the scale at which plants are fragmented affects the distribution and population of different crop pests (Banks 1998). The ability of natural enemies to find prey is also affected by the level of fragmentation of diverse plant assemblages (Banks & Yasenak 2003). It is important to consider the compounding effects of different scales of space, time and community composition. Even if these variables are constant, the results of experiments at different scales could yield different results (Gaolach 2001).

The edge effect of ecotones, or transitional boundaries, between different biomes often increases diversity but can also have negative feedbacks on species richness through facilitation of invasive species (Marshall & Moonen 2002, Planty-Tabacchi et al. 1996). Disturbed or unnatural edges, such as those between riparian buffers and agricultural fields, often promote the introduction of invasive species that can dominate a system, such as argentine ants *Linepithema humile* that outcompete native ants in dry scrub habitats by better utilizing adjacent moist riparian corridors (Holway 2005). In

general, edges are thought to benefit wildlife by creating greater vegetative complexity and access to multiple landscape elements (Yahner 1988).

## **Natural Enemy Diversity**

Agroecosystems, or agricultural systems that utilize ecosystem processes to increase food production, reduce pest outbreak through connectivity of diverse and complex habitat features (Tscharntke et al. 2007). In line with the enemies hypothesis, ecological resilience and stability is created by multiple species filling similar niches (Peterson et al. 1998). Diverse systems allow for greater resilience in the face of climate change and other forms of disturbance through the insurance hypothesis, that a greater number of species with partial redundancies in resource utilization insure continued ecosystem function should some species fail (Tilman 1996, Naeem & Li 1997, Yachi & Loreau 1999).

While acknowledging the many variables related to interacting natural enemy species within diverse communities, there is a growing consensus that high levels of natural enemy diversity are important to agroecosystems as measured at the level of interaction amongst predators and prey (Cardinale et al. 2003, Duelli 1997) as well as at a larger scale comparing variable agricultural intensification (Wilby & Thomas 2002). The correlation between a greater diversity of natural enemies in an agricultural system and a greater biological control of agricultural insect pests is described by the biodiversity-stability theory (Lehman & Tilman 2000, Gardiner et al. 2009). This is attributed to the seasonal population fluctuations of many pests and the variable vulnerability of pests over time through their phases of growth. Each additional natural enemy in the system

has unique temporal and spatial predation habits that control pests in various phases of life or location. As discussed above natural enemy diversity is nuanced by, predator-predator interaction, intra-guild predation and cooperation. However, the dominate ecological theory at the landscape scale is that in an agricultural system with high natural enemy diversity there is more likely to be a natural enemy present to control arthropod pests before rapid population growth occurs (Tscharrntke et al. 2007, Letourneau et al. 2009).

Due to the broad diet of generalist arthropod predators, their populations are more consistent over time than specialists that respond to the variable availability of a particular food source (Gurr et al. 2012). Many generalists, such as beetles, are also predating through most of their life cycle, from early larval stages through maturity. This range of time predating and diverse diet allow for the control of a great number of possible crop pests. Lepidoptera (moths and butterflies), including the corn borer and cutworm are common pests controlled by several families of generalist natural enemies. Sap sucking Hemiptera, including aphids, stink bugs, and white-flies are also commonly controlled by generalist natural enemies (Daly et al. 1998).

The beetles comprise the most families of any arthropod order, including some of the most effective natural enemies, and some of the most damaging agricultural pests, like Chrysomelidae (leaf and flea beetles). The Caribidae family of ground beetles, and the Staphylinidae (rove beetles) control larger ranges of crop pests than most generalist natural enemies, both in farmland soil and on crops (Varchola & Dunn 1999).

Spiders are well suited for biological control by adapting to times of low and high food availability. They have flexible, distensible abdomens that allow for feeding on

large numbers of prey. When prey are not available, spiders are able to decrease their metabolic rate and continue to reproduce. Spiders are almost exclusively predators, feeding on all stages of insect growth, and different families represent unique patterns of biological control (Dippenaar-Schoeman et al. 2013). Lycosidae (wolf spiders) have large geographical ranges of generalist feeding, similar to predatory beetles. Lindyphiidae (weaver spiders) control ground dwelling pests on a smaller spatial scale but are effective through abundance of both individuals and webs across the landscape (Nyffeler et al. 1994). Some common agricultural pest families that are controlled by spiders include Miridae (plant bugs and fleahoppers), Cicadellidae (leafhoppers), Membracidae (treehoppers), Delphacidae (planthoppers), and Aphididae (aphids) (Nyffeler et al. 1994).

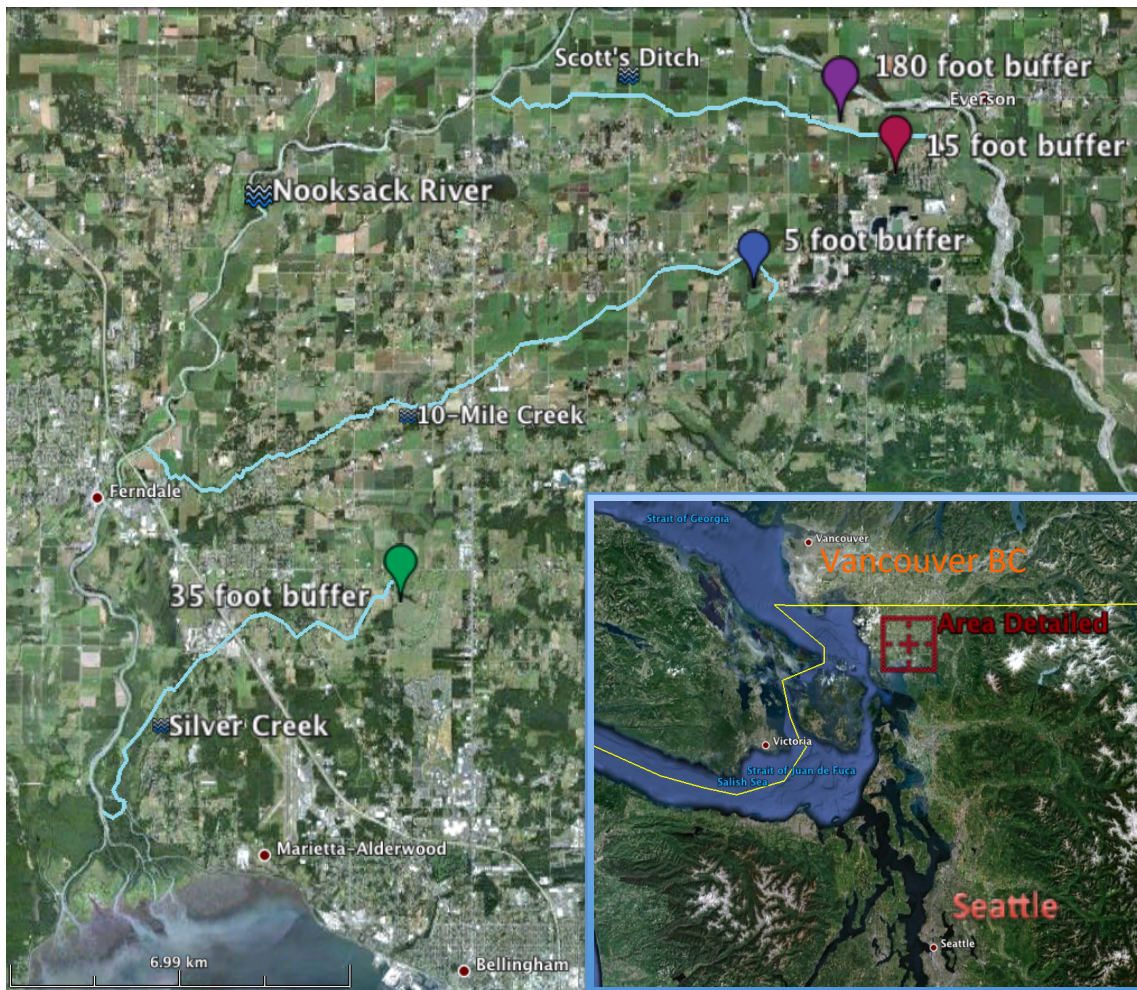
There are a great number of factors that influence, and are correlated with, the ambient quantity and diversity of natural enemies surrounding farmlands. Plant diversity, distance from habitat, microclimate, and many more variables influence ecological population dynamics (Hunter 2002). This study seeks to control some known variables in a field experiment to measure generalist natural enemy diversity at different woodland riparian buffer widths. The sites were selected for their similar riparian buffer vegetation age and species composition, as well as the same adjacent crop systems and management practices. Sampling was conducted at locations and times that maximized representation of generalist natural enemies for both daily and seasonal time variability.

## **Chapter 2: Materials and Methods**

### **Field Experiments**

The study area is in Whatcom County, WA., on three salmon bearing agricultural stream ditches that are tributaries of the Nooksack River (Fig. 1). Whatcom County has

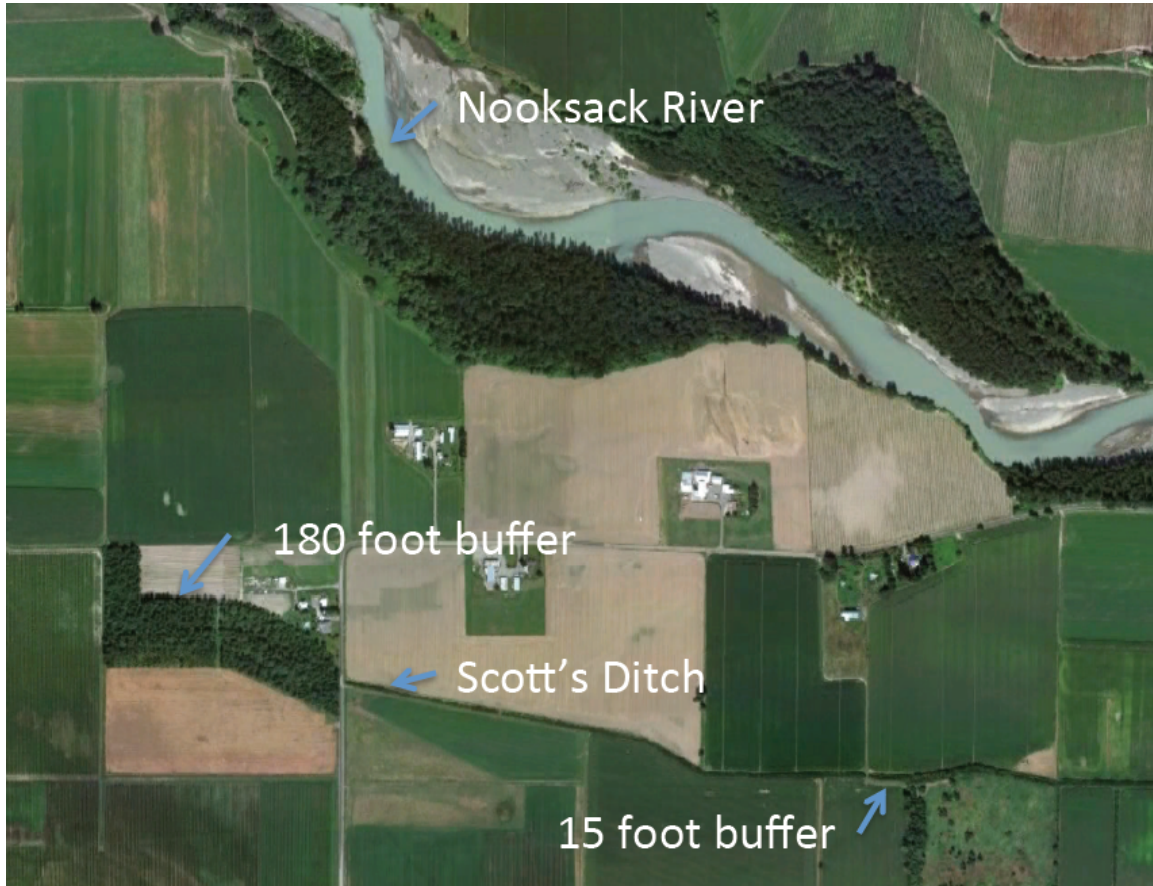
104,000 acres of the most productive farmland in Western Washington (USDA 2007). The soil and land productivity in this area are more typified by the wider and flatter Fraser Valley in British Columbia than the steeper alluvial Puget Sound farming basins to the South (Jones 1999). Four sites were selected for their similar stream characteristics of size and flow and varied riparian buffer widths, for the complementary study on air temperature and effective shade (Benedict et al. 2012).



**Figure 1: Study area showing the four buffer width sites and three creeks along the Nooksack River in Whatcom CO. Washington**

The four sites had average buffer widths, measured perpendicular from the stream channel to the edge of the planted vegetation, of five feet, 15 feet (the U.S. Natural Resources Conservation Service (NRCS) Zone 1, minimum recommendation), 35 feet

(NRCS, Zone 2 standard recommendation), and 180 feet (beyond NRCS Zone 3, erosive cropland recommendation) (NRCS 2011). The 15 and 180 foot buffers are both on Scott's Ditch (Fig. 2). The five foot and 35 foot buffers are part of separate streams, Ten-mile creek and Silver creek, respectively. The five, 15, and 180 foot sites are adjacent to cornfields. The 35 foot buffer is a non-agriculture site and is adjacent to tall wild grasses.



**Figure 2: Scott's Ditch, showing the 180 foot buffer and 15 foot buffer relative to the Nooksack River**

The buffers at the four sites were planted between 2000 and 2005 with a similar native plant species composition, selected for ease of establishment and site suitability, in accordance with the CREP. According to transects plant diversity in the buffers increases in relation to width (Table 1), but this variation has a limited impact on natural enemy

diversity because each buffer site has a similar distribution of plant families that serve the same roles in providing habitat and alternative food sources (Fiedler et al. 2008).

**Table 1: Vegetation and density sampled from transects perpendicular to streams for four buffers widths (Benedict 2012)**

| 5' buffer (planted 2005)                           |           | 15' buffer (planted 2001/2006)                   |           | 35' buffer (planted 2000)                        |           | 180' buffer (planted 2003)                        |            |
|--|-----------|--|-----------|--|-----------|---|------------|
| Species  | #         | Species  | #         | Species  | #         | Species   | #          |
|  |           | <i>Thuja plicata</i><br>(western red cedar)      | 1         | <i>Picea sitchensis</i><br>(sitka spruce)        | 1         | <i>Thuja plicata</i><br>(western red cedar)       | 1          |
|  |           |  |           | <i>Betula papyrifera</i><br>(paper birch)        | 1         | <i>Abies grandis</i><br>(grand fir)               | 2          |
|  |           |  |           | <i>Populus balsamifera</i><br>(black cottonwood) | 2         | <i>Populus balsamifera</i> (black cottonwood)     | 5          |
|  |           | <i>Rhamnus alnifolia</i> (alder buckthorn)       | 1         | <i>Populus tremuloides</i><br>(quaking aspen)    | 1         | <i>Alnus rubra</i> (red alder)                    | 8          |
|  |           | <i>Sambucus racemosa</i> (red elderberry)        | 4         |  |           | <i>Betula papyrifera</i><br>(paper birch)         | 1          |
| <i>Salix hookeriana</i><br>(hooker's willow)       | 3         | <i>Salix hookeriana</i><br>(hooker's willow)     | 5         | <i>Salix sitchensis</i><br>(sitka willow)        | 1         | <i>Salix lucida</i><br>(pacific willow)           | 4          |
| <i>Cornus sericea</i><br>(red osier dogwood)       | 8         | <i>Cornus sericea</i><br>(red osier dogwood)     | 5         | <i>Salix lucida</i><br>(pacific willow)          | 10        | <i>Cornus sericea</i><br>(red osier dogwood)      | 14         |
| <i>Spiraea douglassi</i><br>(spiraea)              | 8         | <i>Spiraea douglassi</i><br>(spiraea)            | 1         | <i>Fraxinus latifolia</i><br>(oregon ash)        | 2         | <i>Corylus cornuta</i><br>(beaked hazelnut)       | 1          |
| <i>Physocarpus capitatus</i><br>(ninebark)         | 1         | <i>Lonicera involucrata</i><br>(black twinberry) | 4         | <i>Lonicera involucrata</i> (black twinberry)    | 1         | <i>Symphoricarpos albus</i> (common snowberry)    | 1          |
| <i>Rosa nutkana</i><br>(nootka rose)               | 4         | <i>Rosa nutkana</i><br>(nootka rose)             | 4         | <i>Amelanchier alnifolia</i><br>(serviceberry)   | 3         | <i>Rosa gymnocarpa</i><br>(balldhip rose)         | 1          |
| <i>Phalaris arundinacea</i><br>(reed canary grass) | 1         |  |           |  |           | <i>Rosa nutkana</i><br>(nootka rose)              | 5          |
| <i>Rubus armeniacus</i><br>(himalayan blackberry)  | 6         |  |           | <i>Malus fusca</i><br>(pacific crab apple)       | 1         | <i>Rubus armeniacus</i><br>(himalayan blackberry) | 3          |
| <b>Plants/ft<sup>2</sup></b>                       | <b>.4</b> | <b>Plants/ft<sup>2</sup></b>                     | <b>.2</b> | <b>Plants/ft<sup>2</sup></b>                     | <b>.1</b> | <b>Plants/ft<sup>2</sup></b>                      | <b>.03</b> |

Each site consisted of trees, shrubs and understory vegetation comprising similar habitat features of thick leaf litter but with variable vegetation density. Plant density is impacted by the width of the buffer with greater light exposure at the edges causing greater survival and density of plants in smaller buffers (Matlack 1994). The four buffers have mature established willow (*Salix species*) in the canopy, large and small shrubs, and grasses and herbs. Siemann et al. (1998) showed an increase in arthropod diversity in response to a greater number of functional plant groups, however all of the four sites represent the same number of functional plant groups so that the variable plant diversity should have little effect on the natural enemy diversity because all of the sites already represent diverse riparian vegetative systems. Furthermore, each of the sites represented more plant species in the buffers along with more similar vegetation density than was recorded by the transects.

The three agricultural sites are planted with silage corn modified to express the toxic *Bacillus thuringiensis* (Bt) bacterium, primarily to control the European corn borer *Ostrinia nubilalis*. Such “Bt corn” has an artificial suppression of natural enemies and reduces the variation of both pests and their associated predators present in the system. If, for example, each site were growing a different crop, then the natural enemy populations would respond to the specific crop pests present and have varied species composition throughout the season. The impact of the Bt corn is also limited because this study targets generalist predators that survive on a diverse array of species both in the buffer and in the field, including secondary pests, not targeted by the Bt corn but prevalent on weak or damaged plants (Schuler et al. 1999). The corn serves as a control in limiting the amount of variation of pest presence and predator response between the buffer width treatments.

Farmers at these sites used, in moderation, the herbicide glyphosate for weed suppression. No severe or direct impact of this herbicide on arthropods and natural enemy populations has been observed from the spraying of glyphosate (Wilson et al. 2004, Norris & Kogan 2005). The spraying may have had a limited effect in reducing arthropod populations utilizing weedy vegetation for food and shelter, and suppressing their associated natural enemies (Carpenter 2011), but it is not expected to have impacted the results.

To compare generalist natural enemy diversity over time and against buffer width, and to account for temporal changes in natural enemy populations from arthropod life cycles and the corn growth cycle, four sample dates were selected during the 2012 corn-growing season, in three-week intervals; July 15<sup>th</sup> and Aug 5<sup>th</sup> (rapid growth stage), Aug 26<sup>th</sup> (canopy closure stage) and Sept 15<sup>th</sup> (maturity). These growth stages have been shown to have variable beneficial species richness, with the greatest diversity of Carabidae present during the rapid vegetative growth in early Summer (Varchola & Dunn 2001).

## **Experimental Design**

Generalist natural enemy presence was sampled with pitfall traps and un-baited sticky traps at the drip line of the buffers' edge. Generalists were targeted because they have a smaller geographic predation range than specialist natural enemies so that the replicate collection points that were only 30 feet apart would be more likely to sample enemies from different sections within the buffer. Additionally, generalists account for both a greater number of species and more abundant individuals than specialists to allow for greater likelihood of measuring differences in the calculated diversity indices.

Sampling was only done at the edge between woodland and field as the edge has been shown to contain a higher diversity of arthropods than the woodlands or field alone as enemies are utilizing one or both environments (Bedford & Usher 1994).

One of each trap was set at four sampling points at the four sites for a total of 16 pitfall and 16 sticky traps per sample period. Traps were separated by at least 30 feet to improve the variance of habitat and food source within the arthropods range (Work et al. 2002). At least 2 traps per site were located next to measuring devices that are part of the complementary air temperature vs. buffer width study. A pitfall trap consisted of three (3) 16 ounce plastic cups, buried in a row parallel to the stream to increase the number of arthropods captured moving between the buffer and field as opposed to along the buffers edge. The pitfall traps did not use screens or guides to select for direction (moving from field to buffer or buffer to field) but were open on both ends, as directional trapping has been shown to not have significant difference for ground beetles moving between corn and vegetated buffers (Varchola & Dunn 2001). Cups were filled with 4 ounces of unscented soapy water (~5% soap). Each pitfall trap had a companion un-baited sticky trap (“fly-paper” ribbon), hung at 6 feet.

Both trap types were left overnight for approximately 18 hours, between 4:00 – 6:00 PM and 10:00 AM – 12:00 PM. Traps were selected to target generalist arthropod natural enemies moving both in and out of the buffer in the evening, at night and early morning when temperatures are lower and the target species are more active (Daly et al. 1998).

Species were counted against vouchers at different taxonomic ranks based on arthropod family and basic morphological differences. A sample of each distinct species

was stored in a centrifuge tube with ethyl alcohol as an identification voucher. University of Washington arachnologist Rod Crawford and entomologist Evan Sugden confirmed the vouchers as separate species. Identifying species against vouchers may have resulted in counting some species as the same when in fact they were different, reducing the overall diversity index across sites.

## **Statistical Analyses**

*Null Hypothesis: Generalist beneficial arthropod diversity in buffers (5', 15', 35', and 180') is equal.  $H'(5') = H'(15') = H'(35') = H'(180')$*

*Alternate Hypothesis: There is some inequality of generalist beneficial arthropod diversity in buffers (5', 15', 35', and 180').*

Diversity indices represent a distribution of diversity across the system per sample point. The Shannon Wiener diversity index is commonly used in ecological studies because of its ability to predict evenness of species composition through proportional diversity, creating values that are easier to compare statistically, particularly when the number of species is >10 and <100 (Molles & Cahill 1999, Stirling & Wilsey 2001). The Shannon Wiener index ( $H'$ ) quantifies the uncertainty of predicting the next species in the dataset and serves to reduce outlying population values by taking the natural log (ln) of the proportion of individuals belonging to the  $i$ th species ( $p_i$ ) for all species at the sample point  $R$  to represent a statistically comparable approximation of the diversity of the subject species sampled (Shannon & Weaver 1949).

$$H' = - \sum_{i=1}^R p_i \ln p_i$$

This diversity index weights the evenness of species in a system and reduces variation in population dynamics, such as the variable scales of spatiotemporal and interaction dynamics including microclimate, intra-guild predation and a high abundance of any species in any given sample. Measuring diversity instead of abundance also reduces the impact of artificial suppression of beneficial arthropods attributed to the Bt corn and other environmental factors.

The dependent diversity indices and sampling periods (i.e. time) were compared against the independent variable buffer widths through a multivariate analysis of variance (MANOVA). This test reduces error from compounding alpha values for each collection date to report whether or not the mean diversity indices are significantly different between at least two buffer treatments for at least one date (Scheiner 2001).

$$\Lambda_{Pillai} = \sum_{i=1 \dots p} (\lambda_i / (1 + \lambda_i))$$

This equation, Pillai's trace, is one of four commonly used multivariate criteria test statistics and is robust to violations of assumptions, such as the independent variables showing serial correlation, common with seasonality (Scheiner 2001).  $\lambda_i$  is the eigenvalue, or the sums of squares and cross products matrix for the hypothesis and error, and  $p$  the number of dependent variables. The *Pillai* value correlates to the probability that if this experiment were done again that there would be a similar response in the difference of means (Scheiner 2001).

Additional postereori analysis was done using Tukey's honestly significant difference test to separate variable mean diversity measurements between buffer treatments. This test was done to compare temporal variability per site to examine the uniformity of seasonal fluctuations.

## Chapter 3: Results

The corn growth stages corresponded with the selected sampling dates as anticipated. On the first sample date, July 15<sup>th</sup>, the corn plants had three - nine leaves, and were on average 50 days old. On August 5<sup>th</sup> the corn was still in rapid growth without canopy closure. On August 26<sup>th</sup> the corn canopy was closed and on September 15<sup>th</sup> the corn was maturing.

A total of 35 arthropod species were counted at the four sites during the four sampling dates, and 23 of the species were classified as generalist natural enemies (Table 2) (Flint & Dreistadt 1998, Ambrosino 2007). These species were used to calculate the Shannon-Wiener diversity indices for each sample site (Table 3).

**Table 2: Abundance of each generalist natural enemy species per sample site for the four sample dates combined**

| Order          | Family          | 5' | 15' | 35' | 180' | Total |
|----------------|-----------------|----|-----|-----|------|-------|
| Coleoptera     | Carabidae 1     | 43 | 27  | 3   | 34   | 107   |
| Coleoptera     | Carabidae 2     | 1  | 0   | 17  | 24   | 42    |
| Coleoptera     | Carabidae 3     | 7  | 3   | 2   | 6    | 18    |
| Coleoptera     | Carabidae 4     | 0  | 0   | 0   | 3    | 3     |
| Coleoptera     | Carabidae 5     | 0  | 8   | 0   | 7    | 15    |
| Coleoptera     | Carabidae 6     | 0  | 0   | 3   | 0    | 3     |
| Coleoptera     | Carabidae 7     | 0  | 1   | 0   | 1    | 2     |
| Coleoptera     | Staphylinidae 1 | 1  | 0   | 0   | 4    | 5     |
| Coleoptera     | Staphylinidae 2 | 2  | 1   | 7   | 3    | 13    |
| Coleoptera     | Staphylinidae 3 | 1  | 1   | 0   | 0    | 2     |
| Coleoptera     | Staphylinidae 4 | 0  | 5   | 5   | 0    | 10    |
| Coleoptera     | Coccinellidae   | 3  | 1   | 11  | 13   | 28    |
| Hymenoptera    | Vespidae 1      | 0  | 0   | 0   | 10   | 10    |
| Hymenoptera    | Vespidae 2      | 5  | 6   | 0   | 8    | 19    |
| Lithobiomorpha | "Centipede"     | 4  | 2   | 3   | 4    | 13    |
| Araneae        | Lycosidae 1     | 4  | 3   | 0   | 0    | 7     |
| Araneae        | Lycosidae 2     | 5  | 14  | 42  | 0    | 61    |
| Araneae        | Araneidae       | 0  | 0   | 4   | 0    | 4     |
| Araneae        | Lindyphiidae 1  | 20 | 10  | 0   | 1    | 31    |
| Araneae        | Lindyphiidae 2  | 2  | 0   | 1   | 0    | 3     |
| Araneae        | Clubianidae     | 2  | 0   | 0   | 3    | 5     |

|           |               |            |           |           |            |            |
|-----------|---------------|------------|-----------|-----------|------------|------------|
| Opiliones | Phylangidae 1 | 0          | 0         | 1         | 5          | 6          |
| Opiliones | Phylangidae 2 | 1          | 0         | 0         | 0          | 1          |
|           |               |            |           |           |            |            |
|           | <b>Total</b>  | <b>101</b> | <b>82</b> | <b>99</b> | <b>126</b> | <b>408</b> |

**Table 3: Shannon-Wiener diversity indices for natural enemies sampled at four replicate sites for each of four riparian buffer width treatments during four sampling dates in 2012.**

| Buffer Width (feet) | 15-Jul | 5-Aug | 26-Aug | 15-Sep |
|---------------------|--------|-------|--------|--------|
| 5                   | 1.386  | 1.040 | 1.011  | 0.693  |
| 5                   | 1.079  | 1.386 | 1.055  | 0.693  |
| 5                   | 0.950  | 1.091 | 1.011  | 0.693  |
| 5                   | 0.886  | 0.831 | 1.242  | 0.500  |
| 15                  | 1.242  | 1.029 |        | 0.950  |
| 15                  | 1.089  | 0.916 |        | 0.900  |
| 15                  | 1.011  | 0.693 |        | 0.956  |
| 15                  | 0.693  | 1.079 |        |        |
| 35                  | 1.011  | 1.297 | 0.637  | 1.040  |
| 35                  | 0.598  | 0.868 | 1.040  | 0.637  |
| 35                  | 0.562  | 0.895 | 0.796  | 0.562  |
| 35                  | 0.673  | 1.273 | 0.637  | 0.673  |
| 180                 | 1.550  | 1.277 | 1.560  | 0.637  |
| 180                 | 1.550  | 1.233 | 1.011  | 0.693  |
| 180                 | 1.330  | 2.025 | 1.011  | 0.693  |
| 180                 | 1.075  | 1.234 | 1.004  | 0.673  |

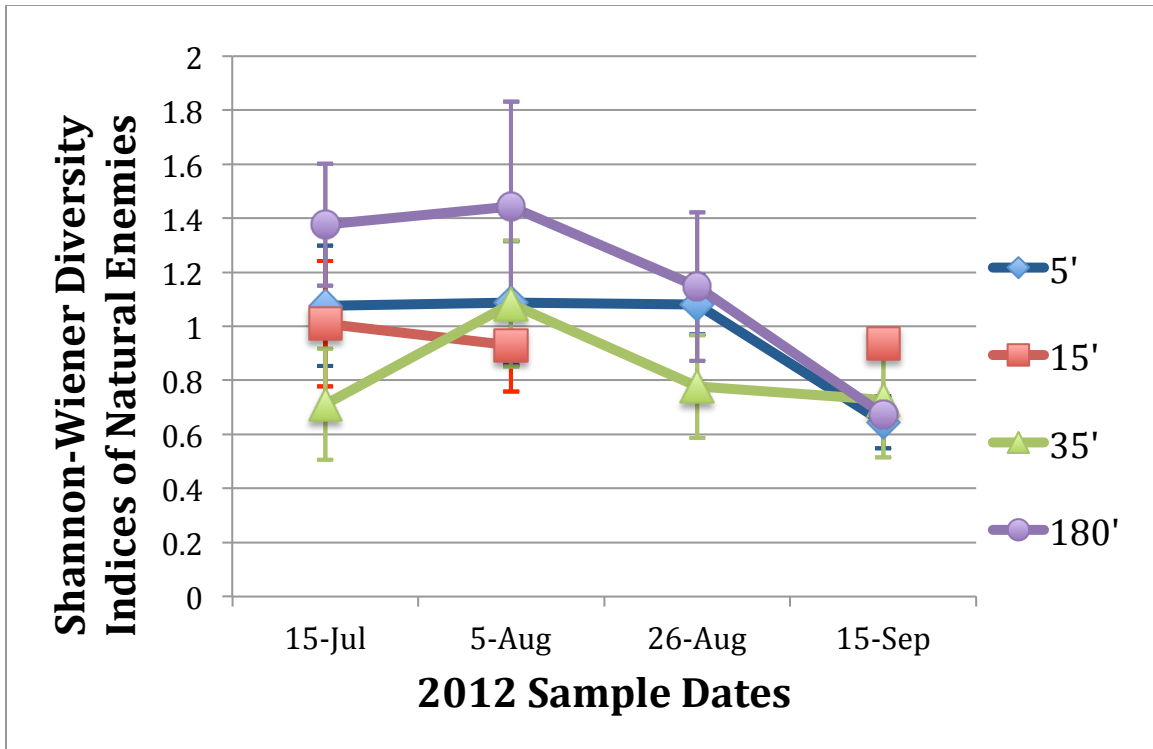
Analysis of the Shannon-Wiener indices using MANOVA, executed with the R statistical package, indicated diversity indices were significantly different between at least two buffer treatments for at least one date (P=0.0032). Multiple inequalities comparison using Tukey’s test showed significant differences between at least two buffer widths for each collection date, July 15 (P=0.006), Aug 5 (P=0.104), Aug 26 (P=0.066), and Sept 15 (P=0.047). The 180 foot buffer had greater diversity for the first three sample dates and dropped below the 15 foot buffer on the last sample date Sept 15 (Table 5).

**Table 5: Multiple inequalities comparisons using Tukey’s test to measure variance of mean diversity indices (mean±SE of diff.) of generalist natural enemy samples against four buffer width treatment plots for four sampling dates, with letters to denote significantly different means.**

| Date   | 5'            | 15'             | 35'           | 180'           |
|--------|---------------|-----------------|---------------|----------------|
| 15-Jul | 1.075±0.16 a  | 1.009±0.16 a    | 0.7113±0.16 a | 1.376±0.16 b** |
| 5-Aug  | 1.087±0.19 a  | 0.929±0.19 a    | 1.083±0.19 a  | 1.442±0.19 b*  |
| 26-Aug | 1.080±0.14 ab |                 | 0.777±0.14 a  | 1.147±0.14 b*  |
| 15-Sep | 0.645±0.09 a  | 0.935±0.09 b ** | 0.728±0.09 ab | 0.674±0.09 a   |
|        | * P<0.1       |                 |               |                |
|        | ** P<0.05     |                 |               |                |

Decreased diversity was observed at both the five and 180 foot buffers during corn maturity on September 15<sup>th</sup> as is consistent with Varchola & Dunn (2001), as well as other corn growth and pest-predator population studies (Dicke & Jarvis 1962, Bardner & Fletcher 1974). Generalist natural enemy diversity was significantly higher in the larger riparian buffer (180 feet) during the corn’s early rapid growth phase on July 15<sup>th</sup> and August 5<sup>th</sup>.

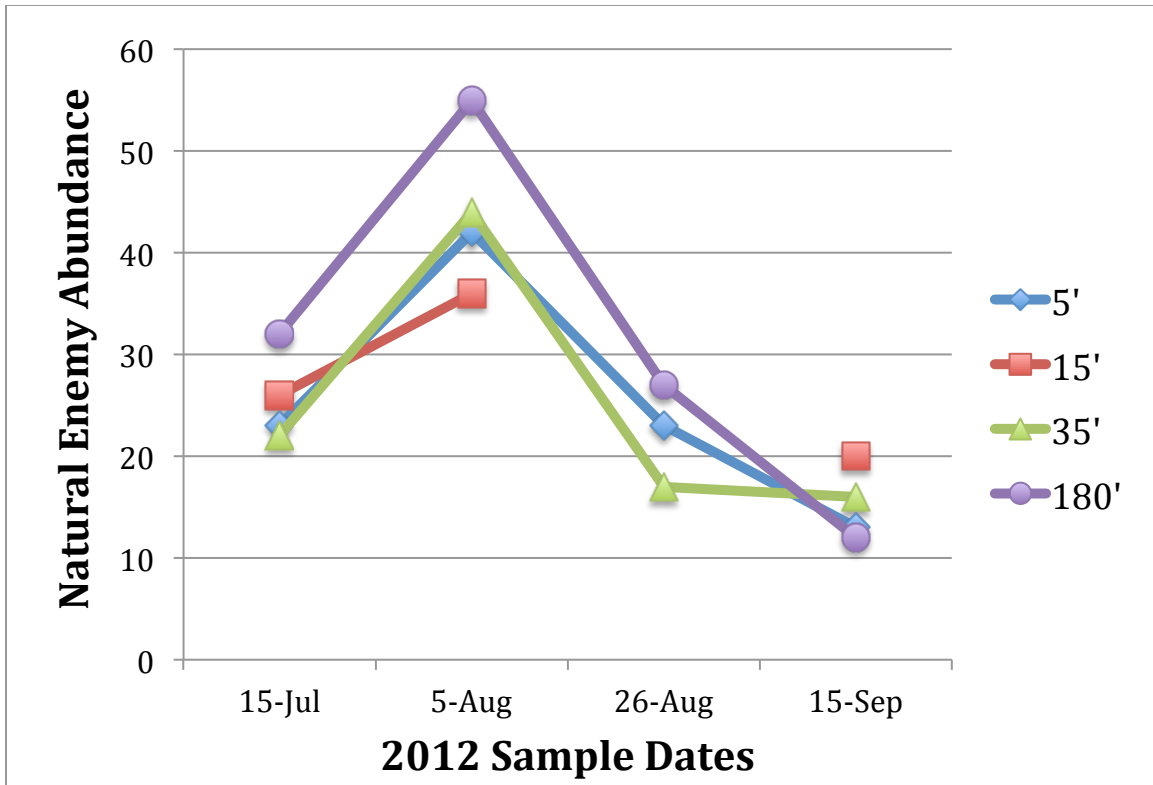
The slopes of diversity indices over time are not the same for the four buffer treatments as can be seen in Figure 3. A linear regression showed that the slopes were significantly different (P=0.022 df=51), with the 5’ and 180’ buffers showing the greatest change, or decrease in slope as measured by whether they are significantly non-zero (5’: P=0.014 df=14, 15’: P=0.519 df=9, 35’: P=0.656 df=14, 180’: P=0.002 df=14). This indicates that natural enemy diversity does not fluctuate uniformly over time between different buffer widths.



**Figure 3: Mean natural enemy diversity indices for four replicates (+/- SE) during four sample periods for four buffer width treatments (n=59)**

The abundance of natural enemies shown in Figure 4 follows a similar distribution as the diversity indices, however the buffer treatments show a more uniform change with no significant difference in slope over time (linear regression,  $P=0.847$ ,  $df=10$ , pooled slope=-5.31). All sites increased in abundance in August and decreased to September, whereas only diversity indices for the 35 and 180 foot sites followed this pattern of increase in August and decrease to September.

The mean abundance of generalist natural enemy species per sample site for each date was calculated to compare variance to diversity indices (Table 4). Sampling resulted in a greater number of species in the 180 foot buffer for all of the four sampling dates as well as a greater number of species during the earlier sampling dates than the later.



**Figure 4: Natural enemy abundance for four replicates during four sample periods for four buffer width treatments**

**Table 4: Mean species abundance for natural enemies sampled at four replicate sites for each of four riparian buffer width treatments during four sampling dates in 2012.**

| Buffer Width (feet) | 15-Jul | 5-Aug | 26-Aug | 15-Sep | Mean |
|---------------------|--------|-------|--------|--------|------|
| 5                   | 3.5    | 3.5   | 3.25   | 2      | 3.06 |
| 15                  | 3.25   | 3     |        | 3      | 3.08 |
| 35                  | 2.25   | 4.25  | 2.5    | 2.25   | 2.81 |
| 180                 | 4.5    | 5.25  | 3.5    | 2      | 3.81 |
| Mean                | 3.38   | 4.00  | 3.08   | 2.31   |      |

## Chapter 4: Discussion

### Agricultural Significance

The 180 foot buffer showed greater natural enemy diversity during the early growth phase, which corresponds with high susceptibility of crops to pests and pest

outbreaks and a resulting higher diversity of arthropods predating those pests. Larger buffers may be better suited along fields growing crops that are more vulnerable to early growth phase pest outbreak, for example leafy vegetables instead of BT corn.

The drop in diversity over time at the 180 foot buffer to the same level as the smaller buffers reflects the possibility that other factors influenced generalist natural enemy diversity outside of buffer width; because there is more habitat and overall plant diversity in the larger buffer the higher natural enemy diversity moving across the buffers edge should have been more consistent over time. This discrepancy is likely attributed to a late season reduction of prey populations in the cornfield causing the natural enemies to utilize the larger buffers greater capacity for alternative food sources at a greater rate than at the smaller buffers. This conclusion that larger buffers may supply sufficient habitat and food sources to keep natural enemies from leaving was put forth by Bedford & Usher in 1993 when they concluded that compact woodland vegetation of 15 feet or less maximizes beetle and spider diversity in adjacent farmland. My results of higher diversity during early summer growth in the 180 foot buffer challenges these findings.

The drop in diversity could also be impacted by some natural enemies shifting their range into the shaded, protected and less competitive cornfields. Additionally, natural enemy populations may have been reduced because the larger buffer is supporting larger predator populations, such as birds and lizards that are reducing the natural enemy populations during times of greater activity later in the summer.

The variability of the 35 foot non agricultural buffer could suggest that the adjacent wild grasses at the 35 foot buffer did not provide a similar supply of herbivorous arthropods as the cornfields. The abundance of natural enemies at the non-agricultural

site was also lower than the other sites on July 15<sup>th</sup> and August 26<sup>th</sup>, but for July 15<sup>th</sup> it was only less one natural enemy, 22 compared to 23 at the five foot buffer suggesting that the non-agricultural site had a less diverse composition of natural enemies but was still comparable to the other sites across time. As discussed earlier the 35 foot buffer also exhibited comparable diversity and species abundance for half of the collection dates suggesting that riparian buffer width has a larger impact on generalist natural enemy diversity than the adjacent field land use.

## **Ecological Significance**

Many arthropods sampled serve as important Salmonidae forage. Four of the orders commonly sampled at each site throughout the season, Diptera, Coleoptera, Hymenoptera, and Arachnida, are listed in the top five juvenile salmon forage taxon by weight (Nielsen 2011). In the increasingly important field of managing flood plains for salmon habitat, these finding further supports the conclusion that riparian buffers provide crucial food sources to salmonid food webs (Allan et al. 2003).

Increasing sample size could reveal differences in invasive vs. native arthropod populations. The data suggest that three introduced species, all of which are top arthropod predators and highly studied (Pianezzola 2013), *Pardosa moesta*, thin legged wolf spider, and the ground beetles *Carabus normalis*, and *Pterastichus melanarius*, were less common at the 180 foot buffer site. This suggests larger woodlands support more resilient native species, something for future study.

## Study Limitations

Some events impacted the results. First, *Formica obscuripines* (Western thatch ant) had great variance of abundance amongst the buffer replicates effectively altering the diversity indices. On August 5<sup>th</sup> the 35 foot buffer had 262 ants in one pitfall trap, located near a nest, and one ant in the pitfall trap 120 feet away. Thatch ant colonies do control important crop pests but also have mutualistic relationships with Hemiptera, such as aphids, by protecting them from predators like lady beetles in exchange for the honeydew excreted as a waste product. Eubanks & Styrsky (2006) describe the ant-Hemipteran mutualism as a net benefit to agriculture because the ants predate more important crop pests than aphids. Unfortunately, due to the variable sampling of ants they were omitted from natural enemy diversity index calculations. Second, on the first collection 70% ethyl alcohol was used in pit fall traps to help preserve arthropods, unfortunately the alcohol attracted 798 slugs, which reduced the precision of counting and identification. Soapy water was utilized in pitfall traps for the following three collections and did not appear to effect preservation or predation in the cups. Third, the 15 foot buffer sampling was abandoned on August 25<sup>th</sup> because irrigation piping was laid across the buffer edge on top of the pitfall sample area. Finally, on September 5<sup>th</sup> at the 15 foot buffer, one set of pitfall cups was upturned, probably by a mole. The experimental design included an extra sample point, buffer site and collection date beyond the three necessary to measure for a difference, allowing the analysis to be statistically valid despite these missing data points (Table 3).

Reducing variability in future studies could be done by replicating buffer width sites, only examining agricultural sites, and selecting buffers on the same stream and/or

on all different streams. Measuring more large buffer width sites would increase significance through replication and could be utilized to measure generalist and specialist natural enemies because many parasitoid specialist natural enemies rely on larger systems, also allowing for comparisons of large vs small buffers in relation to parasitoid vs generalist predator populations.

The variability in plant species composition and abundance as well as planting density between buffers is also a potential driver of the outcome. Greater consistency of both the plants present and the density of the plantings would give greater power to further studies.

The non-agricultural 35 foot buffer site was kept in the central statistical analysis (Table 5) because the other site characteristics including buffer species composition, buffer species age, stream characteristics, and regional proximity allowed for the sites to be similar enough to compare. The data support this conclusion because despite significant differences for two of the sampling periods, the other two dates showed the 35 foot buffer diversity falling in between the larger and smaller buffer diversity indices, as would be expected. Furthermore, the 35 foot buffer species abundance fell between the other buffer width mean species abundance for Aug 5 and Sept 15 (Table 4), and the total natural enemy abundance for the 35 foot buffer site was grouped with the other buffers for all of the collection dates, also exhibiting the same changes in slope (Figure 4).

## **Management Implications**

Further classifications of diversity and buffer width have implications for land management that optimizes ecological benefits or ecosystem services. With the growing

capacity for citizen science and information transfer that allows easier methods for measuring nutrient movement, water cycling, as well as insect species and diversity; a manager has the potential to calculate not only natural enemy diversity, but also the diversity and abundance of other plant, animal, fungi, and bacteria species as they relate to their management needs. For example in a cornfield, a diverse riparian forest stand can support soil retention and protect against wind damage and evaporation, while beneficial insect populations within support pollination and pest control, all of which improve the corn production while creating synergistic benefits to each other. It is possible to evaluate the impact of all of these values in relation to buffer width to optimize buffer distribution for particular land uses.

More practically, there are many reasons land managers may decide that large buffers are desirable including financial incentives to plant in conservation, aesthetics, or control of agricultural pollutant runoff from steep slopes of farmland. These findings that larger buffers have a greater diversity of natural enemies moving into farmlands when crops are most susceptible to pest outbreak is another consideration in their complicated and interdependent cost benefit analysis.

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