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# A COMPARISON OF AQUATIC INSECT COMMUNITIES BETWEEN MAN-MADE AND NATURAL PONDS

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Kristy Kay Whiteson

May 2009

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The Undersigned Thesis Committee Approves the Thesis Titled

A COMPARISON OF AQUATIC INSECT COMMUNITIES
BETWEEN MAN-MADE AND NATURAL PONDS

by
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ABSTRACT

A COMPARISON OF AQUATIC INSECT COMMUNITIES
BETWEEN MAN-MADE AND NATURAL PONDS

by Kristy Kay Whiteson

Throughout history ponds have been created for a variety of reasons. A current goal in pond creation is to increase and maintain biodiversity. Until recently, reserve managers were unaware of how these man-made ponds compared to natural ponds in respect to their aquatic insect diversity. This study serves as the first comparison of aquatic insect communities between the man-made and natural ponds located at ESNERR, MLML, and BLM-Fort Ord public lands in Monterey County, California, USA. Environmental factors (pond size, age, hydroperiod, plant cover, and water chemistry) were evaluated to determine if they had an effect on aquatic insect diversity. Simpson's Diversity Index and similarity indices (Jaccard and Sørensen) were used to compare aquatic insect communities between different ponds.

The environmental factors assessed in this study did not significantly affect aquatic insect diversity. However, the Simpson's Diversity Index revealed that the man-made ponds had a similar amount of aquatic insect diversity compared to the nearby natural ponds. In addition, the similarity indices showed that the man-made and natural study ponds were comparable in aquatic insect species richness and abundance. Specifically, there was a 90% similarity in aquatic insect diversity between the wildlife enhancement and nearby natural ponds. This study demonstrated that these man-made ponds are quite similar to natural ponds and serve as important habitats in conserving biodiversity.

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I appreciate ESNERR, MLML, and BLM- Fort Ord public lands for allowing me to study the aquatic insect communities residing their ponds. I am most grateful to Dr. Jeffrey Honda, Dr. Rodney Myatt, and Ms. Susanne Fork for providing me with exceptional advice in the field and lab, as well as, help with aquatic insect identifications and manuscript editing. Many thanks go to Jenny and Sage Lefebvre, Suzanne Worcester, Cammy Cambre, John Haskins, Peter Slatterly, John Oliver, Bruce Delgado, and the BLM- Fort Ord volunteers for their help in the field. My appreciation goes to the Alameda County Mosquito Abatement team for their assistance with aquatic insect identifications. I'm indebted to Adam Whiteson for helping me dissect the Chao *et al.* (2005) paper and special thanks to Rena Whiteson for her constructive and helpful reviews of this manuscript. I am very grateful to Yoseif Whiteson for his assistance in database construction, project management, and manuscript review.

# DEDICATION

This manuscript is dedicated to my family (Yoseif, Sophia, and Eliza) for their unending support, help, and patience. It is also dedicated to my parents, sisters, and niece (Yvon, Sharon, Jenny, Cher, and Sage) for instilling in me a passion for nature, curiosity, and perseverance.

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# INTRODUCTION

Ponds are ubiquitous and comprise a significant proportion of the world's inland waters. According to Biggs *et al.* (2005), ponds are defined as "water bodies between 1 meter squared and 2 hectares in area which may be permanent or seasonal, including both man-made and natural water bodies." Due to their small size, ponds were once seen as insignificant habitats with respect to conserving biodiversity. They were often destroyed because people were unaware of their significance or even their existence (Biggs and Langley, 1989; Folkerts, 1997; Moorhead *et al.*, 1998; Podrabsky *et al.,* 1998). However, over the past few decades, ponds have gained recognition as important wetland habitats. Scientists from many different fields are now interested in knowing more about how ponds function, their biotic communities, and most importantly their role in conserving biodiversity. According to DeMeester *et al.* (2005), ponds have high conservation value due to their unique and variable species composition. Ponds are also collectively more diverse than rivers, lakes, or wetlands (Céréghino *et al.,* 2008). Throughout history man-made ponds have been created for many purposes, including fishing, duck hunting, water filtration, flood control, water for grazing animals, and aesthetics. According to Hartzell *et al.* (2007), some ponds are created in order to meet the U.S. "No Net Loss" policy for wetlands. These ponds are created for wildlife enhancement purposes to increase or maintain biodiversity.

Many ponds are created and managed without any scientific understanding (Céréghino *et al.,* 2008), and in most cases reserve managers have no idea how macroinvertebrate diversity in man-made ponds compares to that in natural ones

(Williams *et al.*, 2008). It is important for reserve managers to evaluate the macroinvertebrate communities within man-made ponds, because macroinvertebrates have been recognized as important bioindicators of wetlands health (Cao *et al.*, 1998; Briers and Biggs, 2003; Balcombe *et al.*, 2005; Biggs *et al.*, 2005). According to Balcombe *et al.* (2005), several studies have been conducted to evaluate differences in fauna and flora between created and natural wetlands. However, only a few studies have specifically compared macroinvertebrate communities in the two types of wetlands. In three different comparative studies, macroinvertebrate diversity was evaluated in mitigated and adjacent natural wetlands (Stanczak and Keiper, 2004; Balcombe *et al.*, 2005; Hartzell *et al.*, 2007). All three studies observed similar macroinvertebrate richness, abundance, and diversity between the two types of wetlands. These studies concluded that the high degree of similarity in the mitigated and natural wetlands was most likely due to the rapid colonization by macroinvertebrates. Actively dispersing aquatic insects, such as Coleoptera and Diptera, can colonize newly created wetlands within a short period of time, especially if a natural system is within close proximity (Layton and Voshell, 1991; Solimini *et al.*, 2003; Stanczak and Keiper, 2004).

Currently, there is little information about the man-made ponds and their aquatic insect communities located within Elkhorn Slough National Estuarine Research Reserve (ESNERR) (Caffrey *et al.*, 2002). There is also sparse information about the freshwater ponds located at Bureau of Land Management-Fort Ord public lands (BLM-Fort Ord) (Delgado, personal communication, 2003). Reserve managers at both locations are unaware of any macroinvertebrate baseline diversity studies conducted since the creation

of these man-made ponds. Thus, the reserve managers are interested in learning more about these ponds and their role in maintaining biodiversity. The purpose of this study was to investigate these ponds and their aquatic insect communities. Specifically, this study sought to determine whether man-made ponds located at the reserves are comparable in aquatic insect diversity to natural ponds located in the same area. According to DeJong (1975) and Chao *et al.* (2005), two ways to compare different biological communities are to use diversity and similarity indices. Diversity indices are designed to measure the biodiversity of an ecosystem. Similarity indices allow ecologists to determine the similarity of species diversity in two communities. These indices were utilized in this study to make comparisons between the differing pond communities.

## METHODS

### Study area

The fourteen freshwater ponds investigated in this study are located within Monterey County, California, U.S.A. (Figure 1). Five of the ponds are found at Elkhorn Slough National Estuarine Research Reserve (ESNERR), which is located approximately 32 km north of Monterey, California. The maximum distance between the five ESNERR ponds is 800 m and the closest distance is less than 6 m. Two ponds are managed by Moss Landing Marine Laboratories (MLML) and are located approximately 8 km southwest of ESNERR. These ponds are approximately 305 m apart. The remaining seven ponds are managed by the Bureau of Land Management (BLM) and are located within Fort Ord public lands. The BLM ponds are located approximately 29 km south of the ESNERR ponds. The maximum distance between the seven BLM ponds is

approximately 5 km and the closest distance is approximately 402 m. These fourteen ponds were chosen for this study because little is known about aquatic insect diversity in the area, the ponds are easily accessible, and these ponds are managed without insecticides.

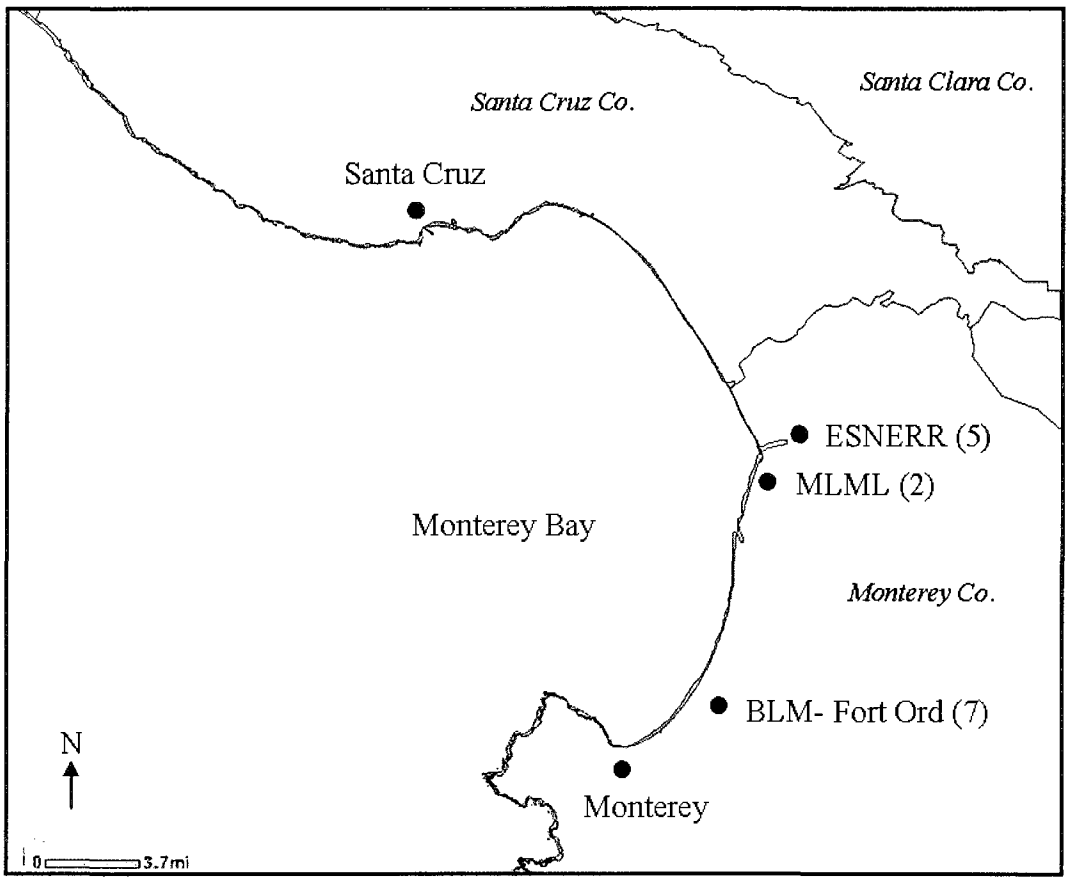


Figure 1. Location of the fourteen study ponds.
Map modified from USGS (nationalmap.gov)

According to ESNERR, MLML, and BLM managers, eleven of the ponds are man-made and the remaining three are categorized as natural vernal pools (seasonally wet depressions created over time). For this study, the fourteen ponds were divided into six different types based on their original creation and usage (Table 1).

Table 1. Original creation and usage of ponds in study.

| Code | Pond Type | No. of Ponds |
|---|---|---|
| AP | Aesthetic Pond | 1 |
| DP | Degraded Pond | 1 |
| NP | Natural Vernal Pools | 3 |
| OP | Overflow/Catchment Basins | 2 |
| SP | Stock Pond | 1 |
| WP | Wildlife Enhancement Ponds | 6 |

Most of the man-made ponds included in this study were created for wildlife enhancement purposes (i.e., fishing, duck hunting, and wildlife sanctuaries). The ponds designed for fishing and duck hunting are approximately 500 $m^2$ to 1 hectare in size, surrounded by riparian vegetation, and have a significant amount of open water. The MLML ponds were created less than ten years ago as wildlife sanctuaries. These ponds are surrounded by native riparian vegetation. One pond has open water while the other pond has a marsh-like appearance. The stock pond located at BLM-Fort Ord does attract wildlife, but its main purpose is to provide water to grazing sheep. The pond is mostly open water and has a high amount of turbidity. It is surrounded by a variety of grasses and willows. The aesthetic pond is located at ESNERR and was created as a community art project in 1976. It is small (32 $m^2$) in size and filled with well water. The aesthetic pond has a concrete bottom and is inhabited by ornamental aquatic plants. The remaining three man-made ponds were created when roads were built within ESNERR and BLM-Fort Ord. Two of these ponds are used as overflow catchment basins to aid against flooding. The degraded pond was once a natural vernal pool until an adjacent road was built. The three ponds range in size from approximately 300-800 $m^2$ and hold water for

only a few months. Lastly, the three natural vernal pools are located at BLM-Fort Ord and their creation began over a hundred years ago. The vernal pools are shallow in depth, have little open water, and range in size from approximately 300-4,600 $m^2$. These ponds are also considered to be in near-pristine condition, because of their rural and semi-private location.

**Data collection**

Aquatic insects and water chemistry data were collected monthly from each pond within the study over a twenty-four month period from January 2004 to December 2005. During each sampling date, aquatic insects were collected from the same three sampling locations within each pond. Sampling locations were determined by using a plant grid (19 x 1,000 cm) to estimate the percent of vegetation cover (low, medium, and high). A D-framed sweep net (1 mm mesh with an 18 x 19 cm opening) was used to collect the aquatic insects. The sweep net was pulled through 1 m of water approximately 0-0.25 m from the shoreline just above the sediment line. In some samples, the vegetation was so dense that it was difficult to impossible to make an entire 1 m sweep. The water volume of each sweep was recorded and used to calculate aquatic insect densities. The use of sweep nets to collect aquatic insects has been successfully utilized in several other pond studies (Friday, 1987; Palik *et al.*, 2001; Smith *et al.*, 2003; Tarr *et al.,* 2005). Compared to other sampling methods, sweep nets are highly effective in detecting differences in aquatic insect communities between wetlands (Cheal *et al.*, 1993; Turner and Trexler, 1997). Water chemistry data were collected at the first sampling location of every pond. A YSI Multi-parameter Sonde was used to gather data on water temperature, pH, salinity,

and turbidity. During the study, decontamination procedures suggested by ESNERR were followed after visiting each pond to avoid the transmission of Chytridiomycosis.

In the laboratory, aquatic insects were removed from vegetative debris, identified to the lowest possible taxon, and counted. In most cases, aquatic insects were identified to genus or species using insect keys (Merritt and Cummins, 1996; Usinger, 1968); however some individuals could only be identified to the family level. All samples were stored in 80% ethanol. Reference collections were deposited at ESNERR, BLM-Fort Ord public lands office, and in the J. Gordon Edwards Museum of Entomology at San José State University, California.

**Statistical analyses**

Many environmental factors can contribute to differences in aquatic insect diversity between ponds (e.g., Collinson *et al.*, 1995; Gee *et al.*, 1997; DeSzalay and Resh, 2000; Alcocer *et al.*, 2001; Oertli *et al.*, 2002). Several statistical analyses were conducted using SPSS 16.0 to determine if some of these environmental factors affected aquatic insect diversity within the study ponds. To test whether there was any correlation between pond size or age and aquatic insect diversity Pearson product-moment correlation analysis was conducted. A linear regression analysis was used to determine if species richness was dependent upon a pond's hydroperiod length. A one-way between groups ANOVA was performed to test whether there was a difference in aquatic insect diversity between three types of vegetation cover (low, medium, and high). In addition, a multiple regression analysis was conducted to determine if aquatic insect diversity was

dependent on certain water chemistry variables (water temperature, pH, salinity, and turbidity).

Finally, a one-way between groups ANOVA was used to test whether there was a difference in aquatic insect diversity between the six types of ponds based on their original creation and usage (see Table 1). Simpson's Index of Diversity was computed for each pond type and the means were compared using an ANOVA. To ensure that the sample sizes between the six pond types were equal, Simpson's Index of Diversity was computed only for sample dates shared by all fourteen ponds. Simpson's Index of Diversity was chosen for this study, because it is a well-known statistical tool used to measure the probability that two organisms randomly selected from a sample will belong to different species (DeJong, 1975). Simpson's Index of Diversity was computed as 1- D where $D = \sum \frac{n(n-1)}{N(N-1)}$ ($n$ = the total number of organisms of a particular species while $N$= the total number of organisms for all species). The index values range between 0.0, which represents no diversity, and 1.0, which represents infinite diversity. Several papers have recommended using Simpson's Index of Diversity to compare species diversity in differing biological communities (Turner and Trexler, 1997; Ravera, 2001; Brady *et al.*, 2002).

In order to help further characterize and compare each pond type, species richness, singularity, and similarity were calculated. Singularity is a tool used to assess rare species and taxonomic distinctiveness between communities. It is calculated by dividing the number of species that are only found within one community by the total number of

species for all communities (Boix *et al.*, 2007). Similarity indices are mathematical tools used to compare species overlap between communities (Chao *et al.,* 2005). This study compared the aquatic insect diversity between the pond types by using both the classic Jaccard and Sørensen's indices and the "new" or replicated incidence-abundance based Jaccard and Sørensen's indices proposed by Chao *et al.* (2005) (Table 2). According to these similarity indices, a value equaling 1.0 means the ponds were exactly similar and a value equaling 0.0 shows complete dissimilarity.

Table 2. Formulas for classic and new Jaccard and Sørensen indices.

| | **Jaccard** | **Sørensen** |
|---|---|---|
| **Classic** | $J_c = \frac{A}{A+B+C}$ | $S_c = \frac{2A}{2A+B+C}$ |
| **New*** | $J_n = \frac{UV}{U+V-UV}$ | $S_n = \frac{2UV}{U+V}$ |

A = Number of shared species between community X and Y
B = Number of species unique to community X
C = Number of species unique to community Y
U = Replicated incidence - abundance based estimator for community X
V = Replicated incidence - abundance based estimator for community Y
*Formulas for calculating U and V can be found in Chao *et al.*, 2005.

## RESULTS

### Ponds summary

There were several environmental differences between the ponds. Table 3 is a ponds summary that lists each pond's type, size, age, and hydroperiod lengths. Overall, pond size varied from 32 – 12,739 $m^2$. Historic maps showed the ponds differing in age from less than 10 to over 100 years old. During the twenty-four month study, there were two

hydroperiods and the ponds held water from 1 to 12 months per hydroperiod. In addition, water chemistry between the pond types varied. Water temperature averaged 15.21-21.73°C; pH was close to neutral 7.34-7.87; salinity varied from 0.13-1.44ppth; and turbidity between the pond types differed the most 14.23-266.06 NTU. Table 4 gives a more complete summary of the water chemistry averages between the different pond types.

Table 3. Ponds summary.

| **Pond #** | **Pond Type** | **Approximate Surface Area** ($m^2$) | **Approximate Age** (yrs.) | **Hydroperiod 1** (months) | **Hydroperiod 2** (months) |
|---|---|---|---|---|---|
| **1** | WP | 6,242 | 65 | 4 | 8 |
| **2** | WP | 540 | 100 | 12 | 10 |
| **3** | OP | 796 | 65 | 12 | 5.5 |
| **4** | AP | 32 | 25 | 12 | 12 |
| **5** | WP | 3,960 | 100 | 12 | 12 |
| **6** | WP | 1,500 | 10 | 12 | 12 |
| **7** | WP | 12,739 | 10 | 12 | 4 |
| **8** | SP | 1,225 | 55 | 10 | 12 |
| **9** | WP | 11,680 | 100 | 6 | 12 |
| **10** | NP | 326 | 100 | 10 | 12 |
| **11** | NP | 4,620 | 100 | 2.5 | 8 |
| **12** | OP | 306 | 55 | 1 | 5 |
| **13** | NP | 2,301 | 100 | 1 | 8 |
| **14** | DP | 402 | 55 | 3 | 6 |

Table 4. Average water chemistry over 24 month period.

| | **AP** | **DP** | **NP** | **OP** | **SP** | **WP** |
|---|---|---|---|---|---|---|
| **Water temperature (°C)** | 15.21 | 20.52 | 21.73 | 18.43 | 20.59 | 17.30 |
| **Salinity (ppth)** | 0.78 | 0.13 | 0.15 | 0.24 | 0.16 | 1.44 |
| **pH** | 7.51 | 7.51 | 7.45 | 7.34 | 7.87 | 7.75 |
| **Turbidity (NTU)** | 14.23 | 24.10 | 51.36 | 38.68 | 266.06 | 109.00 |

There was a mix of vegetation associated with each pond type (Table 5). The aesthetic pond was mostly surrounded by *Artemisia californica, Cupressus macrocarpa,* and *Pinus radiata.* Dense bunches of *Eleocharis* spp. and *Hydrocotyle* spp. were found thriving in the pond water. The degraded, natural, and stock ponds were all surrounded by *Quercus agrifolia.* These pond types also had *Bacccharis* spp., *Bromus* spp., *Eryngium vaseyi,* and *Plantago coronopus* associated with them. There were several non-native plants associated with the overflow/catchment ponds. These included *Conium maculatum, Lolium multiflorum,* and *Plantago coronopus.* The most common plants associated with the wildlife enhancement ponds were *Brassica nigra, Eleocharis* spp., *Juncus* spp., *Lemna gibba, Polygonum* spp., and *Typha latifolia.*

Table 5. Commonly occurring plant species.

| | **Plant species** | **AP** | **DP** | **NP** | **OP** | **SP** | **WP** |
|---|---|---|---|---|---|---|---|
| 1 | *Artemisia californica* | X | | | | | |
| 2 | *Atriplex spp.* | | | | | | X |
| 3 | *Azolla filiculoides* | X | | | | X | X |
| 4 | *Baccharis spp.* | X | X | X | X | X | X |
| 5 | *Brassica nigra* | | | | | | X |
| 6 | *Briza minor* | | | X | | | |
| 7 | *Brodiaea terrestris* | | X | | | | |
| 8 | *Bromus spp.* | | X | X | | X | X |
| 9 | *Carduus pycnocephalus* | | | | | | X |
| 10 | *Carex spp.* | | | | | | X |
| 11 | *Castilleja spp.* | | X | | | X | |
| 12 | *Centaurium davyi* | | | X | | | |
| 13 | *Conium maculatum* | | | | X | | X |
| 14 | *Cotula coronopifolia* | | | | | | X |
| 15 | *Cupressus macrocarpa* | X | | | | | |
| 16 | *Danthonia californica* | | X | | | X | |
| 17 | *Distichlis spicata* | | | X | | X | |
| 18 | *Eleocharis spp.* | X | X | X | X | X | X |
| 19 | *Eryngium vaseyi* | | X | X | | X | |
| 20 | *Eucalyptus spp.* | | | | X | X | X |
| 21 | *Euthamia occidentalis* | | | | X | | |
| 22 | *Geranium dissectum* | | | X | | X | |

Table 5 cont'd. Commonly occurring plant species.

| | Plant species | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|---|
| 23 | *Gnaphalium spp.* | | | X | | | |
| 24 | *Hydrocotyle spp.* | X | | | | | |
| 25 | *Juncus spp.* | X | X | X | X | X | X |
| 26 | *Lasthenia conjugens* | | X | | | | |
| 27 | *Lemna gibba* | X | | | | | X |
| 28 | *Lolium multiflorum* | | X | | X | X | X |
| 29 | *Lupinus nanus* | | | | | X | |
| 30 | *Lythrum hyssopifolia* | | X | X | | X | |
| 31 | *Malvella leprosa* | | | X | | | |
| 32 | *Marrubium vulgare* | | | | | X | |
| 33 | *Mimulus spp.* | | X | | | X | |
| 34 | *Nassella pulchra* | X | | | | X | |
| 35 | *Picris echioides* | | | | | X | |
| 36 | *Pinus radiata* | X | | | | | |
| 37 | *Plagiobothrys chorisianus* | | X | X | X | | |
| 38 | *Plantago coronopus* | | X | X | X | X | |
| 39 | *Polygonum spp.* | | | X | X | X | X |
| 40 | *Potamogeton nodosus* | | | X | | | |
| 41 | *Quercus spp.* | X | X | X | X | | X |
| 42 | *Rumex spp.* | | | X | X | X | X |
| 43 | *Salicornia virginica* | | | | | | X |
| 44 | *Salix spp.* | | | | | X | X |
| 45 | *Scirpus spp.* | | | | X | | X |
| 46 | *Sonchus spp.* | | | X | X | | |
| 47 | *Trifolium spp.* | | X | | | | |
| 48 | *Typha latifolia* | | X | | | | X |
| 49 | *Vinca major* | | | | X | | X |
| 50 | *Xanthium strumarium* | | | | | X | |

**Aquatic insect diversity**

During the twenty-four month study, a total of 34,134 aquatic insects in 41 genera were collected and identified. The seven most abundant aquatic insect genera caught were *Podura* (12,193), *Hesperocorixa* (5,647), *Callibaetis* (2,271), *Culex* (1,840), *Enallagma* (1,446), and *Notonecta* (1,015). The most frequent aquatic insect genera caught (i.e., found in at least 10 out of 14 ponds) were *Culex*, *Notonecta*, *Tropisternus*, *Callibaetis*, *Colymbetes*, *Dytiscidae* spp., *Enochrus*, and *Hesperocorixa*. Chironomidae

larvae were both abundant and frequent in this study, but were difficult to identify below the family level. Table 6 is an aquatic insect species summary that compares species distribution, Simpson's diversity, richness, and singularity between the six pond types. According to the Simpson's Diversity Index the six pond types each contained a high amount of diversity with a range of 0.680-0.886. The overflow/catchment ponds had the highest level of diversity while the aesthetic pond had the lowest. Species richness between the pond types varied from 14-36 species. The aesthetic pond had the lowest number of species while the wildlife enhancement ponds had the highest number. The results from the singularity index showed low values (0.000-0.049) indicating that the aquatic insects captured were commonly found and not rare. The wildlife enhancement ponds had two instances of unique insects (an unidentified scirtid [Coleoptera] and libelluid [Odonata] species) collected exclusively in that pond type. The natural ponds and the overflow/catchment ponds each had one instance of singularity: an unidentified staphylinid [Coleoptera] species was found in the natural ponds while an unidentified psychodid [Diptera] species was captured in the overflow/catchment ponds.

Table 6. Aquatic insect species summary.

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **Coleoptera** | **6** | **5** | **11** | **10** | **9** | **13** |
| Dytiscidae | 2 | 2 | 5 | 5 | 5 | 7 |
| Unknown | 1 | 0 | 1 | 1 | 1 | 1 |
| *Acilius* | 0 | 0 | 0 | 0 | 1 | 1 |
| *Colymbetes* | 0 | 1 | 1 | 1 | 1 | 1 |
| *Dytiscus* | 0 | 0 | 1 | 0 | 1 | 0 |
| *Hydroporus* | 0 | 1 | 1 | 1 | 0 | 1 |
| *Hygrotus* | 1 | 0 | 0 | 1 | 0 | 1 |
| *Oreodytes* | 0 | 0 | 1 | 0 | 1 | 1 |
| *Rhantus* | 0 | 0 | 0 | 1 | 0 | 1 |
| Haliplidae | 1 | 0 | 0 | 0 | 0 | 1 |
| *Peltodytes* | 1 | 0 | 0 | 0 | 0 | 1 |
| Hydraenidae | 0 | 0 | 1 | 1 | 1 | 1 |
| Unknown | 0 | 0 | 1 | 1 | 1 | 1 |
| Hydrophilidae | 3 | 3 | 4 | 4 | 3 | 3 |
| *Berosus* | 1 | 1 | 1 | 1 | 1 | 1 |
| *Enochrus* | 1 | 0 | 1 | 1 | 1 | 1 |
| *Hydrochara* | 0 | 1 | 1 | 1 | 0 | 0 |
| *Tropisternus* | 1 | 1 | 1 | 1 | 1 | 1 |
| Scirtidae | 0 | 0 | 0 | 0 | 0 | 1 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 1 |
| Staphylinidae | 0 | 0 | 1 | 0 | 0 | 0 |
| Unknown | 0 | 0 | 1 | 0 | 0 | 0 |
| **Collembola** | **1** | **0** | **1** | **1** | **0** | **1** |
| Poduridae | 1 | 0 | 1 | 1 | 0 | 1 |
| *Podura* | 1 | 0 | 1 | 1 | 0 | 1 |
| **Diptera** | **6** | **4** | **7** | **9** | **4** | **8** |
| Chaoboridae | 0 | 1 | 1 | 1 | 1 | 1 |
| *Chaoborus* | 0 | 1 | 1 | 1 | 1 | 1 |
| Chironomidae | 1 | 1 | 1 | 1 | 1 | 1 |
| Unknown | 1 | 1 | 1 | 1 | 1 | 1 |
| Culicidae | 3 | 2 | 4 | 4 | 1 | 4 |
| *Aedes* | 0 | 0 | 1 | 1 | 0 | 1 |
| *Anopheles* | 1 | 1 | 1 | 1 | 0 | 1 |
| *Culex* | 1 | 1 | 1 | 1 | 1 | 1 |
| *Culiseta* | 1 | 0 | 1 | 1 | 0 | 1 |
| Dixidae | 1 | 0 | 1 | 1 | 1 | 1 |
| *Dixella* | 1 | 0 | 1 | 1 | 1 | 1 |
| Psychodidae | 0 | 0 | 0 | 1 | 0 | 0 |
| Unknown | 0 | 0 | 0 | 1 | 0 | 0 |
| Tipulidae | 1 | 0 | 0 | 1 | 0 | 1 |
| Unknown | 1 | 0 | 0 | 1 | 0 | 1 |
| **Ephemeroptera** | **0** | **1** | **1** | **1** | **1** | **1** |
| Baetidae | 0 | 1 | 1 | 1 | 1 | 1 |
| *Callibaetis* | 0 | 1 | 1 | 1 | 1 | 1 |

Table 6 cont'd. Aquatic insect species summary.

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **Hemiptera** | **1** | **3** | **7** | **6** | **5** | **8** |
| Belostomatidae | 0 | 0 | 1 | 0 | 1 | 1 |
| *Belostoma* | 0 | 0 | 1 | 0 | 1 | 1 |
| Corixidae | 1 | 1 | 2 | 3 | 1 | 3 |
| *Corisella* | 0 | 0 | 1 | 1 | 0 | 1 |
| *Hesperocorixa* | 0 | 1 | 1 | 1 | 1 | 1 |
| *Trichocorixa* | 1 | 0 | 0 | 1 | 0 | 1 |
| Gerridae | 0 | 1 | 1 | 0 | 1 | 1 |
| *Gerris* | 0 | 1 | 1 | 0 | 1 | 1 |
| Hebridae | 0 | 0 | 1 | 1 | 1 | 1 |
| *Merragata* | 0 | 0 | 1 | 1 | 1 | 1 |
| Notonectidae | 0 | 1 | 2 | 2 | 1 | 2 |
| *Buenoa* | 0 | 0 | 1 | 1 | 0 | 1 |
| *Notonecta* | 0 | 1 | 1 | 1 | 1 | 1 |
| **Odonata** | **0** | **4** | **4** | **4** | **1** | **5** |
| Aeschnidae | 0 | 1 | 1 | 1 | 0 | 2 |
| Unknown | 0 | 0 | 0 | 1 | 0 | 1 |
| *Anax* | 0 | 1 | 1 | 0 | 0 | 1 |
| Coenagrionidae | 0 | 1 | 1 | 1 | 1 | 1 |
| *Enallagma* | 0 | 1 | 1 | 1 | 1 | 1 |
| Lestidae | 0 | 1 | 1 | 1 | 0 | 0 |
| *Lestes* | 0 | 1 | 1 | 1 | 0 | 0 |
| Libellulidae | 0 | 1 | 1 | 1 | 0 | 2 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 1 |
| *Sympetrum* | 0 | 1 | 1 | 1 | 0 | 1 |
| **Total Species Richness** | 14 | 17 | 31 | 31 | 20 | 36 |
| **Simpson's Index of Diversity** | 0.680 | 0.772 | 0.870 | 0.886 | 0.779 | 0.711 |
| **Singularity** | 0.000 | 0.000 | 0.024 | 0.024 | 0.000 | 0.049 |

**Environmental factors and aquatic insect diversity**

There was no statistically significant correlation between pond size or age and aquatic insect diversity. Also, according to the linear regression analysis, the length of a pond's hydroperiod cannot reliably predict aquatic insect species richness $p<0.05$ [$F(1,20)=0.743$, $p<0.399$]. A one-way between groups ANOVA revealed no relationship between the amount of vegetation cover (low, medium, or high) and aquatic insect diversity $p<0.05$ [$F(2,116)=0.271$, $p<0.763$]. Finally, a multiple regression analysis

showed no statistically significant relationship between aquatic insect diversity and water temperature, pH, salinity, or turbidity $p<0.05$ [$F(4,177)=2.074$, $p<0.086$].

**Comparison of aquatic insect communities**

Based on the one-way between groups ANOVA there was no statistically significant difference in the mean diversity (1-D) between the six different pond types $p<0.05$ [$F(5,101)= 1.171$, $p= 0.329$]. Table 7 compares the number of shared species and species richness between the six pond types. Out of the 41 genera collected only 4 genera were shared by all pond types. These genera were *Berosus, Tropisternus, Culex* and Chironomidae. The wildlife enhancement ponds and the overflow/catchment ponds shared the most species (28), while the aesthetic pond and degraded pond shared the least number of species (5).

Table 7. Comparison of shared species between pond types.

| | **AP** | **DP** | **NP** | **OP** | **SP** | **WP** | Total Taxa |
|---|---|---|---|---|---|---|---|
| **AP** | | 5 | 10 | 13 | 6 | 14 | 14 |
| **DP** | | | 17 | 15 | 11 | 15 | 17 |
| **NP** | | | | 24 | 19 | 27 | 31 |
| **OP** | | | | | 15 | 28 | 31 |
| **SP** | | | | | | 19 | 20 |
| **WP** | | | | | | | 36 |

Table 8 summarizes the results from both the classic and new Jaccard and Sørensen similarity indices. All of the indices indicated that the aesthetic and degraded ponds had the lowest degree of similarity, whereas, the wildlife enhancement and overflow/catchment ponds had the highest degree of similarity. The classic Jaccard similarity index results showed that only 1 out of 15 pond comparison values were greater than 0.70 in similarity. In contrast, the new Jaccard similarity index revealed 6

out of 15 comparisons to be greater than 0.70. The classic Sørensen index showed 5 out of 15 pond comparisons to be 0.70 or greater and the new Sørensen index illustrated 8 out of 15 comparisons to be highly similar. It should be noted that in both the new Jaccard and Sørensen indices, which account for both species incidence and abundance, the wildlife enhancement ponds were highly similar (> 0.90) to the natural ponds.

Table 8. Results summary of similarity indices.

Classic Jaccard Similarity Index

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **AP** | | 0.192 | 0.286 | 0.406 | 0.214 | 0.389 |
| **DP** | | | 0.548 | 0.455 | 0.423 | 0.395 |
| **NP** | | | | 0.632 | 0.594 | 0.675 |
| **OP** | | | | | 0.417 | 0.718 |
| **SP** | | | | | | 0.514 |
| **WP** | | | | | | |

New Jaccard Similarity Index

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **AP** | | 0.140 | 0.315 | 0.429 | 0.143 | 0.858 |
| **DP** | | | 0.710 | 0.670 | 0.380 | 0.339 |
| **NP** | | | | 0.800 | 0.745 | 0.906 |
| **OP** | | | | | 0.554 | 0.908 |
| **SP** | | | | | | 0.459 |
| **WP** | | | | | | |

Classic Sørensen Similarity Index

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **AP** | | 0.323 | 0.444 | 0.578 | 0.353 | 0.560 |
| **DP** | | | 0.708 | 0.625 | 0.595 | 0.566 |
| **NP** | | | | 0.774 | 0.745 | 0.806 |
| **OP** | | | | | 0.588 | 0.836 |
| **SP** | | | | | | 0.679 |
| **WP** | | | | | | |

New Sørensen Similarity Index

| | AP | DP | NP | OP | SP | WP |
|---|---|---|---|---|---|---|
| **AP** | | 0.246 | 0.479 | 0.601 | 0.251 | 0.924 |
| **DP** | | | 0.831 | 0.802 | 0.550 | 0.506 |
| **NP** | | | | 0.889 | 0.854 | 0.951 |
| **OP** | | | | | 0.713 | 0.952 |
| **SP** | | | | | | 0.629 |
| **WP** | | | | | | |

## DISCUSSION

According to Biggs *et al.* (1994), Heino (2000), and Phillips (2003), having a mosaic of pond habitats will increase the amount of macroinvertebrate biodiversity within an area. The fourteen ponds evaluated in this study varied in size, age, hydroperiod length, vegetation, and water chemistry. These environmental differences have provided a suitable habitat for a diverse group of aquatic insects. As indicated by the Simpson's Index of Diversity, all of the study ponds were notably diverse. The study ponds contained approximately 30% of California's known lentic aquatic insect genera (Richards, 2006). Even the aesthetic pond, which had the lowest number of species, had at least 10% of California's known lentic aquatic insects. These results illustrate the importance of Monterey County's freshwater ponds as valuable habitat for increasing and maintaining biodiversity.

The results from this study indicated that certain environmental factors characteristic of these study ponds do not have a significant effect on aquatic insect diversity. A few studies have stated that pond size is positively correlated with species diversity (Adams and Robbins, 1988; Bazzanti *et al.*, 1996; and Nilsson, 1984). However, Oertli *et al.* (2002), and Gee *et al.* (1997) stated that two small, but sufficiently different ponds can retain more species than one large pond. In this study, there was a variety of pond sizes and no correlation was found between pond size and aquatic insect diversity. According to Brady *et al.* (2002), pond age does not affect aquatic insect diversity if the insects captured have an active dispersing phase. In their study, Brady *et al.* (2002) observed no relationship between pond age and actively dispersing

macroinvertebrates. However, they did observe a positive relationship between pond age and poorly dispersing macroinvertebrate diversity. A majority of the aquatic insect species collected during this study are able to fly during their adult phase. This could explain why there was no relationship between pond age and aquatic insect diversity. This study also observed no relationship between the length of a pond's hydroperiod and aquatic insect species richness. This was surprising, because the study ponds varied in hydroperiod length from 1-12 months, and several papers state that pond hydroperiod is one of the most important factors in determining macroinvertebrate species composition (Schneider and Frost, 1996; Williams, 1996; Brooks, 2000; Sanderson *et al.*, 2005; Tarr *et al.*, 2005). The most logical explanation for a lack of difference between ponds of varying hydroperiods may be because the majority of aquatic insects captured in this study could easily migrate between bodies of water during their adult stage (e.g., Coleoptera, Diptera, Hemiptera, and Odonata). Even though, two macroinvertebrate diversity and plant cover studies found aquatic insect species richness and abundance to be affected by the amount of vegetation cover present (Batzer and Resh, 1992; DeSzalay and Resh, 2000), this study found no relationship between the two variables. Finally, water chemistry variables, such as pH and salinity, have been known to affect aquatic insect diversity (Courtney and Clements, 1998; Grillet, 1999; Alcocer *et al.*, 2001), yet no significant differences were observed in this study between aquatic insect diversity and water temperature, pH, or salinity. It should be pointed out that average water temperature, salinity, and pH between the six pond types did not significantly differ. Turbidity also did not have an effect on aquatic insect diversity. The fourteen ponds

NTU ranged from 14.23-266.06. The stock pond which had the highest level of diversity also had the highest NTU level and the aesthetic pond had the lowest levels of diversity and NTU. It would be interesting to pursue this observation further, because of the concern of agriculture runoff in the area and its effect on aquatic life.

This study also attempted to uncover any differences in aquatic insect diversity between ponds created for different purposes (i.e., six pond types). Again, the results indicated no statistically significant difference. This means that the man-made ponds may, in fact, support similar levels of aquatic insect diversity as that found in natural ponds. In addition, out of the five different man-made ponds, the wildlife enhancement ponds' aquatic insect diversity was most similar to the natural ponds (Table 8). These results are in agreement with previous studies that compared macroinvertebrate diversity in mitigated and natural wetlands (Stanczak and Keiper, 2004; Balcombe *et al.*, 2005; Hartzell *et al.,* 2007). In a very similar study, Hartzell *et al.* (2007) used the Jaccard index to compare macroinvertebrate diversity between created and natural wetlands. They observed a 56% similarity, whereas, this study observed a 67.5% similarity between the wildlife enhancement and natural ponds (Table 8).

It should be noted that until recently, most diversity studies have used the classic Jaccard or Sørensen similarity indices to compare species diversity between different communities. However, these indices only account for species incidence and not species abundance. According to Chao *et al.* (2005), the classic indices tend to underestimate similarity because they do not account for rare or missing species. In order to correct this underestimation, Chao *et al.* (2005) devised a replicated incidence-abundance based

formula to enhance the classic Jaccard and Sørensen similarity indices. In their study the classic Jaccard index showed low compositional similarity between two different plant communities. However, the new Jaccard formula accounted for several rare and infrequent plant species that were shared between the communities and therefore the formula was able to give a better estimation of community similarity. In this study the classic Jaccard and Sørensen indices did appear in most cases to underestimate the degree of similarity between the pond types when compared to the new indices (Table 8). The classic Jaccard similarity index showed a 67.5% similarity between the wildlife enhancement and natural ponds, whereas, the new Jaccard similarity index showed a 90.6% similarity between the two pond types (Figure 2). According to the new Jaccard similarity index, the wildlife enhancement and natural ponds contained many of the same species even though some of those species were captured in one pond type but not the other. These results showed that the new similarity indices do adjust for undersampling and account for shared infrequent and missing species.

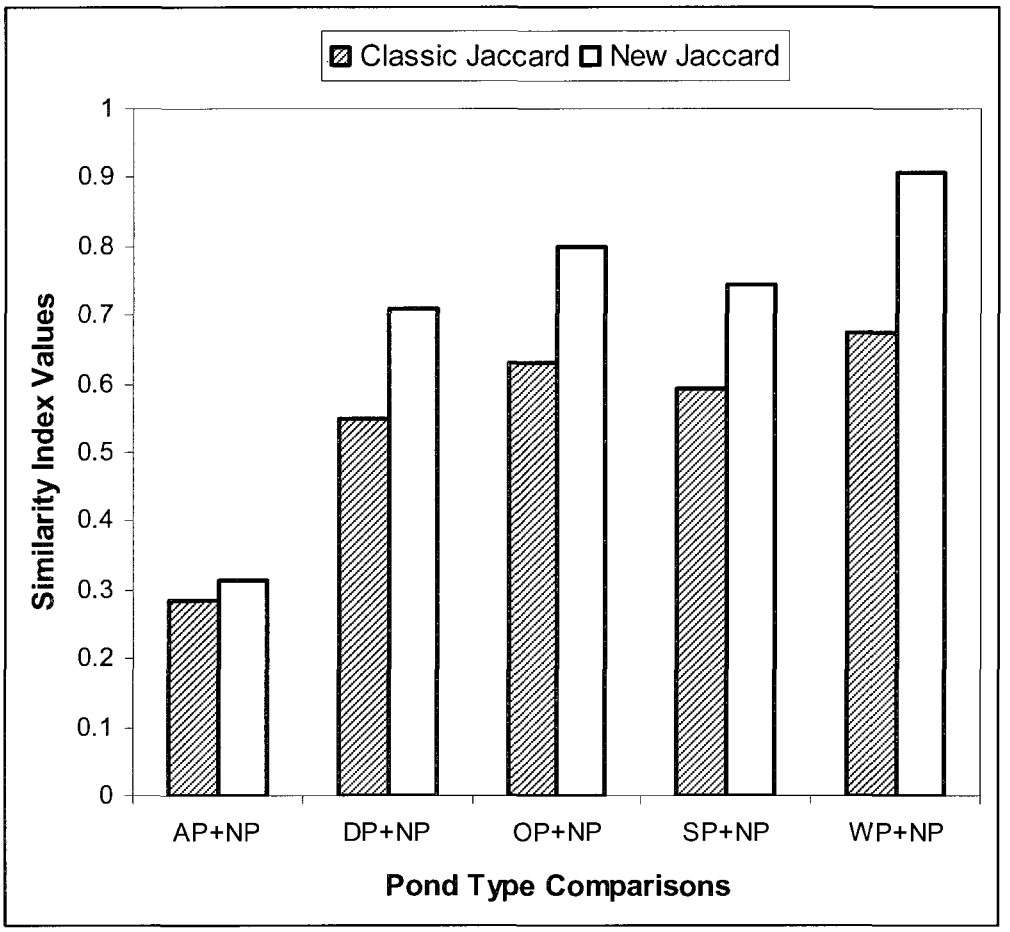


Figure 2. Comparison between classic and new Jaccard indices. Comparing aquatic insect diversity similarity between natural ponds and five different man-made ponds.

## CONCLUSION

The loss of biodiversity is a world-wide concern. Within the United States there are over 1,300 species listed as endangered, and 309 of those species reside in the State of California (USFWS, 2009). Furthermore, half of the United States' endangered species use or live in wetland habitats (USEPA, 2009). In order to conserve and maintain biodiversity, wetland habitats must be protected and managed properly. To alleviate the loss and destruction of wetlands, the United States' government initiated the "No Net

Loss" policy. According to the U.S. Fish and Wildlife Service (1994), the "No Net Loss" policy is defined as "wetland losses must be offset by wetland gains in terms of actual acreage and, to the extent possible, ecosystem function". According to Balcombe *et al.* (2005), the United States is gaining wetlands acreage, but little is known about whether the gain in ecosystem function is occurring. Palmer *et al.* (1997) note one possible way to reestablish ecosystem function is to restore the community's species diversity. In other words, are man-made wetlands comparable to natural wetlands in their biodiversity? Until recently, this question had not been studied within the realm of macroinvertebrate communities, especially those residing in ponds. This paucity of information is unfortunate because in comparison to other freshwater habitats, collectively ponds are known to be more diverse (Céréghino *et al.*, 2008). This was the first study to compare aquatic insect diversity between man-made and natural ponds located within ESNERR, MLML, and BLM-Fort Ord public lands. According to the Simpson's Diversity Index, the man-made ponds in this study had a similar amount of aquatic insect diversity compared to the nearby natural ponds. The new Jaccard and Sørensen's similarity indices also revealed that the wildlife enhancement ponds were remarkably similar to the natural ponds in aquatic insect species richness and abundance. It appears that the ESNERR, MLML, and BLM-Fort Ord man-made ponds are indeed functioning properly and this would seem to fit Palmer's *et al.* (1997) "Field of Dreams" hypothesis that, "if you build it, they will come."

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