Managing Mosquitoes in Surface-Flow Constructed Treatment Wetlands

William Walton

Department of Entomology
University of California
Riverside, CA 92521

Overview

• Why is mosquito production from wetlands a concern in southern California?

• Why are mosquito control efforts focused on the aquatic, immature stages of the life cycle?

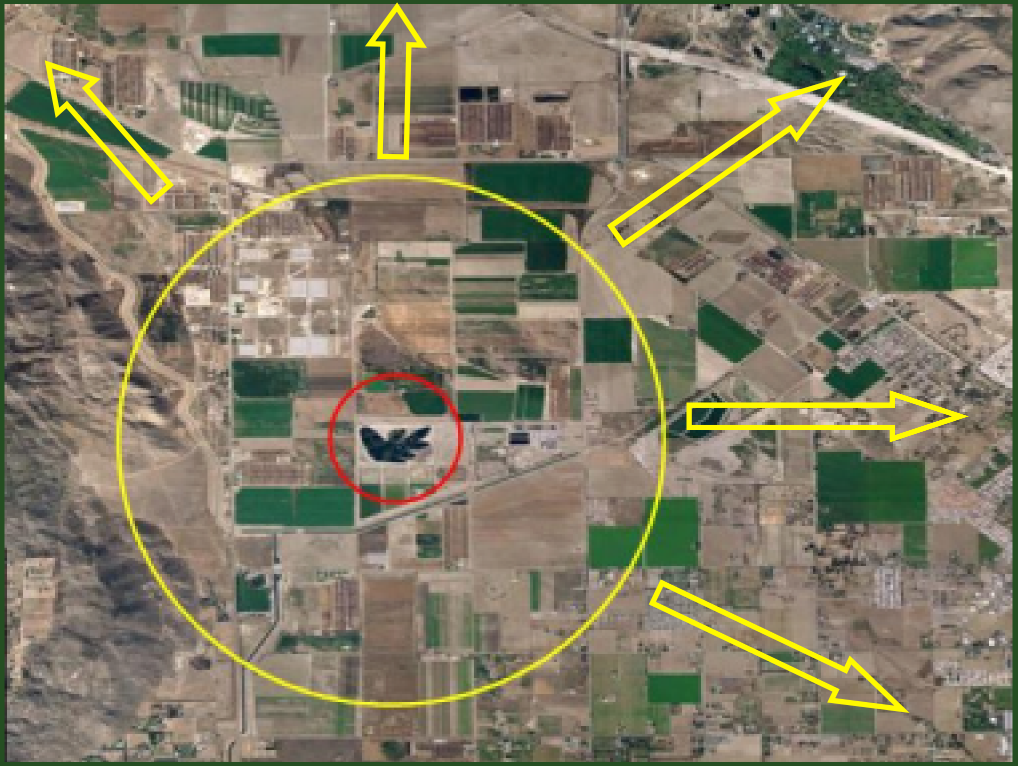
• What design features of constructed treatment wetlands contribute to mosquito production?

Design features that are thought to be necessary for water quality improvement, such as shallow water and dense emergent vegetation, can cause significant mosquito production.

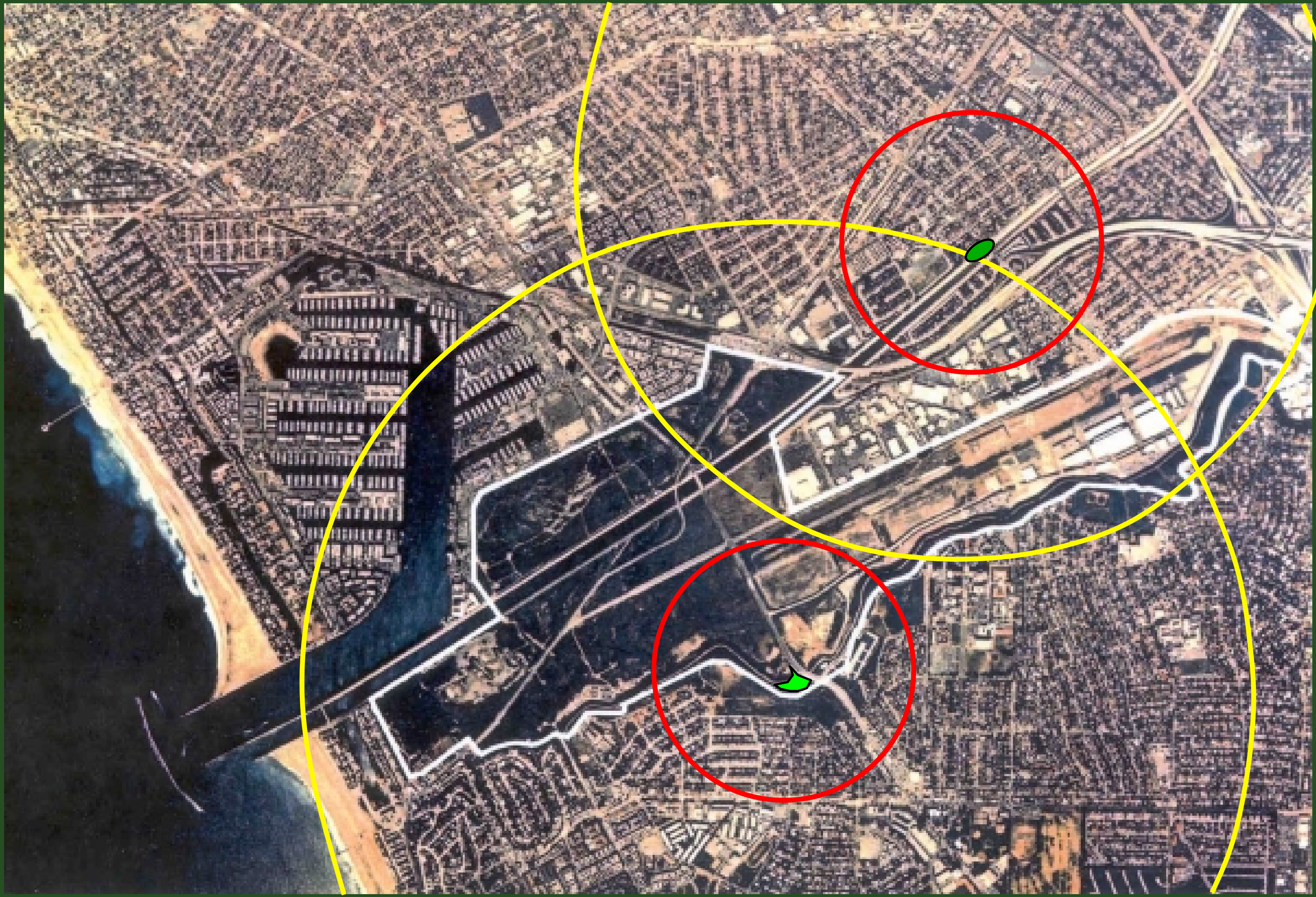
• There is a need for long-term planning for maintenance and mosquito control and for land-use planning on a large geographic scale, particularly in regions of dense human development.

The geographic area potentially affected by mosquito production is much greater than the area circumscribed by the wetland water surface.

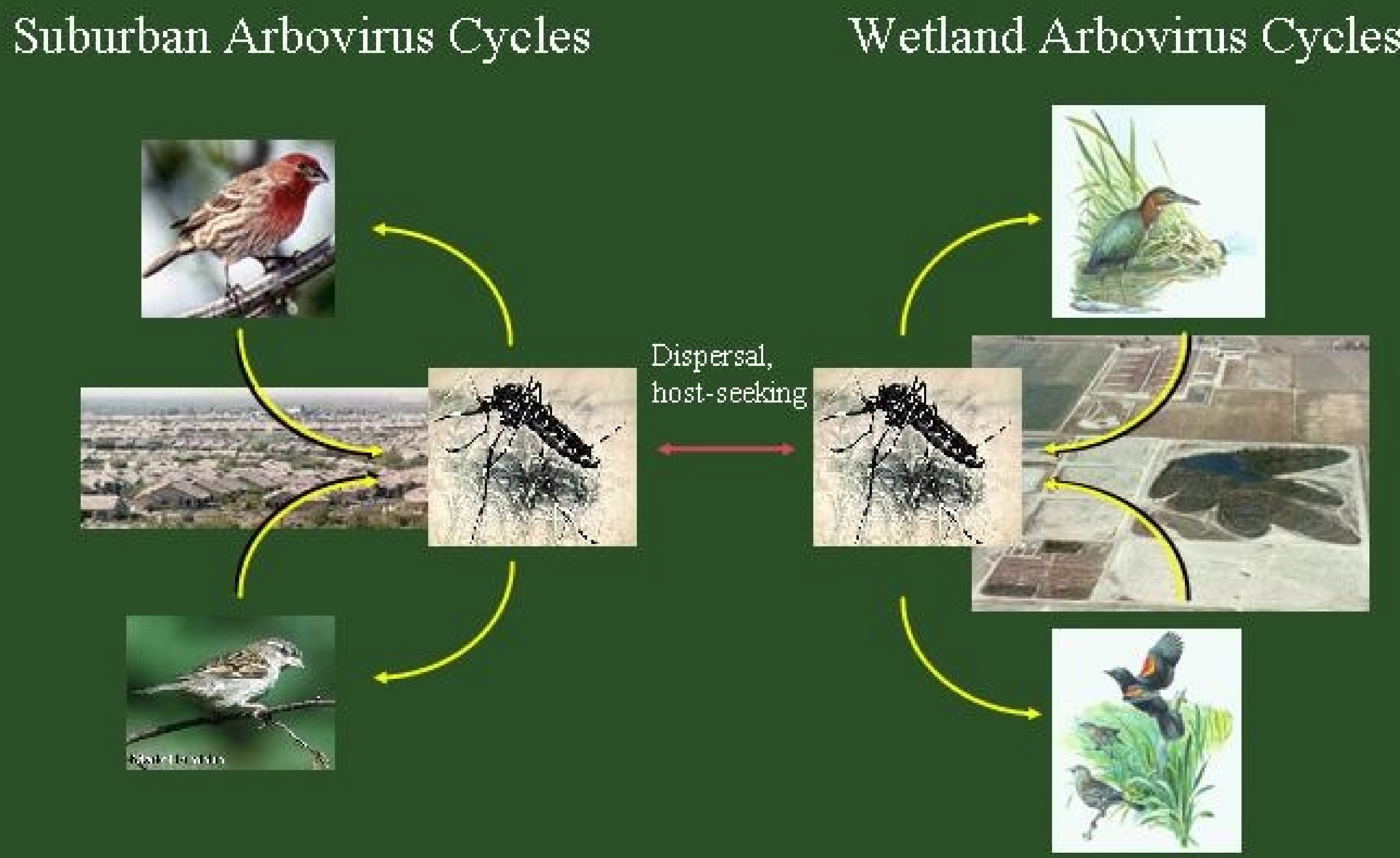
San Jacinto Demonstration Constructed Treatment Wetland: 9.9 ha; 1-2 MGD



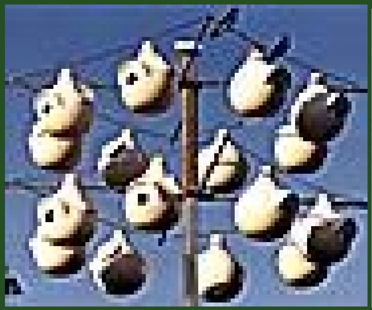
The dispersal (mean distance traveled) of adult *Culex erythrothorax* (red) and *Culex tarsalis* (yellow) marked with fluorescent dusts during a 3 day period in September in the San Jacinto Valley, CA.



In highly urbanized environments, unchecked mosquito production from wetland sites could potentially result in multiple foci from which mosquitoes are dispersing.

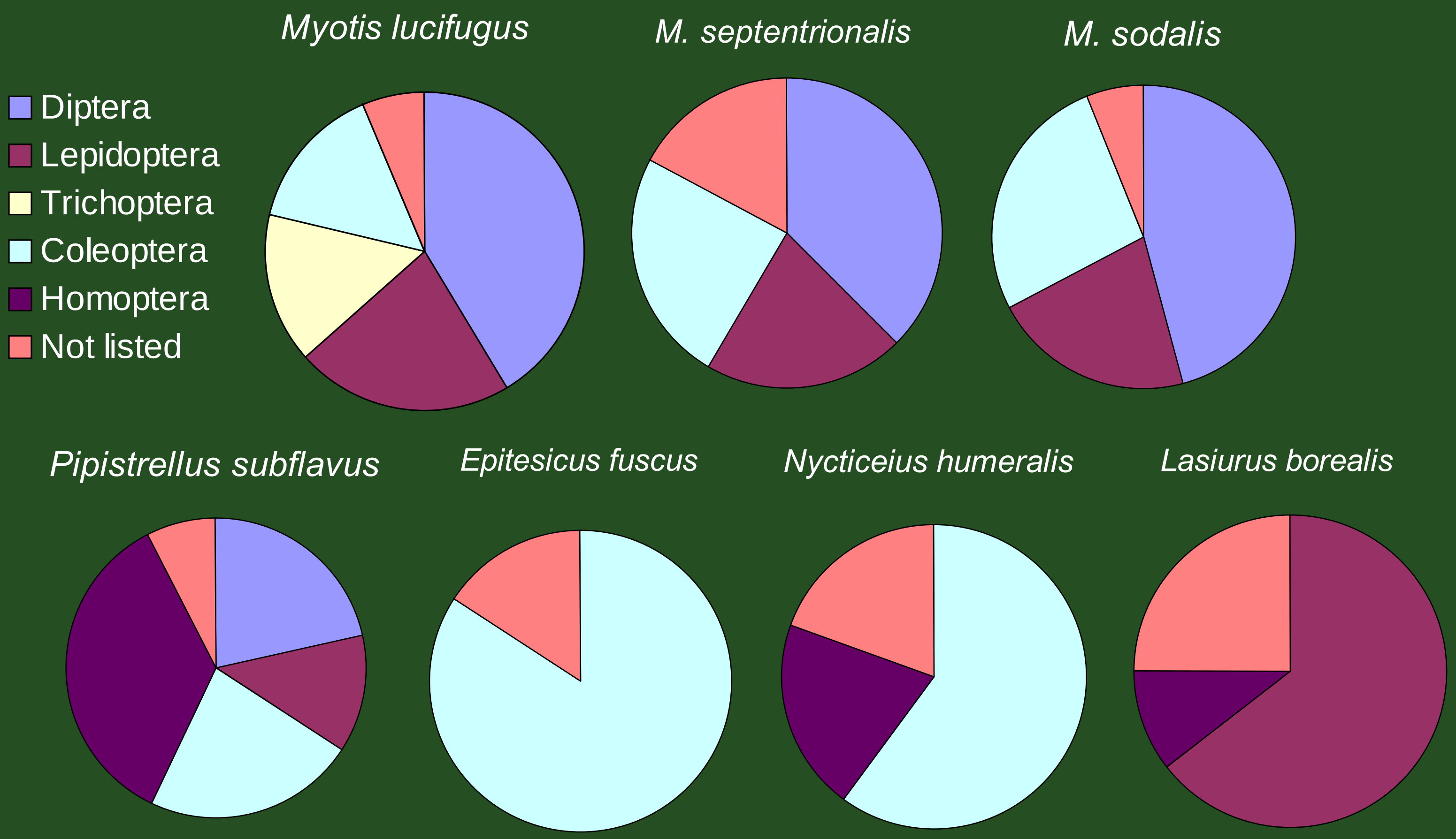

Suburban Arbovirus Cycles
Wetland Arbovirus Cycles
Dispersal,
host-seeking

Are bats, swallows and purple martins effective biological control agents for adult mosquitoes?



Photos from: http://www.bestnest.com/

Diet Composition of Bats in Southwestern Indiana



Whitaker, J. O., Jr. 2000. Bat Research News.

Diet Composition of Purported Biological Control Agents of Adult Mosquitoes

	Species	% in diet
Arnold et al. (2001)	*Pipistrellus nathusii*	4.86-9.91 Culicidae & Chaoboridae
	Myotis daubentoni	0-8.25
Boggasch and Bernauer (1991)		
	Delichon urbica (Common House Martin)	0.09 (Culicidae)
Muschketat (1999)		
	Acrocephalus palustris (Marsh Warbler)	0 Culicidae (17.1% Diptera)

"…a martin consumes 2,000 mosquitoes per day."

Beal (1918): examined the stomach contents of 205 birds: ***no*** mosquitoes in the diet from February to September. Same result in 5 other studies.

Johnston (1967): stomach contents of 34 birds between April and August: mosquitoes were 3% of the insects in the diet in April and 0% in all other months.

Micks (unpublished): *Ochlerotatus* (*Aedes*) *sollicitans* in the stomach of one bird killed by a car.

Kale (1968): The five studies that attribute a significant mosquito-feeding habit to martins failed to substantiate such a claim with data or citations. Wade's (1966) statement above is not based on data.

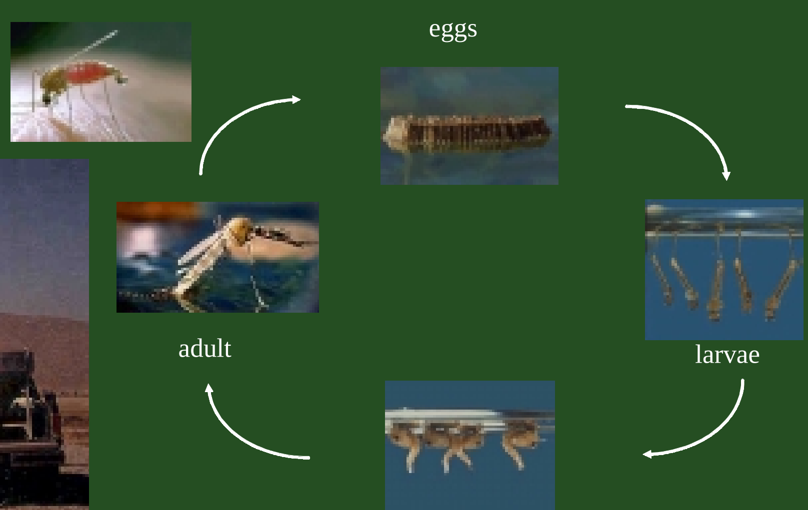
If the statement were true, then > 2,000 martins/acre would be needed to control a typical emergence of several million adult mosquitoes/acre of salt marsh or freshwater wetland/pond receiving nutrient-enriched water.

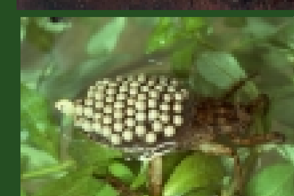
“…a martin consumes 2,000 mosquitoes per day.”

Control of larval mosquitoes is critical. After mosquitoes become adults capable of dispersing from a wetland, mosquito control becomes more difficult, costly and requires pesticides.

Birds, bats, and adult dragonflies either are active when most mosquitoes are not active or eat few mosquitoes relative to other prey.

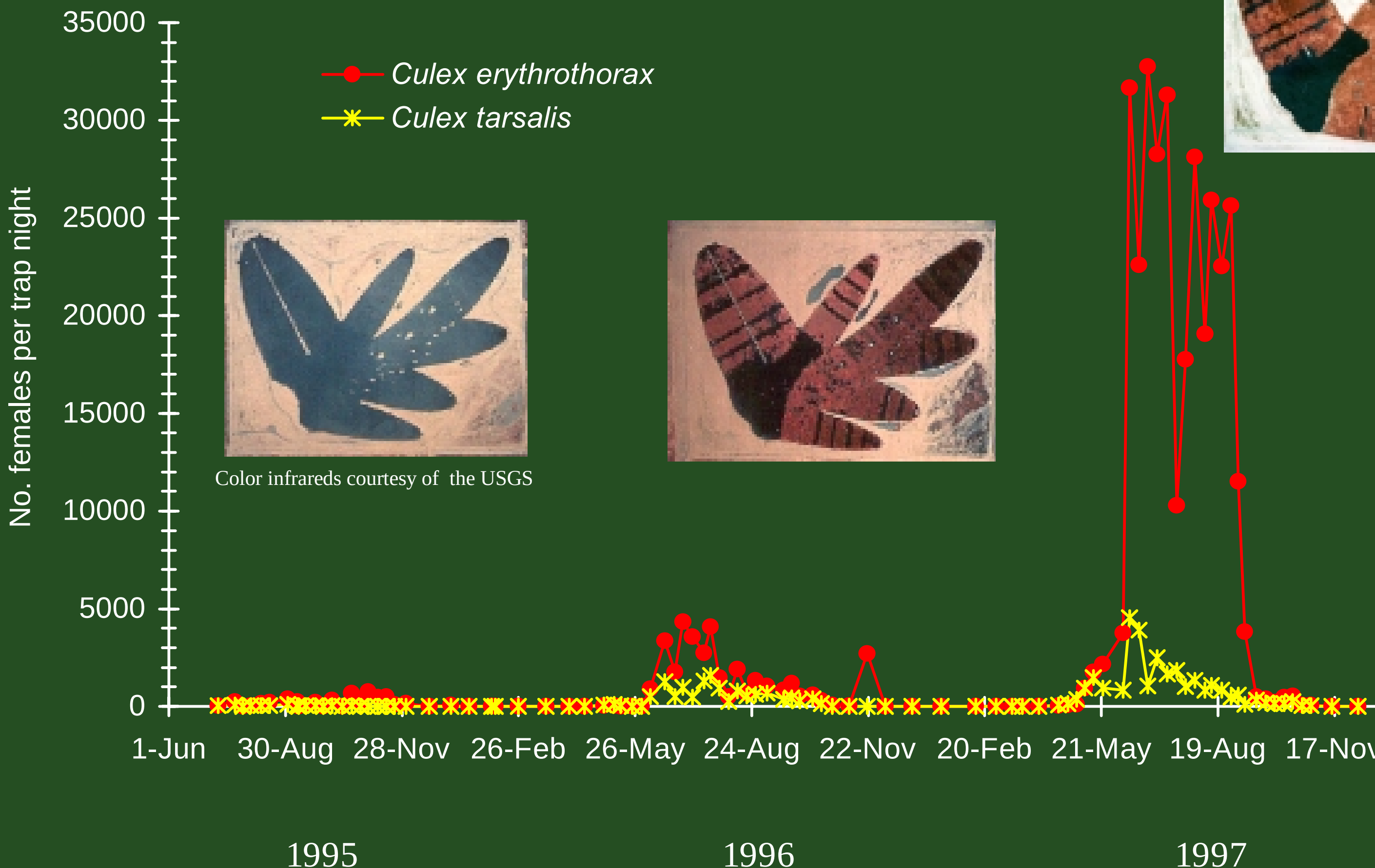
Life Cycle of a *Culex* Mosquito





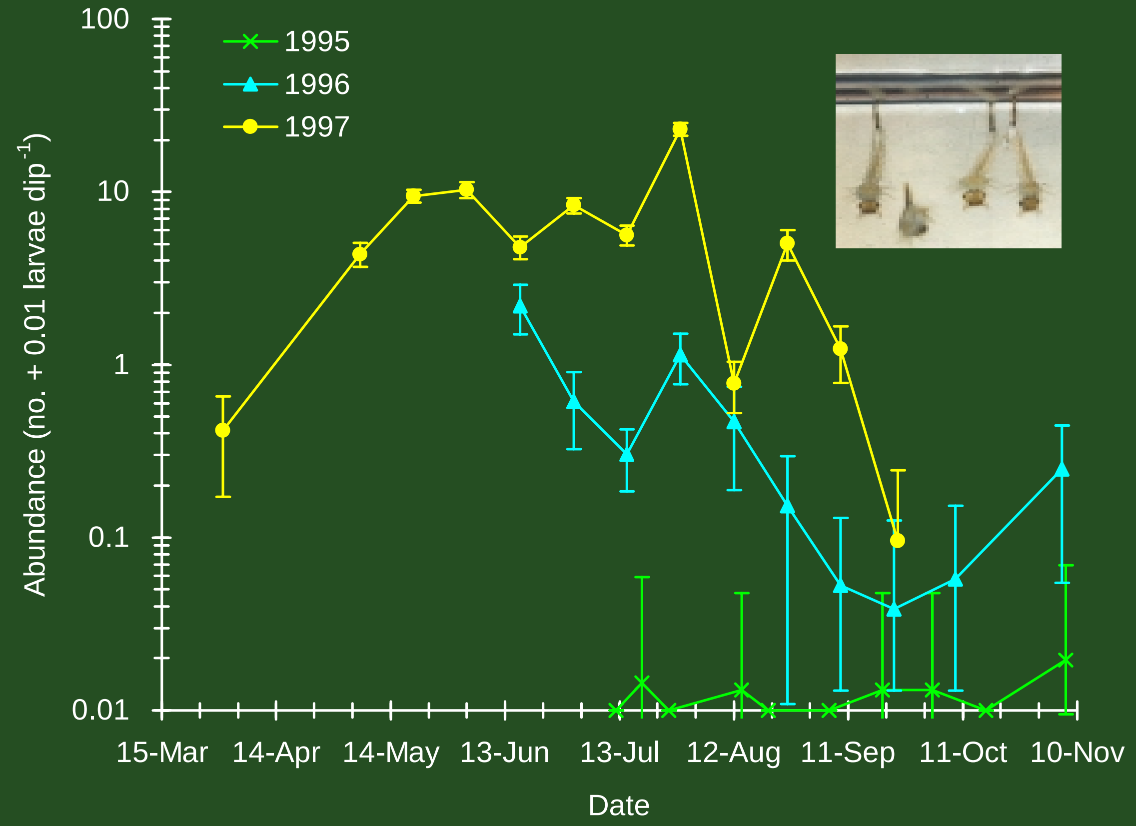
What design features of constructed treatment wetlands contribute to mosquito production?

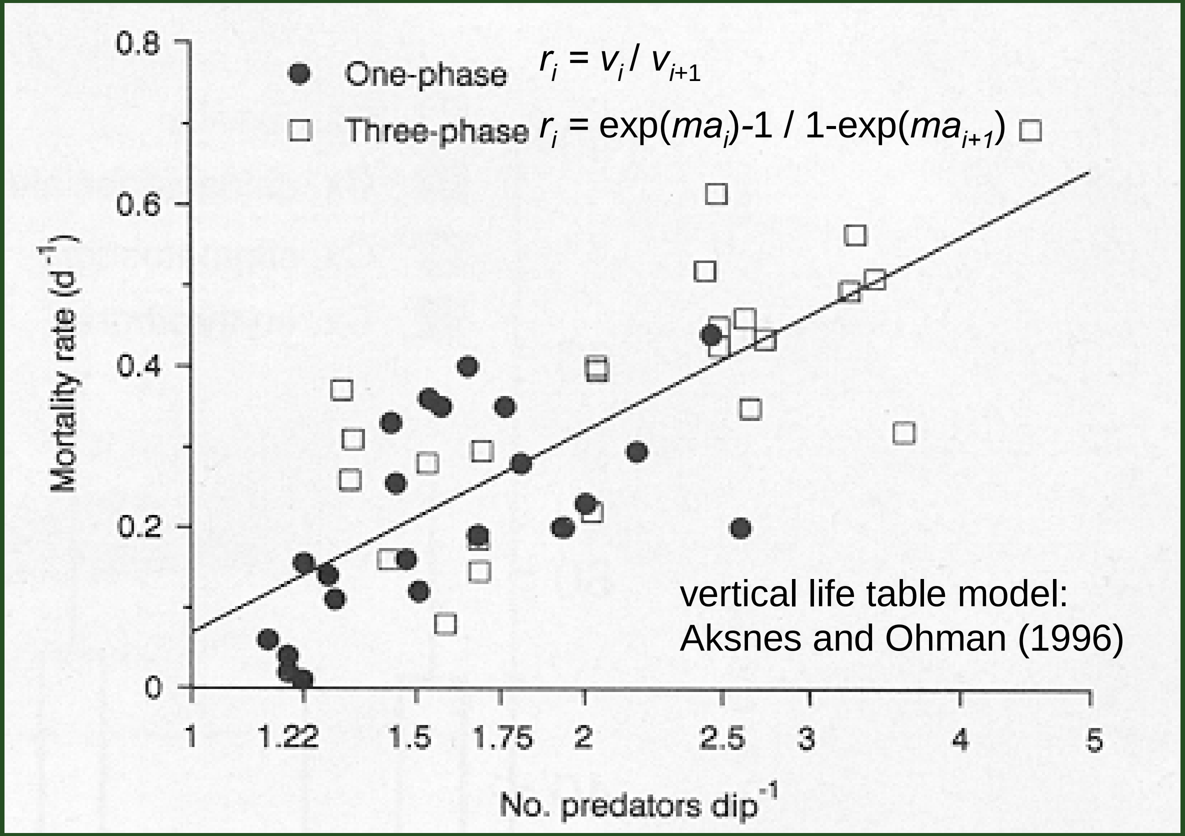
Abundance of Host-seeking Female Mosquitoes
Demonstration Wetland: 1995-1997



Color infrareds courtesy of the USGS

Abundance of *Culex* Larvae in Composite Dip Samples from the Hemet/San Jacinto Demonstration Wetland





ANOVA Results:

Homogeneity of slopes

$F_{1,44} = 0.006$, $P > 0.93$

Marsh type after controlling for predator abundance

$F_{1,45} = 3.33$, $P > 0.07$

Predator abundance

$F_{1,45} = 40.57$, $P < 0.001$

Larval mosquito mortality increased directly with aquatic insect predator abundance irrespective of marsh type. Predators in marshes with open water zones were more abundant than in fully vegetated marshes.

- Vegetation management:
  a) is needed in most surface-flow treatment wetlands;
  b) can be expensive;
  c) can cause significant levels of mosquito production if done inappropriately.
  d) Design features that limit the proliferation of emergent vegetation may provide a more cost-effective long-term solution for mosquito control than does repeated harvesting of dried vegetation from shallow zones.

How can vegetation management be carried out to limit mosquito production?

Vegetation removal by harvesting is expensive ($5,000 - $7,000/ha) and costs may be higher if off-site disposal is required. Controlled burning is an alternative method that costs less than removal, but requires extensive permitting and may release significant levels of pollutants upon inundation of burned matter. Inundation of knocked down and dried vegetation to enhance bacteria populations responsible for nitrogen removal is contraindicated for mosquito management.

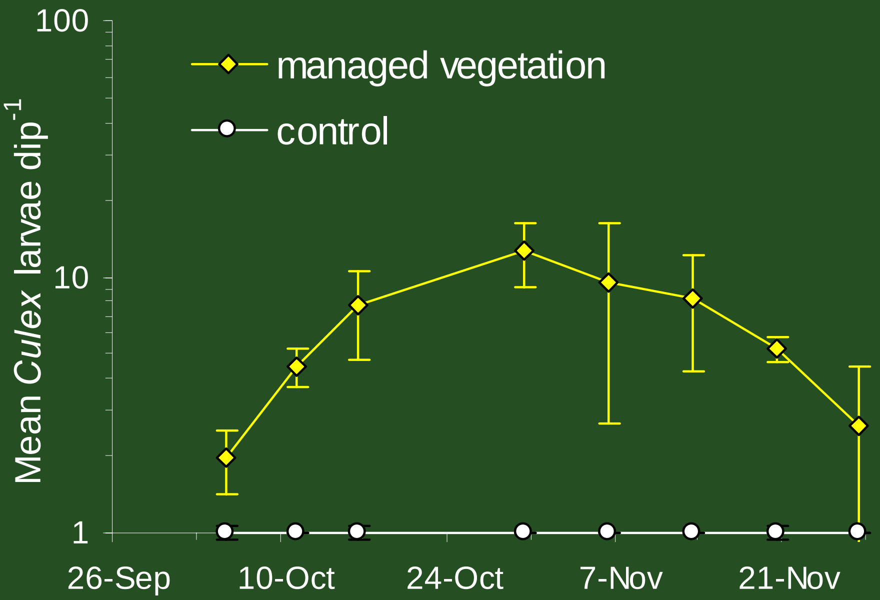
Knocked down vegetation

Vegetation removed

Burning vegetation

Following inundation of knocked down and dried vegetation, large (~5 ha) wetlands were attractive to mosquitoes for ~ 9 weeks. Mosquito abundance was directly related to the amount of dried vegetation that was inundated in other studies not shown here.

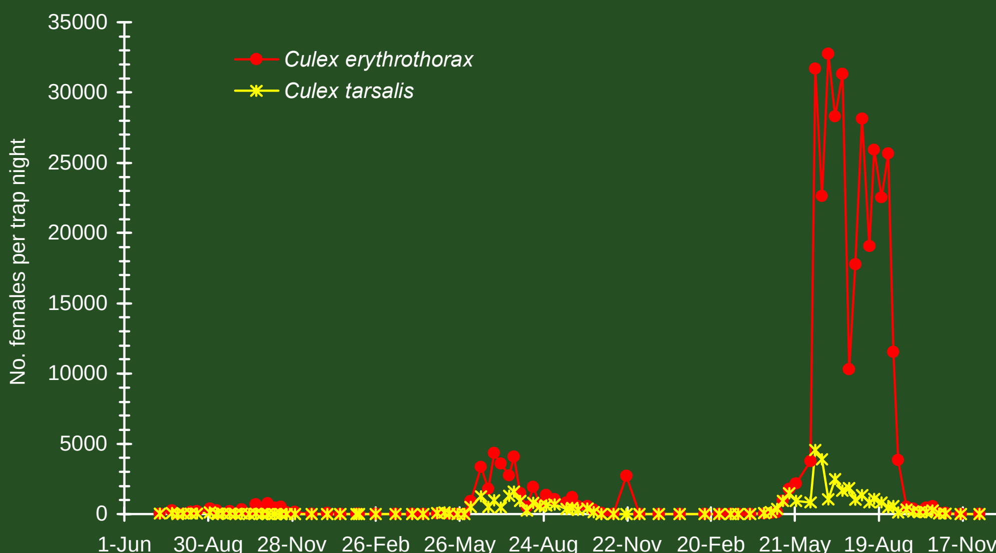
3 to 4 larvicide treatments might be required.

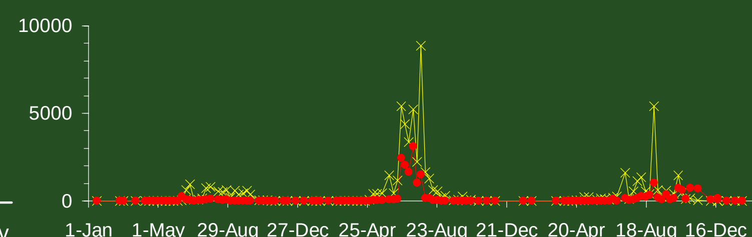


The abundance of mosquitoes was compared in ponds where the vegetation was knocked down vs. non-manipulated (control) wetlands at the Prado Wetland in Corona, CA.

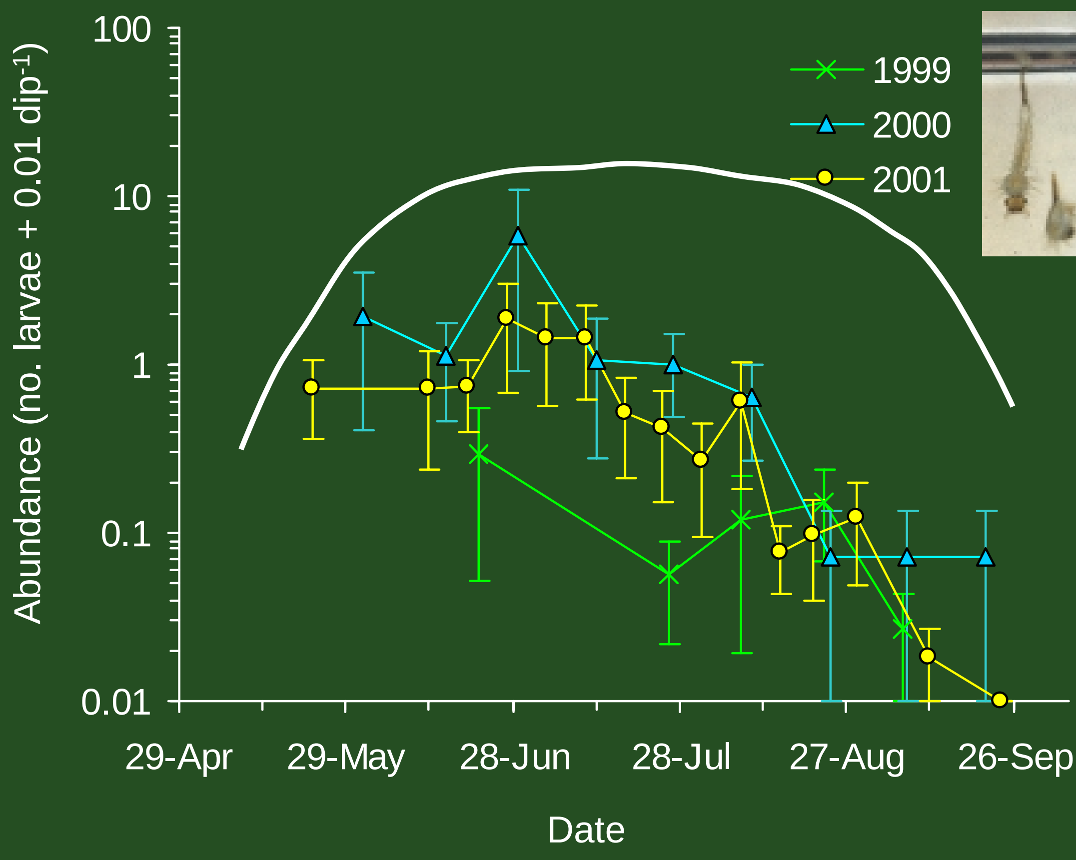
1995 - 1997

1999 - 2001

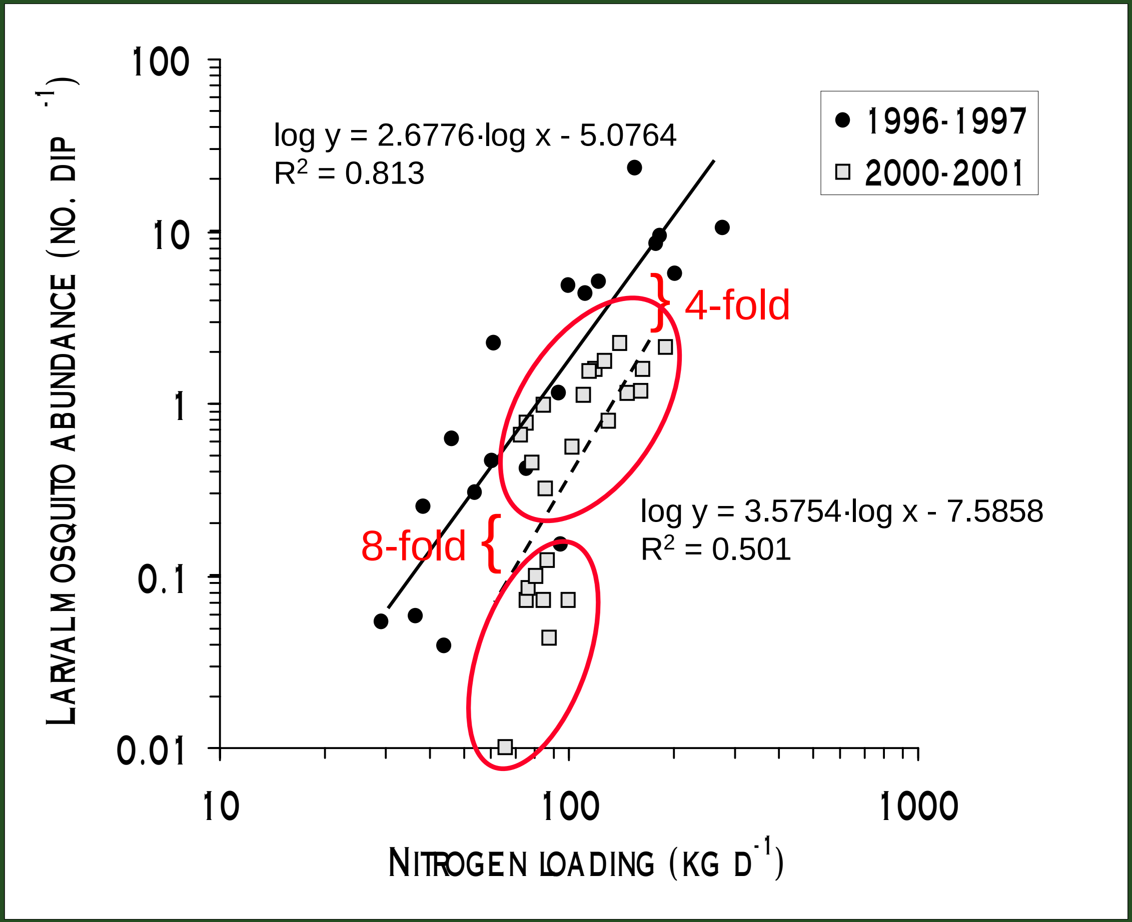




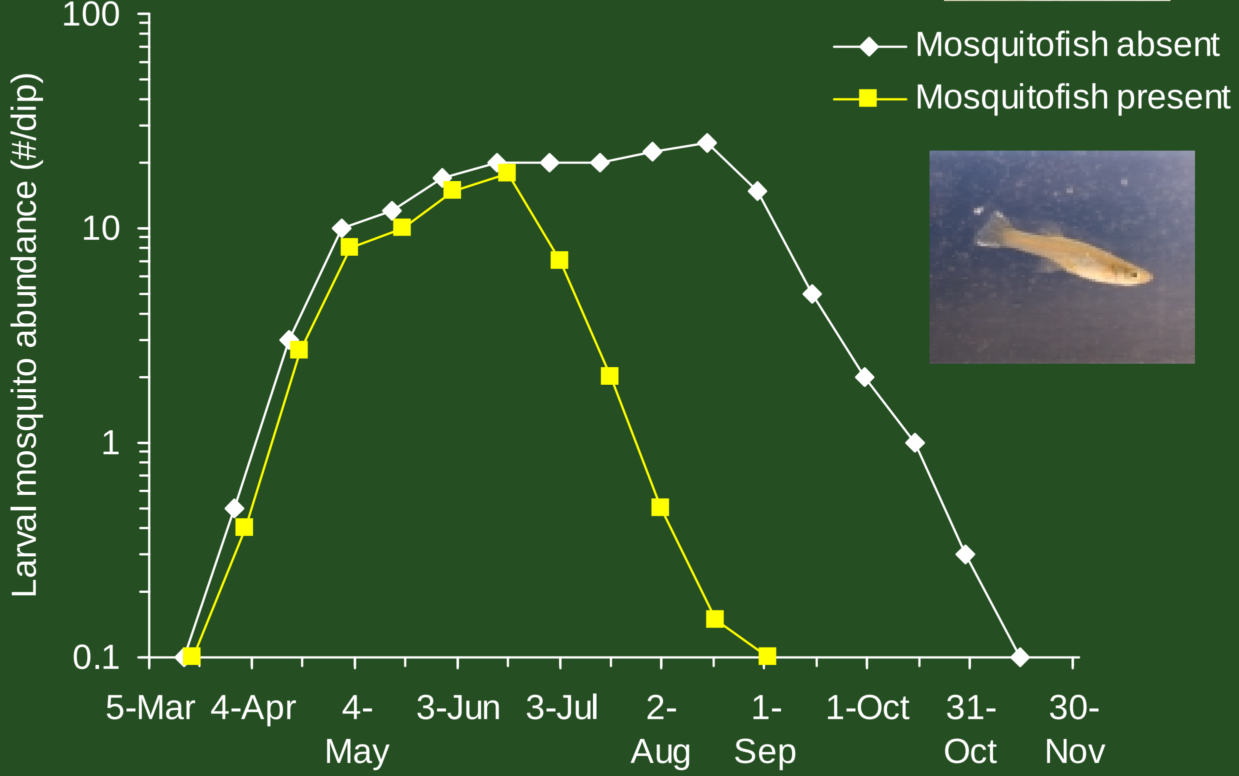
Abundance of *Culex* Larvae in Composite Dip Samples from the Hemet/San Jacinto Demonstration Wetland



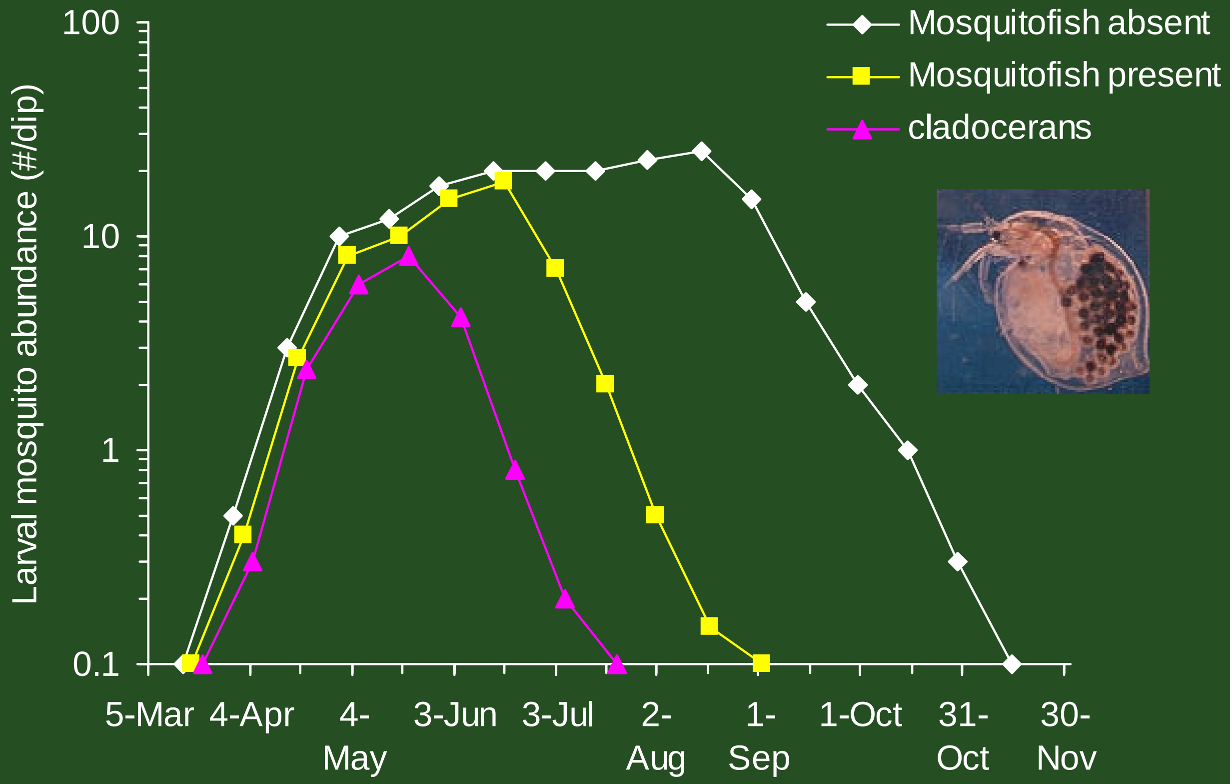
Effect of Nitrogen Loading on *Culex* Abundance in a Vegetated Constructed Wetland, San Jacinto, CA



Mosquitofish reduce mosquito populations during the summer.



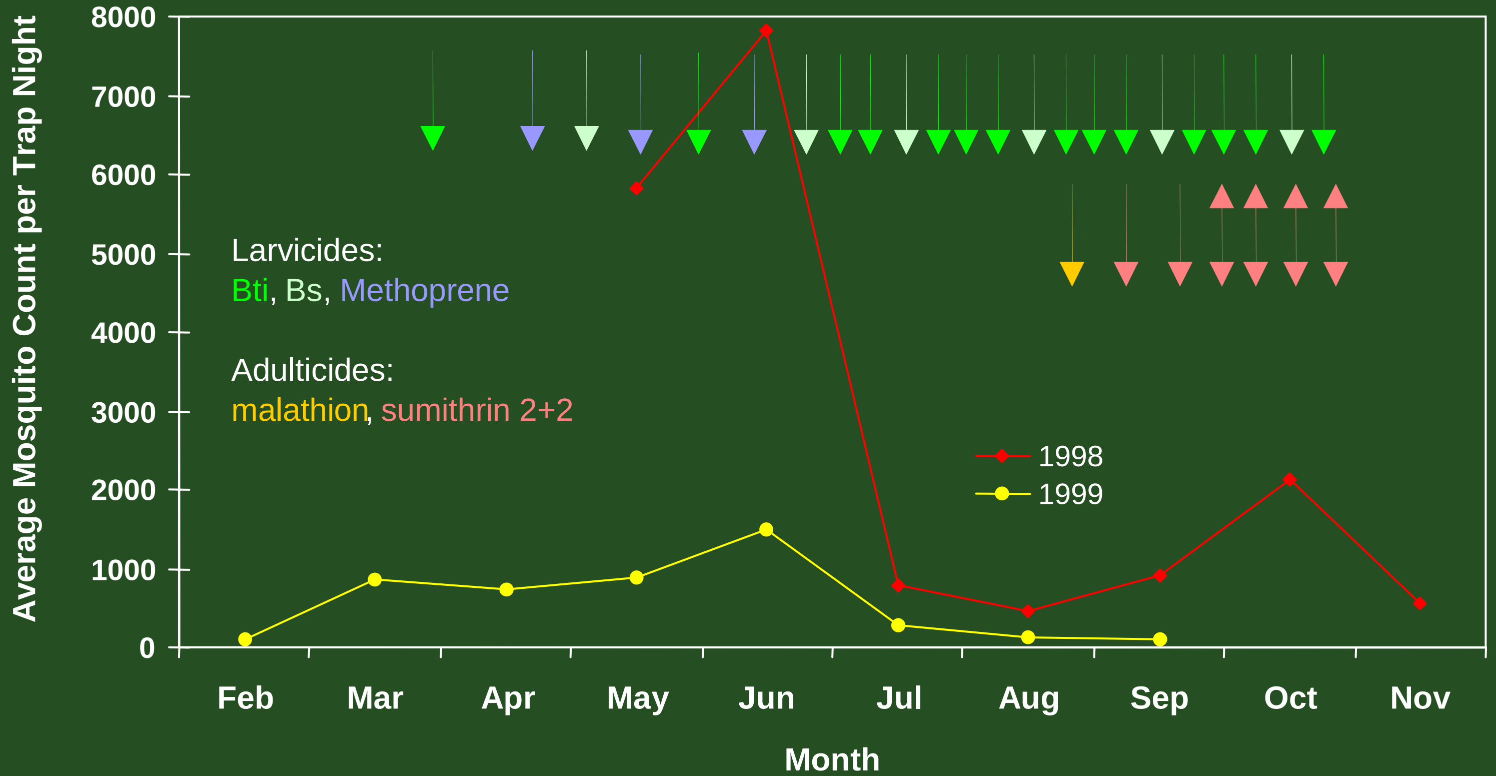
Mosquitofish reduce mosquito populations during the summer.



Mosquito control in surface-flow constructed treatment wetlands will rely on a an integrated control strategy.

Does proactive mosquito abatement successfully reduce mosquito populations at wetlands receiving poor quality water and containing dense emergent vegetation? How much does it cost?

1999 Mosquito Abatement - Sweetwater Wetlands, Tucson, AZ



Mosquito abatement at constructed wetlands receiving secondary-treated municipal effluent that contain dense stands of emergent vegetation is expensive and is often ineffective. Weekly, even semi-weekly, application of larvicides and adulticides can be required.

Costs of Mosquito Abatement

Demonstration Wetland San Jacinto, CA (1997)		Tres Rios Wetlands Phoenix, AZ (1998)		Sweetwater Wetlands Tucson, AZ (1999)	
Larvicides	$13,664	Larvicides	$6,538	Larvicides	$18,500
Adulticides	$ 406	Application	$4,500	Adulticiding	$ 2,000
Helicopter	$12,000			Helicopter	$27,700
Total (~½ yr)	$26,000	(~½ yr)	$11,038		$48,200
Cost ha^{-1} yr^{-1}	$5,266		$5,250		$6,665

Costs of Mosquito Abatement

Prado Wetlands (2001)

Larvicides	\$2,200
Adulticides	\$ 0
Helicopter	\$ 0
Total	\$4,600
Cost ha^{-1} yr^{-1}	\$ 25

- 3 out 50 ponds at 6 ha (~\$767 ha $treated^{-1}$)
- 60,000 *Gambusia* were stocked.

Design Features and Operational Procedures that Help to Limit Mosquito Production at the Prado Constructed Wetland

- Comparatively high quality of water
- Low coverage of vegetation/reduction by natural processes
- High rates of water flow
- Mosquito predators naturally occur within the river system
- Compartmentalization
- Dikes that can accommodate mosquito control vehicles
- Excellent working relationship between agencies

Challenges for Designing Constructed Wetlands for Stormwater and Combined Sewage Overflow

- highly stochastic nature of hydraulic and pollutant loading

Stochastic Inputs Into Constructed Treatment Wetlands

Stochastic inputs in wastewater treatment wetlands (Kadlec 1996)

• influence of precipitation, evapotranspiration and infiltration on the background concentration and hydraulic loading

• influence of temperature variation and seasonality on the biological processes in the wetland

Stochastic inputs in stormwater treatment wetlands (Wong and Geiger 1997)

• variable intermittent runoff resulting from variability of rainfall depth, storm duration and storm temporal pattern

• variable intermittent loading of pollutants from the factors above and dry deposition and variable time distribution of pollutant concentration during a storm event

• different time distribution characteristics of pollutant concentration of multiple target pollutants

Challenges for Designing Constructed Wetlands for Stormwater and Combined Sewage Overflow

- highly stochastic nature of hydraulic and pollutant loading
- uncertainty of the areal rate constant (*k*) and background concentration of the water quality parameter (*C**) in sizing models for stormwater wetlands

$$\frac{C_o - C^*}{C_i - C^*} = e^{-k/q} = e^{-kA/Q}$$

k_{TSS} = 1000 m yr^{-1} (range: 1000 – 10,000 m yr^{-1})
k_{BOD} = 34 m yr^{-1} (range: 6.5 – 93.7 m yr^{-1})
k_{TN} = 22 m yr^{-1} (SD = 6.1 m yr^{-1})
k_{TP} = 12 m yr^{-1} (range: 0.56 – 66 m yr^{-1})

Uncertainty is caused by (Wong and Geiger 1997):
- wetland physical and ecological characteristics
- catchment and pollutant characteristics
- variation from assumptions of plug flow and constancy of *k*

wetland depth, shape, inlet and outlet locations, vegetation type and density, soil type, level of mixing, etc.

Challenges for Designing Constructed Wetlands for Stormwater and Combined Sewage Overflow

- highly stochastic nature of hydraulic and pollutant loading
- uncertainty of the areal rate constant (*k*) and background concentration of the water quality parameter (*C**) in sizing models for stormwater wetlands
- Because wetlands often need to be retrofit into small parcels of land, *distance* is not a viable option for sedimentation processes.
- Sedimentation is the principal process in the removal of pollutants from constructed wetlands but other processes such as biological assimilation and chemical transformation can play important roles (Walker and Hurl 2002).

Best Management Practices for Stormwater Affecting Public Health: Gaffield et al. 2003

- Infiltration BMPs

  - have the highest documented pollutant removal efficiency

  - high removal rates of heavy metals and > 50% of total nitrogen and phosphorus

- Wetlands and ponds

  - can remove ~70% of bacteria but are less effective for other pollutants

  - sedimentation and photolysis

- Drainage ditches and swales

  -have limited pollutant-removal capabilities

Integrate BMPs with local site design and operations as well as regional-scale planning to reduce stormwater volume and improve water quality.

CONCLUSIONS

- ***Poor water quality, shallow water and dense emergent vegetation typically enhance mosquito production.***
- ***Vegetation management is needed in most surface-flow treatment wetlands. Inundation of dried, dead emergent vegetation greatly enhances mosquito production.***
- ***Biological control can greatly assist control efforts. There are no effective biological control agents for adult mosquitoes. An integrated pest management strategy against the immature stages of the mosquito life cycle may be needed.***
- ***Planning for mosquito management is needed:***
  - ***a) design features and operational procedures that reduce mosquito production,***
  - ***b) plans for public health emergencies,***
  - ***c) long-term planning for costs of mosquito abatement and vegetation management.***
- ***Wetlands may not be the best stormwater BMP. Are alternative approaches to wetlands feasible?***

Acknowledgements

U. C. Mosquito Research Program
Mosquito and Vector Control Association of California
Northwest Mosquito and Vector Control District
U. S. Department of Agriculture
U. S. Geological Survey

Eastern Municipal Water District
Orange County Water District

Collaborators:

U. C. Riverside
- Parker Workman
- Peggy Wirth
- Joshua Jiannino
- Lou Randall
- Michelle Sanford
- Joe Keiper
- Karrie Chan
- George Peck
- Dave Popko

U. S. G. S.
- Doug Anderson
- Jim Sartoris
- Joan Thullen

U. C. Berkeley
- Constantine Tempelis

Riverside Co. Dept. Health
- Hugh Murray

University of Colorado
- Lesley Smith