Water Pool Management in Relation to Mosquito Abundance and Control Methods at the University of British Columbia

Aidan Lindsay

CONS 449

Abstract

A study conducted at the University of British Columbia examined the effects of vegetation, chlorination, aeration, and presence of fish, on species abundance in relation to mosquitoes, in ten difference water pools around campus. Floating vegetation was associated with an increased abundance of mosquito non-predatory species ($p=0.01$), emergent vegetation was associated with an increased abundance of predatory species ($p=0.01$), and submerged vegetation was associated with an increased abundance of mosquito non-predatory ($p=0.02$) and predatory species ($p<0.01$). Presence of chlorination significantly reduced the overall species abundance, both non-predatory ($p=0.02$) and predatory species($p<0.01$), aeration was shown to reduce predatory species abundance ($p=0.05$) and the presence of fish was associated with a reduced abundance of non-predatory species ($p=0.01$) and increased abundance of predatory species ($p=0.02$). Based on these results and other studies a number of recommendations have been made for effective development and maintenance of water pools on campus.

Table of Contents

INTRODUCTION

Mosquitoes have colonized almost every habitat type on earth, with a few exceptions, and the understanding of their relationship within urban environments is important in creating efficient and successful control methods for their populations (Russel 1999). Studying mosquito distribution and abundance in relation to emerging infectious diseases, such as West Nile virus, is important to human populations, especially in densely population urban areas.

Mosquitoes are holometabolous, require water for proper development, and have the capability of overwintering in order to persist throughout the years (Baker et al. 2010; Belton 1983, Leopoldo 2008). Holometabolism describes a class of insects that undergo four distinct life stages and exhibit complete metamorphosis, the four stages are egg, larva, pupa, and adult (Leopoldo 2008; Russel 1999). Mosquito larvae molt four times before becoming pupae and both larval and pupae stages require standing or running water for proper development (Leopoldo 2008; Russel 1999). Mosquitoes have the ability to overwinter; meaning they can pass through winter stages by shielding themselves from adverse conditions (Belton 1983). Different genera of mosquitoes will overwinter at various life cycle stages, but *Culex* will tend to overwinter as adults (Burkett-Cadena et al. 2011). Exposure of larvae and pupae to cool temperatures and shortened light cycles results in adult females that enter a state of reproductive diapuase (Burkett-Cadena et al. 2011). The adult females will seek out hibernating shelters that typically remain free of frost, such as sewers, caves, and cellars (Burkett-Cadena et al. 2011). Overwintering is observed in locations where climatic factors do not promote the development and growth of mosquitoes year round, thus the mosquitoes must develop a dormant stage in order to maintain their species development (Belton 1983). The nature of the habitat will influence which mosquito species will colonize it and the extent of their productivity (Russel 1999).

There are many predators of mosquitoes, making them an important component of the biological food chain. Predator characteristics are important to consider when determining control methods for mosquitoes, as the environmental conditions will not only affect the development of the mosquitoes, but of their predators as well. The ability to maintain high predator concentrations within a given habitat may be effective in reducing the mosquito populations (Russel 1999; Metro Vancouver 2009). Thus careful consideration must be taken when determining how to reduce mosquito counts.

Habitat also plays a large role in mosquito distribution and abundance. Mosquitoes do not exhibit parental care, thus the survival, growth and fecundity of the offspring are extremely influenced by the quality of the habitat in which the eggs are laid (Arav and Blaustein 2006). Two important conditions for mosquito oviposition include risk of desiccation and risk of predation to larvae (Arav and Blaustein 2006). Many species choose habitats based on suitability for egg laying and development, and microclimatic conditions in various vegetation types favor larval development for different species (Metro Vancouver 2009). Floating, emergent, and edge vegetation, as well as surface algae, support mosquito development (Russel 1999). In addition, the distribution of vegetation within a water pool can affect the success of mosquitoes. Areas with dense emergent plant stands, or regions of fallen or dead plants are attractive to mosquitoes (Russel 1999). Vegetation has also been shown to protect larvae from predation and physical disturbance, as well as provide a food source (Russel 1999). Although vegetation has been shown to provide suitable breeding locations, there is variation in the preference for some mosquitoes.

Reports have indicated that many mosquitoes prefer laying eggs in sunlit areas, and that *Culex pipiens* and *Culex tarsalis* mosquitoes tend to breed in open, non-vegetated water pools (Metro Vancouver 2009). In addition to vegetation influencing the success rate of mosquitoes, aquatic and terrestrial plants influence the success of mosquito predators.

Vegetation around the perimeter of water pools can provide habitats for adult mosquito predators, such as amphibians, birds, and spiders and aquatic vegetation can provide habitats for other predators such as dragon flies, damsel flies, water beetles and fish (Russel 1999; Metro Vancouver 2009). Understanding the requirements and preferences of mosquitoes and their predators is important when considering how to alter the habitat and surface waters for controlling mosquito populations.

A common concern with regards to standing water pools in urban environments is the cleanliness of the pool. Maintenance of standing water pools in urban environments directly affects the conditions of the water pool and whether organisms will be able to grow and thrive in the water. Chlorination is a popular method of water pool treatment and cleaning, however it has can have drastic affects on the ecological conditions of the pool, often rendering the water uninhabitable for many species (Brungs 1973). High levels of residual chlorine can be lethal to a number of mosquito predator species, for example the fathead minnow (Brungs 1973). Residual concentrations of greater that 0.79 mg/l have been shown to be toxic to such species (Brungs 1973).

Factors such as aeration, chlorination, temperature, vegetation, and algae, may all contribute to the overall health of the water pool, but determining which factors contribute to mosquito populations can be challenging. There are many factors that change with artificial and managed water bodies in the urban environment, but not many studies have been conducted on the outcomes of such management with respect to mosquito and predator control.

Although there are many practices engaged at UBC for water body management, a larger body of evidence regarding urban water body management with respect to mosquito and predator control could lead to improved management practices. This study aims to understand how vegetation, chlorination, and aeration affect species abundance in the water pools, as well as understanding the relationship between predator and non-predator species. UBC provides an appropriate location for this study, as the conditions are ideal for mosquito development. UBC offers a temperate climate within an urban setting containing standing water pools.

MATERIALS AND METHODS

In the summer of 2011, multiple data sets were collected at various locations around the University of British Columbia (UBC), in Vancouver, British Columbia, Canada. Ten pond sites (Fig 1) were sampled for aquatic invertebrates and evaluated for various characteristics like chlorination, aeration, water temperature, whether the site was natural, semi-natural, or artificial, type of vegetation, and level of algae (Table 1).

Between June 23, 2011, and September 2, 2011, each pond was sampled five times in accordance to the Metro Vancouver procedure for mosquito monitoring (Table 2) (Metro Vancouver 2009). Surface water sampling was carried out using a 500mL long-handled dip sampler. Three samples were taken with each sample and the average number of mosquitoes per 500ml of water was calculated. Samples were also taken to determine the type and abundance of aquatic insects present. Where possible, species identification was done on site in order to reduce the number of organisms killed. Some individual

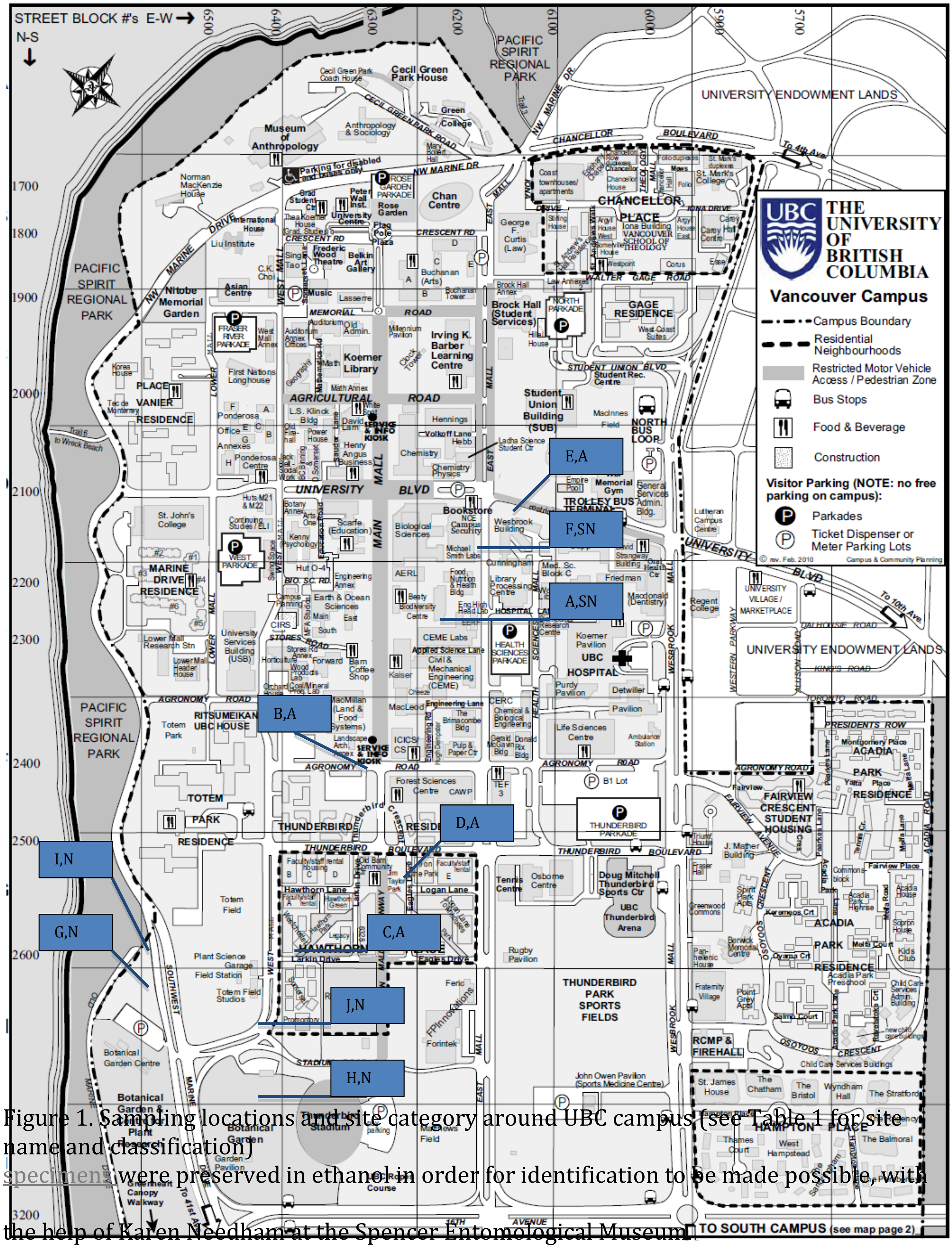


Figure 1. Sampling locations and site category around UBC campus (see Table 1 for site name and classification)

specimens were preserved in ethanol in order for identification to be made possible, with the help of Karen Needham at the Spencer Entomological Museum.

Qualitative habitat information was taken at each site and each time sampling was completed, to record changes in the conditions of the water features. The level of vegetation was recorded as being emergent, floating, or submerged. Aeration and chlorination were recorded as being either present or absent, and water temperature was recorded using a thermometer.

Table 1. Sampling site names and categorizations.

Site Name	Categorization (Natural=N) (Semi-natural=SN) (Artificial=A)	Chlorination (Yes=Y) (No=N)	Aeration (Yes=Y) (No=N)	Vegetation (Floating=F) (Emergent=E) (Submerged=S)	Avg. Mosquito Density (#/100ml)
Beaty Biodiversity (A)	SN	N	N	F/E	5.2
Old Barn (B)	A	N	Y	None	0
Promenade (C)	A	Y/N*	Y/N*	None	10.8
Reflections (D)	A	Y/N*	Y	F/E/S	0
Westbrook (E)	A	N	Y	None	0
Michael Smith Laboratories (F)	SN	N	Y	S	0
Botanical Garden Entrance (G)	N	N	N	F/S	0
Native Pond (H)	N	N	N	F/E/S	0.12
Outside Botanical Garden (I)	N	N	N	F/E/S	0.16
Meadow Pond (J)	N	N	Y	F/E	0

*Data was inconsistent for these recordings. On some sampling days the water pool was aerated and other days it was not, similarly with chlorine detection.

Table 2. Sampling locations and dates sampled.

Sampling Locations	Sampling Dates
Beaty Biodiversity (A), Old Barn (B), Promenade (C), Reflections (D), Westbrook (E), Michael Smith Laboratories (F)	23/06/11,06/07/11, 19/07/11, 17/08/11, 31/08/11
Botanical Garden Entrance (G), Native Pond (H), Outside Botanical Garden (I), Meadow Pond (J)	26/06/11, 07/07/11, 20/07/11, 19/08/11 02/09/11

Data analyses were carried out using the statistical analysis program JMP10 (Cary, NC, SAS), to test the relationships between various factors. In all cases, a student's t-test was used to assess the difference between the means. Each variable, for example predator abundance, was first tested for normality by analyzing the distribution and if the distribution was not normal, a log transformation was performed. The log transformation formula used was [log (variable +1)]. An F test was performed on each relationship to test for equal variances. In cases where an equal variance was not observed, a parametric t-test was still used.

RESULTS

Each sampling location was found to be natural, semi-natural, or artificial (Table 1). Over the course of the sampling period (Table 2), eleven predatory and non-predator organisms were found (Table 3). The water temperature over the sampling duration was found to be between 14-26 ^{0}C.

Table 3. Species observed, location of observation, and ecological role of species found during sampling (see Table 1 for site names).

Order	Family	Ecological Role	Location Observed
Hemiptera	Notonectidae	Predator	A,E,F
Hemiptera	Corixidae	Predator	C,E,F,H,I,J
Hemiptera	Gerridae	Predator	G,H,I,J
Hemiptera	Nepidae	Predator	J
Diptera	Chironomidae	Non-predator	A,B,C,E,F,G,H,I,J
Diptera	Culicidae	Non-predator	A,C,H,I,J
Trichoptera	Limnephildae	Non-predator	C,E,F,G,H,I
Ephemeroptera	Baetiscidae	Non-predator	C,E,F,G,H,I,J
Coleoptera	Dytiscidae	Predator	C,E,F,G,H,I,J
Odanata	Anisoptera	Predator	C,G,H,I,J
Odanata	Zygoptera	Predator	A,E,F,G,H,I,J

VEGETATION AND SPECIES ABUNDANCE

Three of the ten sampling locations did not appear to have any vegetation growing, where as the other seven locations exhibited a variety of combinations of floating, emergent, and submerged vegetation (Table 1).

The presence of floating vegetation in water pools was shown to support predator abundance (Fig 2, p=0.01) but not affect the overall species abundance (p=0.11, data not shown) or non-predator abundance (Fig 3, p=0.60).

The presence of emergent vegetation in water pools was shown to support predator abundance (Fig 2, p=0.01) but did not appear to affect the overall species abundance (p=0.42, data not shown) or non-predator abundance (fig 3, p=0.97)

The presence of submerged vegetation was shown to support the overall species abundance (p<0.01, data not shown), predator abundance (Fig 2, p<0.01), and non-predator abundance (Fig 3, p=0.02).

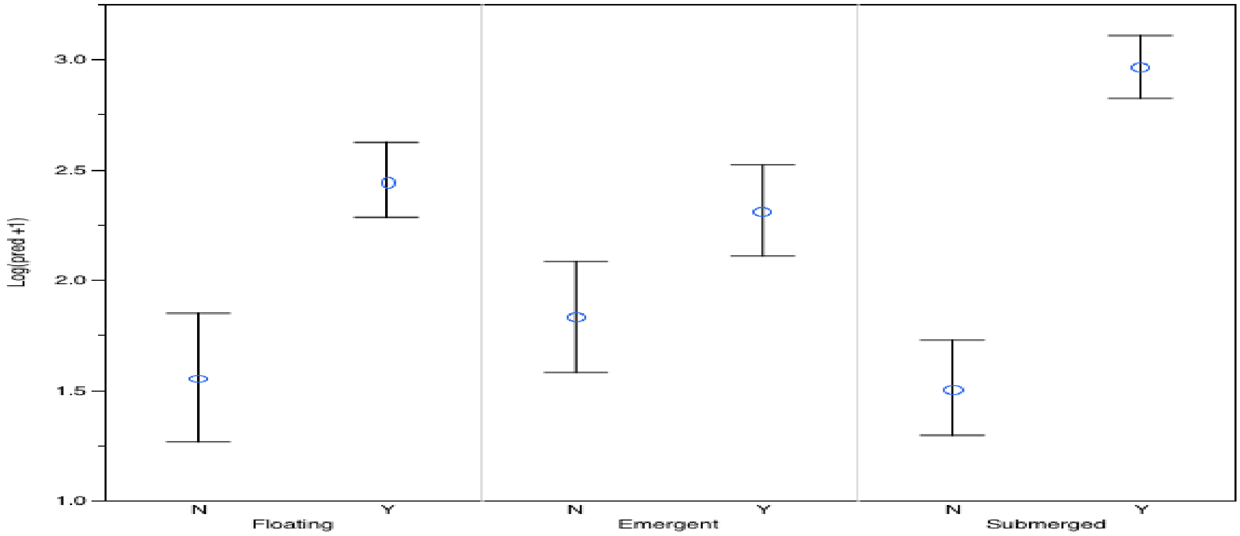


Figure 2. Effects of vegetation type predatory species abundance (floating p=0.01*, emergent p=0.01*, submerged p<0.01*). Floating vegetation n=25 for presence and absence, emergent vegetation n=31 for absence, n=18 for presence, submerged vegetation n=33 for absence, n=17 for presence. Standard error of the mean is shown for all.

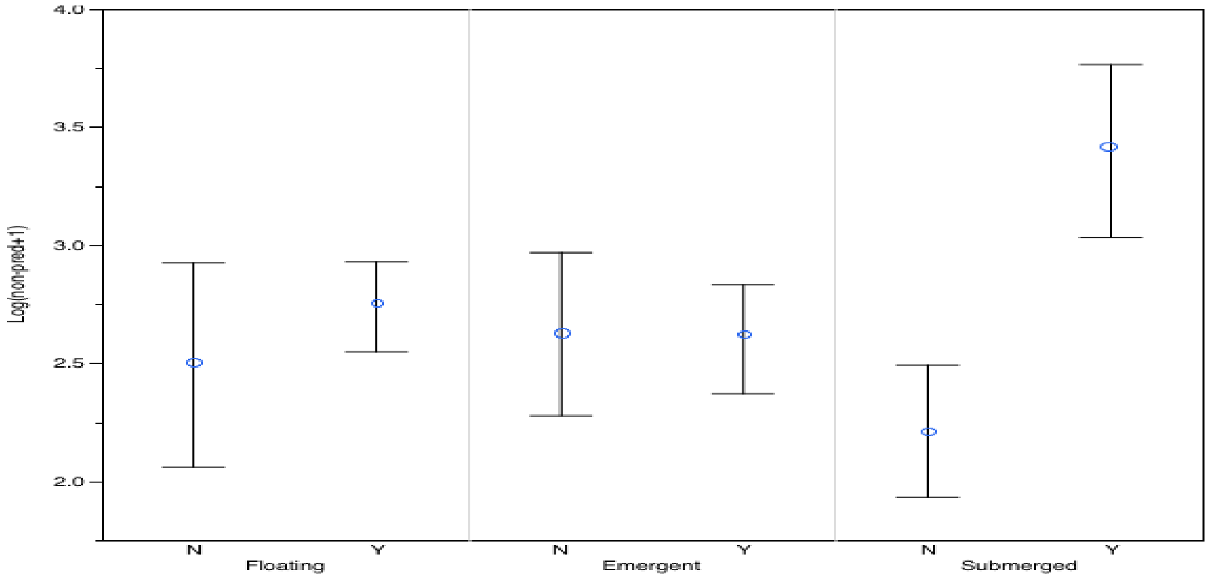


Figure 3. Effects of vegetation type on non-predatory species abundance (floating p=0.60, emerged p=0.97, submerged p=0.02*).Floating vegetation n=25 for presence and absence, emergent vegetation n=31 for absence, n=18 for presence, submerged vegetation n=33 for absence, n=17 for presence. Standard error of the mean is shown for all.

MANAGEMENT PRACTICES AND SPECIES ABUNDANCE

The average number of predators increased as the average number of non-predators in a pool increased (Fig 4A, p<0.01), however there was no significant difference between the predator density and mosquito density (Fig 4B, p=0.37).

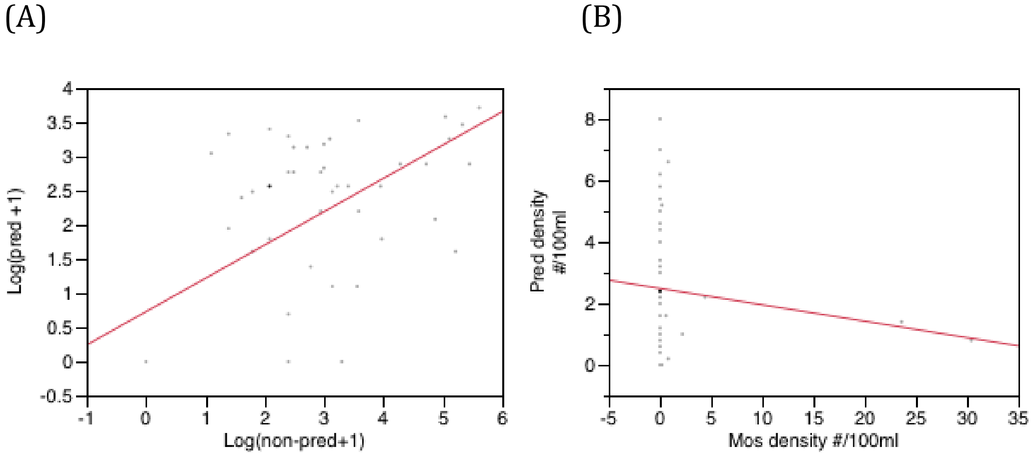


Figure 4. A) The relationship between the average number of predators and average number of non-predators (n=50, $p<0.01^*$, $R^2=0.41$) and B) the relationship between predator density and mosquito density (n=50, p=0.37, $R^2=0.02$).

Chlorinated pools were found to be unsupportive of species abundance. Water pools with chlorine were shown to have fewer species overall ($p<0.01$), both in predator abundance (Fig 5, $p<0.01$), and non-predator abundance (Fig 6, $p=0.02$).

Aeration was shown to affect the abundance of predators more so than non-predators. Pools that were aerated tended to have significantly fewer predators (Fig 5, $p=0.05$), but non-predators were unaffected (Fig 6, $p=0.08$). Overall, aeration did seem to result in reduced species abundance ($p=0.02$).

There was no significant difference observed in mosquito density with pools that contained fish versus those that did not ($p=0.59$). The presence of fish was correlated with an increase in predatory species abundance (figure 5, $p=0.02$) and a decrease in non-predatory species abundance (Fig 6, $p=0.01$).

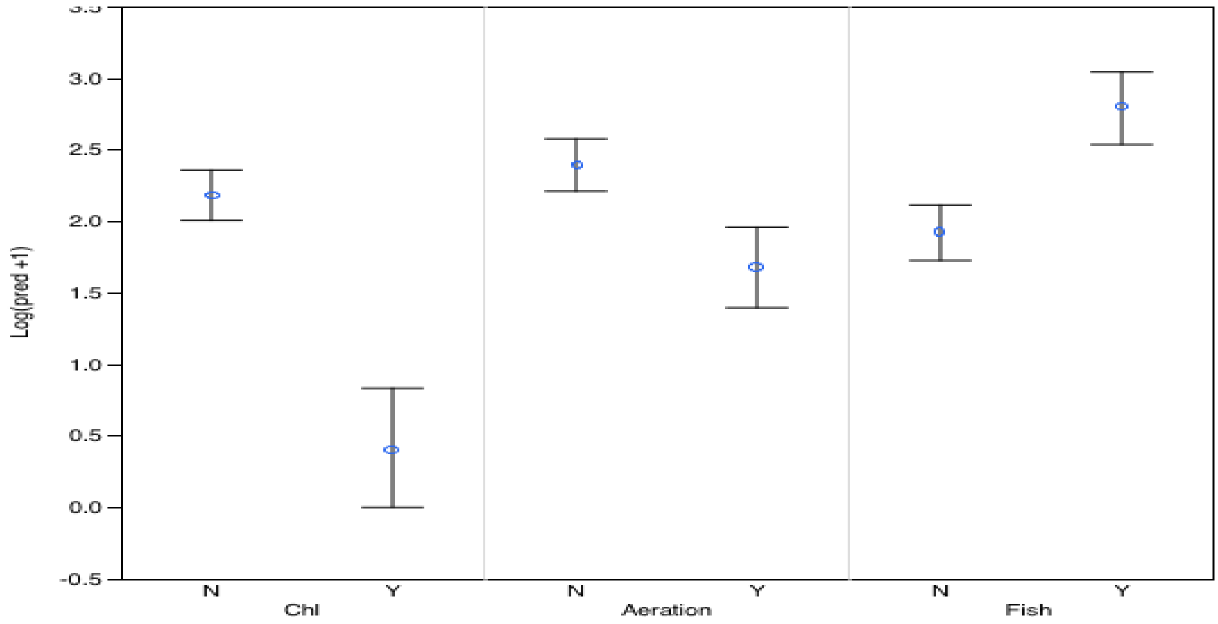


Figure 5. Effects of management practices on predatory species abundance (chlorination $p<0.01^*$, aeration $p=0.05^*$, fish $p=0.02^*$). Chlorination n=45 for absence, n=5 for presence, aeration n=23 for absence, n=27 for presence, fish n=5 for presence, n=45 for absence. Standard error of the mean is shown for each management practice.

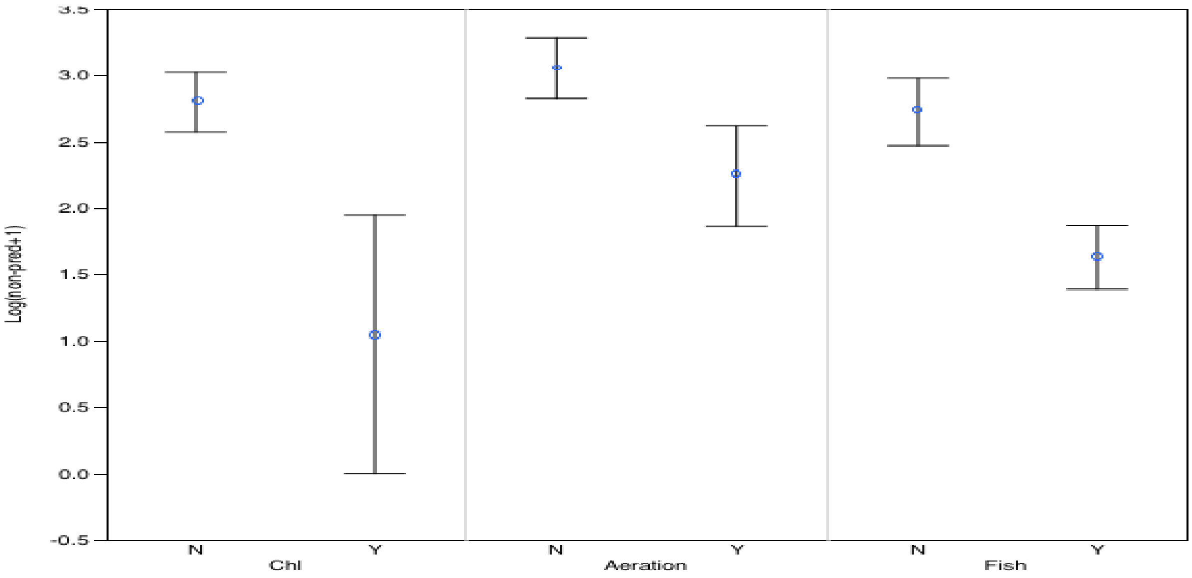


Figure 6. Effects of management practices on non-predatory species abundance (chlorination p=0.02*, aeration p=0.08, fish p=0.01*). Chlorination n=45 for absence, n=5 for presence, aeration n=23 for absence, n=27 for presence, fish n=5 for presence, n=45 for absence. Standard error of the mean is shown for each management practice.

DISCUSSION

Predator species were most affected by the presence of vegetation. In general, the presence of any given type of vegetation was supportive of predator species, but submerged vegetation was shown to have the greatest influence on predator abundance. Our results are consistent with those of other studies, which indicate the vegetation contributes to the overall water quality and thus contributes to suitability of the habitat (Dill 1989; Russel 1999)

Shahira et al. (2009) found that aeration was not only necessary for the survival of *Gammarus* but also that predators survived for a significantly greater length of time in aerated environments than non-aerated (Shahira et. al. 2009). Thus, it was expected that aeration would have produced more significant results, however there was no difference in species abundance in aerated versus non-aerated water bodies. This was unexpected, as previous studies have indicated that aeration is an effective method for preventing oviposition by agitating the water and preventing adult females from successfully laying eggs, as well as increasing suitability for predator species (Metro Vancouver 2009; Russel 1999; Shahira et al 2009). There are a number of factors that may have led to the discrepancy between our results and other studies. Although no significant difference was detected for overall species abundance in aerated and non-aerated water pools in our report, the data was collected from a wild environment that is subject to many other environmental factors compared to Shahira et.al.'s (2009) study which was conducted in a controlled laboratory setting. In a controlled lab environment factors that may have contributed to survival rates could be eliminated. Chlorination was found to be significant in reducing habitat suitability for both predators and non-predators. Many of the pools that were aerated, were also chlorinated and although analyses were carried out on individual factors, experimentally separating all variables was difficult. In addition, our sample sizes were small and the predator and non-predator categories contained organisms from across various families and orders.

The presence of fish in a water body was not expected to yield a significant difference, as the use of larvivorous fish have been highly regarded as an effective control mechanism for mosquitoes (de Oliveira Lima et al 2010; Metro Vancouver 2009; Russel 1999). However, our sample size from ponds with fish was extremely small (n=5). In addition, the specific species of fish was not documented and it cannot be determined whether the fishes present were in fact larvivorous.

Given that some of our results are inconsistent with other literature, concrete conclusions from this study cannot be made. However, from consulting other literature some recommendations can still be made with regards to water body management and mosquito control

RECOMMENDATIONS

Mosquitoes can travel long distances, over 12 km, to find prey and therefore it is not possible to eliminate the nuisance of mosquitoes in most areas (Russel 1999). Determining problem levels of mosquitoes is challenging, and often threshold levels are site specific. Weekly monitoring of larvae counts and bi-monthly monitoring of adult mosquitoes can generate a more comprehensive understanding of how each site is supporting mosquito populations but, this is generally very time consuming. However, there are effective methods in controlling mosquitoes that can be efficient and easy to carry out. Certain characteristics of water pools make them more susceptible to breeding mosquitoes, including the shape, depth, presence of vegetation and predators, and surface water conditions. The following are important characteristics to consider when designing and maintaining ponds and water pools in residential areas.

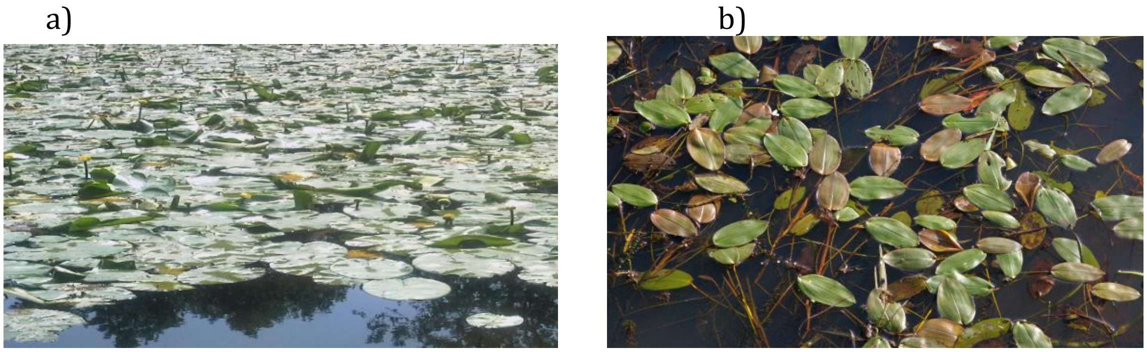
Pond Shape and depth

Water pools of simple shapes and low edge to surface area ratios have been found the least supportive of mosquitoes (Russel 1999). Water depths of less than 30 cm have been found to be more supportive of mosquito populations, where as depths greater than 60cm are much less supportive. Deeper ponds have been shown to be more supportive of predators, which are a valuable component of control methods (Russel 1999). The edge characteristics also contribute to the pond suitability for mosquitoes: steep, deep edges decrease the habitat suitability for mosquitoes(Russel 1999). It is therefore recommended that ponds be designed with simple shapes, containing at least one region with significant depth in order to sustain predators.

Vegetation

Emergent and floating vegetation have shown to support mosquito development and success, a few recommendations can be made to prevent such vegetation from growing out of control (Metro Vancouver 2009). An in-depth analysis of water control, done in Australia, indicates that steep edges, greater than 30^o, and deep bottoms , greater than 1.3m, should be sufficient to prevent emergent vegetation (Russel 1999). The preference of vegetation varies across mosquito species as some prefer to lay eggs in vegetated pools, where as others, such as *Culex tarsalis* and *Culex pipiens*, prefer open non-vegetated water pools (Metro Vancouver 2009). In general, areas that are thick with emergent vegetation, or that have fallen or dead plants, are attractive sites for oviposition for mosquitoes (Russel 1999). It is therefore recommended that adequate maintenance and control over vegetative growth of the water pools be done to ensure these conditions are not persisting. Removal of excess dead plants and thinning of emergent stands should reduce the attractiveness of these sites for mosquitoes.

Introduction of plants to the water pool may also be beneficial in controlling oviposition by mosquitoes. In BC, introducing native plants such as the yellow pond lily (Fig 8a) and the floating leaved pondweed (Fig 8b), have been shown to aid in control (Metro Vancouver 2009).



http://commons.wikimedia.org/wiki/File:Nuphar_luteaLeeds3.jpg

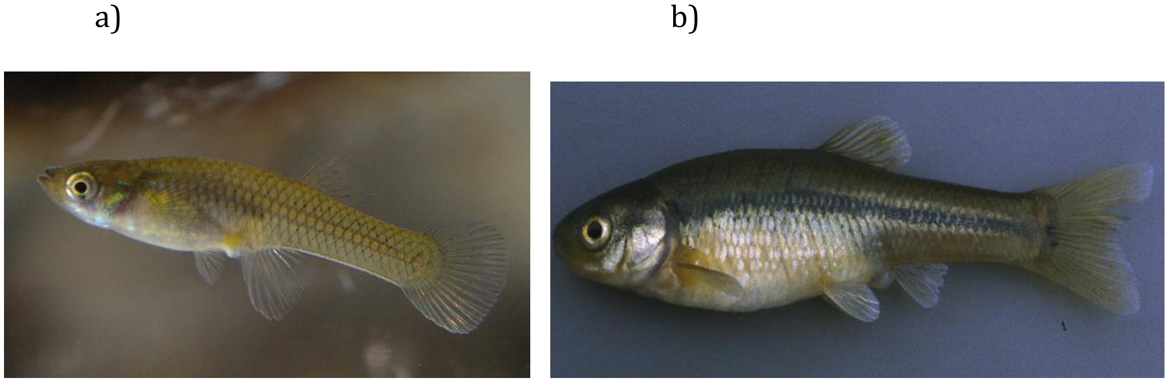
http://commons.wikimedia.org/wiki/File:Potamogeton Natans1.jpg

Figure 8. Recommended native vegetation a) yellow water lily (*Nuphar lutea*) and b) floating-leaved pondweed (*Potamogeton natans*)

Water Quality

Water quality affects both mosquitoes and their predators. Waters with high oxygen levels are more supportive of predators, which will contribute to controlling the mosquito density (Russel 1999). Agitation, aeration, and sprinkler systems all contribute to the water quality, as they prevent the water from becoming stagnant and polluted. In addition, these methods reduced the efficacy of oviposition by mosquitoes, thus preventing mosquitoes from succeeding in such environments (Russel 1999). It is therefore recommended that water pools have one of these features.

A number of studies have reported high success with the introduction of predators into water pools for controlling mosquito populations (Quin 1990; Russel 1999) A well-known predator, the mosquito fish (Fig 9a), has been commonly used in controlling mosquito populations, however, the introduction of this fish is not recommended in BC (Metro Vancouver 2009). The mosquito fish is an invasive species to BC and has been known to cause displacement of native species in other studies (Metro Vancouver 2009). It is therefore recommended, if the introduction of predators is desired, that the fathead minnow (Fig 9b), or a species of the like, be used (Metro Vancouver 2009). The fathead minnow preys on mosquito larvae, despite whether another food source is present, and is able to withstand harsh winter conditions, which would prevent having to re-stock annually (Metro Vancouver 2009). In addition, the fathead minnow is able to survive in low oxygen conditions, which might provide a useful control method for pools that cannot be aerated or agitated (Quinn 1990).



http://commons.wikimedia.org/wiki/File:Gambusia_affinis.jpg http://denr.sd.gov/des/sw/wet.aspx

Figure 9. a) An invasive, well-known mosquito predator, the mosquito fish (*Gambusia affinis*) (and b) a native BC mosquito predator, the fathead minnow (*Pimephales promelas*)

Chemical control

Although not explicitly analyzed in this study, the use of chemicals, such as pesticides, is not recommended. Chemical control is generally effective on a short-term basis, usually when immediate action must be taken. Long-term application is likely to lead to resistant strains of mosquitoes as well as increasing the environmental impact of the control methods.

Given that UBC provides a suitable habitat for mosquito development, these results and recommendations should be considered when constructing and managing water bodies around campus. Ensuring the pond has some form of control technique, such as aeration or predation, as well as constructing the pond with steep edges, should be beneficial in reducing mosquito infestations.

REFERENCES

Arav, D., and Blaustein, L. 2006. Effects of pool depth and risk of predation on oviposition habitat selections by temporary pool dipterans. Journal of Medical Entomology 43:493-497.

Belton, P. 1983. The mosquitoes of British Columbia. Victoria, BC. British Columbia Provincial Museum. 1-187. Retrieved from http://www.env.gov.bc.ca/wld/documents/techpub/rbcm_hb41/mosquitoes.pdf

Brungs W.A. 1973. Effects of residual chlorine on aquatic life. Water Pollution Control Federation 45:2180-2193.

Burkett-Cadena, N.D., White, G.S., Eubanks, M.D., Unnasch, T.R. 2011. Winter biology of wetland mosquitoes at a focus of eastern equine encephalomyelitis virus transmission in Alabama, USA. Journal of Medical Entomology. 48:967-973

de Oliveira Lima, J.W., de Goes Cavalcanti, L.P., Pontes, R.J. and Heukelback, J. 2010. Survival of *Betta splendens* fish (Regan, 1910) in domestic water containers and its effectiveness in controlling *Aedes aegypti* larvae (Linnaeus, 1762) in Northeast Brazil. Tropical Medicine & International Health*.* 15:1525-1532.

Dill, C.H., 1989. Wastewater wetlands: user friendly mosquito habitats. In: Hammer, D.A. (Ed.), Constructed wetlands for wastewater treatment: municipal, industrial and agricultural. Lewis Publishers, Michigan, USA, pp. 664–667.

Leopoldo, M.R. 2008. Global diversity of mosquitoes (Insecta*:* Diptera*:* Culicidae) in freshwater. Hyrdobiologia 595:477-487.

Metro Vancouver. 2009. Mosquito Pest Management Plan #701-002-09/14. Available at http://www.metrovancouver.org/about/publications/Publications/Metro_Vancouver_Mosquito_PMP_701-002-0914.pdf. Accessed September 2012.

Roberts, D. 2012. Responses of three species of mosquito larvae to the presence of predatory dragonfly and damselfly larvae. Entomologia Experimentalis et Applicata 145: 23–29.

Russel, R.C. 1999. Constructed wetlands and mosquitoes: health hazards and management options-and Australian perspective. Ecological Engineering 12: 107–124.

SAS.2012. *JMP10 software*. Cary, North Carolina, USA.

Shahira, M., El Bishlawy, O., Afify, A., and Shamseldean. M. 2009. Description and factors affecting activities of *Gammarus* sp., a crustacean predator of *Culex pipiens* mosquito larvae in Egypt. Egyptian Journal of Biological Pest Control 19:99-104.

Quinn, J.R. 1990. *Our Native Fishes: The Aquarium Hobbyist's Guide to Observing, Collecting, and Keeping Them*. The Countryman Press, Woodstock, VT. P.76.