Duncan Dam Water Use Plan

Lower Duncan River Mosquito Monitoring and Management Plan Development

Implementation Year 4

Reference: DDMMON-9

Lower Duncan River Mosquito Monitoring and Management Plan Development

Study Period: June 20, 2012 – September 7, 2012

Jackson, M., McMahon, S., Thielman, A., Herbison, B., Rodman, S., Howay, T., and Phelan, C.

Culex Environmental, Ltd.
#4 – 4075 Kingsway Avenue
Burnaby BC V5H 1Y9

March 11, 2014

DDMMON#9: Lower Duncan River Mosquito Monitoring and Management Plan Development (Year 4)
Reference: Q9-9077

Prepared for BC Hydro

Prepared by:
Michael Jackson, PhD., RPBio, Scott McMahon, MSc., Aynsley Thielman, PhD., Brenda Herbison, Sean Rodman, and Tim Howay

Executive Summary

The Duncan Dam Water Use Plan (WUP) consultative process was initiated by the Comptroller of Water Rights in 2001 with the objective of balancing economic, environmental, and social values associated with Duncan Dam operations. The Duncan Dam WUP Consultative Committee was particularly interested in the effect that dam operations had on nuisance mosquito production in the Lower Duncan River floodplain. The WUP was approved with significant operational constraints to downstream flooding, which were assumed to minimize mosquito production. A monitoring program was recommended to test this assumption and provide recommendations for improved mosquito controls.

In 2009, Culex Environmental Ltd. was contracted to deliver the first phase of the recommended monitoring program. The primary objective of this program is to determine whether there are water management strategies and operating alternatives that can be implemented to minimize potential impacts of nuisance and West Nile virus (WNv) vector mosquito production in the Duncan floodplain. The summer of 2009 was drier than average and peak water discharges were delayed until late August and the Lower Duncan floodplain was relatively nuisance free.

The second year of sampling, 2010, was another dry year. Water levels were comparatively low after the spring freshet and in mid-August an increase in discharge from the Dam caused additional flooding in some areas which was captured by two sampling events. A small number of *Aedes* larvae were recorded in mid-August and early September, including *Aedes vexans* in one location, suggesting that there had been a limited second hatch. Two new species were found in this year, *Aedes excrucians* and *Culiseta inornata*.

Because of higher than normal snow pack levels over the winter of 2010/11 a strong freshet with high levels of flooding was anticipated. As a result some additional sampling was conducted to ensure that data was collected to record the peak in mosquito production in the Lower Duncan floodplain during the freshet. As expected 2011 turned out to be a high water year and there were considerable problems with nuisance mosquitoes. Potential high-risk WNv species, *Culex tarsalis* and *Culiseta inornata*, were also found in both larval and adult sampling this year.

In 2012, larval monitoring frequency was increased although the total number of mosquitoes collected was actually less than in 2011. Carbon dioxide cylinders were also added to the adult CDC light traps as an added attractant which markedly increased the numbers captured.

The current hypothesis is that in years in which water storage prevents river levels from exceeding the maximum freshet, such as 2009 and 2010, mosquito production is minimized. In 2012, although dam operations helped to contain water early in the season and curtail the magnitude of the spring hatch of *Aedes*, once the reservoir reaches full pool, operators have no choice but to release larger than normal volumes later in the summer. Under these circumstances a statistically significant second hatch of *Aedes* mosquitoes may occur in newly inundated areas where the water reaches beyond areas that were originally flooded by the initial freshet.

Through literature searches and additional analysis of the four years of data, it has been shown that there is a potential to use vegetation as a proxy for determining where the larvae of nuisance and potential vector mosquito species can be located, allowing for a more targeted approach to mosquito control. In the next phase of the study the relationship between the distribution and abundance of mosquito populations in different habitat types and flooding regimes will be further investigated. This additional data will provide all the information required to develop a predictive model of the populations in space and time throughout the floodplain. It will also enable the refinement of the Performance Measure and assist abatement activities.

Executive Summary Appendix: DDMMON #9: Status of objectives, management questions, and hypotheses after Year 4

Objective	Year 4 (2012) Status	Progress/Impediments WRT answering Management Question(s)
Refine the mosquito nuisance performance measure originally designed for the DDM WUP by improving the resolution of the flow-habitat flooding relationship and increasing the understanding of mosquito production drivers and migration in the lower Duncan River floodplain	**Pending**	**Enhanced sampling in 2012 provided excellent temporal data for the model. Future work should focus on fully understanding the spatial dynamics of the mosquito populations.**
Provide meaningful recommendations towards improving the effectiveness of the current mosquito abatement program	**Ongoing**	**The program is constantly finding additional opportunities to improve abatement techniques and logistics**
Provide meaningful recommendations towards identifying and addressing the potential threat of WNv	**Ongoing**	**As more data is collected, recommendations are revised and improved as the study progresses**

Management Hypothesis	Year 4 (2012) Status	Progress/Impediments WRT answering Management Question(s)
Nuisance mosquito productivity is correlated to environmental and stochastic factors, such as precipitation and temperature, and to the frequency and amplitude of flooding.	**Partially Completed**	**Further analysis required, upon completion of spatial data collection in future years**
Existing nuisance and WNv mosquito management programs on the Lower Duncan River can be improved through increased understanding of drivers of mosquito productivity.	**Partially Completed**	**Cottonwood areas known to be a good habitat for nuisance species. Further implementation with hydrologic model required.**

Management Question(s)	Year 4 (2012) Status	Progress/Impediments WRT answering Management Question(s)
How may discharges from the Duncan Dam affect production of *Aedes* mosquitoes through inundation of Low Bench areas in the Lower Duncan and Lardeau floodplains from May to September?	**Partially Complete**	**Further analysis with hydrologic model input required, however high levels of secondary flooding has been shown to contribute additional nuisance mosquito production**
Do groundwater variations in different areas at different dam discharge rates relate to flooding regimes, vegetation types and mosquito production?	**Pending**	**Further analysis with hydrological model input required**

Management Question(s)	**Year 4 (2012) Status**	**Progress/Impediments WRT answering Management Question(s)**
How widely do adult mosquitoes disperse from their breeding grounds and how significant is the Duncan Dam in creating adult mosquito nuisance to residents of the Lower Duncan Floodplain? Can we better predict the potential nuisance mosquito production associated with vegetation types?	**Partially Complete**	**The Duncan Dam may be affecting mosquito production in high water years– need to consider more data collection from areas outside of the influence of the dam. Certain vegetation types (cottonwoods) are certainly linked with nuisance mosquito production**
Is the current Performance Measure effective at predicting the potential production of late outbreaks of nuisance mosquitoes related to Duncan Dam operations?	**Partially Complete**	**Results from the hydraulic and digital elevation models are required to update the Performance Measure**
Can we more accurately predict when outbreaks of nuisance mosquitoes are most likely to occur given particular environmental and climatic conditions?	**Partially Complete**	**Hydraulic and digital elevation models will be combined with mosquito monitoring results to provide an assessment of the environmental and climatic conditions that lead to outbreaks of nuisance mosquitoes. PRIMER multivariate analysis software will be used to analyze the data statistically.**
What can the current mosquito abatement program (managed by the Regional District of Central Kootenay, RDCK) do to improve its effectiveness based on the information collected in this program?	**Ongoing**	**Plan the timing of treatments using thresholds to target specific species, Include mosquito identification in the program to enable focused treatment of target species, and to eliminate unnecessary treatments, Conduct a survey of cottonwood areas as they may be habitat for a re-emerging species of mosquito, *Aedes sticticus.* Use species ecology and larval monitoring to ensure treatment applications are conducted at the optimal time to result in maximum effectiveness Consider the possibility of larvicide resistance management in future programs.**
Is the operation of the Duncan Dam linked to production of high competence WNv vector mosquitoes?	**Partially Complete**	**It appears that in high water years, low populations of *Culex tarsalis* can be found in the floodplain. Further analysis would be required to determine if high water discharges have contributed specifically to increased mosquito production.**

Table of Contents

List of Tables:

List of Figures:

1.0 INTRODUCTION

1.1. Project Rationale

Construction on the Duncan Dam began in 1965 and the facility became operational in 1967. The 40 m high earth-fill dam acts as a storage reservoir for a drainage basin of some 2,400 km^2 and receives the largest inflows in May and June from snowmelt. Inflow from precipitation is generally heaviest during the July to October (or later) period. The dam is operated under the terms of the Columbia River Treaty through the Water Use Plan, whereby full pool is ideally achieved in July (Jackson *et al.* 2002). The Duncan Reservoir is 45 km long and holds 1,727 million m^3 of storage with an average drawdown of 30 m. Because of the restrictions of the treaty, it is unusual for large volumes of water to be discharged from the dam between May and early- to mid-July. Thus, there is uncertainty as to the degree of influence that discharges from the dam may have on mosquito production annually between May and June (Jackson *et al.* 2002). The unregulated Lardeau River upstream of the dam, combined with the Duncan Dam discharge, causes considerable flooding of low-lying grassland in the Meadow Creek area at this time. Fluctuation in Kootenay Lake levels may also have an impact on mosquito production along the shores and in other areas of the floodplain.

The Duncan Dam Water Use Plan (WUP) consultative process was initiated in 2001 with the objective of balancing economic, environmental, and social values associated with Duncan Dam operations. The Duncan Dam WUP Consultative Committee was particularly interested in the effect that dam operations had on nuisance mosquito production in the Lower Duncan River floodplain. The WUP was approved with significant operational constraints to downstream flooding, which were assumed to minimize mosquito production. A monitoring program was recommended to test this assumption and provide recommendations for improved mosquito controls.

1.2 Current Project DDMMON#9, Contract Q9-9077

In 2009, Culex Environmental Ltd. was contracted to deliver the initial phase of the recommended monitoring program. This monitoring program is designed to address the following management questions as they pertain to mosquito production in the Duncan Floodplain area:

1. How may discharges from the Duncan Dam affect production of Aedes mosquitoes through inundation of Low Bench areas in the Lower Duncan and Lardeau floodplains from May to September?
2. Do groundwater variations in different areas at different dam discharges relate to flooding regimes, vegetation types and mosquito production?
3. How widely do adult mosquitoes disperse from their breeding grounds and how significant is the Duncan Dam in creating adult mosquito nuisance to residents of the Lower Duncan Floodplain? Can we better predict the potential nuisance mosquito production associated with vegetation types?
4. Is the current Performance Measure effective at predicting the potential production of late outbreaks of nuisance mosquitoes related to Duncan Dam operations?
5. Can we more accurately predict when outbreaks of nuisance mosquitoes are most likely to occur given particular environmental and climatic conditions?
6. What can the current mosquito abatement program (managed by the RDCK) do to improve its effectiveness based on the information collected in this program?
7. Is the operation of the Duncan Dam linked to production of high competence West Nile virus vector mosquitoes?

Two primary hypotheses will be tested in this monitoring program:

- H1: Nuisance mosquito productivity is correlated to environmental and stochastic factors, such as precipitation and temperature, and to the frequency and amplitude of flooding.

This hypothesis will be refuted where theorized correlations cannot be statistically validated.

- H2: Existing nuisance and West Nile virus mosquito management programs on the Lower Duncan River can be improved through increased understanding of drivers to mosquito productivity.

This hypothesis will be refuted where no reduction in monitored levels of mosquito production are documented following the implementation of management initiatives recommended in this monitoring program on an annual basis. This assessment will consider other environmental factors, including local natural inflows, temperature and previous outbreaks, that may influence current results.

The three objectives of this monitoring program are:

- To refine the mosquito nuisance performance measure originally designed for the DDM WUP by improving the resolution of the flow-habitat flooding relationship and increasing the understanding of mosquito production drivers and migration in the lower Duncan River floodplain;
- To provide meaningful recommendations towards improving the effectiveness of the current mosquito abatement program; and
- To provide meaningful recommendations towards identifying and addressing the potential threat of West Nile virus.

In general, the objective of this monitoring program will be to determine whether there are water management strategies and operating alternatives that could be implemented to minimize potential impacts on nuisance and West Nile vector mosquito production in the Duncan floodplain.

The results from this monitoring program will be used to refine the design of the Mosquito Nuisance Performance Measure used during the DDM WUP process to assess the impacts of operations on mosquito production. During the review period, these results will be applied where applicable to the improvement of the mosquito abatement program managed by the Regional District of the Central Kootenay area. At the conclusion of the DDM WUP review period, this refined performance measure may be applied in decision processes towards mitigating operations that potentially exacerbate mosquito nuisance in the Lower Duncan River and Lardeau River floodplains, or, where applicable, information will be provided to Fortis BC, an electrical power provider in south central BC, for consideration in their operations of Kootenay Lake.

1.3 Factors Affecting Mosquito Development

1.3.1 Temperature

Temperature is a critical factor in determining the timing and duration of certain life cycle stages for many species of mosquitoes. In particular temperature is known to be a specific trigger for egg hatching and timing of larval development. Belton (1986), for example, maintains that a water temperature above 14 degrees Celsius is required for the hatching of the eggs of *Aedes vexans* in British Columbia. *Aedes vexans* eggs, which are laid throughout the floodplain, are stimulated to hatch when flooded although not all will hatch on the first flood – some will only hatch after the second or third time that they become inundated. The temperature of the water is directly related to water depth. With the onset of the spring freshet very cold water results from snowmelt and rain on snow events in the mountains providing a sudden influx of extremely cold water. As this water disperses however the shallower pools towards the edges of the flood will soon warm up and reach ambient air temperatures. Shallow pools may also form as high river flows back up side channels and cause back-flooding. Severe flooding can also wash out larvae from main channels, and replace the warmer water with much cooler snow-melt water, preventing another hatch until water temperatures rise and exceed, to above 14 degrees in the case of *Aedes vexans*. Under natural conditions, there will be larval mortality from severe flooding as well as opportunities for new eggs to hatch where new shallow warm waters appear.

1.3.2 Mosquito Life Histories

From a series of hypotheses developed concerning the life cycles and behavior patterns of different species, scenario diagrams were drawn up as a first step towards modeling the expected relative abundance at different times of the year. These preliminary scenarios are shown in Figure 14. A small hatch and emergence of *Aedes* species was predicted after a dam discharge. *Anopheles, Culex,* and *Culiseta* complete more than one generation in a season.

2.0 Materials and Methodology

In 2012, the monitoring program was expanded to capture information about the species and abundance of mosquitoes present during high water conditions throughout the entire summer. The 13 mosquito sampling sites (12 below the Lardeau-Duncan confluence, and one above as a control) chosen in consultation with local abatement operators, RDCK (Area D) advisory committee, BC Hydro representatives, and Culex Environmental (Figure 1, Table 2) were again sampled as in the three previous years. Five of these sites, DDM-03 (Lake's), DDM-05 (Control), DDM-06 (Halloran's), DDM-07 (Janet's Swamp) and DDM-11 (Block Swamp) are located in close proximity to residential areas.

Table 1: List of Site Codes, Local Site Names and Coordinates of each Sampling Location

Database Site Code	"Local" Site Name	Northing	Easting
DDM-01	Old Mill	5562488.395	501762.641
DDM-02	Meadow Creek Cedar	5561506.849	503196.949
DDM-03 & DDM-03A	Lake	5559881.750	503651.785
DDM-04	Jacob's	5562230.019	503335.090
DDM-05	Lardeau - Control Site	5566590.018	502482.482
DDM-06 & DDM06A	Halloran Site	5564532.817	501040.256
DDM-07 & DDM-07A	Janet's Swamp	5564625.625	502226.414
DDM-08 & DDM-08A	Old Channel	5564728.637	502970.392
DDM-09 & DDM-09A	Gravel Pits	5563275.997	502923.268
DDM-10 & DDM-10A	Carex Beds	5563088.192	502795.401
DDM-11 & DDM-11A	Block Swamp	5564712.988	502166.600
DDM-12 & DDM-12A	Lardeau-Duncan Flats - Cottonwoods	5559185.281	502970.474
DDM-13	Lardeau-Duncan Flats	5559049.881	502760.718

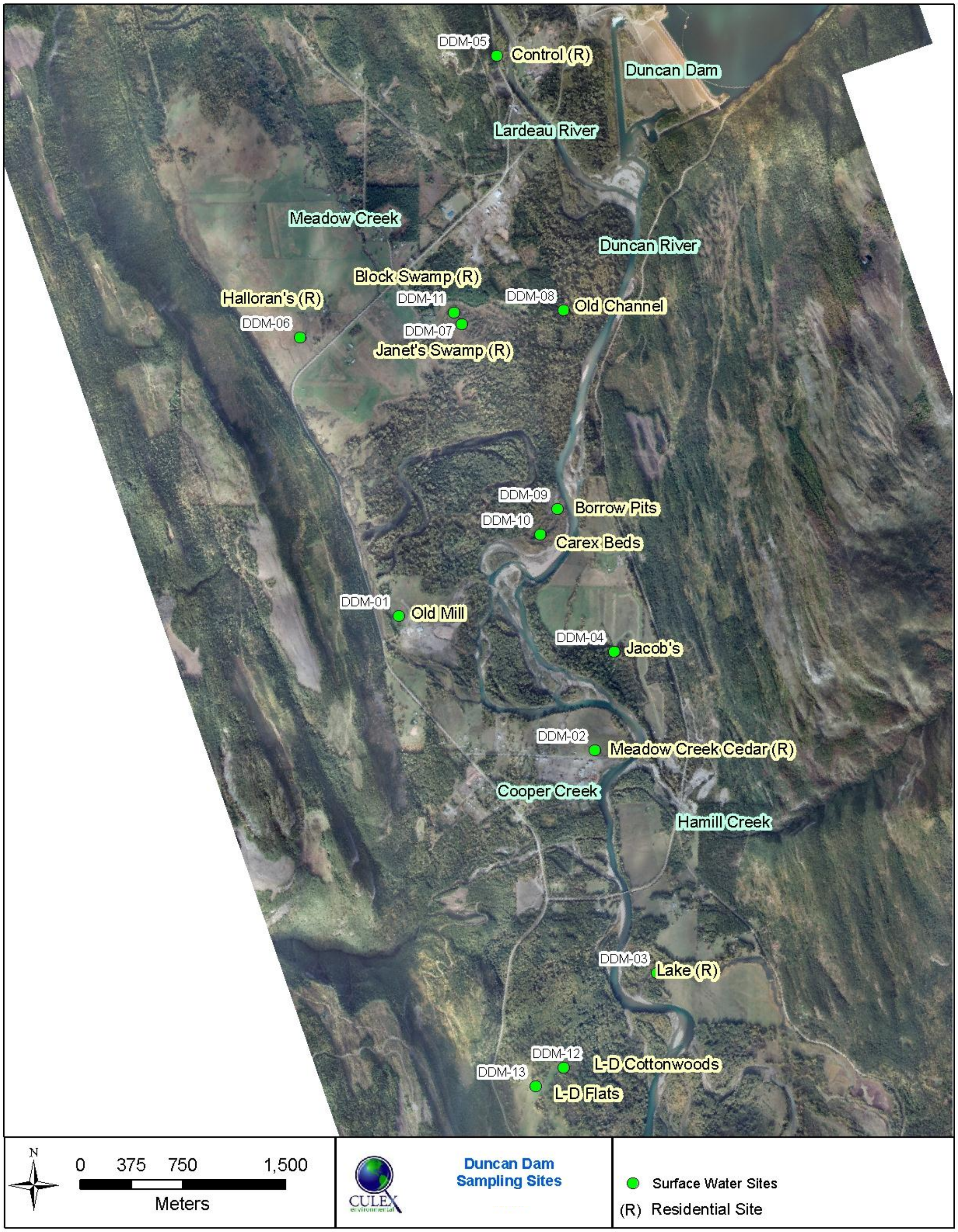


Figure 1: Mosquito monitoring locations in 2009-2012

In 2009, a 2m rebar stake was driven into the ground at each site to ensure that water depth measuring occurred at the same location each time. All stake locations were recorded using GPS and the data was differentially corrected to be accurate to within 1 m. The same stake locations have been used in each of the study years (2009-2012). Water levels have been monitored at each site every two to four days during the study periods.

Larval Sampling Frequency: At the start of the season in 2012, all 13 sites were visited on a four day interval beginning on June 20th. During these sampling events, ten dips were taken at each site to monitor temporal trends in the mosquito populations and provide information to the mosquito abatement team. During the peak of the mosquito season, a two-day interval was used to ensure peak populations were not missed. The timing of the two large-scale sampling events (fifty dips per site) was based on the data collected from our ten dip samples. As populations decreased the sampling frequency was again reduced to four day intervals.

***Larval Mosquito Sampling Techniques**:* At each larval sampling site, immature mosquitoes were sampled using a standard 500 mL long handled dip sampler (Silver 2008), following the standard larval sampling procedure described in the Municipal Mosquito Control Guidelines (Ellis 2004). Because mosquito larvae prefer warmer water, they are most reliably collected along the shallow edges of standing water. Therefore, samples were taken at the edges of the pools of water near each rebar stake. All samples were taken within 15m of the stake at each site to ensure that all collections were taken from the same vegetative and hydrologic conditions.

Twenty-two of the sampling rounds required larval samples of ten dips each to be taken at all wet sites in 2012. In addition, during two of the sampling rounds, five samples of ten dips were taken at each sampling site. All pupae and instars of larval mosquitoes collected in the field were retained. All samples were placed in Whirlpac® bags with the water from the site, and kept in a cooler to minimize heat-related mortality during transportation. Each bag was clearly labeled with the site number, sample number (when 50 dips were taken), date, and collector initials to ensure a proper chain of custody in the laboratory.

When processing samples in the lab, all 3rd and 4th instar larvae were preserved in 75% ethanol as they are identifiable in these stages. Earlier instars were kept in water, and depending on the number of larvae collected, reared in a specimen bottle for smaller samples, or a larger container for larger samples. Larvae were fed ground fish food at regular intervals. When the larvae entered the third and fourth instar, they were then preserved with ethanol. Pupae were kept in water inside covered containers and allowed to emerge as adults. The adults were kept in a separate labeled container, and frozen.

Once the samples were preserved and/or frozen, they were shipped to the Burnaby laboratory for identification by experienced mosquito taxonomists using the identification key in Wood et al. (1979). Wherever possible, larvae and adults were identified to species. For quality assurance of species identifications, any “difficult” specimens were double-checked by Dr. Peter Belton - Professor Emeritus at Simon Fraser University. After identification, larvae were preserved in ethanol, and archived in labeled boxes in the Culex Environmental lab in case referencing is needed.

Adult Sampling Frequency: Adult mosquito populations were monitored every seven to eight days depending on weather. Adults are much longer-lived than their larval stages and the larger interval between sampling is standard practice.

***Adult Mosquito Sampling Techniques**:* Center for Disease Control (CDC) light traps were set on a low-hanging branch of a nearby tree in eight of the 13 sampling locations to determine which species of adults were active at the larval sampling sites. Adult traps are hung from the branches of trees close to the larval sampling location; the traps were set between 12:00 pm and 8:00 pm and collected the next morning between 8:00 am and 12:00 pm. In 2012, carbon dioxide cylinders were secured to a nearby tree and equipped with a regulator to provide a constant stream of carbon dioxide which was diffused through an air stone to disperse in close proximity to the adult trap. Adult mosquitoes can have considerable flight ranges of at least 11km (Brust 1980) - CDC light traps are designed to sample the adults from an area of several hundred square meters.

Temperature Measurements: Water temperatures at six sites were recorded using HOBO® TidbiT® v2 Temperature Loggers manufactured by Onset. The loggers were attached to the bottom of the rebar stakes at DDM-01, DDM-04, DDM-06, DDM-07, DDM-09, and DDM-10 with plastic straps. In 2012, data loggers were placed on June 20th and retrieved on the last day of sampling, September 7th.

Vegetation Analyses: Vegetation types were mapped using GPS to obtain accurate (within 1 metre) measurements of extent of the various vegetation types around the floodplain. The vegetation classification methods follow the most current BC standard, the Ministry of Forests Land Management Handbook #52 (Mackenzie and Moran 2004). A map of the vegetation classifications is included as Appendix 1.

Where appropriate, the acronyms used in Mackenzie and Moran (2004) were used. When existing acronyms were not accurate, unique acronyms were created using the same criteria as Mackenzie and Moran (2004). Visible vegetation boundaries were identified on an ortho-rectified aerial photo. Existing information provided sufficient data to differentiate wetlands from terrestrial groups, and to classify each polygon by wetland realm. However, field data was required to obtain the level of detail to make class and site associations.

DDMMON#8-1 vegetation transects (from 2009 and 2011) sampled suitably representative sites to provide classification for the low-bench flood areas. Over the remainder of the area, 20m by 20m plots were selected in representative sites. In each plot, plant communities were described; plant species, percent cover, height, predominant substrate, apparent flood regime, and micro-macro landscape position were recorded. When wetland boundaries were discovered that were not visible in the ortho photo, these were plotted with Trimble GPS receivers.

The thirteen larval sampling sites fell into the following classifications outlined in Table 2.

Table 2: The vegetation types found at each of the thirteen larval sampling sites.

Sample ID	Name	Vegetation Type
DDM-01	Old Mill	Low bench flooded grass
DDM-02	Meadow Creek Cedar	Low bench flooded grass
DDM-03	Lake	"Old Swamp-Marsh: Scirpus-Glyceria"
DDM-04	Jacobs	"Alder-Spruce Swamp"
DDM-05	Control	"Alder-Spruce Swamp"
DDM-06	Halleran's	"Sheltered Channel Marsh on edge of low bench flooded grass"
DDM-07	Janet's Swamp	"Mixed species Fen"
DDM-08	Old Channel	"Old Swamp-Marsh: Flava-Osier"
DDM-09	Borrow pits	Anthro. Being colonized by Wm01 and WmA
DDM-10	Carex Beds	Pond. Shallow at Culex rod. Deeper downstream30 m
DDM-11	Block Swamp	"Alder-Skunk Cabbage-Lady Fern "
DDM-12	LD Flats "Cottonwoods"	Low bench flooded grass
DDM-13	LD Flats	"Old Swamp-Marsh: Scirpus-Glyceria"

Data Analysis Techniques: To illustrate the relative similarities or differences between species at different sampling sites and dates of sampling, Canoco 5.0 and R software was used to generate Canonical Correspondence Analysis (CCA) and Detrended Correspondence Analysis (DCA). CCA and DCA Ordination plots aid in the visualization of large multivariate datasets by extracting the most dominant patterns in species composition and arranging objects (species or sampling units) along synthetic axes based on those patterns (Ter Braak 1986, Ter Braak and Smilauer 2012).

Communications: Communications strategies were discussed at the interested stakeholders meeting on June 20th. The tentative plan was to have a field technician collect the data and relay that information to the Project Manager as soon as possible, given weather and unreliable internet. The collection data would then posted to a password protected webpage, and the interested parties would be notified via email. This plan was finalized after further discussion at the start of July, with the first notification going out on July 3rd.

3.0 Results

3.1 Summary of Previous Sampling Years

3.1.1 Study Year 2009:

Thirteen mosquito sampling locations were chosen in consultation with an advisory committee of the Regional District of Central Kootenay (RDCK), with Richard Brenton as Committee Chair, as well as abatement program staff, BC Hydro representatives and Culex Environmental. In 2009, the mosquito sampling effort included more than 3,500 larval sampling dips collected from the 13 sites over six sampling events from May to August 2009. In addition, eight adult mosquito light traps were operated six times for a total of 48 trap nights. In total, the larval sampling program collected 3,506 mosquito larvae while the adult trapping program collected 77 mosquitoes. Between the two programs, ten different mosquito species were collected.

Mosquito production was relatively low on the Duncan floodplain during 2009, probably as a result of the unusually low water levels. Many of the larval sampling locations were dry for part or all of the summer due to a combination of unusually dry weather and relatively low Dam discharges. We observed a distinct shift in species composition of the mosquito larvae collected from June to August. In June, *Aedes* and *Culiseta* species were the primary species collected. In August, the composition shifted to *Anopheles* species. No high risk West Nile virus vector species were discovered in 2009. There was no evidence that late season discharge from the Duncan Dam on August 20th, 2009 impacted mosquito species composition or abundance.

3.1.2 Study Year 2010:

A total of six sampling events of both adults and larvae were conducted in 2010. In total, the larval sampling program collected 3,142 larvae compared to 3,506 in 2009. Eight adult light traps were set on six occasions and trapped 68 individuals. The inclusion of Mosquito Magnets® in the sampling methods showed that *Anopheles* species adults are active as early as late April. Two additional species that were not recorded in 2009 were *Aedes excrucians*, a nuisance species and *Culiseta inornata,* a potentially high-risk WNv vector species.

Many of the larval sampling locations were dry for part or all of the summer due to a combination of dry weather and relatively low discharges from the Duncan Dam. However in mid-August, there was an increase in the discharge and some late-season flooding was observed which was captured by two sampling events. Although the majority of nuisance mosquitoes hatched in late May and June, there was some evidence to indicate that *Aedes* species can hatch late in the season, with several larvae recorded at a number of sites in mid-August and early September 2010 including some *Aedes vexans* at one location.

3.1.3 Study Year 2011:

In response to extremely high snowpack levels, which predicted above average flooding of the Duncan Floodplain, BC Hydro authorized an enhanced monitoring program to capture data from a high-water year. Although this sampling was not part of the original terms of reference, environmental monitoring provided advance warning that a high water year was probable. This gave us an important opportunity to study the mosquito populations in a high water year. It was therefore decided to conduct three sampling events through the season.

The first sampling round was conducted on June 2nd. The objectives of this sampling event were to collect larvae and adults after the peak in the spring freshet which occurred around May 27th. Sampling was conducted several days after peak water levels to allow water temperatures to rise and initiate the hatch of mosquito eggs. A total of 3,448 larvae were collected during this sampling round, but no adults were collected. Of the 1,523 larvae identified, 97% were *Aedes* species mosquitoes, with the majority being *Aedes vexans*, a nuisance species. Sites DDM-12, DDM-13, DDM-06 and DDM-07 had over 100 *Aedes vexans* larvae each.

The second sampling event (July 20th) was conducted in mid-July after a surge in the river level. A total of 744 larvae were collected with 303 of these being identifiable to species. During this sampling event, DDM-01 and DDM-02 were wetted for the first time in the three years of this study. The larvae identified from DDM-01 and DDM-02 were primarily *Aedes vexans*. Unfortunately, it was determined by the abatement contractor that the larval numbers and the stage of development warranted immediate treatment of DDM-01 and DDM-12 in the days just prior to sampling. Only three larvae were collected from these two sites on July 20th. The adult traps collected 196 adults, with over two-thirds of the collection being comprised of the nuisance mosquito *Aedes sticticus.* The other two most common species were the nuisance mosquito *Aedes vexans*, and the potential WNv vector *Culiseta inornata* (Table 5).

The third sampling round (August 19th) occurred after a significant increase in river levels. During this round, 385 larvae were collected, of which 206 were identified to species. The high risk vector species *Culiseta inornata* and *Culex tarsalis* were the most commonly collected larvae. Sixty-nine *Culex tarsalis* larvae were collected in total from sites DDM-12, DDM-01, DDM-02 and DDM-10. In the days just prior to sampling, it was determined by the abatement program manager that the larval numbers and stage of development warranted immediate treatment of DDM-09 and DDM-12. Despite treatment, 43 larvae were still collected from DDM-12, but only one larva was collected at DDM-09. Adult traps collected 26 adults, 25 of which were identified to species. The most common species collected was *Aedes sticticus*, followed by *Culiseta inornata.*

3.1.4 Study Year 2012:

In the summer of 2012, ten dip samples were taken at each of the thirteen larval sampling sites every two to four days from June 20th to September 7th. Sites were sampled 24 times throughout the summer, including two major sampling events where 50 dips were taken at each site. In addition, carbon dioxide baited adult traps were operated weekly at eight of the sites. A total of ten adult trapping rounds were conducted for a total of 80 trap nights. The numbers of adults caught in 2012 increased significantly compared to previous years. The species collected and their potential for being a potential West Nile virus (WNv) vector, as well as the life stage in which they were detected is listed in Appendix 2.

A total of 3,684 larvae were collected in 24 sampling visits and 11,272 adults were collected in ten trap nights.
A summary of the results from the past four years is given in Table 3.

Table 3: Summary of Research Effort and Collections 2009-2012.

Year	Larval Dips (Wet Sites)	Larvae Collected	Adult Trap Nights	Adults Collected	Water Depth Measurements	Temperature Measurements
2009	1850	3506	47	77	247	May 27 - August 30
2010	2100	3142	48	68	416	May 19 - October 3
2011	1800	4577	24	222	455	not recorded
2012	3850	3684	80	11272*	312	June 20 - September 7
Total	**9600**	**14909**	**199**	**11639**	**1430**	

(* Adult CDC Light traps baited with CO_2)

3.2 Communications

Following the discussions regarding the communications methodology at the June 20th stakeholder's meeting and finalized in July, information was relayed from the field technician and posted on the webpage as quickly as possible. Table 4 shows the sampling dates and the dates on which the data was posted to the website and the parties were notified.

Table 4: Sampling dates, and notification dates of larval sampling information.

Sampling Date	Date Notified
20-Jun	N/A
24-Jun	N/A
28-Jun	N/A
02-Jul	03-Jul
06-Jul	07-Jul
10-Jul	11-Jul
14-Jul	15-Jul
18-Jul	19-Jul
20-Jul	23-Jul
22-Jul	23-Jul
24-Jul	25-Jul
27-Jul	29-Jul
29-Jul	30-Jul
31-Jul	01-Aug
02-Aug	03-Aug
05-Aug	06-Aug
09-Aug	10-Aug
14-Aug	14-Aug
17-Aug	18-Aug
21-Aug	22-Aug
26-Aug	27-Aug
29-Aug	31-Aug
02-Sep	04-Sep
07-Sep	09-Sep

3.3 Environmental Data

Through monitoring environmental factors in the winter of 2011-2012, it was predicted that 2012 would be another high water year, similar to 2011. The snowpack levels observed in each year of the study are shown in Figure 2, and are usually a reliable indicator of the size of the freshet, although this may be determined by a number of other factors such as temperature and precipitation which often affects the rate of snowmelt. On the first day in May, the snow pillow levels exceeded 1300 mm in both 2011 (1421mm) and 2012 (1357mm), and did not exceed 1000 mm in 2009 (820mm) and 2010 (947mm). A summary of environmental variables recorded in 2012 is shown in Figure 3. The minimum hatching temperature shown in Figure 3 is for *Aedes vexans* mosquitoes only. Unlike other *Aedes* species, the eggs of *Ae. vexans* require higher water temperatures in order to hatch (greater than 14°C) (Belton 1986).

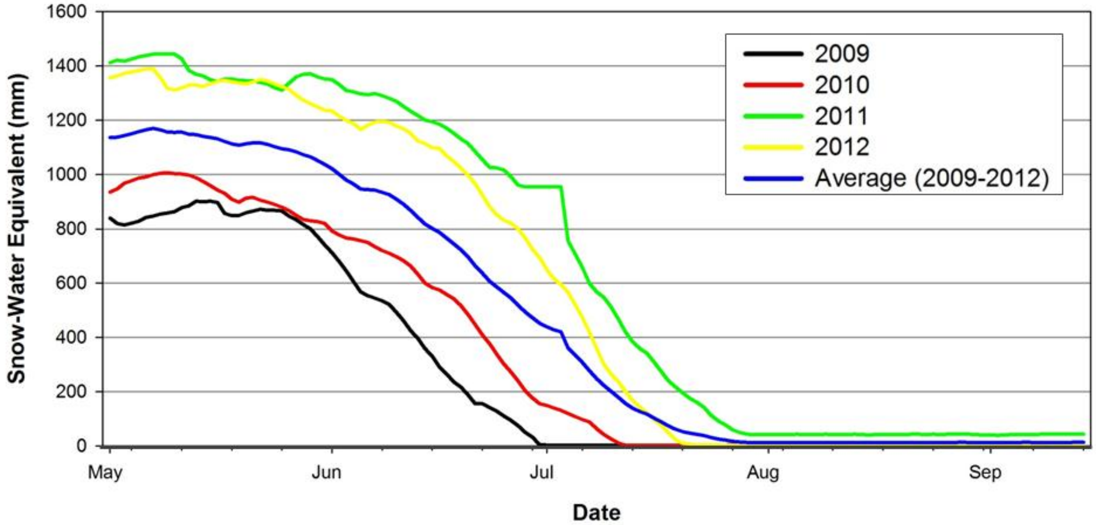


Figure 2: Snowpack Levels 2009-2012

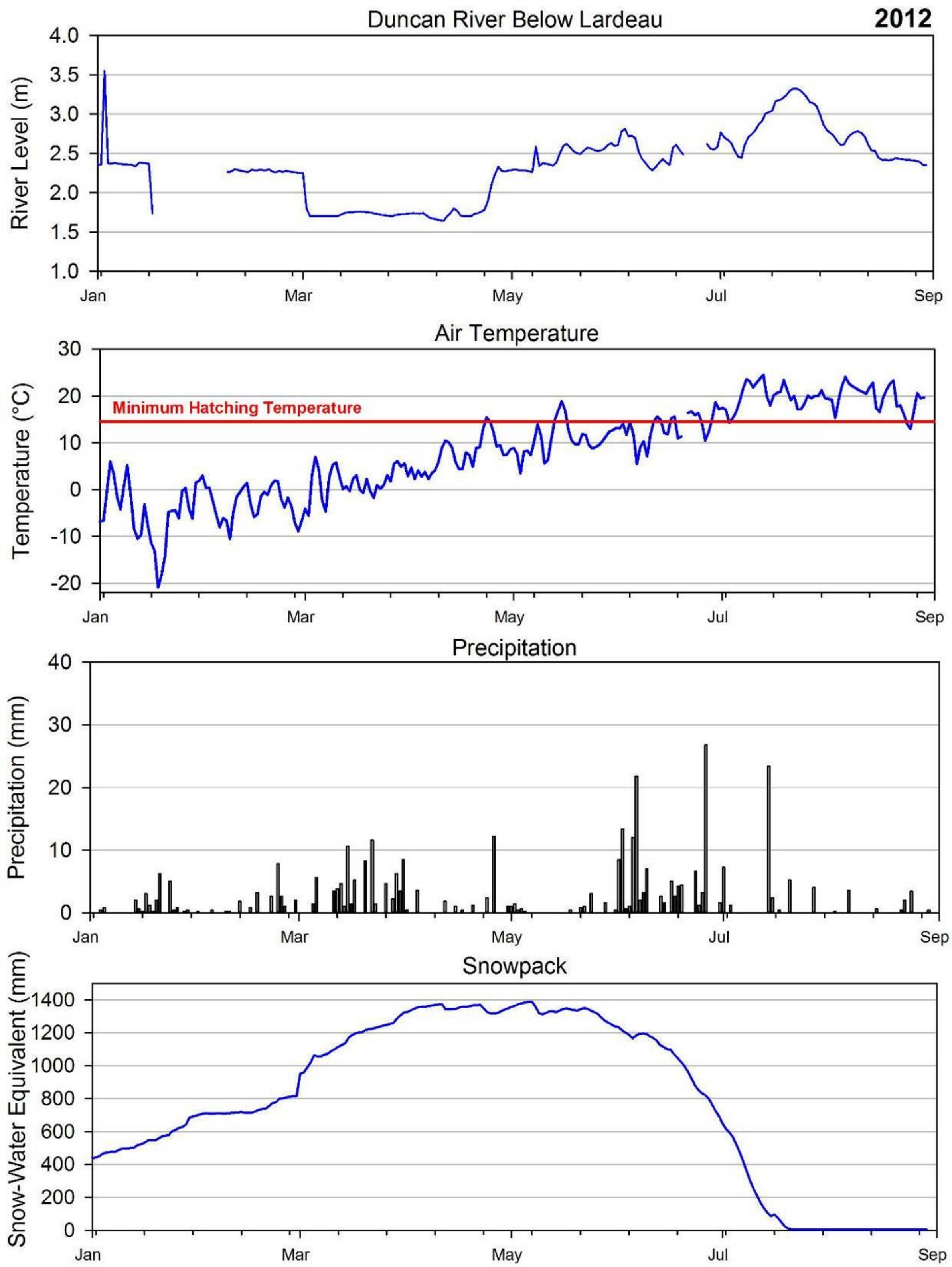


Figure 3: Environmental variables recorded in 2012

3.4 Larval Sampling Results

Species Identifications of Larvae

A total of 3,684 larvae were collected in 2012 and, of these, 1,452 were identified (Table 5). Species of which fewer than ten larvae were found were excluded from Table 3 for clarity. Collection information for these rarer species is shown in Appendix 3.

Table 5: Species identifications of larvae collected in 2012.

Date	Total Collected	Total ID'd	*Aedes cinereus*	*Aedes communis*	*Aedes vexans*	*Aedes sticticus*	*Aedes sp.*	*Anopheles earlei*	*Anopheles punctipennis*	*Culiseta alaskensis*	*Culiseta inornata*	*Culiseta impatiens*	*Culiseta minnesotae*	*Culiseta sp.*	*Culex tarsalis*	*Culex territans*	*Culex sp.*
20-Jun-12	268	209	5	0	195	0	0	0	0	6	0	3	0	0	0	0	0
24-Jun-12	66	49	4	0	39	0	0	0	0	1	0	5	0	0	0	0	0
28-Jun-12	140	40	5	0	26	0	0	0	1	2	0	5	0	0	0	1	0
2-Jul-12	154	124	8	0	86	0	2	0	0	12	0	16	0	0	0	0	0
6-Jul-12	56	47	19	0	19	0	1	0	0	5	0	3	0	0	0	0	0
10-Jul-12	26	22	7	0	0	0	1	2	0	0	0	12	0	0	0	0	0
14-Jul-12	123	15	1	0	1	0	0	0	0	2	1	5	0	4	0	1	0
18-Jul-12	100	71	6	0	40	0	1	0	0	9	6	4	0	2	2	1	0
20-Jul-12	179	136	0	0	40	59	6	0	0	27	0	0	0	0	1	3	0
22-Jul-12	67	26	0	0	13	9	0	0	0	3	0	0	0	0	1	0	0
24-Jul-12	124	68	1	9	28	8	5	0	0	14	0	0	0	3	0	0	0
27-Jul-12*	733	254	3	21	44	20	86	2	3	16	15	7	2	9	16	3	7
29-Jul-12	116	19	0	0	0	0	0	0	0	9	2	0	0	2	4	2	0
31-Jul-12	140	6	0	0	0	0	0	0	0	0	0	0	0	1	2	3	0
2-Aug-12	60	25	0	0	7	0	1	1	0	6	5	0	0	2	3	0	0
5-Aug-12	45	12	0	0	0	0	0	0	0	0	1	1	0	0	5	5	0
9-Aug-12	110	16	0	0	0	0	0	1	0	1	0	0	0	0	7	6	1
14-Aug-12	160	48	0	0	0	0	0	5	3	6	9	1	1	2	5	16	0
17-Aug-12*	763	166	0	0	0	0	0	0	0	0	24	4	2	15	70	49	2
21-Aug-12	67	36	0	0	0	0	0	0	0	2	11	0	5	1	3	14	0
25-Aug-12	66	23	0	0	2	0	1	0	5	0	1	0	1	2	3	8	0
29-Aug-12	61	20	0	0	0	0	0	0	4	1	2	1	2	0	2	8	0
2-Sep-12	45	7	0	0	0	0	0	0	0	0	1	0	1	1	0	4	0
7-Sep-12	15	13	0	0	0	0	0	0	0	0	1	0	3	0	2	7	0
Grand Total	**3684**	**1452**	**59**	**30**	**540**	**96**	**104**	**11**	**16**	**122**	**79**	**67**	**17**	**44**	**126**	**131**	**10**

*** = 50 dips, all other samples consist of 10 dips**

Genus Composition of Larvae

Figures 4 and 5 show several important changes in larval species composition over the season:

- *Aedes* were the most abundant genus in June and much of July
- *Ae.vexans* was most abundant species, numbers of which peaked on June 20th
- *Aedes* larvae reappeared after the discharge from the dam on July 18th
- *Aedes sticticus* larvae were found in small numbers in July but none were found in August
- *Anopheles* larvae were collected mostly in late season samples
- *Culiseta* mosquitoes were present throughout the season in varying numbers
- *Culex* mosquitoes were primarily found from the end of July onwards

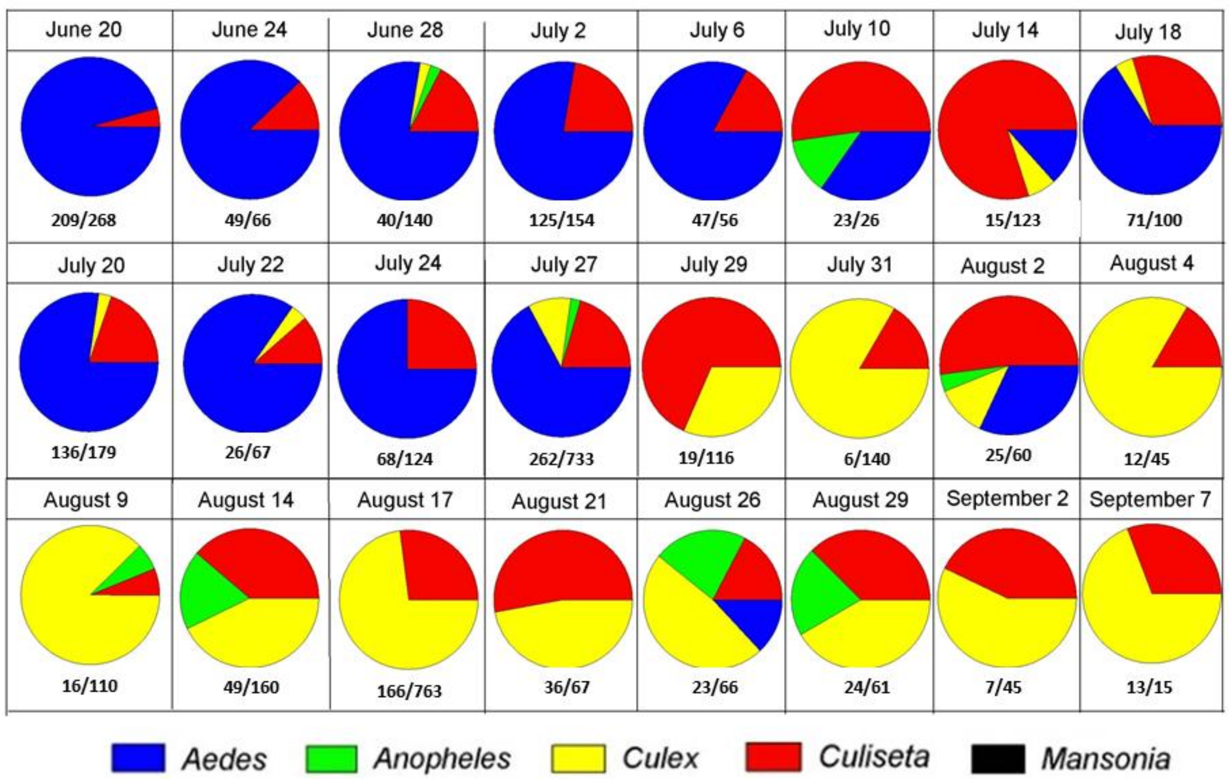


Figure 4: Temporal variation in larval genera, numbers indicate total identified larvae/total number of larvae collected.

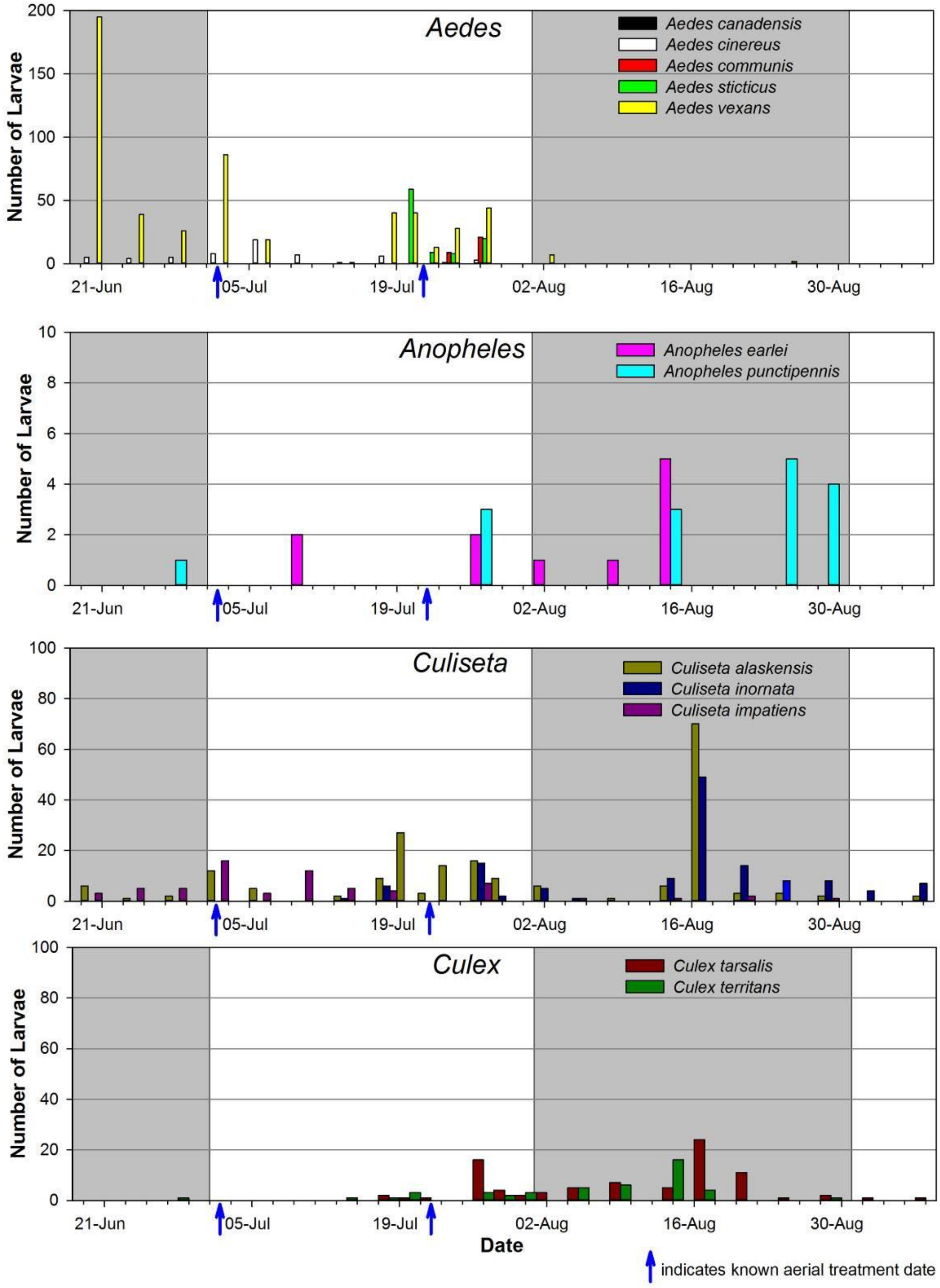


Figure 5: Larval numbers of each species collected in 2012.

Species Composition of Larvae at Each Sampling Site

The species composition of larvae at each site during each month in 2012 is shown in Figure 6. The numbers of larvae collected in sampling events in which 50 dips were taken were divided by five to ensure that the data was comparable across sampling events.

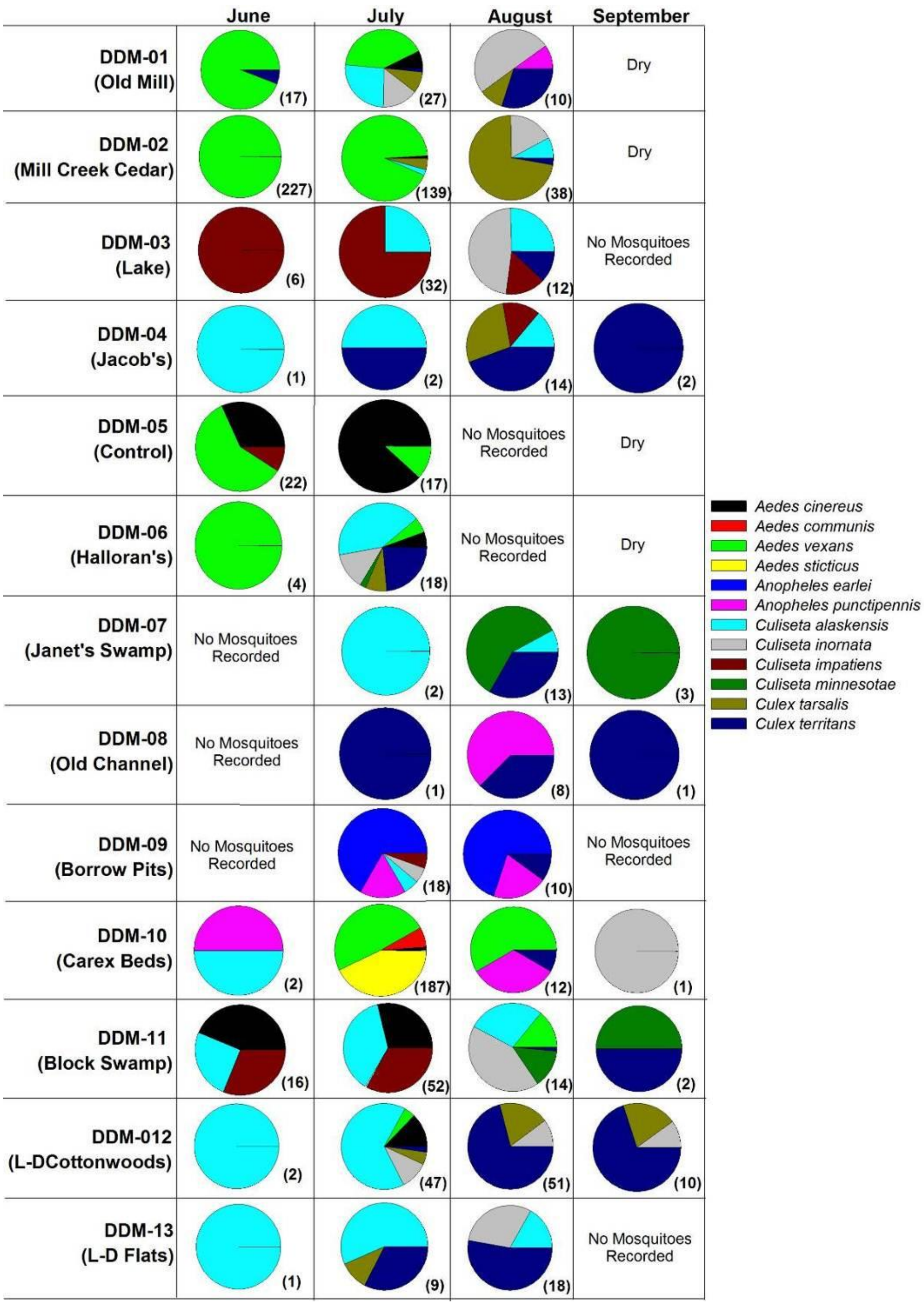


Figure 6: Species composition of larvae collected in 2012.

The most larvae were collected from DDM-02 in June. The same general trend as in previous years can be seen with larval species composition transitioning from *Aedes*-dominated in the early season to *Culex*/*Anopheles* dominated later in the season.

DDM-02 on July 27th, 2012

3.5 Adult Sampling Results

Species Identifications of Adults

The species identifications of the adult females collected in 2012 are shown in Table 5. Species in which fewer than five adults were collected have been omitted from the table for clarity (see Appendix 4 for additional species). A total of 11,335 adult mosquitoes were collected, of which 4,953 could be identified. The most commonly collected adult was the nuisance species *Aedes vexans*. *Aedes sticticus* also was collected in large numbers throughout the season.

Table 6: Species identifications of adult females collected in 2012.

Date	Total Collected	Total ID'd	*Culex tarsalis*	*Culiseta alaskensis*	*Culiseta impatiens*	*Culiseta inornata*	*Culiseta minnesotae*	*Culiseta morsitans*	*Culiseta sp.*	*Aedes canadensis*	*Aedes cinereus*	*Aedes communis*	*Aedes sierrensis*	*Aedes sticticus*	*Aedes vexans*	*Aedes sp.*	*Anopheles earlei*	*Anopheles punctipennis*	*Mansonia perturbans*
20-Jun-12	272	272	1	17	166	0	1	0	0	2	1	36	13	4	26	1	1	3	0
28-Jun-12	433	340	0	2	78	0	0	0	0	0	0	16	0	163	77	0	3	1	0
6-Jul-12	1505	590	6	3	0	0	2	0	1	0	0	0	0	507	68	2	1	0	0
14-Jul-12	3354	925	2	1	0	0	11	3	3	2	24	382	0	4	478	10	0	0	5
21-Jul-12	1340	982	16	6	1	9	47	5	3	3	9	127	0	112	613	6	3	0	22
29-Jul-12	1065	622	10	0	1	1	21	3	13	11	10	113	1	12	329	57	12	2	25
9-Aug-12	2799	656	8	0	0	3	5	0	4	2	47	135	0	44	292	106	1	0	8
17-Aug-12	313	313	1	0	1	0	0	0	1	1	55	0	0	36	183	30	3	2	0
25-Aug-12	191	191	0	0	1	0	0	0	1	0	59	27	0	0	61	42	0	0	0
7-Sep-12	63	62	0	0	0	0	1	0	5	1	22	5	0	0	7	20	1	0	0
Grand Total	**11335**	**4953**	**44**	**29**	**248**	**13**	**88**	**11**	**31**	**22**	**227**	**841**	**14**	**882**	**2134**	**274**	**25**	**8**	**60**

Genus Composition of Adults

- *Aedes* mosquitoes were the dominant species collected in all trapping rounds (Figure 7)
- *Culiseta* adults were most common in the early season, but a few individuals were found in each subsequent round
- *Culex* and *Anopheles* adults were found in low numbers.
- Small numbers of *Mansonia perturbans* were detected in July.

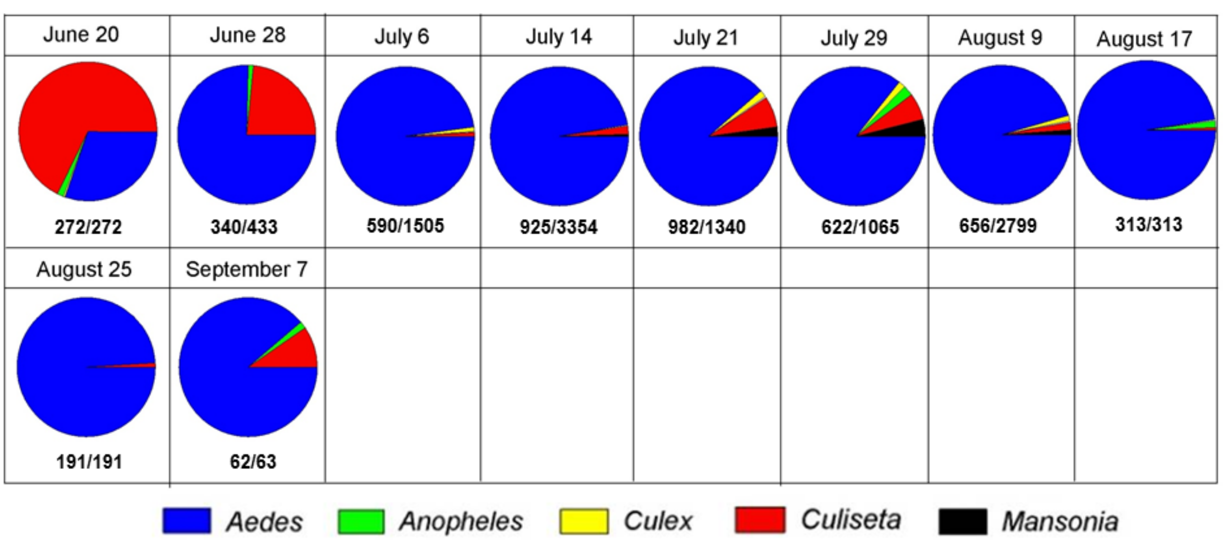


Figure 7: Genus composition of adult females collected in 2012. Numbers are presented as total number identified/total number collected.

Seasonal Activity of Adults

- *Culiseta impatiens* was most prevalent early in the season, peaking at 23 adults per trap on June 20th
- *Aedes vexans* peaked in July at 77 adults per trap on July 21st
- *Anopheles* species peaked at 2 adults per trap on July 29th
- *Culex tarsalis* adults peaked at 2 adults per trap on July 21st

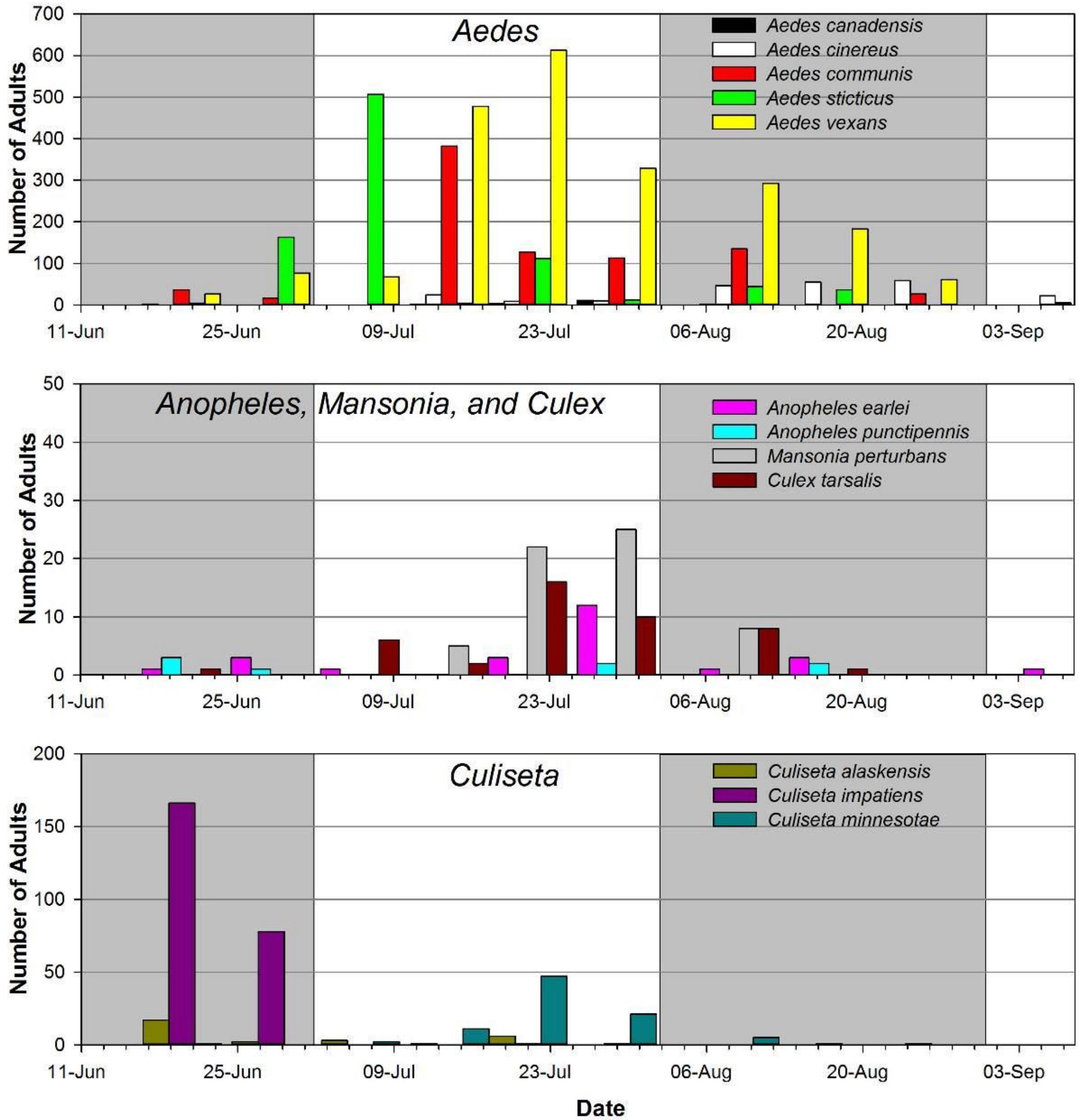


Figure 8: Species composition of adult samples collected in 2012

Species Composition of Adults at Each Sampling Site

- *Culiseta* was most commonly found in June
- *Aedes* was the most common genus in July, August, and September
- *Aedes sticticus* adults were collected primarily in June and July
- *Aedes vexans* adults were collected primarily in July and August
- Very few adults were found during two trapping rounds in September

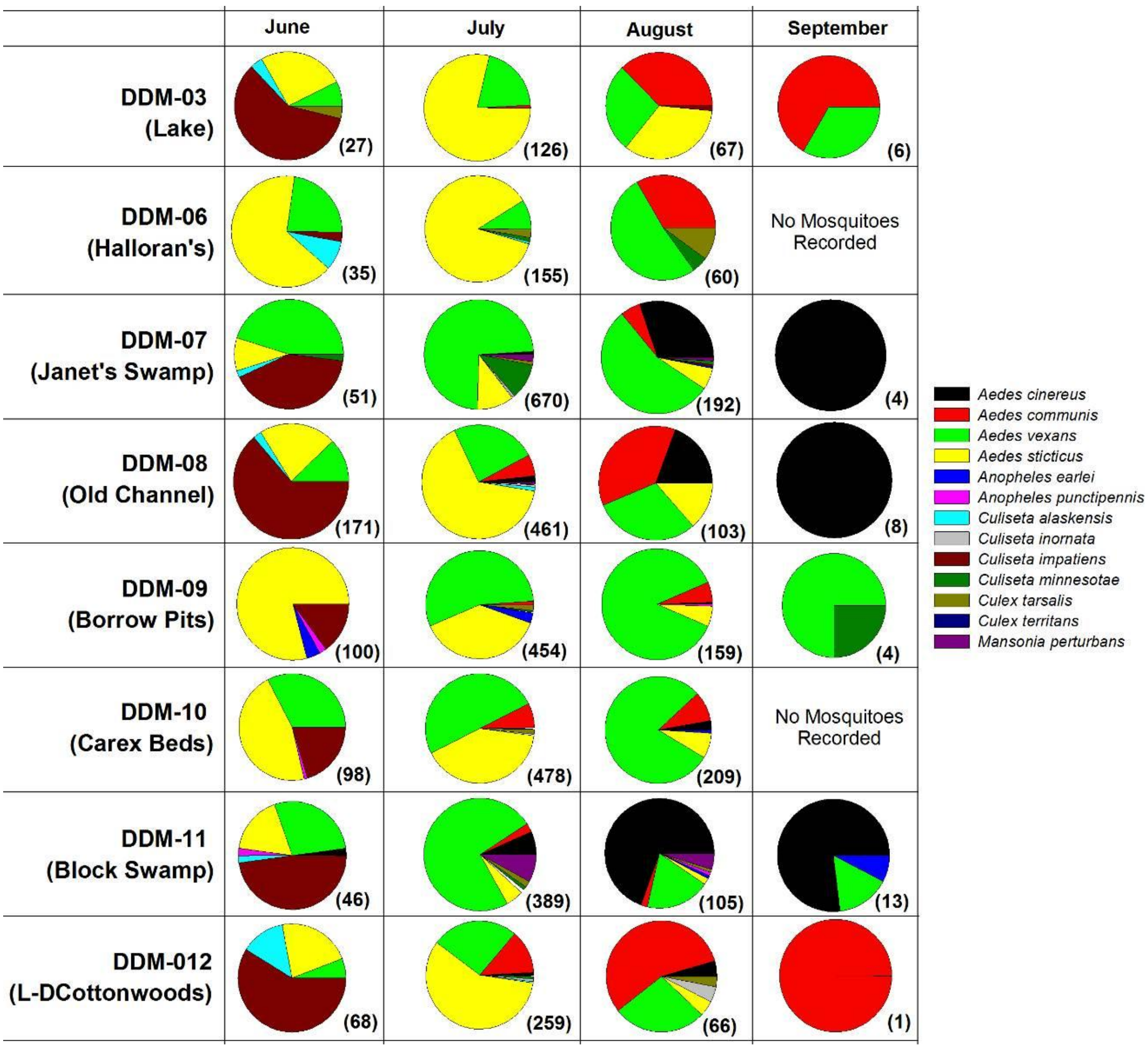


Figure 9: Species composition of adults collected.

KEY FINDINGS

1. The complete dataset for 2009-2012 now includes a total of 9,600 dip samples representing 15,000 larvae and 12,000 adult mosquitoes including a total of 22 different species.

2. Twenty-two different mosquito species were identified from the 1,467 larvae (18 species) and 4,953 adults (17 species) identified from 24 rounds of larval sampling and 10 rounds of adult trapping respectively in 2012.

3. *Aedes vexans* and *Aedes sticticus* larvae and adults were most abundant in the first sampling events from June 20 to July 6.

4. Large numbers of *Aedes sticticus* adults were collected in July although larval samples did not produce such high numbers of this species

5. A shift in larval species composition was observed from *Aedes* dominated in June and early July to *Culex/Anopheles* dominated mosquito communities in late July and August.

6. *Culiseta* were the second most common genera, although generally not considered nuisance species, *Cs. inornata* is a known potential vector of West Nile virus (WNv)

7. *Culex tarsalis*, the primary potential vector of WNv, was most abundant in August.

8. Adult *Coquillettidia* (formerly *Mansonia) perturbans* were recorded for the first time in 2012 at Block Swamp and Janet's Swamp.

4.0 Discussion

Overview: what we know, where we are going, and why

The data collected to date show that environmental factors and habitat characteristics impact mosquito productivity. Larvae of different species are associated with different sites, hydrological regimes, vegetation profiles, and time of year (Figures 4-9). Larval and adult species compositions do not closely reflect one another (Figures 4 and 7). Data collected to date have captured a substantial portion of the environmental and biological variability that drive distribution and abundance of the various mosquito species of the Duncan-Lardeau flood plain. Data to date include a range of environmental conditions encompassing both dry and wet years, and they indicate typical temperature regimes (Figures 18-21 below).

While there is strong evidence that mosquito production is shaped by environmental factors, a simple relationship between one or two main factors and mosquito production is not obvious. Mosquito populations are affected by multiple environmental factors, and different factors can interact with one another to influence mosquitoes in complex ways (Phelan and Roitberg 2013). Consequently, it is challenging to predict how mosquito populations will respond to levels of a given environmental variable at a given time. Being able to make useful predictions requires considering multiple factors simultaneously, along with the distinct biology of different mosquito species (Klowden 2007). The data collected from the study area to date are invaluable for understanding local mosquito habitat productivity, and they will provide the foundation for development of a comprehensive model that predicts how hydrology interacts with other ecological variables to shape mosquito abundance.

One such ecological variable that is very important is vegetation. Vegetation communities are determined by local hydrological regimes (Nilsson and Svedmark 2002). Hydrological regime coupled with vegetation community often determines productivity of larval mosquito habitats (Rejmankova et al. 1992, Munga et al. 2006). Consequently, species and age composition of plant communities can be used to predict mosquito productivity (Hayes et al 1985), This approach has typically been used on larger spatial scales with remote sensing technology (e.g., Wood et al. 1991, Diuk-Wasser et al. 2007). Plant communities at the study sites on the on the Duncan-Lardeau flood plain have been characterized in detail. However, many of these sites only represent a single sample of a vegetation community (Table 7 below). With replicated sampling of mosquito productivity across plant community classes it will be possible to develop a predictive model that uses vegetation, along with other environmental factors, to predict mosquito productivity. Once the relationships between mosquito productivity and vegetation classes of the region have been determined, such a model could be applied beyond the study area.

Our knowledge of species-specific environmental effects along with the detailed information available from the study sites provides an outstanding opportunity to develop and test a comprehensive site-specific model of mosquito habitat for the Duncan-Lardeau floodplain. Such a model would assist mosquito management and abatement activities. Building a useful predictive model of environmental effects on mosquito populations at the fine temporal and spatial scale of the study area presents a significant challenge. Several models have used environmental data and habitat characteristics to successfully predict average mosquito productivity over larger spatial and temporal scales (Hayes et al. 1985, Rejmankova et al. 1992, Munga et al. 2006). Making reliable fine-scale predictions will require an approach that is both informed and innovative because so many factors interact to affect productivity at any given site. Culex Environmental has recently enlisted Dr. Conan Phelan, an expert in larval mosquito ecology from Simon Fraser University, to develop a site-specific, spatially-explicit predictive model using the wealth of available data. To develop this model of mosquito productivity we will use a combination of two modeling approaches: correlative and mechanistic. We will use statistical associations (correlations between physical parameters - including vegetation composition and mosquito abundance) as well as information about and understanding of species-specific biological mechanisms (thermal tolerances, oviposition preferences, timing of hatches, and life history traits of different mosquito species).

4.1 Spatial and Temporal Patterns in Species Composition and Abundance

A common method of analyzing data which contains many variables (e.g. many species) is to use a technique known as ordination. Ordination helps to identify the underlying structure in otherwise complex data sets by identifying similarity between variables, in this case, different species, sampling sites and dates. Multi-dimensional analysis is presented in two dimensions so that species and samples most similar to one another are shown closest together, and species and samples most dissimilar from one another are shown farther apart.

Temporal Patterns of Larval Abundance

The temporal distribution pattern of the different species of larvae was analysed using Detrended Correspondence Analysis (DCA) to generate ordination plots and illustrate the relationship between the sampling date and the average number of larvae collected during each sampling event (Figure 10).

- *Aedes vexans*, *Ae. cinereus*, *Cs. alaskensis* and *Cs. impatiens* were most strongly associated with June and July (yellow and purple ellipses)
- *Aedes sticticus* and *Ae. communis* were found largely in July (purple ellipse)
- *Anopheles earlei* and *An. punctipennis* were found in August (green ellipse)
- *Culex tarsalis* and *Cs. inornata* were associated with mid-to-late season (green ellipse)
- *Culex territans* and *Cs. minnesotae* were found late in the season (blue ellipse)

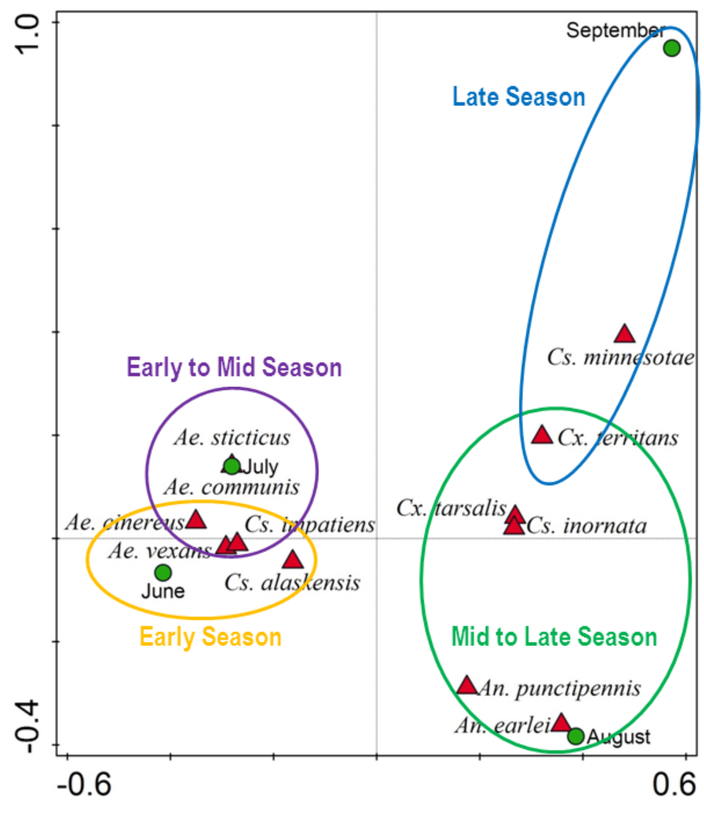


Figure 10: DCA of the average number of larvae collected (red triangles) and month (green circles) for common species.

Temporal Patterns of Adult Abundance

Figure 11 plots the sampling dates as a function of their species compositions, with dates plotted close together indicating similarity in species composition. Several trends can be seen from this ordination plot:

- There was a clear shift in species composition across the sampling period
- *Cs. alaskensis* and *Cs. impatiens* were most often found in the early season (yellow ellipse).
- *Aedes vexans* was found the entire season, and is represented in the middle of the sampling date points
- Mid-season samples included *An. earlei* and *Ae. sticticus, Cx. tarsalis*, *Cs. minnesotae* and *Mn. perturbans* (green ellipse).
- Late season collections were characterized by primarily *Ae. vexans*, and *Ae. cinereus,* (blue ellipse) but *Ae. communis*, *An. earlei,* and *Cx. tarsalis* were also present.

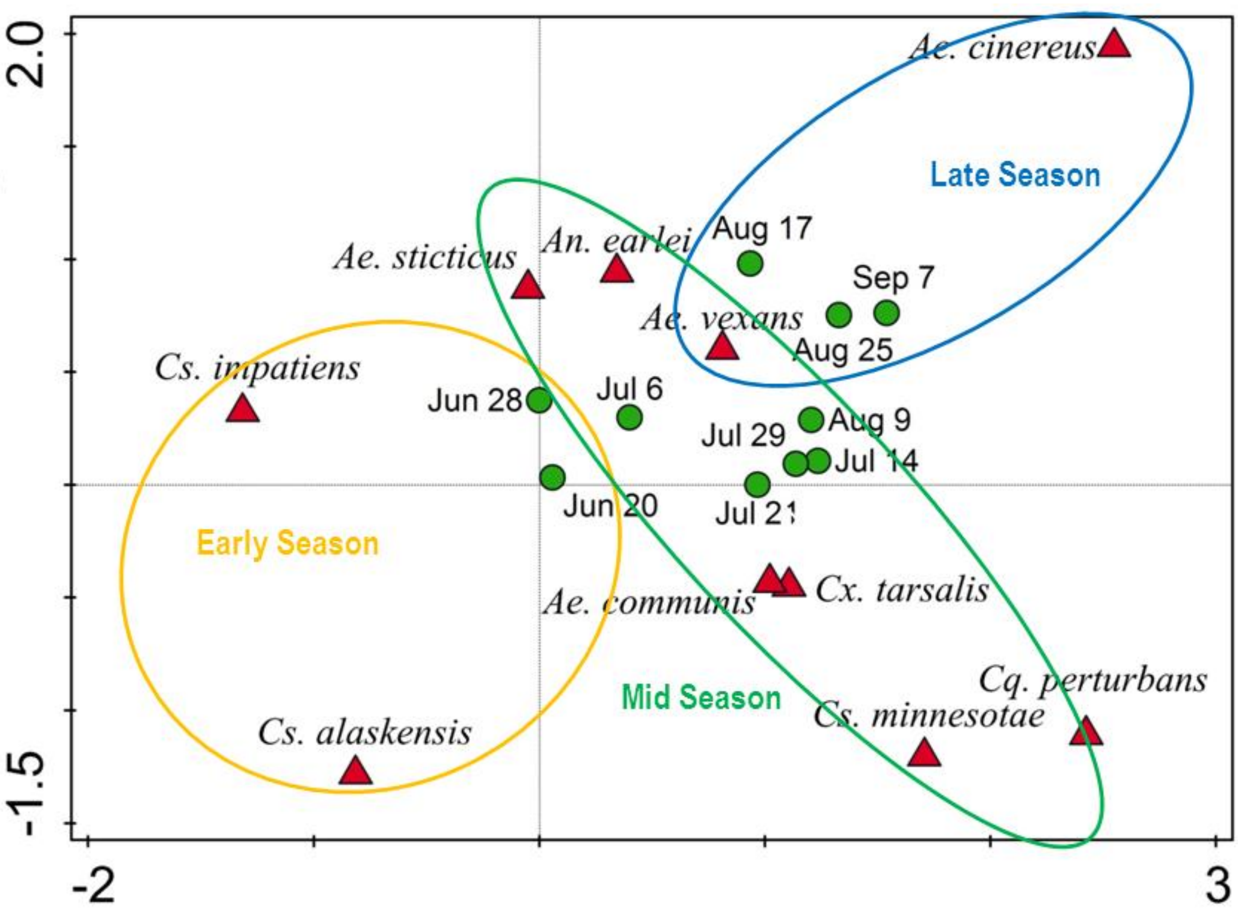


Figure 11: DCA of the average number of adult females collected (red triangles) and date (green circles) for common species.

Spatial Patterns of Adult Distributions

- Janet's Swamp and Block Swamp were associated with *Cs. minnesotae*, *Mn. perturbans* and *Ae. cinereus* (yellow ellipse)
- Lake's, Jacob's and Lardeau-Duncan Cottonwoods had similar species compositions and were associated mainly with *Cs. alaskensis*, *Cs. impatiens* and *Ae. communis* (green ellipse)
- Borrow Pits and Carex Beds were closely associated with *Cx. tarsalis* and *An. earlei* (blue ellipse)
- Halloran's was associated with many species including *Ae. vexans*, *Ae. sticticus* and *Ae. communis*, *Cx. tarsalis*, *Ae. cinereus*, and *Cs. alaskensis*.

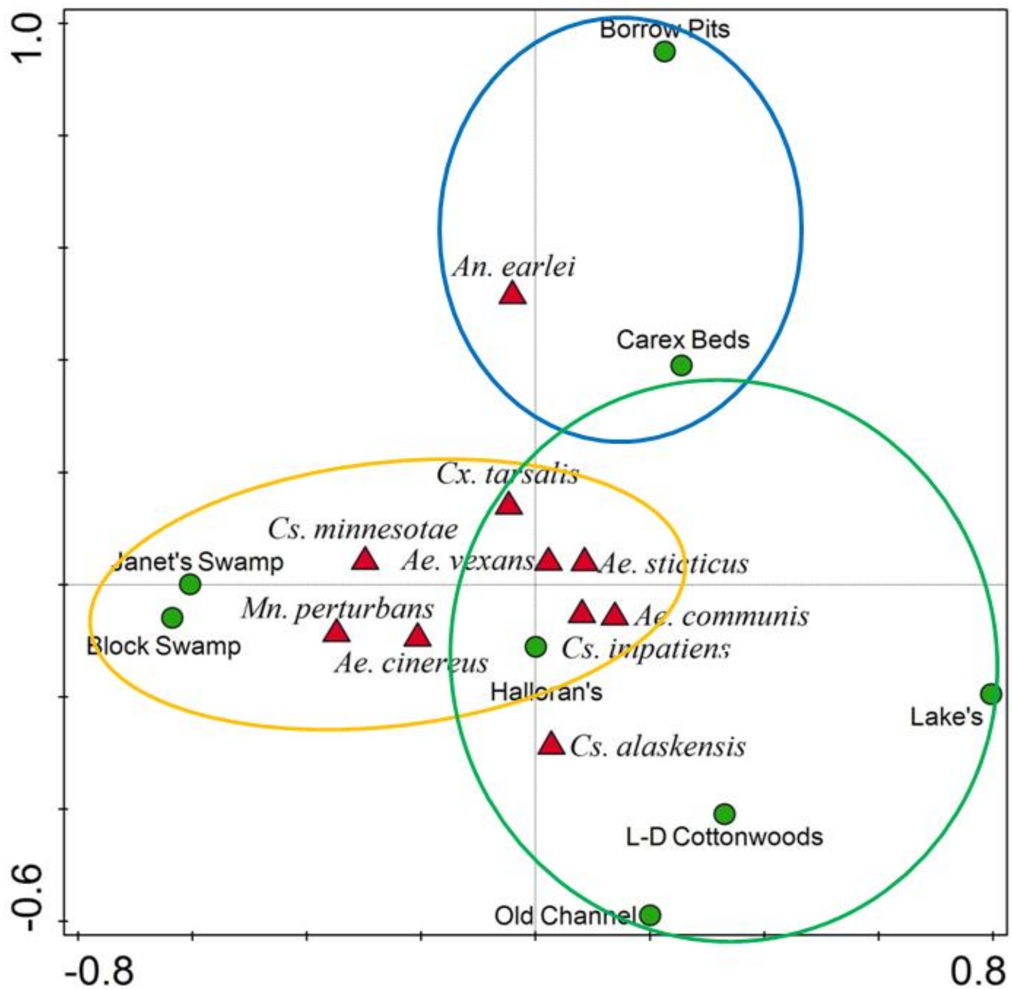


Figure 12: DCA of the average number of adult females collected (red triangles) and site (green circles) for common species.

Spatial Patterns of Larval Distributions

- Janet's Swamp was strongly associated with *Culiseta* species (blue circle).
- Lake's, Jacob's and Lardeau-Duncan Flats sites were similar, associated with *Cx. territans* and *Culiseta* species (yellow circle)
- Old Channel and Borrow Pits sites were similar, associated most often with *Ae. communis*, *Ae. sticticus*, *An. punctipennis* and *An. earlei* (green circle)
- Meadow Creek Cedar, Block Swamp, Halloran's, Lardeau-Duncan Cottonwoods and Old Mill were mostly associated with *Cx. tarsalis* and *Cs. inornata*

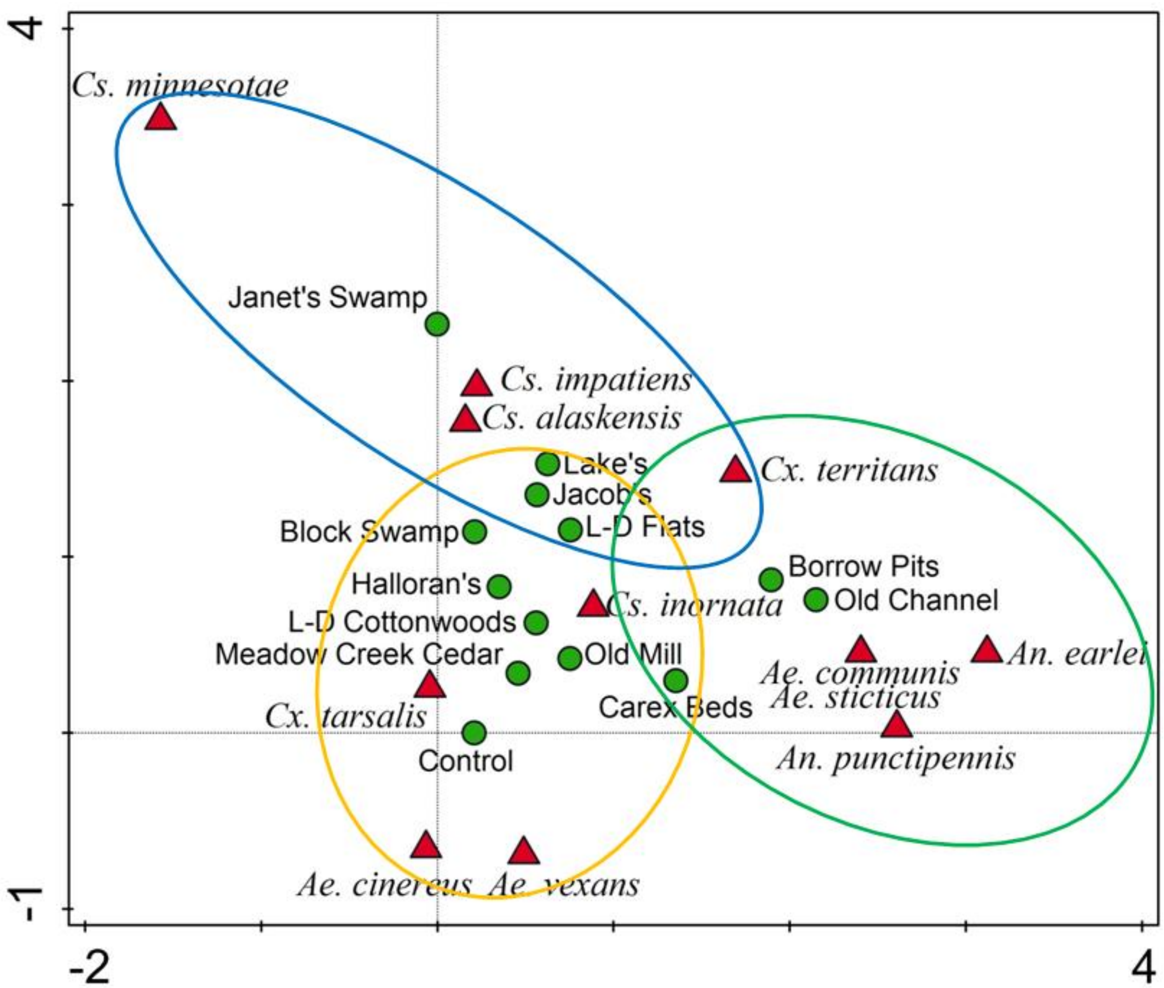


Figure 13: DCA of the average number of each species of larvae collected (red triangles) and site (green circles) for common species.

Hypothesized Seasonal Patterns of Larval and Adult Abundance

From a series of hypotheses developed concerning the life cycles and behavior patterns of different species, scenario diagrams were drawn up as a first step towards modeling the expected relative abundance at different times of the year. These preliminary scenarios are shown in Figure 14. A small hatch and emergence of *Aedes* species was predicted after a dam discharge *Anopheles, Culex,* and *Culiseta* complete more than one generation in a season.

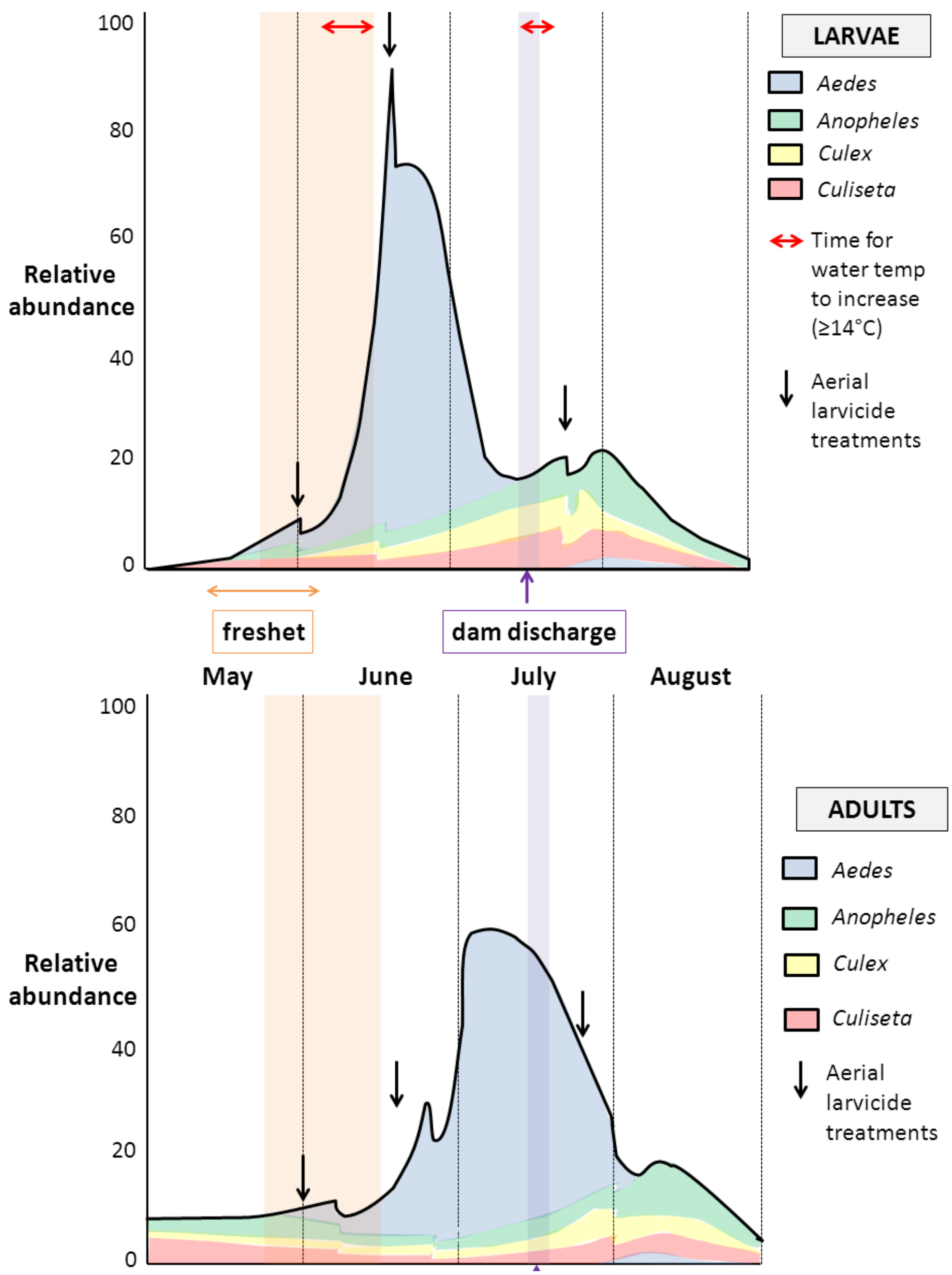
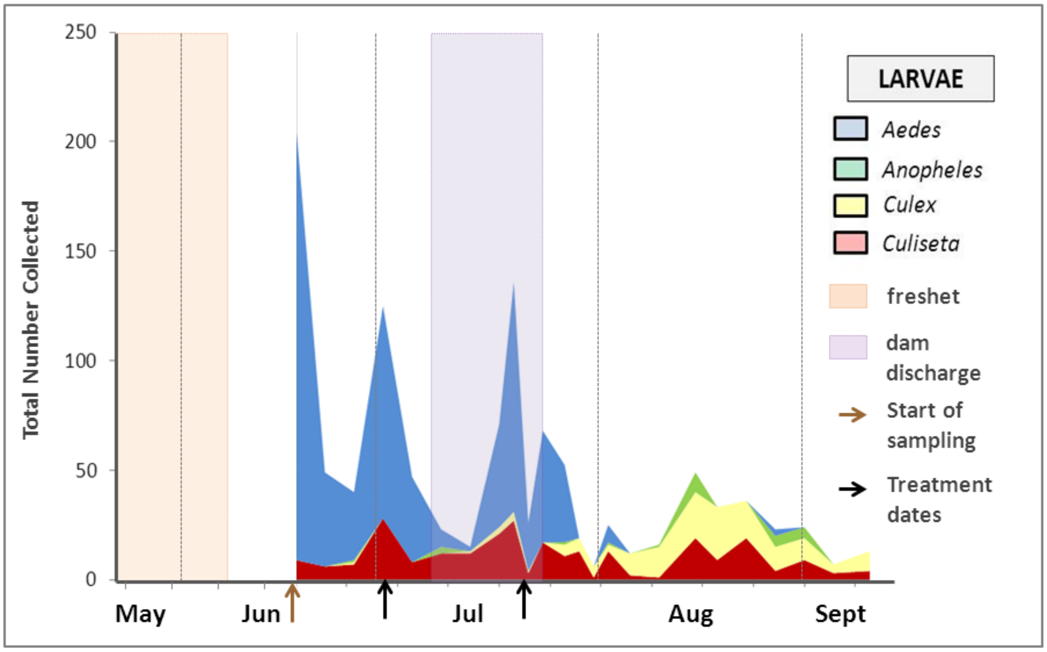


Figure 14: Expected relative abundance of larvae (above) and adults (below) of mosquito genera present in the Lower Duncan floodplain during an average season.

Observed Seasonal Patterns (2012 Data)



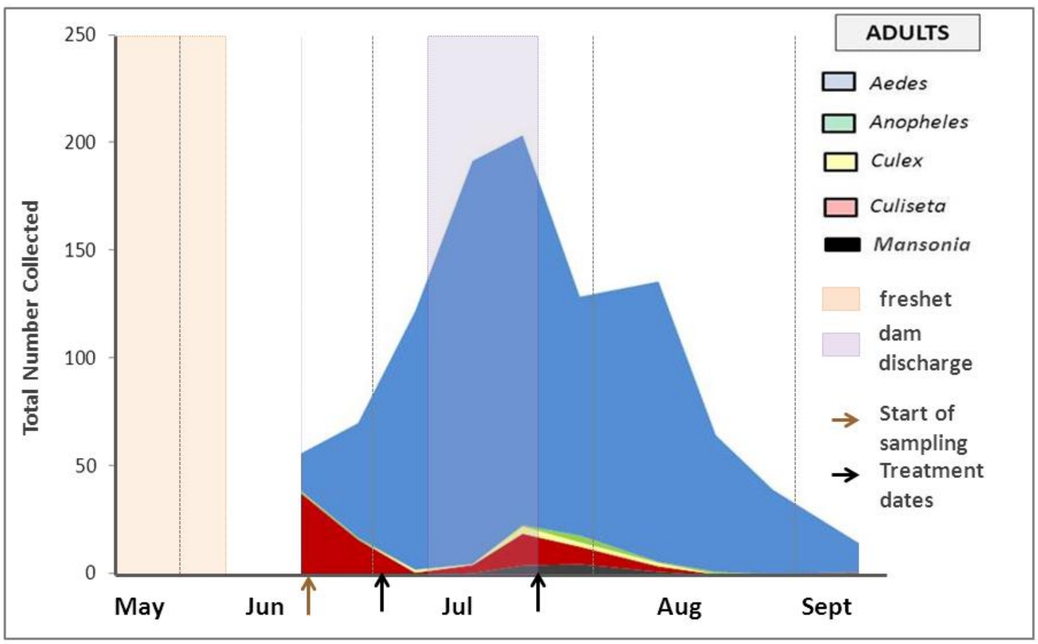


Figure 15: Observed relative abundance of larvae (above) and adults (below) of mosquito genera in 2012.

The actual empirical data from 2012 is shown in Figure 15 which can now be compared with the predicted scenario shown in Figure 16. The predicted trends in relative abundance of larval and adult populations of different genera are broadly reflected in the empirical data but with a more distinct second hatch of *Aedes* mosquitoes.

As sampling did not begin in 2012 until after the first hatch had begun, the relative overall size of the first *Aedes* hatch is calculated by assuming a linear increase in the number of *Aedes* larvae from late May to the first peak in late June followed by a linear decrease to mid-July (orange triangle in Figure 16). The second hatch was fully captured in routine sampling and is represented by the light blue triangle area. According to these calculations the second hatch is approximately 32% of the size of the initial hatch.

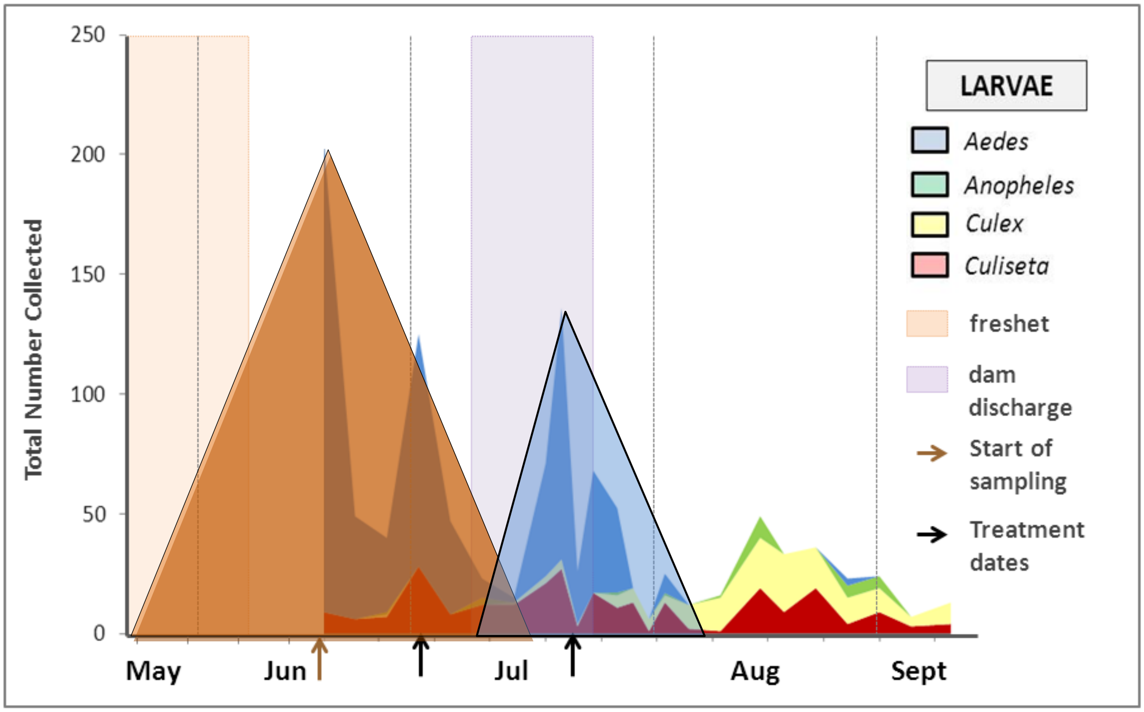


Figure 16: Observed relative abundance of larvae of mosquito genera in 2012, with estimated true population sizes illustrated.

4.2 Temperature Effects

Our hypothesis is that we would expect very few eggs to hatch below 14 degrees and that waters above this temperature will initially be formed as the flooding creates new shallow pools through backwashing and then continues to create more warmer shallow areas for hatching as the floodwaters subside. Figure 17 shows the number of larvae collected from all sites at mean air temperatures. In 2012, we found no evidence of larval development prior to mean daily air temperatures reaching 13 degrees Celsius. This finding upholds Dr. Peter Belton's contention that *Aedes vexans* larvae do not hatch at water temperatures below 14 degrees.

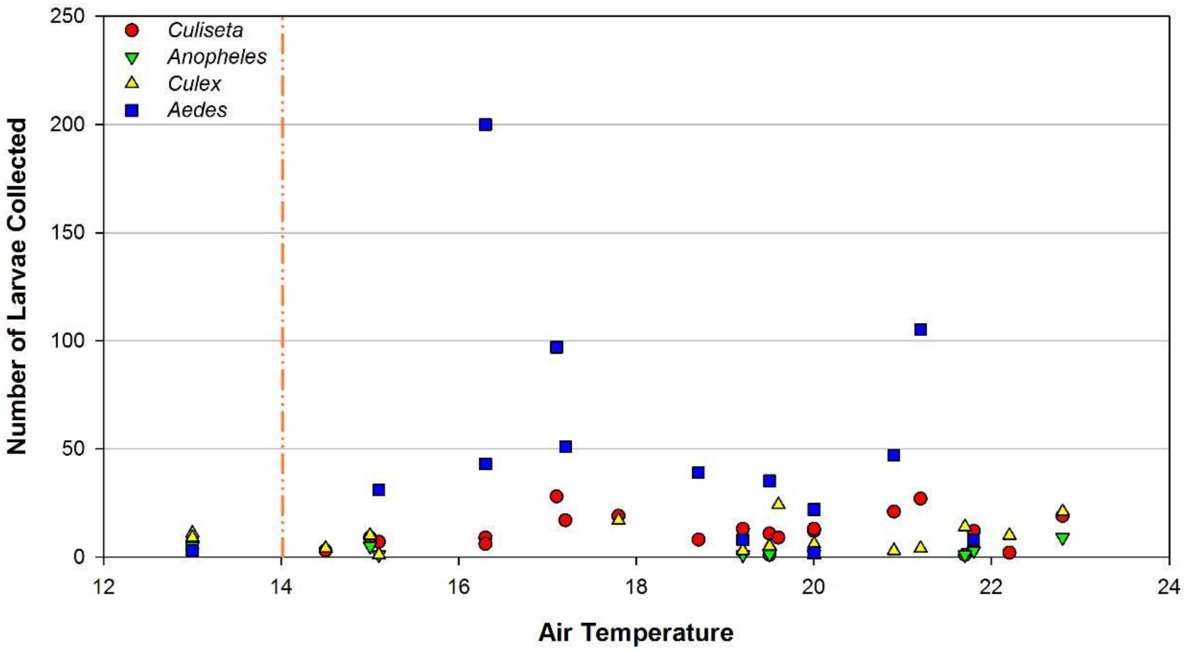


Figure 17: The relationship between daily mean air temperature and number of larvae recorded (per 10 dip sample) at each site.

4.3 Hydrology

Comparing the hydrological conditions in The Lower Duncan Floodplain between the four years of this study allows us to compare the differences between subsequent mosquito production in two dry (2009-10) and two wet years (2011-12). The series of charts below show the environmental data for each year where an arbitrary green line has been inserted to show the 3m level below the Lardeau. In terms of mosquito production in the latter part of the season the two dry years showed no evidence at all of a second hatch of *Aedes* mosquitoes. In the wet years on the other hand in 2011 there was some evidence of hatching and in 2012 there was a significant hatch. There are a number of clear differences between these years that suggest a common pattern:

1. In the dry years the river level experienced during the freshet remains well below 2.5m but in the wet years it exceeds the 2.5 m mark particularly in 2012.
2. In the dry years the discharge from the dam comes late in the year and does not exceed the extent of the freshet.
3. In the wet years the river level reaches 3m in 2011 and exceeds 3m in 2012 well beyond the levels experienced after the freshet earlier in the year.

These observations suggest that if the area inundated by the freshet is exceeded by a flood later in the season, due to environmental conditions and operations management, then a significant second hatch of mosquitoes would be expected.

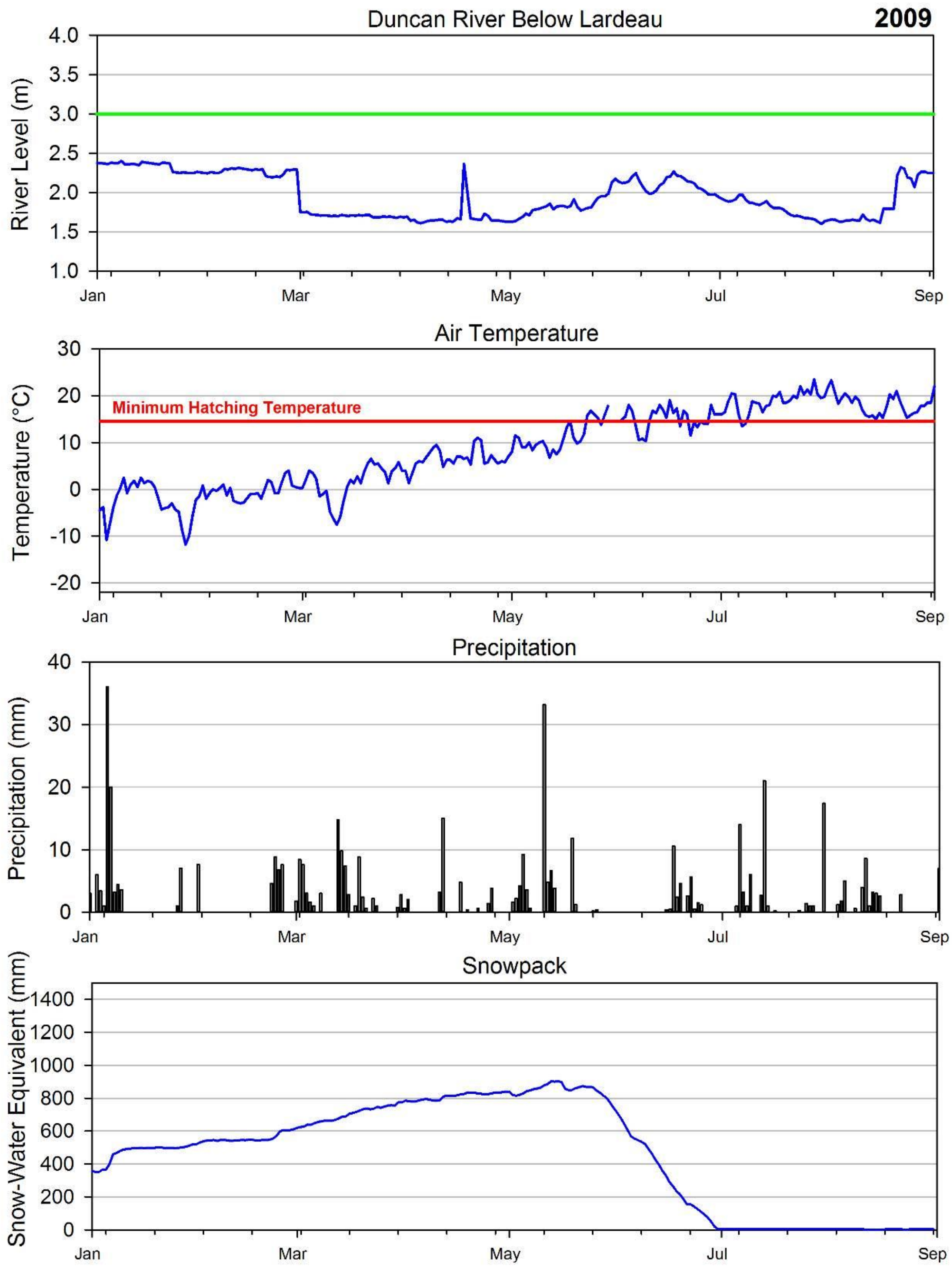


Figure 18: Environmental conditions in the Duncan Floodplain in 2009.

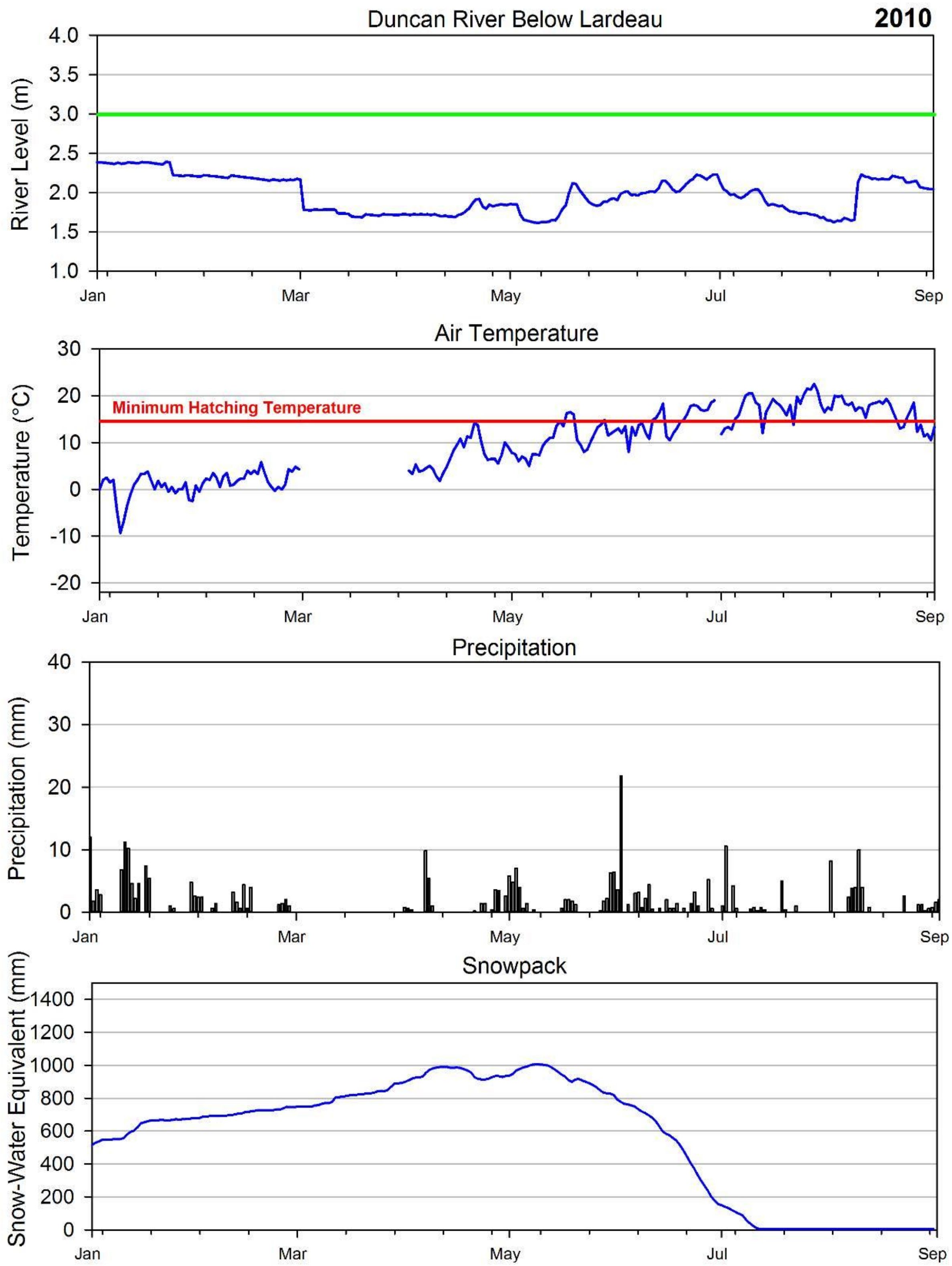


Figure 19: Environmental conditions in the Duncan Floodplain in 2010.

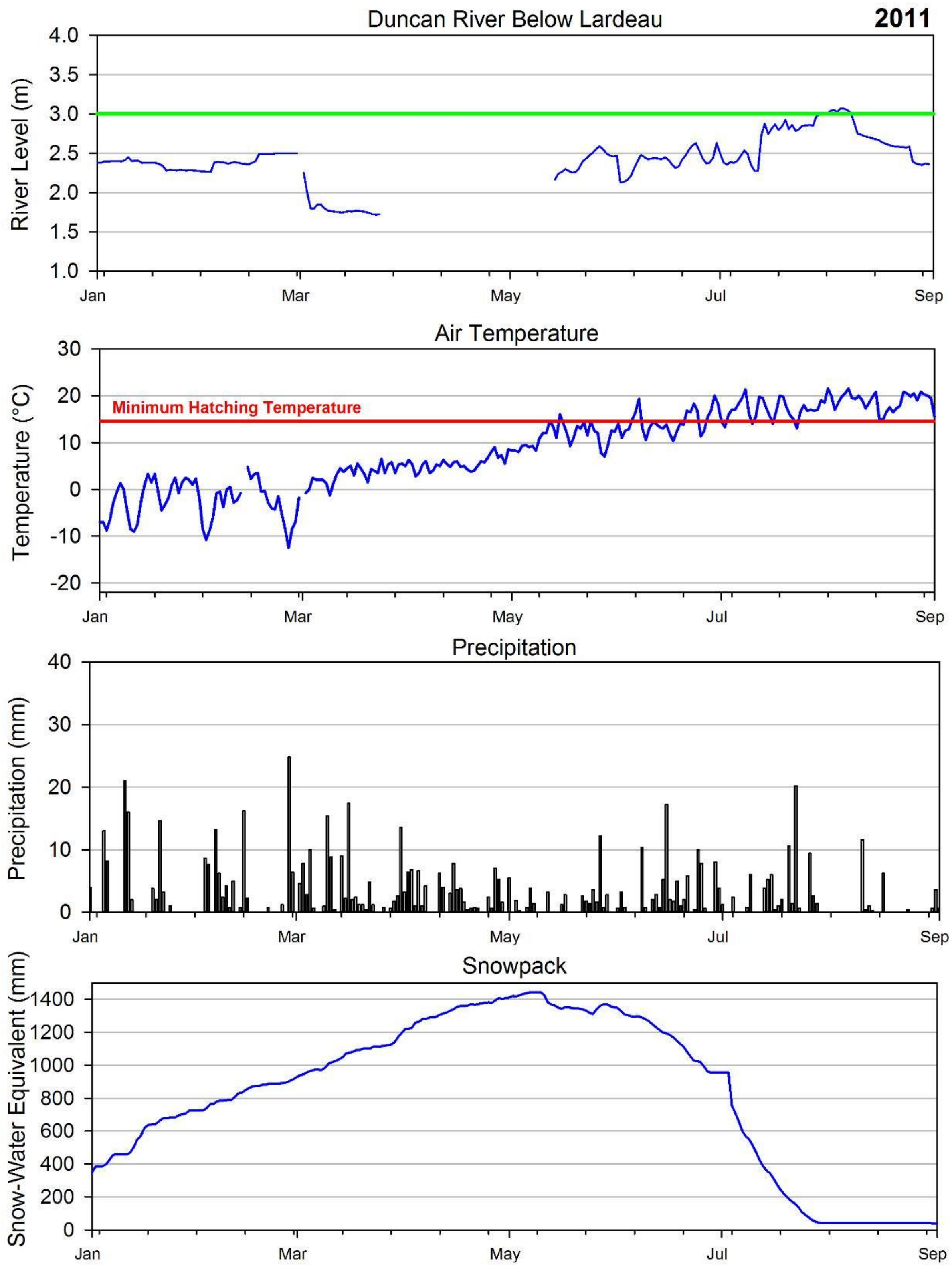


Figure 20: Environmental conditions in the Duncan Floodplain in 2011.

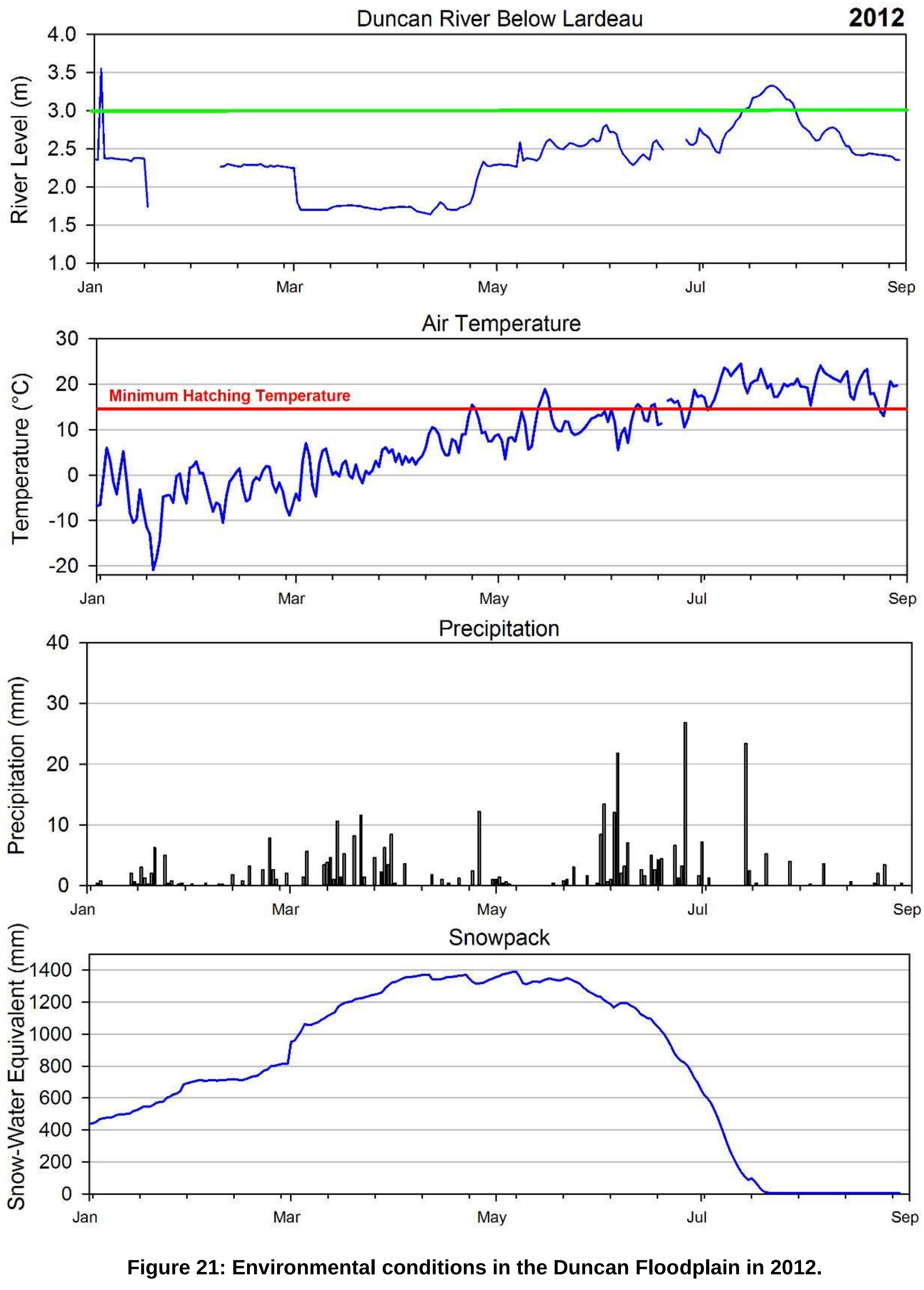


Figure 21: Environmental conditions in the Duncan Floodplain in 2012.

4.4 Vegetation as Proxy for Nuisance Mosquito Habitat

Some species have very strict larval habitat requirements while others can utilize a wide variety of larval habitats types. In addition, the degree of association can vary depending on the environmental conditions experienced across a species' distribution range. It is important to bear in mind that distributions can vary depending on ecological and environmental factors.

Mosquito species known from the Lower Duncan River Floodplain can be classified into different types of habitat groups:

Floodwater Species:

- *Ae. vexans* primarily in flooded open meadows (temporary open swamps)
- *Ae. sticticus* primarily in areas with dense vegetation such as cottonwoods, willow, and rose
- *Ae. cinereus*: mainly cottonwood swamps but also in shallow surface pools and ditches

Pool and Swamp Species:

- *An. punctipennis*: mainly ponds and swamps
- *An. earlei*: mainly ponds and swamps but also cottonwoods swamps and surface pools near willow
- *Cx. tarsalis*: surface pools, flooded fields, ditches, permanent swamps and ponds, cottonwood swamps
- *Cx. territans*: ditches, ponds, swamps, surface pools near willow, cottonwood swamps
- *Cs. inornata*: surface pools near willow, open meadows, ditches, swamps, and cottonwood swamps

Marsh Species: Larvae mainly associated with marsh habitat:

- *Culiseta* species

Relation to Flooding Regimes

During the initial selection of sampling sites, the variety of habitat types identified in different regions suggested that vegetation mapping could be used to determine larval habitat associations for the species present in the Lower Duncan Floodplain and effect of flooding regimes on mosquito production in these sites. Sites were selected at a range of proximities to the main river channel and the vegetation mapped according to the wetland classification system developed by MacKenzie and Shaw (1999).

Plant associations were based on differences in flooding regimes and plant species compositions. Water levels at most sites have been recorded regularly throughout the sampling periods to link flooding regimes with habitat and vegetation types and thus the larval habitat associations of species present in the study area. These data will be used to model temporal and spatial patterns of mosquito species distribution to predict potential outbreaks of nuisance mosquito species in relation to the flooding regimes of the Duncan River and improve the effectiveness of mosquito abatement activities.

Most of the *Aedes* mosquitoes collected through this study were identified as the floodplain species *Ae. vexans*. Physical factors associated with the oviposition site are known to be important components of site selection. Substrate moisture is particularly important for *Ae. vexans* (Bentley and Day 1989). Eric Hearle of the federal Department of Agriculture wrote a comprehensive review of the mosquitoes in British Columbia in 1926, and found that *Ae. vexans* laid their eggs in flood pools in meadows, and other open places. *Aedes* lay their eggs singly in damp soil, usually in open, shallow, grass-filled depressions and other low-lying areas, but sometimes along roadsides and temporary woodland pools. This characterization has been borne out by our study, with *Aedes vexans* most commonly associated with grassy sites such as Old Mill, Meadow Creek Cedar, Lardeau Duncan Cottonwoods and Lardeau Duncan Flats.

The other primary nuisance mosquito in the Lower Duncan Floodplain is *Aedes sticticus*. According to Hearle (1926), the adults of this species lay eggs under cottonwood trees, in depressions created by tree roots which form natural bowls that fill with water. This species has also been associated with willows (Hearle 1926). In the study so far, *Aedes sticticus* has been found most often from DDM-12 (Lardeau-Duncan Cottonwoods). However, just one site has been identified as containing cottonwood stands. Expansion of the spatial scope of the sampling would provide more information about the habitat preferences of this very important nuisance species.

4.5 Site Vegetation Comparisons

The results of the vegetation survey are summarized in Table 7. The dominant vegetation type is listed for each site, along with the species that was most commonly found in 2012. Table 8 compares the dominant vegetation type at each site with the dominant mosquito species found over the four years of study implementation. The total number of larvae identified was divided by the total number of dips taken at the site over the four years of study.

Sites DDM-01, 02, 06, and 12 had similar vegetation types, being comprised of grassy areas that flooded during spring freshet and dam spill. The sites with alders seemed to be habitat for *Culiseta* species predominately (DDM-04, DDM-05, and DDM-06). DDM-07, Janet's Swamp is recorded as an alder habitat (Table 8), but mosquitoes were collected from where the water pooled in amongst the grassy tussocks, leading to the predominance of *Aedes vexans*, rather than *Culiseta*. Up until 2012, the *Carex* sites (DDM-09 and DDM-10) were predominately habitat for *Anopheles* larvae. In 2012, a very high number of *Aedes vexans* larvae were collected from DDM-10, enough to cause them to be the most common species over the four years. It is possible that these larvae were flushed from other sites into DDM-10 with the high river levels experienced in that year.

Table 7: Vegetation classifications and site association names for each site.

Site Name	Classifcation	Site Association Name
Old Mill	Fl-g	Low bench flooded grass
Meadow Creek Cedar	Fl-g	Low bench flooded grass
Lake's	Wm/sB	"Old Swamp-Marsh: Scirpus-Glyceria"
Jacob's	WsC	"Alder-Spruce Swamp"
Control	WsC	"Alder-Spruce Swamp"
Halleran's	Wm02C/edge of Fl-g	"Sheltered Channel Marsh edge low bench flooded grass"
Janet's	Wf01(05)	"Mixed species Fen"
Old Channel	Wm/sA	"Old Swamp-Marsh: Flava-Osier"
Borrow Pits	see right	Anthro. Being colonized by Wm01 and WmA
Carex Beds	Pond/WmA on pond edges	Pond. Shallow at Culex rod. Deeper downstream30 m
Block Swamp	Ws01	"Alder-Skunk Cabbage-Lady Fern "
LD Flats "Cottonwoods"	Fl-g	Low bench flooded grass
LD Flats	Wms/B	"Old Swamp-Marsh: Scirpus-Glyceria"

Table 8: Dominant vegetation type and top three most commonly found mosquito species (in order of frequency) at each site for in four years.

Site Name	Dominant Vegetation	Top Three Dominant Mosquito Species 2009-2012
Old Mill	High % Sedges with grass	*Culiseta inornata, Aedes vexans, Culex tarsalis*
Meadow Creek Cedar	High % Sedges with grass	*Aedes vexans, Culex tarsalis, Culiseta inornata*
Lake's	Carex, Horsetail, Willow	*Culiseta incidens, Aedes cinereus, Culiseta alaskensis*
Jacob's	Alder, Spruce, Swamp	*Culiseta impatiens, Culiseta incidens, Aedes cinereus*
Control	Alder, Spruce, Swamp	*Aedes cinereus, Culiseta impatiens, Aedes vexans*
Halleran's	Flood Meadows - Grazed	*Aedes vexans, Aedes cinereus, Aedes sticticus*
Janet's	Alder, Skunk Cabbage, Lady Fern	*Aedes vexans, Culex territans, Culiseta alaskensis*
Old Channel	Willow, Horsetail	*Aedes vexans, Aedes cinereus, Culiseta alaskensis*
Borrow Pits	Carex and Scirpus	*Anopheles earlei, Anopheles punctipennis, Anopheles freeborni*
Carex Beds	Carex and Juncus	*Aedes vexans, Anopheles punctipennis, Aedes sticticus*
Block Swamp	Alder, Skunk Cabbage, Lady Fern	*Culiseta alaskensis, Culiseta impatiens, Culiseta inornata*
LD Flats "Cottonwoods"	Flooded Grasses	*Aedes vexans, Aedes cinereus, Culex territans*
LD Flats	Carex, Horsetail, Willow	*Aedes vexans, Aedes cinereus, Aedes sticticus*

Table 9 lists the most commonly collected species in the four years of study, and the three sites in which they were most often found. Sites and species are both listed in decreasing prevalence. *Aedes vexans* was the most frequently identified species, and *Anopheles earlei* the least frequent. The site with the most *Aedes vexans* was DDM-02, Meadow Creek Cedar. *Anopheles freeborni* and *Anopheles earlei* were only found at two sites (DDM-10 and DDM-09).

Table 9: The 12 most commonly found mosquito species (in order of frequency) and the three sites at which they were most frequently detected over the four year study period.

Species	Top Three Sites
Aedes vexans	DDM-02, DDM-12, DDM-13
Aedes cinereus	DDM-12, DDM-06, DDM-05
Culiseta impatiens	DDM-04, DDM-05, DDM-11
Culex tarsalis	DDM-12, DDM-01, DDM-04
Aedes sticticus	DDM-12, DDM-10, DDM-06
Culiseta inornata	DDM-01, DDM-11, DDM-02
Culex territans	DDM-12, DDM-01, DDM-04
Culiseta alaskensis	DDM-11, DDM-12, DDM-03
Culiseta incidens	DDM-03, DDM-04, DDM-02
Anopheles punctipennis	DDM-10, DDM-09, DDM-08
Anopheles freeborni	DDM-10, DDM-09
Anopheles earlei	DDM-09, DDM-10

To examine the relationship further, a canonical correspondence analysis was used to graphically display the association between vegetation type and mosquito species based on the 2012 data (Figure 22). The ordination plot groups sites and species closer together the more similar that they are (i.e. found in similar habitat).

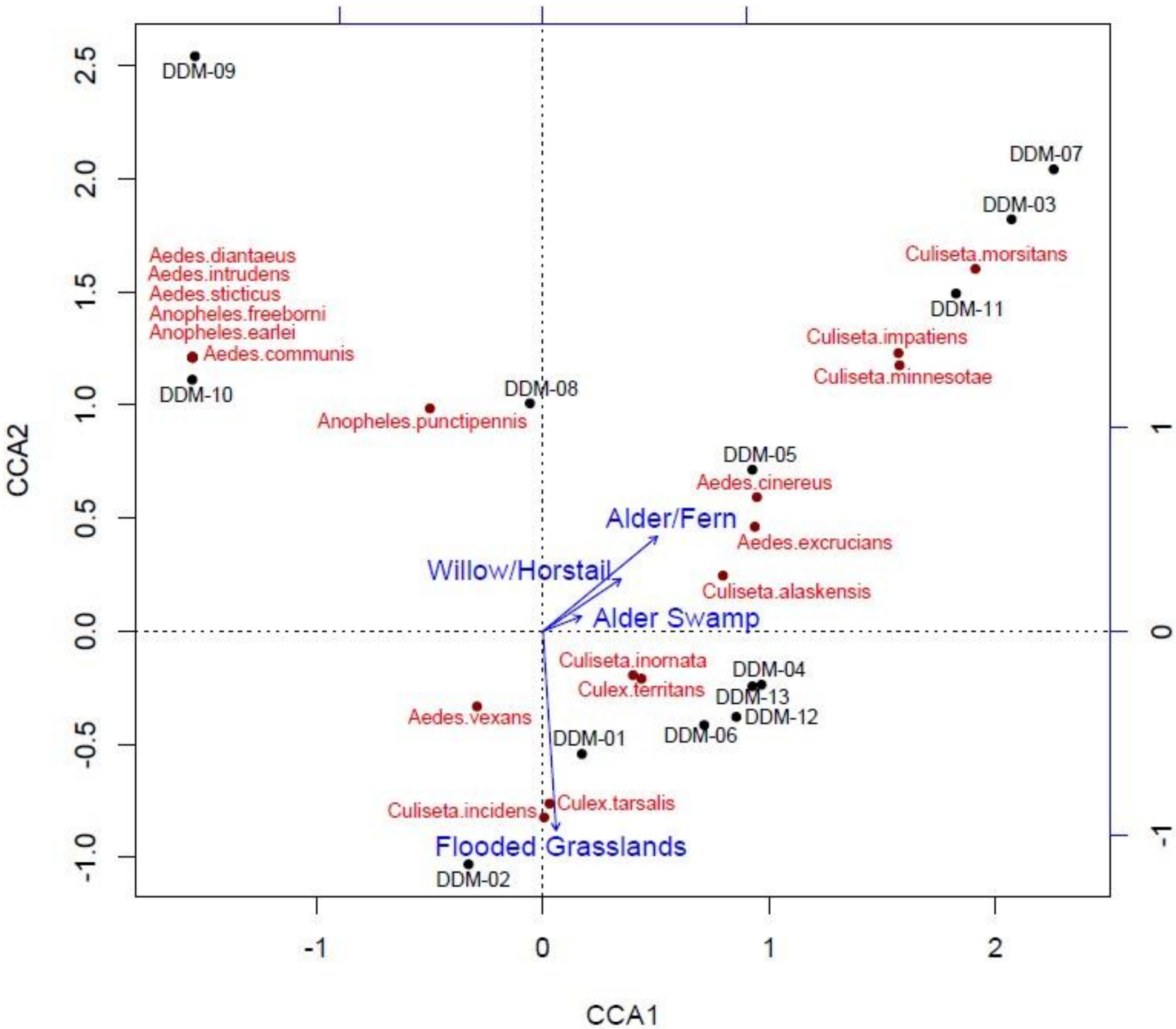


Figure 22: Canonical Correspondence Analysis of the vegetation and species identified from each site in 2012.

SUMMARY OF CONCLUSIONS:

1. There is a clear temporal shift in the species composition of larval mosquito communities in the floodplain from *Aedes* early in the season to *Culex/Culiseta* in the late season.

2. There are site specific associations that may be explained by the vegetation and hydrology at each site.

3. In years in which the late season flood exceeds levels reached by the spring freshet, a statistically significant hatch of *Aedes* mosquitoes has been detected

4. Numbers of *Aedes* mosquito larvae after Dam spills have not been found to exceed the initial hatch caused by the freshet.

5. Based on four years of data, *Aedes vexans* larvae are most often found in flooded grassland areas, while *Aedes sticticus* is most commonly detected the cottonwood site. Further research is required to provide more evidence of habitat associations and identify opportunities for operational improvements to mitigate mosquito production.

6. *Aedes vexans* larvae are rarely found below a daily mean air temperature of below 14 degrees Celsius.

5.0 Recommendations for Future Work

The 2012 sampling season was successful in collecting comprehensive data on the distribution and abundance of larval and adult mosquitoes in a high water year in the Lower Duncan Floodplain. This data is essential to understanding the complex and dynamic factors that influence mosquito production. The temporal shift in species composition has been adequately captured and described for the species found in the floodplain. Another critical factor in the distribution and abundance of mosquitoes is their spatial distribution. The development of a model based on vegetation type to prioritize abatement efforts would assist efforts to control both nuisance and potential disease vector species. The sites chosen so far show that there is some association between vegetation and the species found inhabiting a site. However there is still work required to confirm the trends observed between vegetation types and mosquito habitat as described in the discussion section. While the sites compared are generally similar, it would be beneficial to increase the number of sites from each vegetation type to improve statistical tests.

We propose taking multiple samples in different vegetation types across the whole floodplain simultaneously over the course of a 24 hour period at a mutually agreed date following consultation with the RDCK and the abatement contractors. The sampling should occur in early to mid-June depending on environmental conditions, and in consultation with the abatement team. Sampling should be early enough to collect the larvae of *Aedes sticticus*, which in 2012 appeared earlier than June 20th. The sampling would then be repeated shortly after the dam discharge in mid-July to investigate if the vegetation-mosquito relationship holds for a second flood. This would give us all the data we require to fully test this hypothesis.

The concluding phases of this study should involve refining the data analysis in relation to a number of parameters to create a predictive model of the distribution and abundance of different mosquito species based on environmental factors such as vegetation type, flooding regime and climatic factors. The vegetation types of each of the sampling sites will be matched to similar classifications across the whole Lower Duncan floodplain using newly acquired mapping information from 2012. Digital Elevation Modeling and other hydraulic information relating groundwater to different flooding regimes produced from The Lower Duncan River Hydraulic Model Development can be matched to the different vegetation types and utilized as a substitute for predicting the extent of development habitat of different mosquito species.

An additional factor that has a large role in the distribution and abundance of mosquito populations is the abatement efforts that occur throughout the floodplain. It has been shown that mosquitoes can develop resistance (a hereditary ability to survive larviciding treatments) through repeated use of the same active ingredient. As treatment has occurred with the same larvicide (*Bacillus thuringiensis israelensis*) for many years in the floodplain, there is a potential for resistance to have built up and affect the success of the abatement program. If abatement operations could use a different product (*Bacillus sphaericus*) and measure the level of control achieved, the variation in treatment could help determine if efficacy is being impacted by the buildup of resistance.

RECOMMENDATIONS:

1. Formulate a sampling protocol for 2014 to examine the relationship between different habitats and mosquito production to include a range of wetland vegetation classifications.

2. Ensure that sampling begins early enough in the year to capture the entire freshet hatch and to identify areas where larvae of *Aedes sticticus* develop.

3. Continue to develop a predictive model of mosquito production in the Lower Duncan Floodplain linked to the existing Hydrological model

6.0 References

Belton P. 2006. British Columbia Mosquitoes as Vectors of West Nile Virus (http://www.sfu.ca/~belton)

Bentley, M.D. and Day, J.F. 1989. Chemical ecology and behavioural aspects of mosquito oviposition. Ann. Rev. Entomol. **34:** 401-421.

Brust, R.A.1980. Dispersal behavior of adult *Aedes sticticus* and *Aedes vexans* (Diptera: Culicidae) in Manitoba. Canadian Entomologist. **112:** 31-42.

Diuk-Wasser, M.A., Touré, M.B., Dolo, G., Bagayoko, M., Sogoba, N., Sissoko, I., Traoré, S.F., and Tayler, C.E. 2007. Effect of rice cultivation patterns on malaria vector abundance in rice-growing villages in Mali. American Journal of Tropical Medicine and Hygiene. **76:** 869-874.

Ellis R. 2004. Municipal Mosquito Control Guidelines. Health Canada Bureau of Infectious Diseases. 54pp.

Hayes, R.O., Maxwell, E.L., Mitchell, C.J., Woodzick, T.L. 1985. Detection, identification, and classification of mosquito larval habitats using remote sensing scanners in earth-orbiting satellites. Bulletin of the World Health Organization. **63:** 361-374.

Jackson, MJ, Bull, J, and Phelan, C. 2002. The influence of the Duncan Dam on the Mosquito Populations of the Lower Duncan Floodplain. 2002 Final Report. Submitted to BC Hydro.

Jackson, MJ, Evelyn, MJ, McMahon, TJS, and Sheppard, J. 2009. Lower Duncan River Mosquito Monitoring and Management Plan Development. Implementation Year 1. Reference: DDMMON#9. Study Period: 2009

Jackson, MJ, McMahon, TJS, and Sheppard, J. 2010. Lower Duncan River Mosquito Monitoring and Management Plan Development. Implementation Year 2. Reference: DDMMON#9. Study Period: 2010

Jackson, MJ and McMahon, TJS. 2011. Mosquito abatement program recommendations: enhancing the control of nuisance mosquito larvae in the Duncan floodplain. Submitted to BC Hydro April 7, 2011.

Jackson, MJ, McMahon, TJS, and Sheppard, J. 2011. Lower Duncan River Mosquito Monitoring and Management Plan Development. Implementation Year 3. Reference: DDMMON#9. Study Period: 2011

Klowden, M.J. 2007. Making generalizations about vectors: is there a physiology of "the mosquito"? Entomological Research. **37:**1-13.

MacKenzie, W.H. and Moran, J.R. 2004. Wetlands of British Columbia: a guide to identification. Res. Br., B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 52.

Munga, S., Minakawa, N., Zhou, G., Mushinzimana, E., Barrack, O.J., Githeko, A.K., and Yan, G. 2006. Association between land cover and habitat productivity of malaria vectors in western Kenyan Highlands. American Journal of Tropical Medicine and Hygiene. **74:**69-75.

Nilsson, C. and Svedmark, M. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management. **30:**468-480.

Phelan C., Roitberg B.D. 2013. An age-size reaction norm yields insight into environmental interactions affecting life-history traits: a factorial study of larval development in the malaria mosquito Anopheles gambiae sensu stricto. Ecology and Evolution. **3:**1837-1847.

Polzin M.L., Herbison, B., Gill, K.M., and Rood S.B. 2010. DDMMON #8-1 Lower Duncan River Riparian Cottonwood Monitoring Program. Year 1 Annual Report – 2009. Interior Reforestation Co. Ltd. and University of Lethbridge, Alberta. Unpublished report by Interior Reforestation Co. Ltd., Cranbrook, B.C., for BC Hydro Generations, Water License Requirements, Castlegar, B.C. 110 pp.

Rejmankova, E., Savage, H.M., Rodriguez, M.H., Roberts, D.R., and Rejmanek, M. 1992. Aquatic vegetation as a basis for classification of Anopheles albimanus Weideman (Diptera: Culicidae) larval habitats. Environmental Entomology. **21:** 598-603.

Silver J. 2008. Mosquito ecology: Field sampling methods third edition. Springer. 1477 pp.

Ter Braak, CJF. 1986. Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis. Ecology. **67:** 1167-1179

Ter Braak C.J.F. & Smilauer P. 2012. Canoco Reference Manual and User's Guide: Software for Ordination, Version 5.0. Microcomputer Power, Ithaca, USA, 500 pp.

Wood, B., Washino, R., Beck, L., Hibbard, K., Pitcairn, M., Roberts, D., Rejmankova, E., Paris, J., Hacker, C., Salute, J., Sebesta, P., Legters, L. 1991. Distinguishing high and low anopheline-producing rice fields using remote sensing and GIS technologies. Preventive Veterinary Medicine. **11:** 277-288

Wood, DM, Dang, PT, and Ellis, R. 1979. The mosquitoes of Canada Diptera: Culicidae. 390pp. Agriculture Canada Publication 1686, Hull, PQ.

Appendix 1: Site by Site Results

Site DDM-01 (Old Mill)

Location and Wetland Classification: The Old Mill site is located just off Highway 31, approximately 3.5 km south of the Duncan Dam (Figure 22). This site is classified as "low-bench flooded grass". The lowest areas are dominated by sedges. This site was recommended by the mosquito abatement operator as having a historical presence of mosquito larvae.

Water Level and Larvae: In 2009 and 2010, this site remained dry for the entire summer. Water was found and larvae were collected from this site in 2011 and 2012. The site at Old Mill is flooded in high water years, and dries out quickly after floodwaters recede. Larval composition in 2012 was mainly *Aedes* species (Figure 23).

Water Temperature: A HOBO® data logger was installed at this site.

Figure 23: DDM-01 (Old Mill)

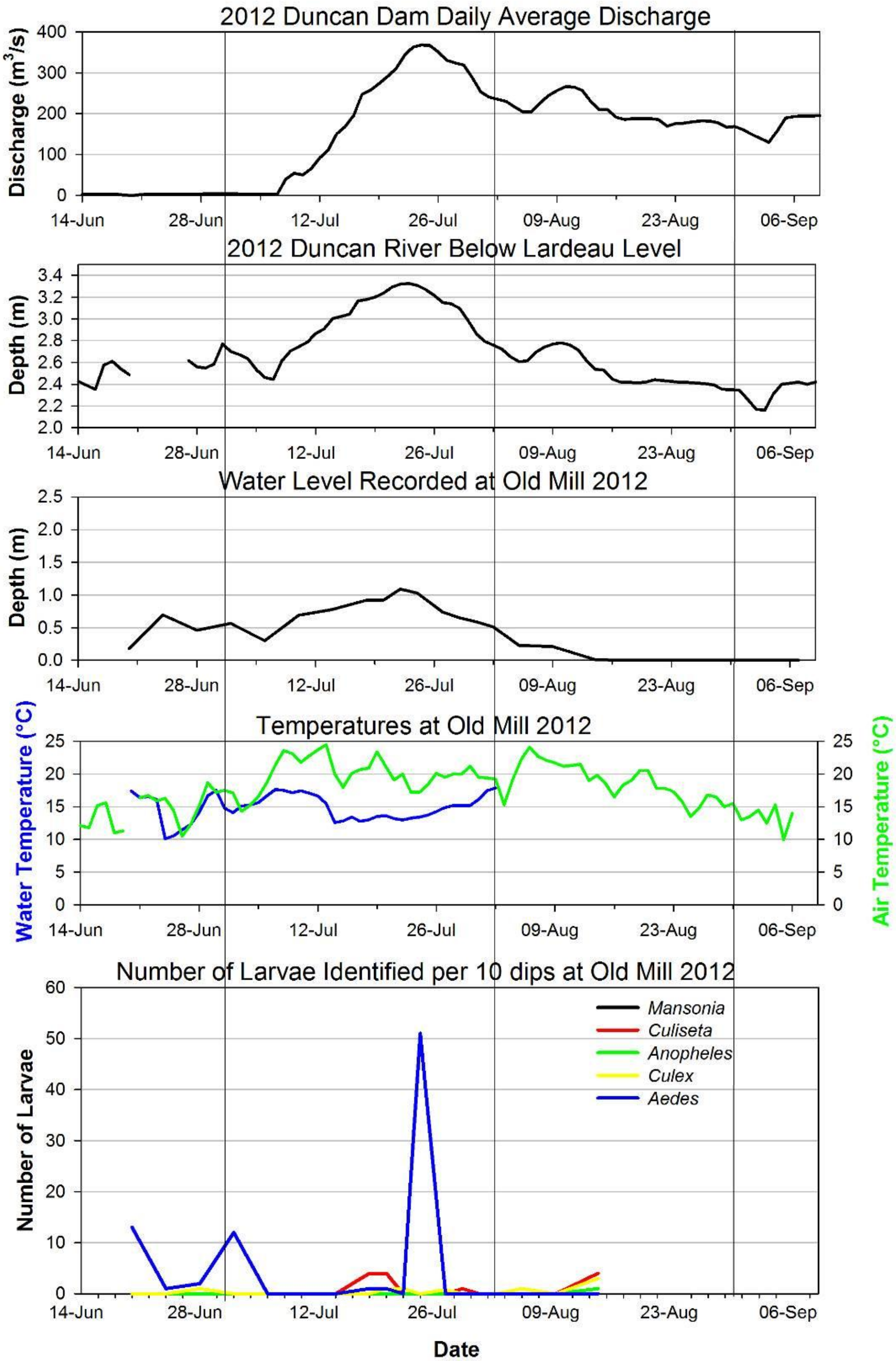


Figure 24: Environmental factors and number of larvae collected at DDM-01, Old Mill in 2012.

Site DDM-02 (Meadow Creek Cedar)

Location and Wetland Classification: The Meadow Creek Cedar (MCC, Figure 24) site is located just off the highway, approximately 4 km south of the Duncan Dam. This site is classified as "low-bench flooded grass". The lowest areas are dominated by sedges. This site was recommended by the mosquito abatement operator as historical mosquito breeding location.

Water Level and Larvae: Water levels at this site corresponded with changing Duncan River levels until it dried up in August. Larvae were found at this site until mid-August when it dried up (Figure 25). Species composition at this site underwent a shift in 2012, beginning in the early season with *Aedes* species larvae, and becoming dominated by *Culex* species mosquitoes later in the season up until such time as it became dry.

Water Temperature: No data logger is installed at DDM-02.

Figure 25: DDM-02 (Meadow Creek Cedar)

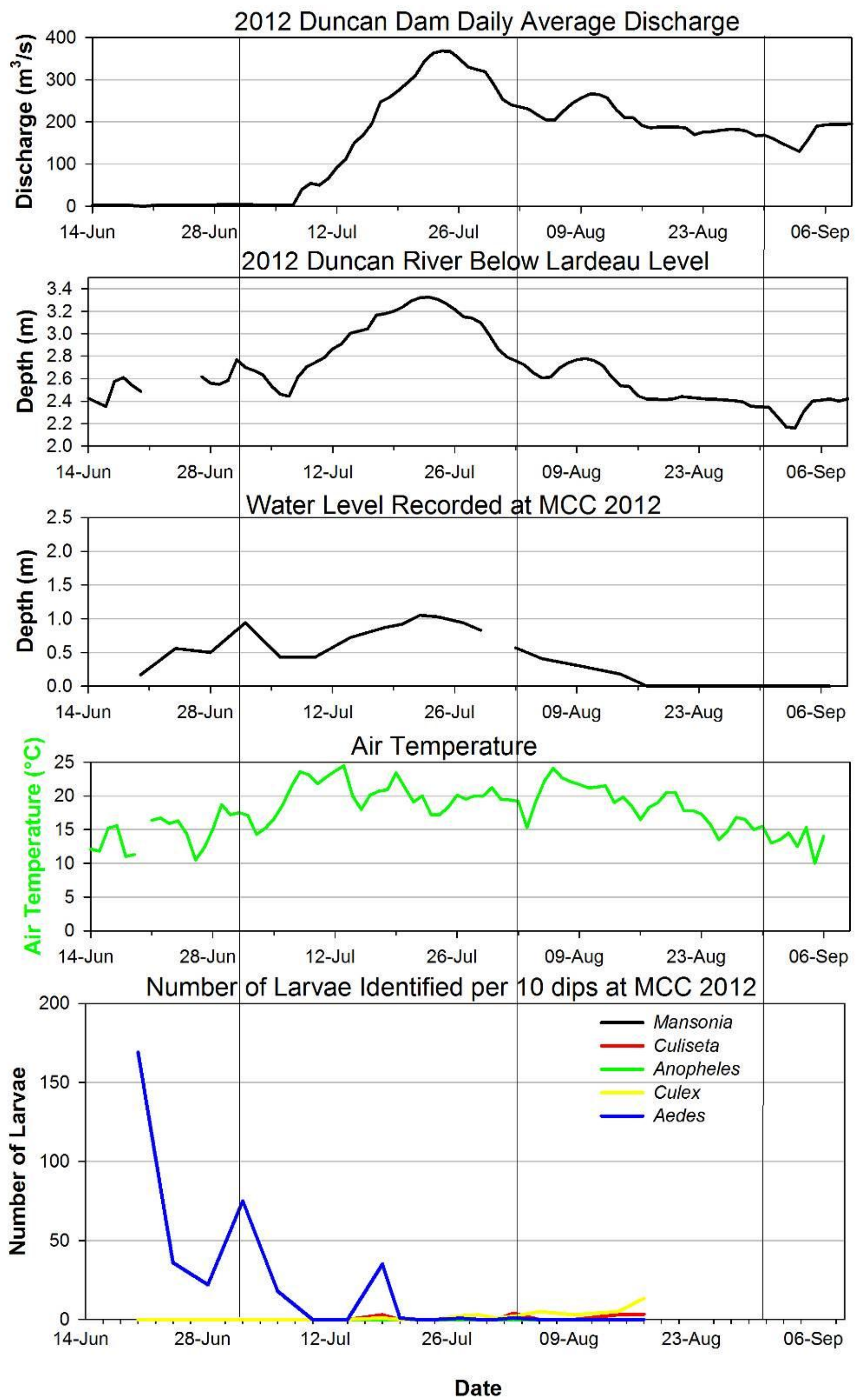


Figure 26: Environmental factors and number of larvae collected at DDM-02, Meadow Creek Cedar in 2012.

Site DDM-03 (Lake)

Location and Wetland Classification: The Lake site is located on the east side of the Duncan River, approximately 6 km south of the Duncan Dam. The vegetation in this area consisted of grasses around the stake, but the permanent water body nearby contained some emergent vegetation and duckweed (Figure 26). The vegetation classification at this site is "Old Swamp-Marsh: Scirpus-Glyceria". This site was recommended by the mosquito abatement operator as having a historical presence of larvae.

Water Level and Mosquitoes: The location of the stake was placed on higher ground and designed to capture water levels under high flood conditions. Sampling occurs along the edges of the pool of water. Water levels did not seem to show a correlation to the Duncan River levels observed in 2012. No *Aedes* larvae were collected at this site in 2012. The majority of larvae collected were *Culiseta* larvae with a couple of *Culex territans*, a non-nuisance, non-vector species (Figure 27).

Water Temperature: No data logger is installed at DDM-03.

Figure 27: DDM-03 (Lake's)

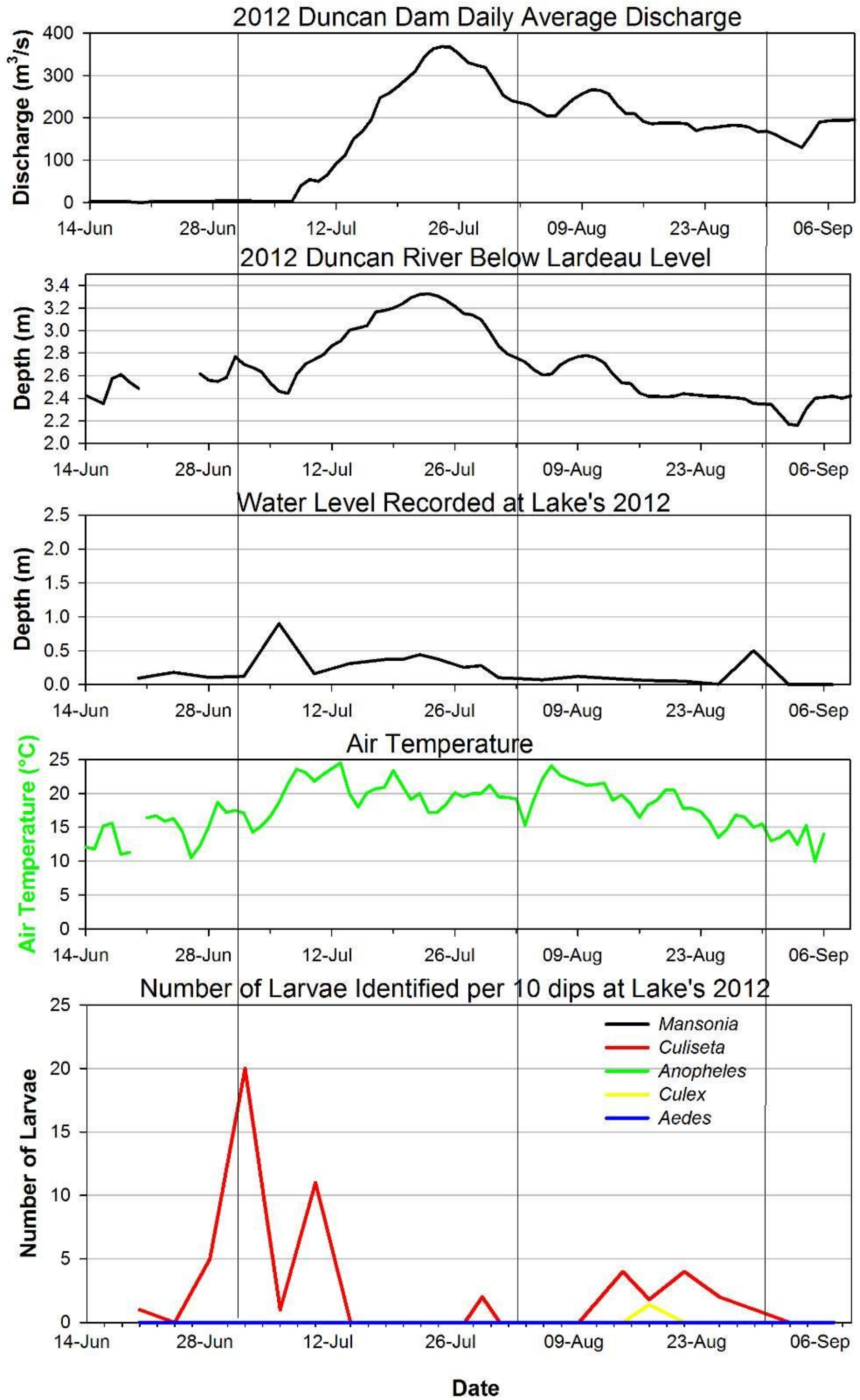


Figure 28: Environmental factors and number of larvae collected at DDM-03, Lake's in 2012.

Site DDM-04 (Jacob's)

Location and Wetland Classification: The Jacob's site is located on the eastern side of the Duncan River and is approximately 3.5 km south of the Duncan Dam (Figure 28). The vegetation classification at this site is "alder-spruce swamp". This site was recommended by the mosquito abatement operator as having a historical presence of larvae.

Water Levels and Larvae: Water levels fluctuated at this site throughout the season and corresponded to changes in the Duncan River below the Lardeau. This site was unproductive for mosquito larvae during the early portion of the season, but larvae began to be found later in the season, mostly *Culex* species mosquitoes (Figure 29).

Water Temperature: A HOBO® data logger was installed at this site. Temperatures remained constant at approximately ten degrees Celsius for the entire summer.

Figure 29: DDM-04 (Jacob's)

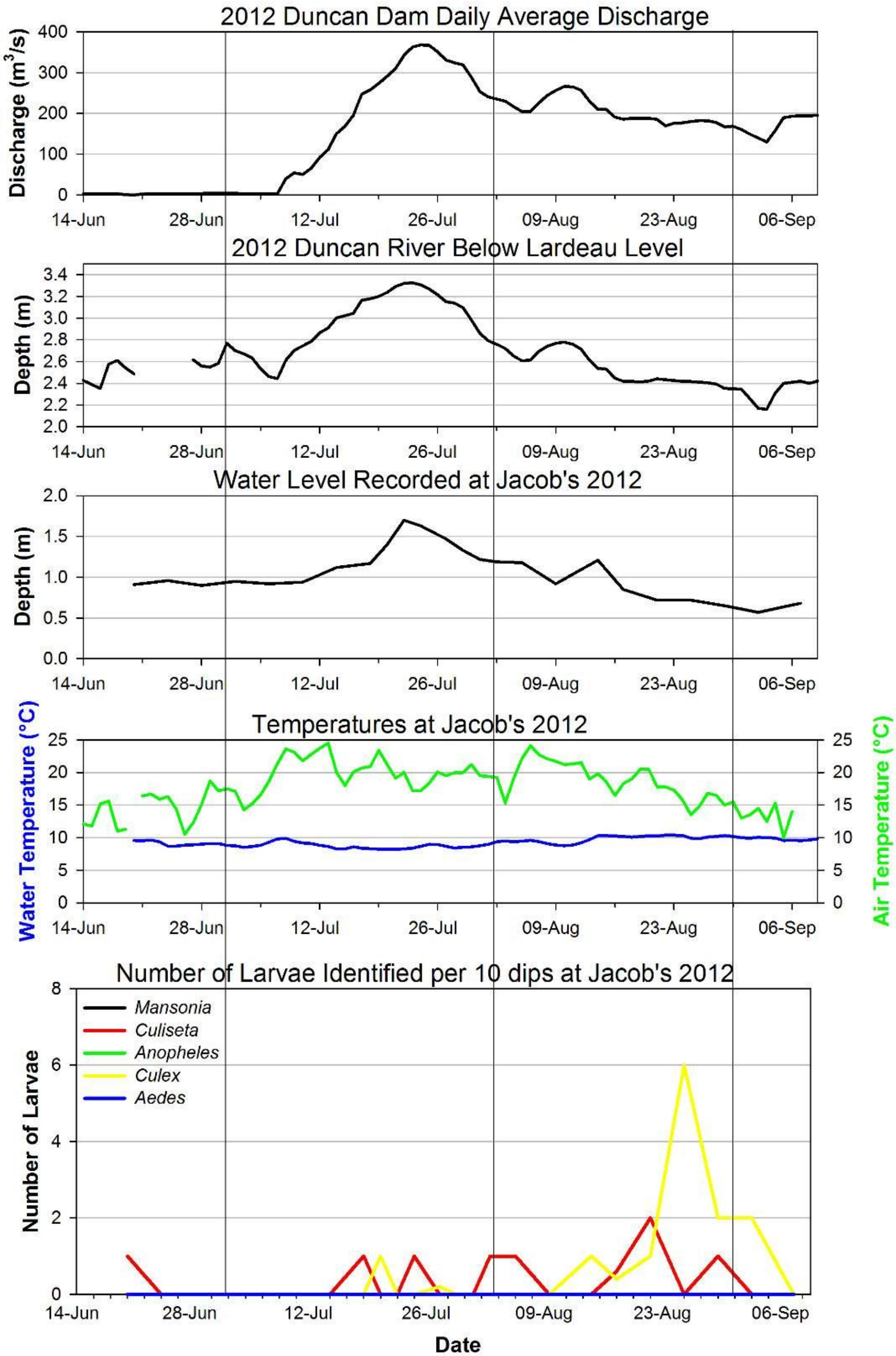


Figure 30: Environmental factors and number of larvae collected at DDM-04, Jacob's in 2012.

Site DDM-05 (Lardeau Control Site)

Location and Wetland Classification: The control site is located 0.5 km west of the Duncan Dam (Figure 30). The vegetation classification at this site is "alder-spruce swamp". This location was chosen as a larval control site because it is outside both the abatement program area and the direct influence of the operation of the Duncan Dam. Adult mosquitoes are not directly affected by either of these factors and so there is no need for an adult control - because there is no 'treatment'.

Water Levels and Larvae: As expected, the water levels at DDM-05 did not respond to changing discharge levels from the Dam. Both *Culiseta* and *Aedes* larvae were collected from this site early in the season, but became unproductive later in the season (Figure 31).

Water Temperatures: No data logger is installed at this site.

Figure 31: Site DDM-05 (Control)

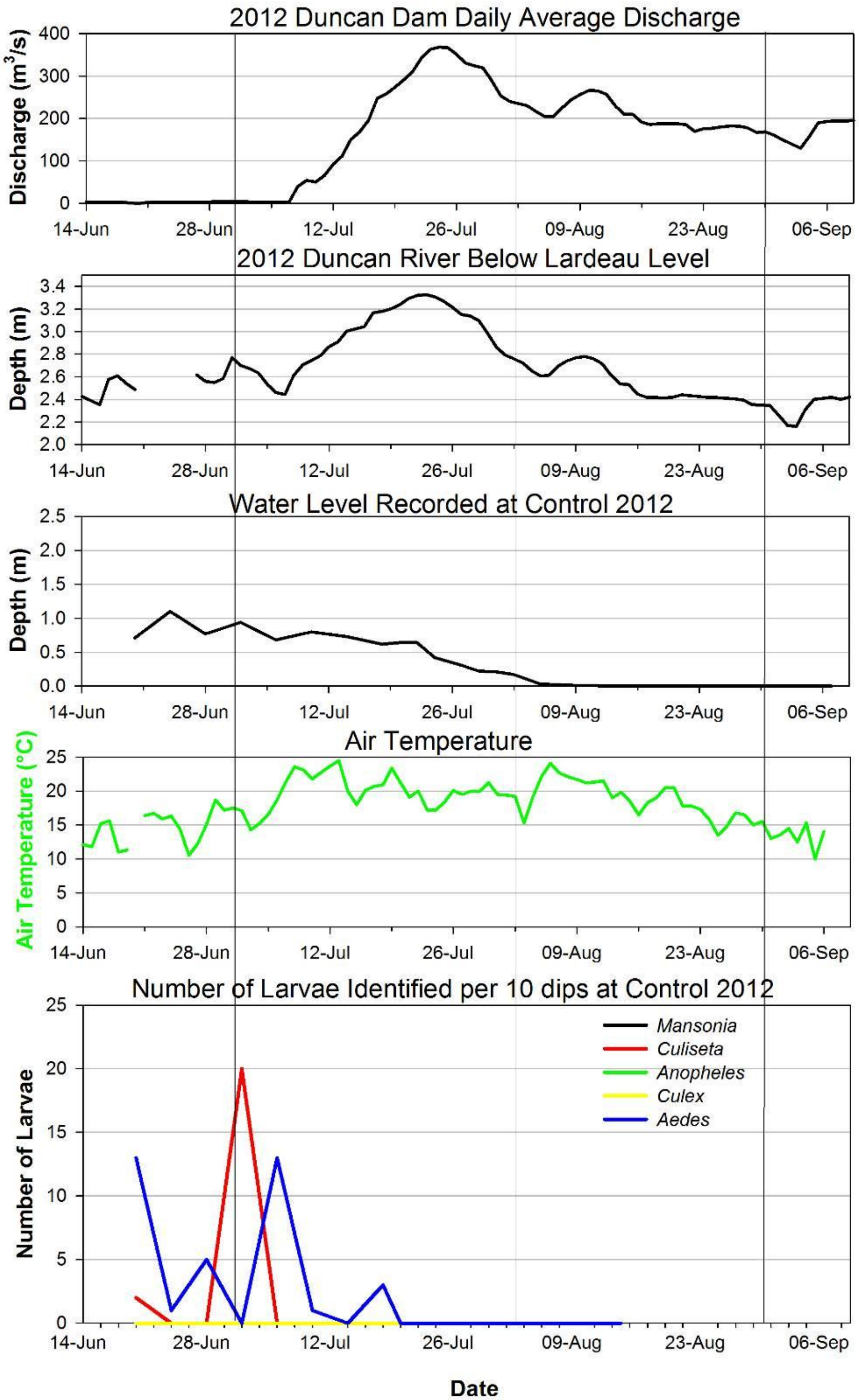


Figure 32: Environmental factors and number of larvae collected at DDM-05, Control in 2012.

Site DDM-06 (Halloran's)

Location and Wetland Classification: DDM-06 (Halloran's) is located 3.5 km south-west of the Duncan Dam, just off of Highway 31 in Meadow Creek (Figure 32). The vegetation classification at this site is "channel marsh - edge of low bench flooded grass". This site was chosen in agreement between Culex Environmental and the mosquito abatement operator as a modification of the "Meadow Creek" site from the 2002 Acroloxus study. At the request of the landowner, the site was moved off the property to a nearby similar location on August 2nd (Figure 33).

Water Level and Larvae: Larvae were collected from this site, prior to it drying up in August (Figure 34). Three of the four genera of mosquitoes were detected from this site in 2012 (no *Anopheles*).

Water Temperature: A HOBO® data logger is installed at this site.

Figure 33: Site DDM-06 (Halloran's) prior to August 2nd, 2012

Figure 34: Site DDM-06 (Halloran's) after August 2nd, 2012

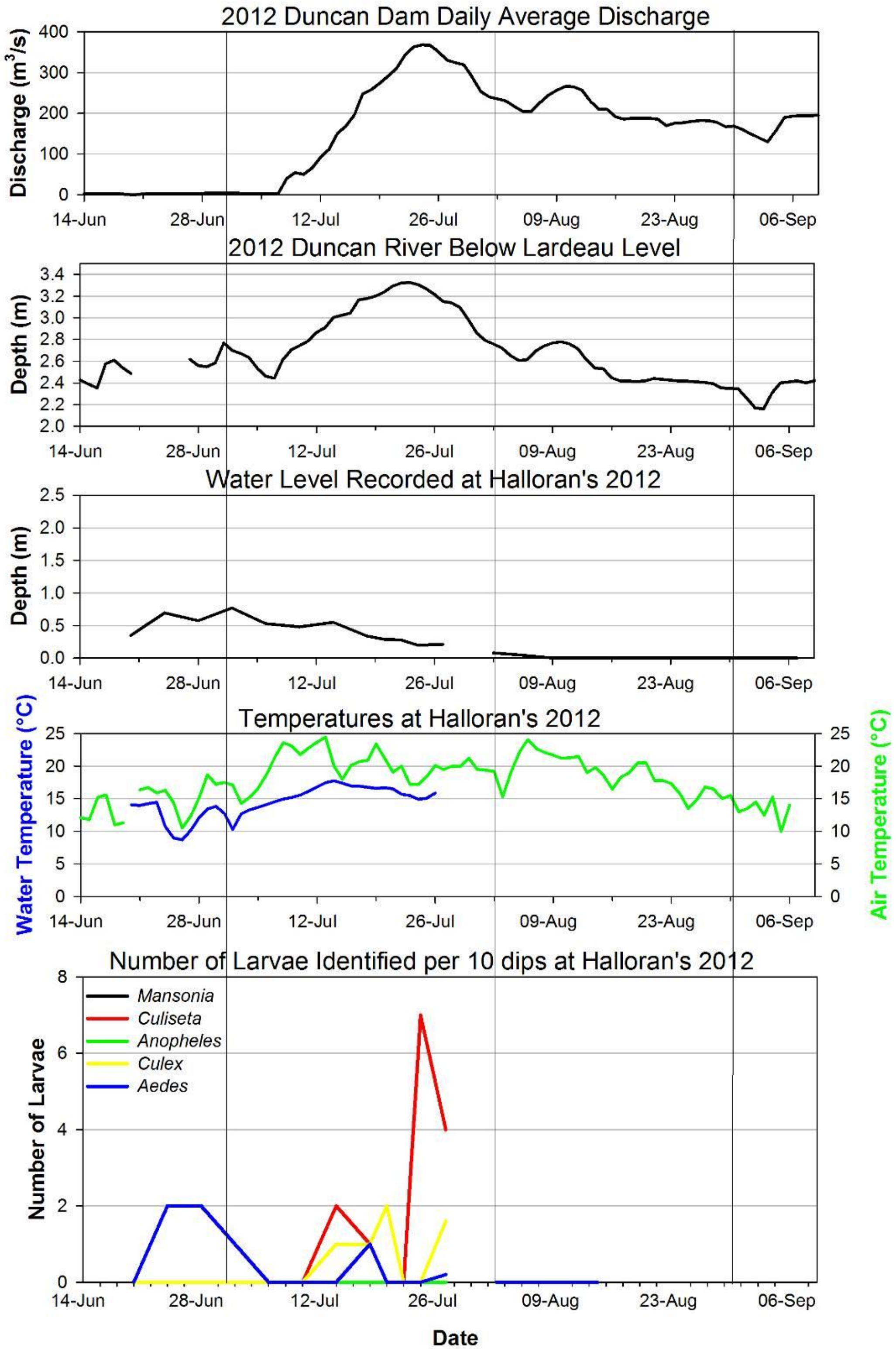


Figure 35: Environmental factors and number of larvae collected at DDM-06, Halloran's in 2012.

Site DDM-07 (Janet's Swamp)

Location and Wetland Classification: The Janet's Swamp (DDM-07) site is located about 1.5 km below the Duncan Dam (Figure 35). In 2002, the vegetation at this site consisted of a diverse mix of marshland plants such as Bebb's sedge (*Carex bebbii*), two-stemmed sedge (*Carex diandra*), yellow sedge (*Carex flava*), inland sedge (*Carex interior*), saw beak sedge (*Carex stipata*) and dagger-leaved rush (*Juncus ensifolius*). The vegetation classification at this site is "mixed species fen". This site was chosen during the 2002 study, as it is indirectly affected through ground water seepage related to the hydrology of the river and the low-lying topography of the area.

Water Level and Larvae: Water levels remained constant throughout the season at this site, and did not appear to be influenced by the river levels (Figure 36). The primary species collected at this site are *Culiseta* mosquitoes, although *Anopheles* and *Culex* were also found.

Water Temperature: A HOBO® data logger is installed at this site.

Figure 36: Site DDM-07 (Janet's Swamp)

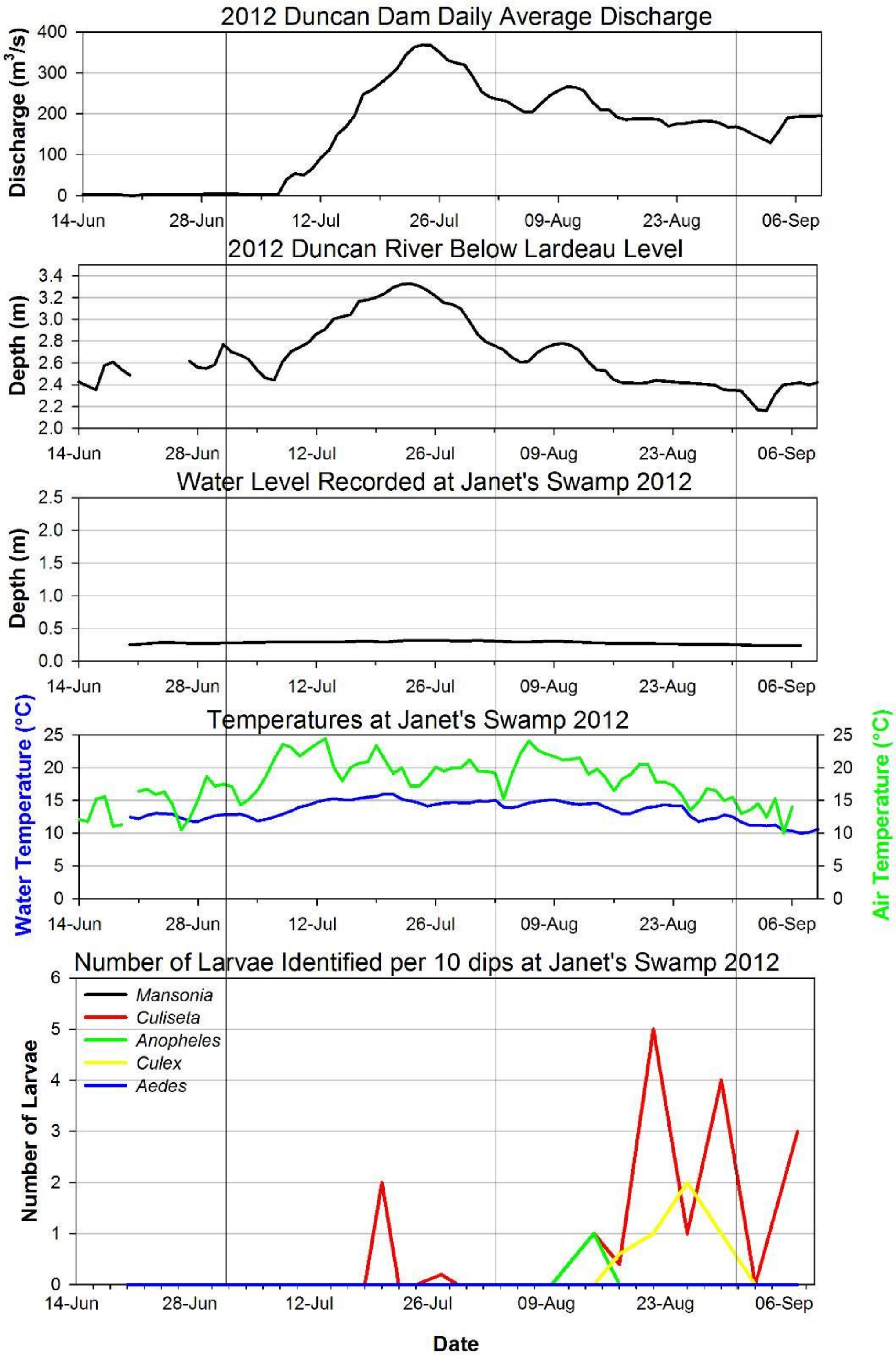


Figure 37: Environmental factors and number of larvae collected at DDM-07, Janet's Swamp in 2012.

Site DDM-08 (Old Channel)

Location and Wetland Classification: The Old Channel (DDM-08) site is located about 1 km below the Duncan Dam (Figure 37). The vegetation at this site consisted of predominately tall horsetails and some tall sedges such as Bebb's sedge (*Carex bebbii*), awned sedge (*Carex retrorsa*), beaked sedge (*Carex rostrata*), and sawbeak sedge (*Carex stipata*) in 2002. The vegetation classification at this site is "Old Swamp-Marsh: Flava-Osier". This site was chosen in the 2002 Acroloxus study, as it is indirectly affected through ground water seepage related to the hydrology of the river and the low-lying topography of the area.

Water Level and Elevation: The water levels at this site were tied to the river level, but larvae were only collected near the end of the season. No *Aedes* larvae were collected at this site in 2012 (Figure 38).

Water Temperature: No HOBO® data logger is installed at this site.

Figure 38: Site DDM-08 (Old Channel) in 2010 (Left), and 2012 (Right)

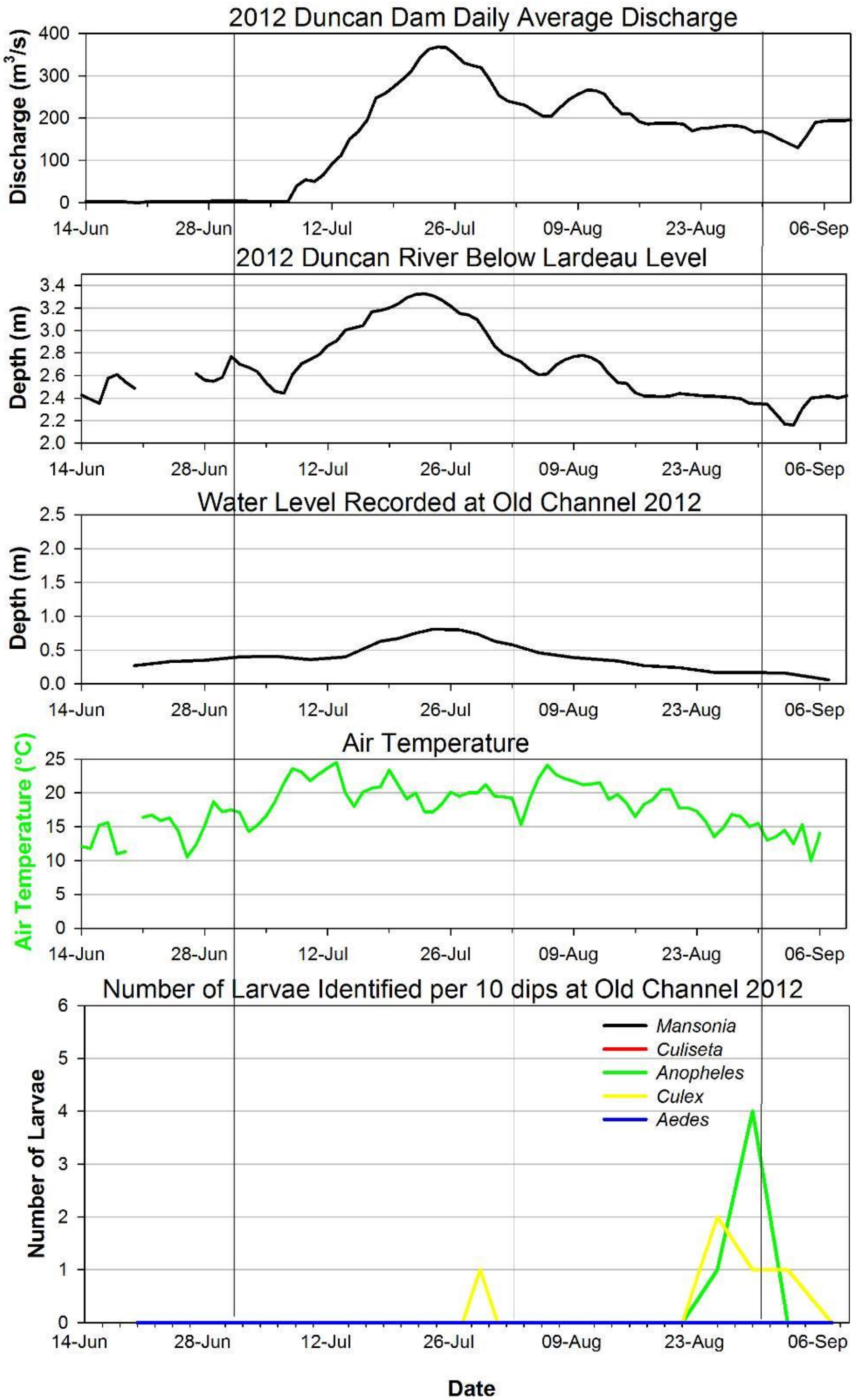


Figure 39: Environmental factors and number of larvae collected at DDM-08, Old Channel in 2012.

Site DDM-09 (Borrow Pits)

Location and Wetland Classification: The Borrow Pits (DDM-09) site is located about 3 km below the Duncan Dam. There was little vegetation at this site. The site consisted of algae-covered water in a gravel pit receiving organic input from surrounding trees (Figure 39). The location of this site closely corresponds to Segment 3 of the DDMMON#8 project. The five most common plant species (and their percent cover) are: *Salix bebbiana,*(10) *Salix lucida,* (10) *Alnus incana,* (7) *Carex aperta* (6), and *Populus trichocarpa* (6) (Polzin et al. 2010). This site was chosen because it is indirectly affected through ground water seepage related to the hydrology of the river and the low-lying topography of the area The vegetation type at this site has been classified as "man-made".

Water Level and Larvae: The site contained water throughout the summer, and at one point was flowing into DDM-10. Changes in water level corresponded to the river levels observed in 2010. Larvae collected from this site were mostly *Anopheles* species as has been the case in previous years (Figure 40).

Water Temperature: A HOBO® data logger was installed at this site.

Figure 40: Site DDM-09 (Borrow Pits)

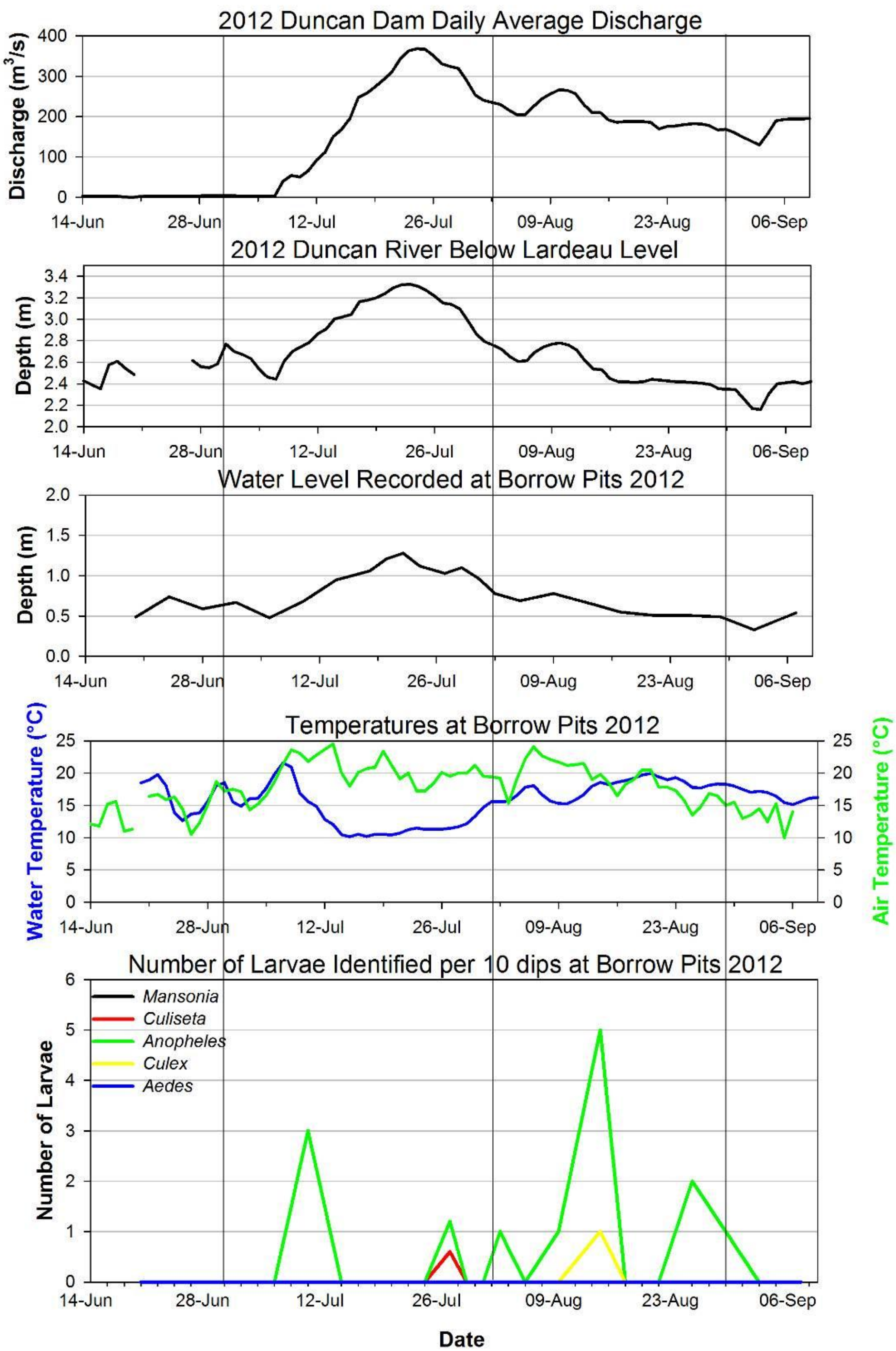


Figure 41: Environmental factors and number of larvae collected at DDM-09 Borrow Pits in 2012.

Site DDM-10 (Carex Beds)

Location and Wetland Classification: The *Carex* Beds (DDM-10) site is located about 2.5 km below the Duncan Dam. The vegetation at this site consisted of one sedge species, yellow sedge (*Carex flava*) (Figure 41). The location of this site corresponds to Segment 3 of the DDMMON#8 project. The five most common plant species (and their percent cover) are: *Salix bebbiana,*(10) *Salix lucida,* (10) *Alnus incana,* (7) *Carex aperta* (6), and *Populus trichocarpa* (6) (Polzin 2010). This site was chosen because it is a side channel of the Duncan River, which is liable to flood during high discharge periods.

Water Level and Larvae: In 2012 this site had high levels of water throughout the season, coinciding with changes in the river level. The majority of the larvae collected here were *Aedes* species, a finding that is unusual give the past trend of collecting *Anopheles* larvae at this site (Figure 42).

Water Temperature: A HOBO® data logger was installed at this site.

Figure 42: Site DDM-10 (Carex Beds)

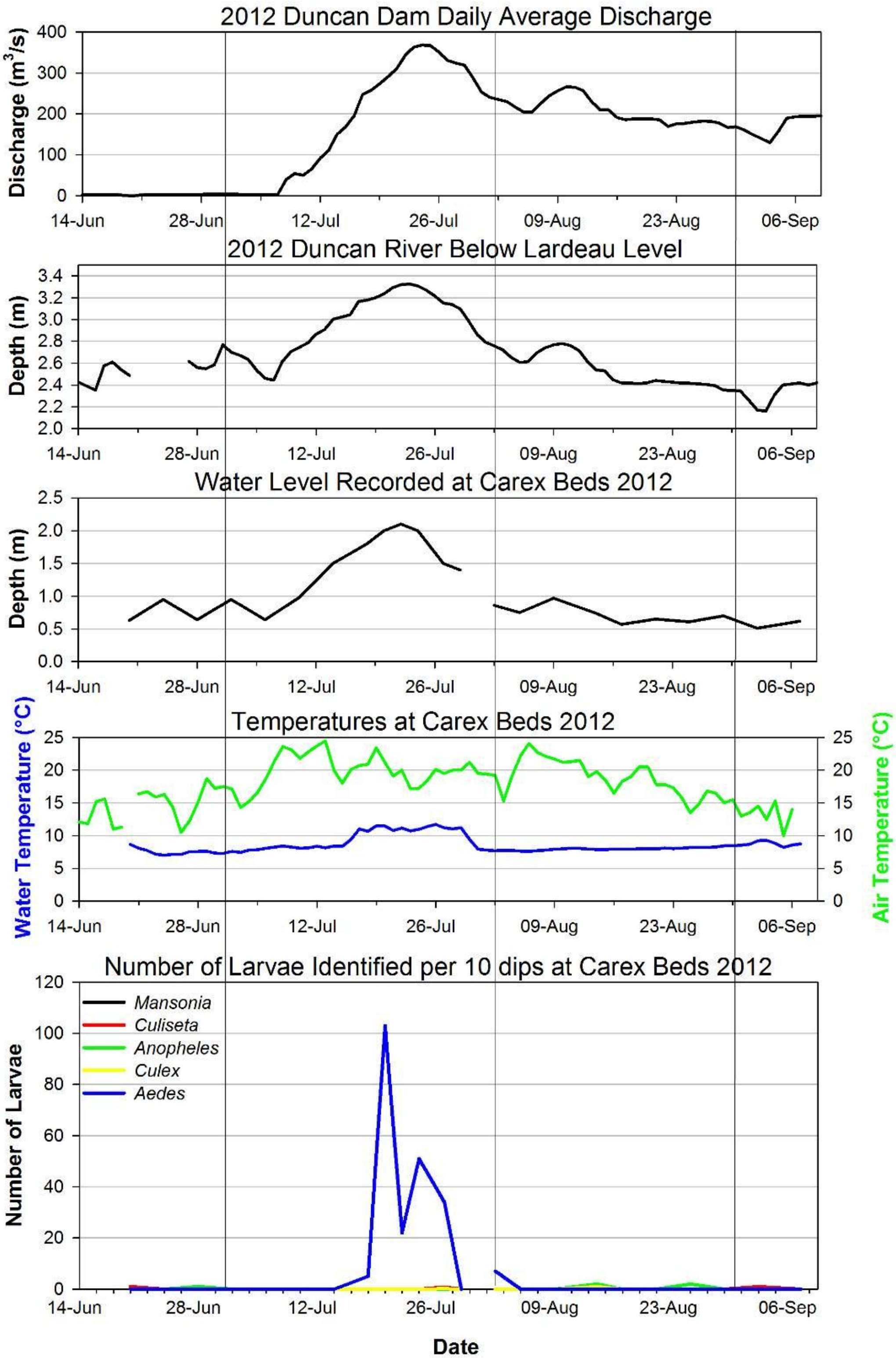


Figure 43: Environmental factors and number of larvae collected at DDM-10, Carex Beds in 2012.

Site DDM-11 (Block Swamp)

Location and Wetland Classification: The Block Swamp (DDM-11) site is located about 1.5 km below the Duncan Dam. The vegetation at this site consists of two distinct types – mixed sedge in the north-eastern half and wooded swamp in the south-western half. The dominant species present in 2002 was golden sedge (*Carex aurea*) (Figure 43). The vegetation type at this site has been classified as "Alder-Skunk Cabbage-Lady Fern".

Water Level and Elevation: As with Janet`s Swamp (DDM-07) water levels remained constant at this site and no correlation to river level was observed. Larvae were collected frequently from this site, often larvae of *Culiseta* genus (Figure 44).

Water Temperature: No HOBO® data logger is installed at this site.

Figure 44: Site DDM-11 (Block Swamp)

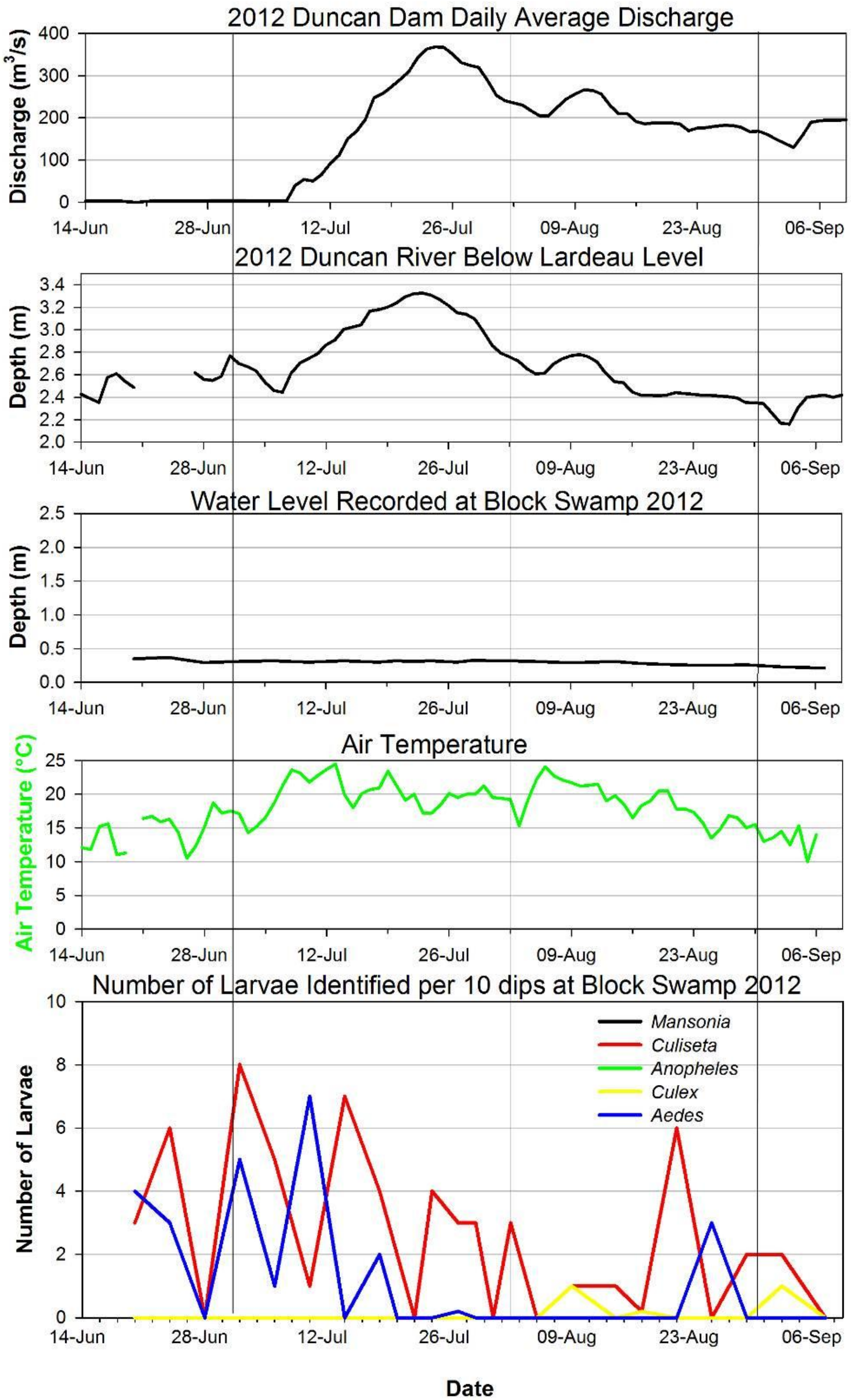


Figure 45: Environmental factors and number of larvae collected at DDM-11, Block Swamp in 2012.

Site DDM-12 (Lardeau-Duncan Cottonwoods)

Location and Wetland Classification: The Lardeau-Duncan Cottonwoods (DDM-12) site is located about 6 km below the Duncan Dam. The vegetation at this site consisted of cottonwood stands and low bench flooded grasslands (Figure 45). With the knowledge that cottonwood stands provide ideal habitat for the aggressive day time biter, *Aedes sticticus*, this site was chosen to detect activity, if any, of this particular mosquito.

Water Level and Elevation: This site remained wet the entire year and was influenced by river level. Identified larvae from this site included *Aedes, Culex,* and *Culiseta* (Figure 46). A large number of earlies suffered high mortality later in the season and identifications for those individuals was not possible.

Water Temperature: No HOBO® data logger is installed at this site.

Figure 46: Site DDM-12 (Lardeau-Duncan Cottonwoods)

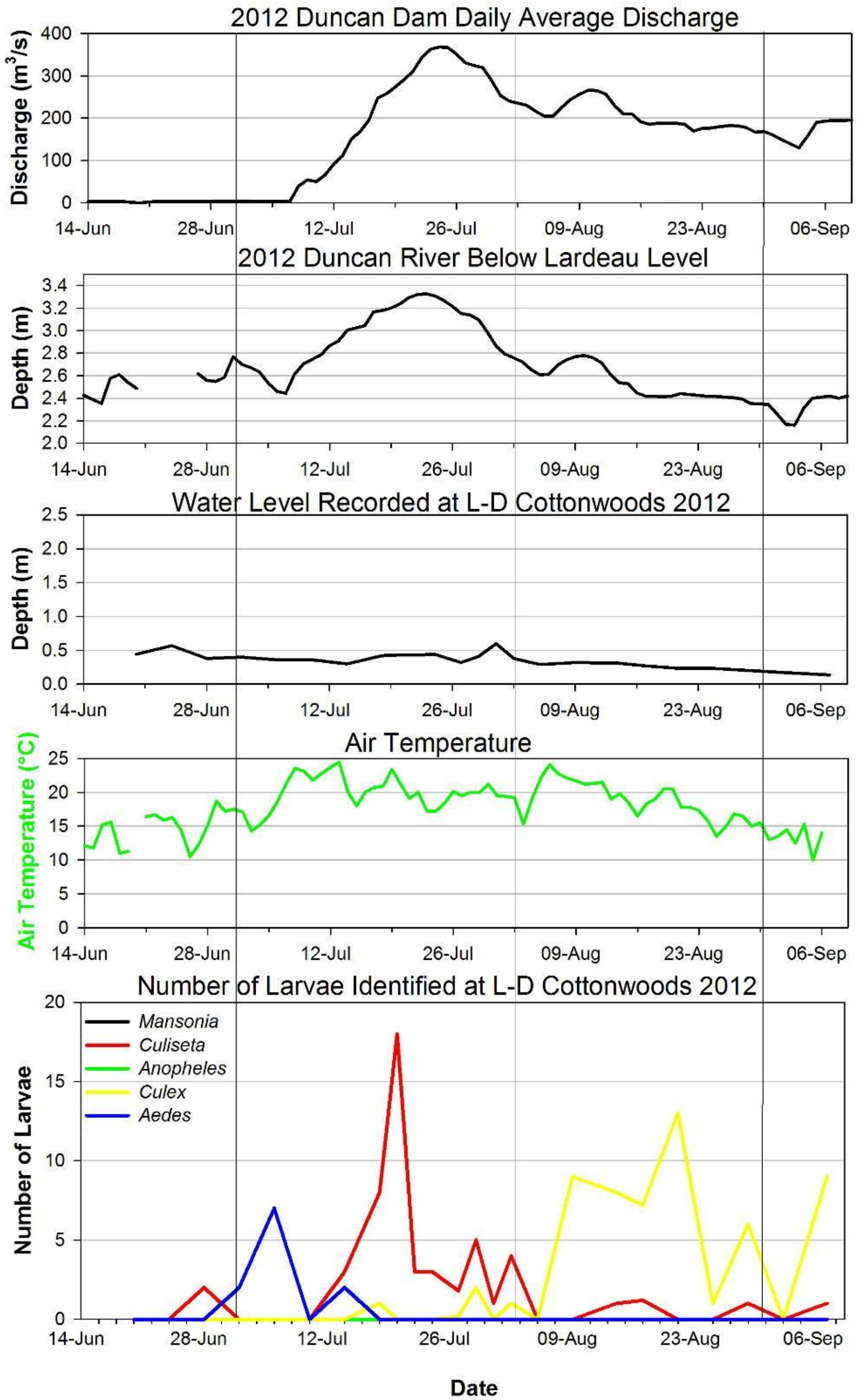


Figure 47: Environmental factors and number of larvae collected at DDM-12 L-D Cottonwoods in 2012.

Site DDM-13 (Lardeau-Duncan Flats)

Location and Wetland Classification: The Lardeau-Duncan Flats (DDM-13) site is located about 6 km below the Duncan Dam. The vegetation at this site consisted of Bebb's sedge (*Carex bebbi*), beaked sedge (*Carex rostrata*), Sawbeak sedge (*Carex stipata*), small-flowered bulrush (*Scirpus microcarpus*), and dagger-leaved rush (*Juncus ensifolius*) and the classification has been designated as "Old Swamp-Marsh: Scirpus-Glyceria" (Figure 47).

Water Level and Larvae: This site was wet throughout the year, and the main species collected in 2012 were *Culex and Culiseta* species. The water levels observed do not appear to be closely influenced by river levels (Figure 48).

Water Temperature: No HOBO® data logger is installed at this site.

Figure 48: Site DDM-13 (Lardeau-Duncan Flats)

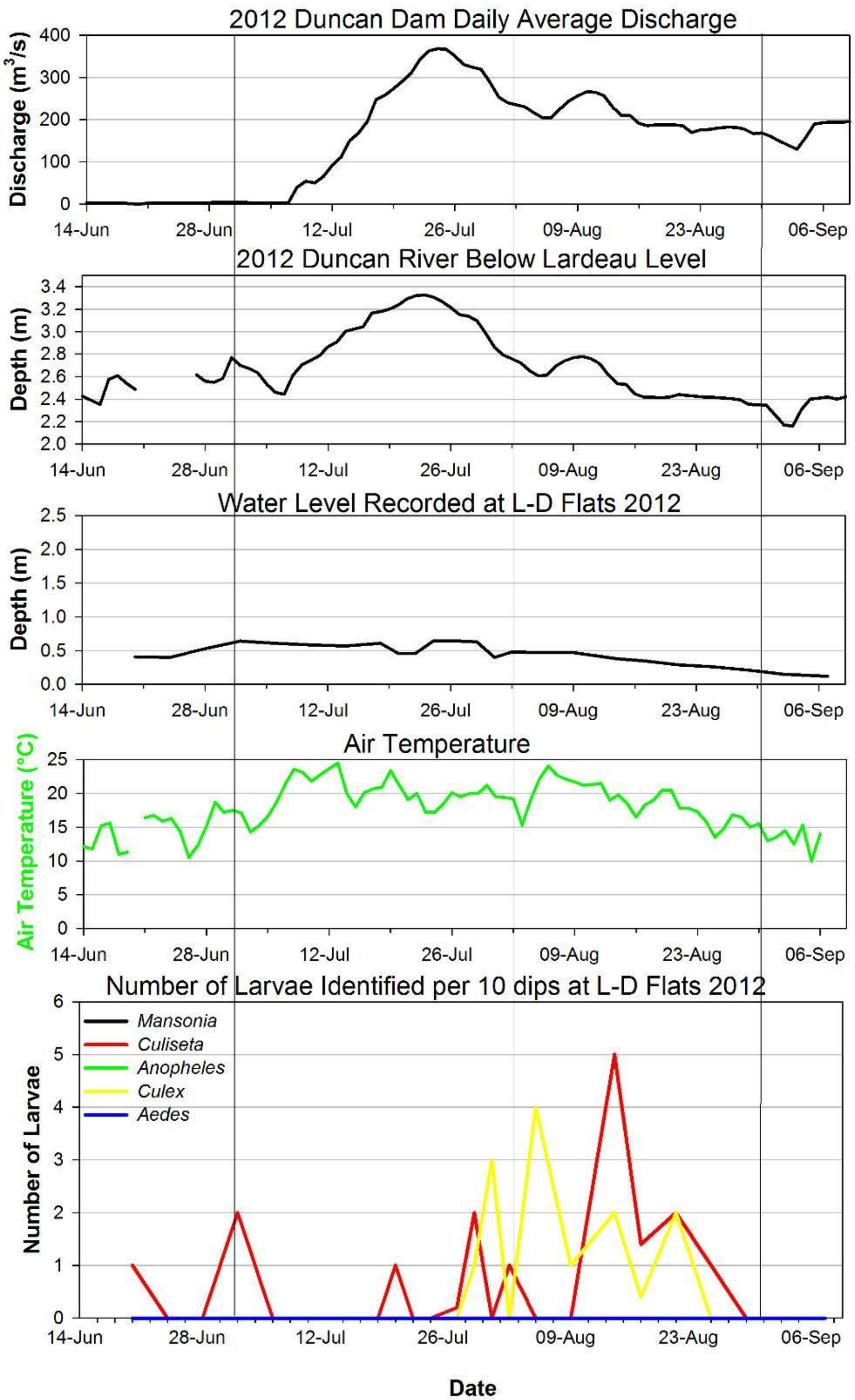


Figure 49: Environmental factors and number of larvae collected at DDM-13, Lardeau-Duncan Flats in 2012.

Appendix 2: Vegetation Mapping of the Lower Duncan Wetlands 2012

Appendix 3: List of Species Collected in 2012

	Species	Larvae	Adults	WNv
1	*Aedes canadensis*		+	++
2	*Aedes cinereus*	+	+	+
3	*Aedes communis*	+	+	
4	*Aedes diantaeus*	+		
5	*Aedes excrucians*	+		
6	*Aedes intrudens*	+		
7	*Aedes sierrensis*		+	+
8	*Aedes sticticus*	+	+	+
9	*Aedes vexans*	+	+	++
10	*Anopheles earlei*	+	+	+
11	*Anopheles freeborni*	+	+	
12	*Anopheles punctipennis*	+	+	+
13	*Culex tarsalis*	+	+	++++
14	*Culex territans*	+	+	
15	*Culiseta alaskensis*	+	+	
16	*Culiseta inornata*	+	+	+++
17	*Culiseta impatiens*	+		
18	*Culiseta incidens*	+		+
19	*Culiseta inornata*		+	
20	*Culiseta minnesotae*	+	+	
21	*Culiseta morsitans*	+	+	+
22	*Mansonia perturbans*		+	

Appendix 4: Rare Species collected as larvae in 2012

Date	Total Collected	Total ID'd	*Aedes diantaeus*	*Aedes excrucians*	*Aedes intrudens*	*Anopheles freeborni*	*Anopheles sp.*	*Culiseta incidens*	*Culiseta morsitans*
20-Jun-12	268	0	0	0	0	0	0	0	0
24-Jun-12	66	0	0	0	0	0	0	0	0
28-Jun-12	140	0	0	0	0	0	0	0	0
2-Jul-12	154	1	0	1	0	0	0	0	0
6-Jul-12	56	0	0	0	0	0	0	0	0
10-Jul-12	26	1	0	0	0	0	1	0	0
14-Jul-12	123	0	0	0	0	0	0	0	0
18-Jul-12	100	0	0	0	0	0	0	0	0
20-Jul-12	179	0	0	0	0	0	0	0	0
22-Jul-12	67	0	0	0	0	0	0	0	0
24-Jul-12	124	0	0	0	0	0	0	0	0
27-Jul-12*	733	8	1	0	1	1	0	5	0
29-Jul-12	116	0	0	0	0	0	0	0	0
31-Jul-12	140	0	0	0	0	0	0	0	0
2-Aug-12	60	0	0	0	0	0	0	0	0
5-Aug-12	45	0	0	0	0	0	0	0	0
9-Aug-12	110	0	0	0	0	0	0	0	0
14-Aug-12	160	1	0	0	0	0	1	0	0
17-Aug-12*	763	0	0	0	0	0	0	0	0
21-Aug-12	67	0	0	0	0	0	0	0	0
25-Aug-12	66	0	0	0	0	0	0	0	0
29-Aug-12	61	4	0	0	0	0	1	0	3
2-Sep-12	45	0	0	0	0	0	0	0	0
7-Sep-12	15	0	0	0	0	0	0	0	0
Grand Total	**3684**	**15**	**1**	**1**	**1**	**1**	**3**	**5**	**3**

Appendix 5: Rare Species collected as adults in 2012

Date	Total Collected	Total ID'd	*Anopheles freeborni*	*Anopheles sp.*
20/6/12	272	0	0	0
28/6/12	433	0	0	0
6/7/12	1505	0	0	0
14/7/12	3354	0	0	0
21/7/12	1340	0	0	0
29/7/12	1065	1	0	1
9/8/12	2799	1	1	0
17/8/12	313	0	0	0
25/8/12	191	0	0	0
7/9/12	63	0	0	0
Grand Total	**11335**	**2**	**1**	**1**