NASA Public Health Program Review
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Integration of Remote Sensing into Encephalitis Virus Intervention Decision Support Systems

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63 Mosquito and Vector Control Association of California

Supported by: **NASA Applied Sciences Program Decision Support through Earth Science Research Results**

Overall goal: Improve the California Mosquitoborne Virus Surveillance and Response Plan decision support system [DSS] through the integration of data from NASA satellites and models as provided by the Terrestrial Observation and Prediction System (TOPS)

Specific aims:

- Link TOPS data to mosquito and arbovirus data compiled by UCD, MVCAC and CDPH
- Integrate best models into TOPS applications
- Distribute risk estimates, maps and data statewide using the DSS
- Extrapolate system to western USA

CMVSRP & ArboNET: Integrated System Solutions Architecture

INPUTS

Earth Science Models

- Terrestrial Observation & Prediction System (TOPS), NASA Ames
- Entomological Models, UC Davis CVEC

Earth Observations

- MODIS (NDVI, LST, Snow Cover, LAI, Landcover)
- AVHRR (NDVI)
- Landsat (Landcover)
- SOGS (Meteorology)
- Virus surveillance
- Mosquito surveillance

OUTPUTS

Predictions

TOPS computational framework at NASA Ames used to automate:

- Processing of observation data
- Monitoring & forecasting of ecosystem parameters
- Forecasts of mosquito abundance
- Forecasts of virus transmission risk

Observations

DHS-CDC-UCD-NASA

OUTCOMES

Decision Support Tools

CA Dept. Health Services CMVSRP & CDC ArboNET DSS:

- Virus activity surveillance
- New forecast capability for mosquito abundance and virus transmission risk.
- New capability for tracking anomalies in ecosystem and meteorological conditions.

IMPACTS

Value & benefits to citizens & society

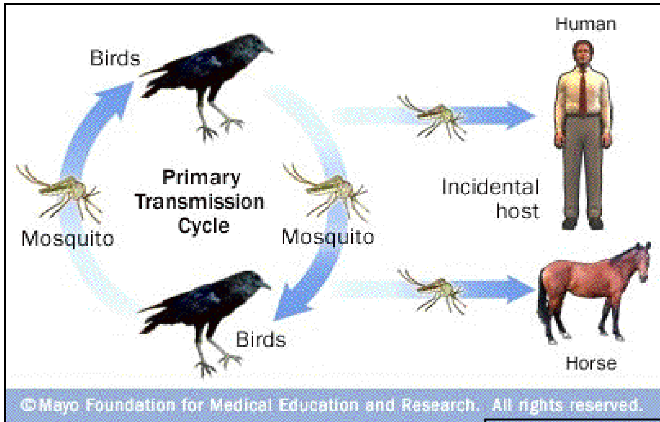
Policy Decisions

- Annual resource and funding allocations
- Public education and outreach
- Statewide alerts

Management Decisions

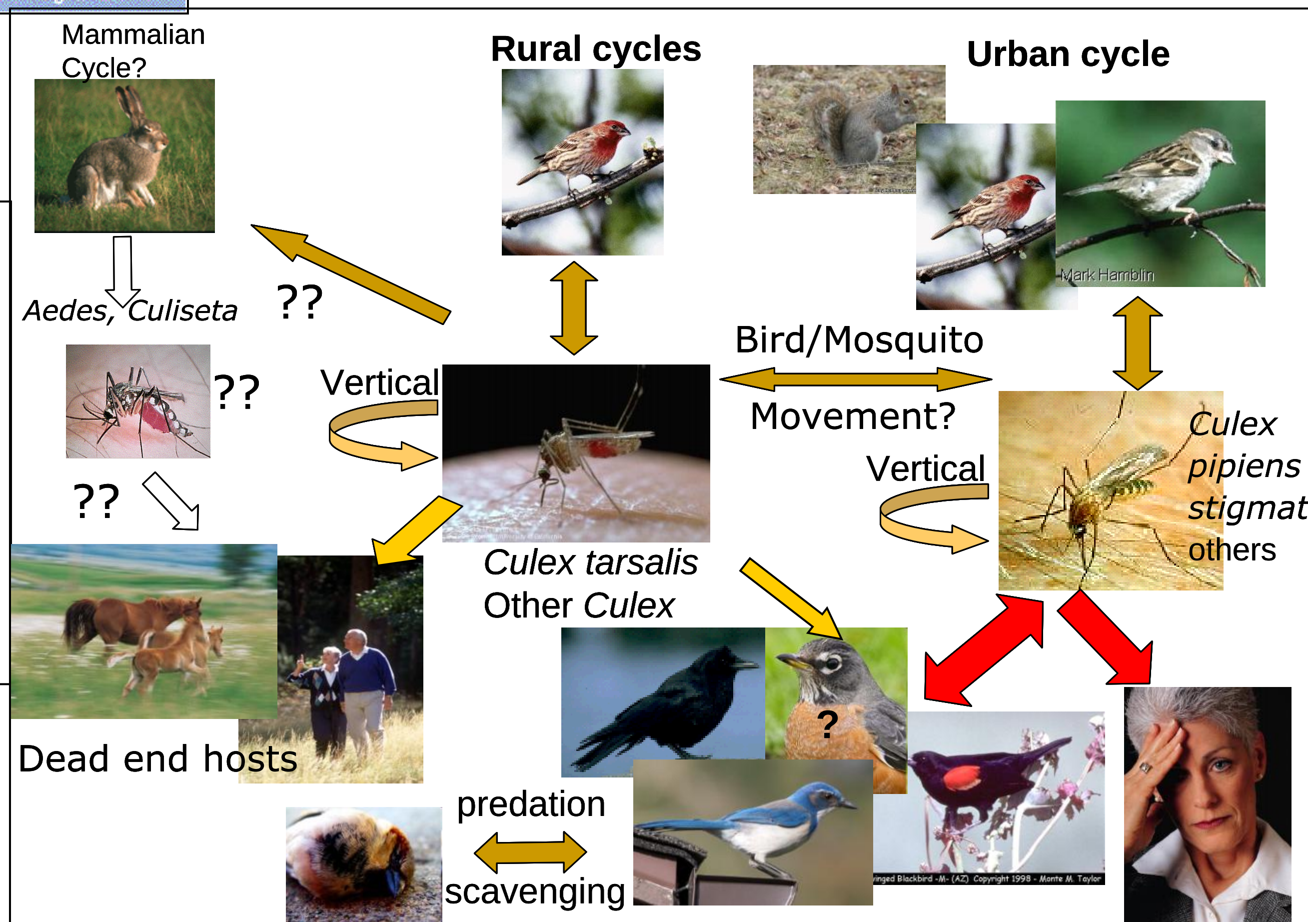
- Integrated vector management decisions
- Extent of vector control efforts
- Timing of vector control efforts
- Inter-annual allocation of resources at county level
- Coordination w/medical and emergency personnel

NASA & Research Partners | **Partners w/DSS Tools**



Focus: West Nile virus, a mosquitoborne zoonosis

Actual rural and urban WNV transmission cycles in western NA:
- several *Culex* vectors
- variety of avian maintenance and amplification hosts
- no mammalian cycle

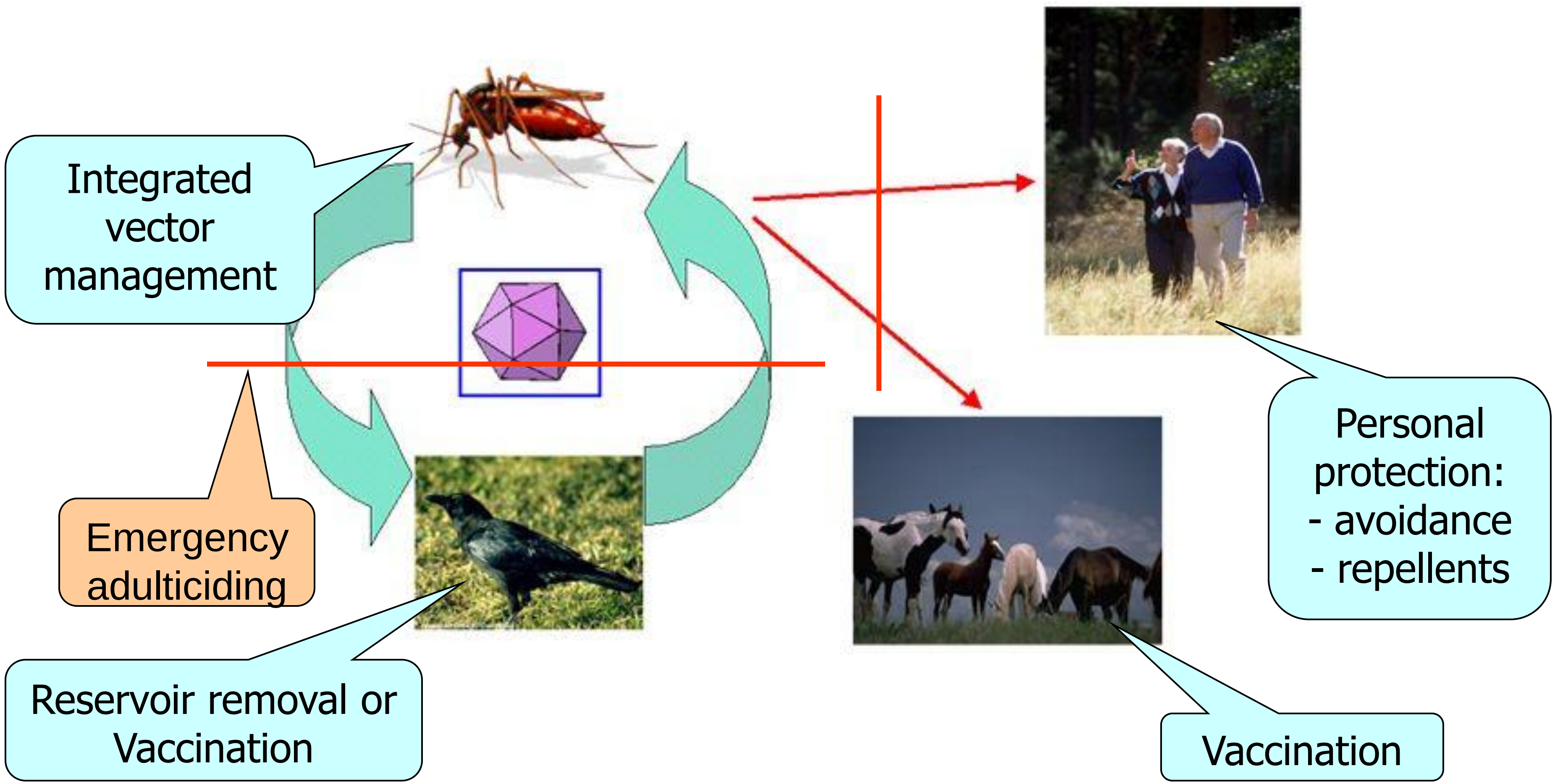


Numbers of laboratory-confirmed cases reported to CDC or CDPH

	USA			California			
	Humans	deaths	Horses	Humans	Incidence	deaths	Horses
1999	62	7					
2000	21	2					
2001	66	9	821				
2002	4,156	284	14,571	1	0.003	0	0
2003	9,862	264	5,145	3	0.008	0	2
2004	2,539	100	1,441	830	2.306	28	540
2005	3,000	119	1,139	935	2.597	19	456
2006	4,052	146	997	276	0.767	6	56
2007	3,630	124	507	380	1.056	20	54
2008	1,370	37	218	411	1.142	13	64
2009	663	30	260	105	0.292	0	18
Totals	29,421	1,122	25,099	2,941		86	1,190

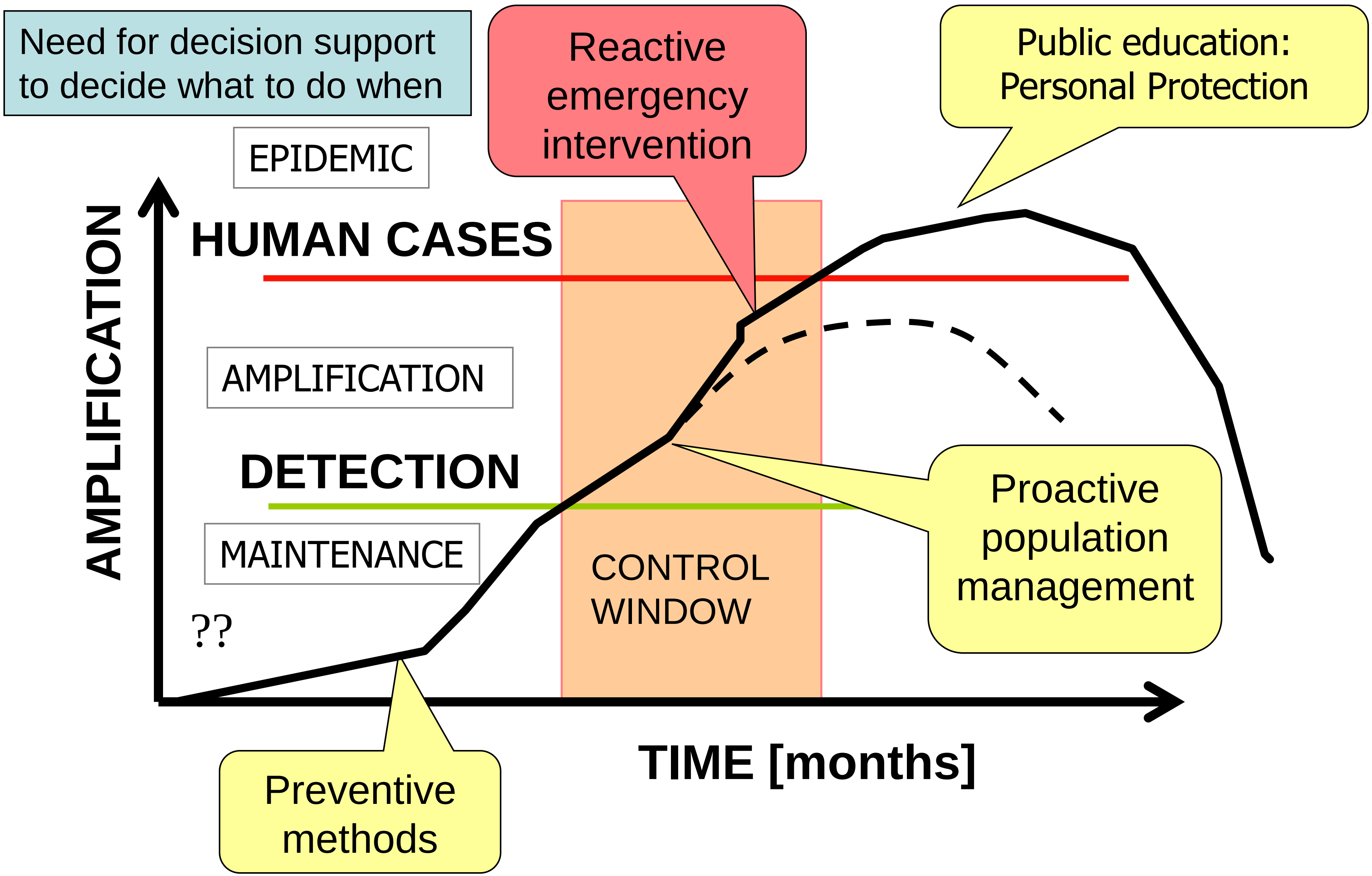
Current on-going epidemic is the largest mosquito-borne encephalitis epidemic in USA history and the largest WNV epidemic documented globally. California has 12% population and has had 10% of reported cases nation-wide.

Mosquitoborne encephalitides: points of intervention

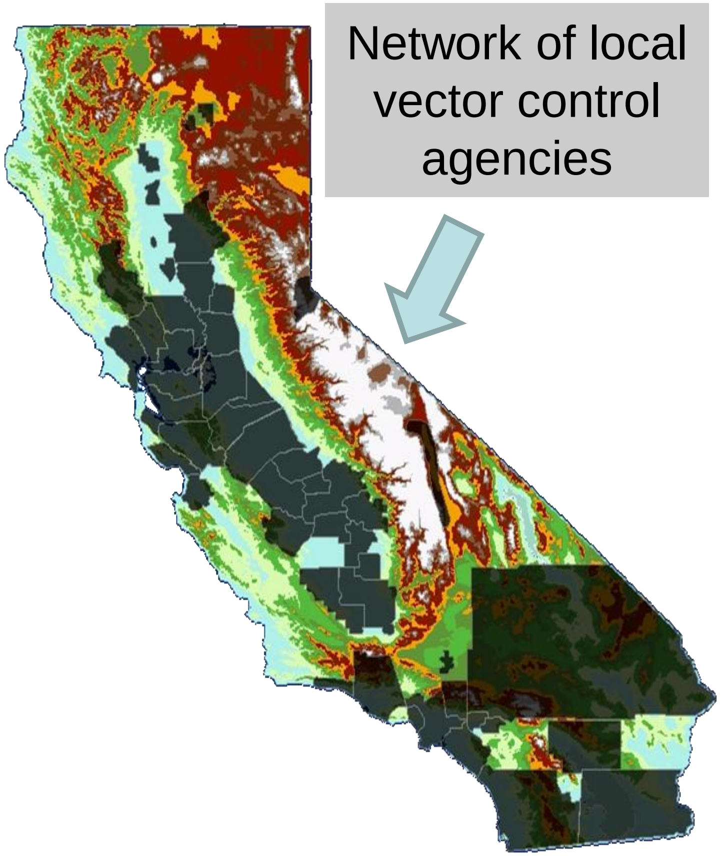


Modified from CDC website

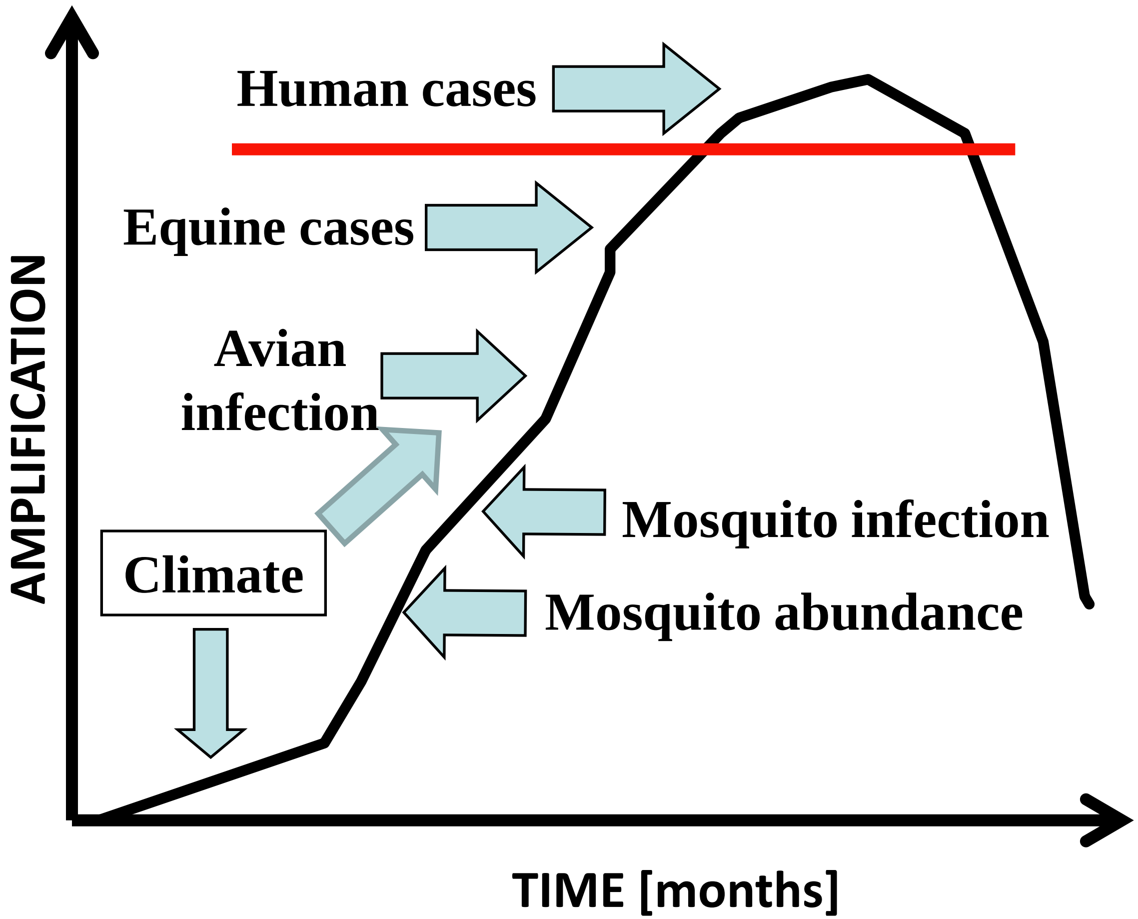
INTEGRATED VECTOR MANAGEMENT: RESPONSE PARADIGM

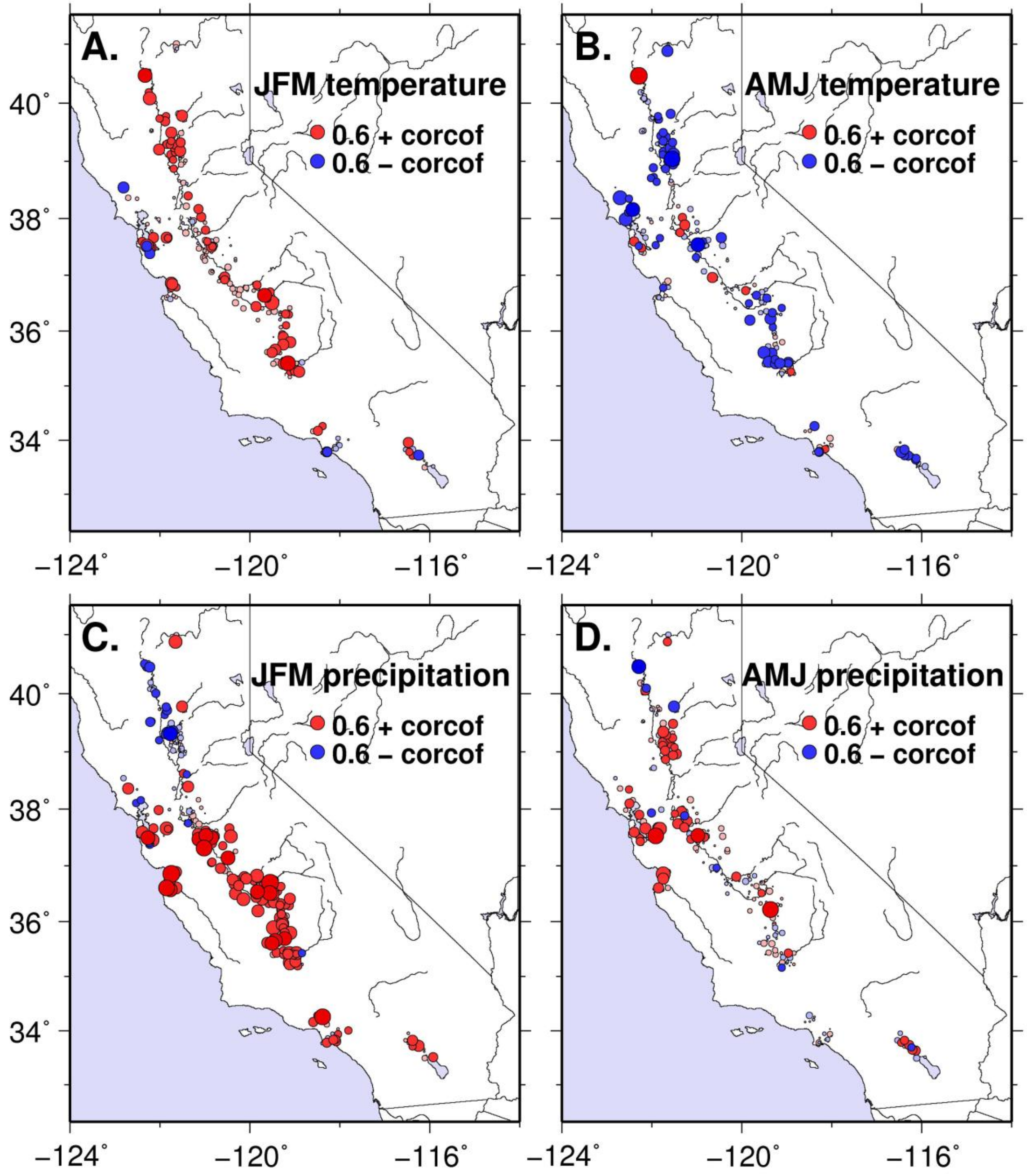


California Mosquitoborne Virus Surveillance System



A typical season…





Correlation of *Cx. tarsalis* abundance with regional antecedent climate measures

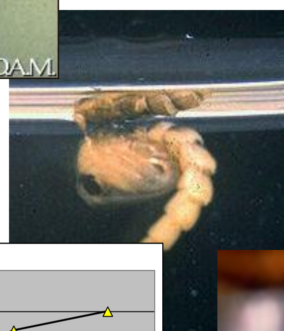
A. JFM temp vs. AMJ abundance
B. AMJ temp vs. JAS abundance
C. JFM precipitation vs. AMJ abundance
D. AMJ precipitation vs. JAS abundance

Reisen et al. 2008. J Vector Ecol.

Effects of temperature on mosquito life cycle

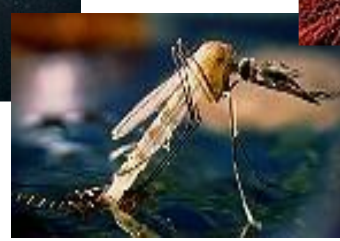
Aquatic stages

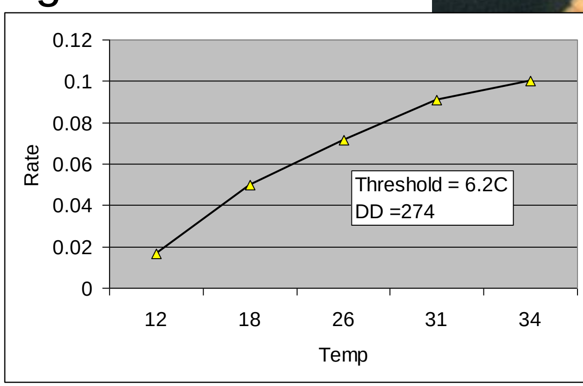
Terrestrial stages

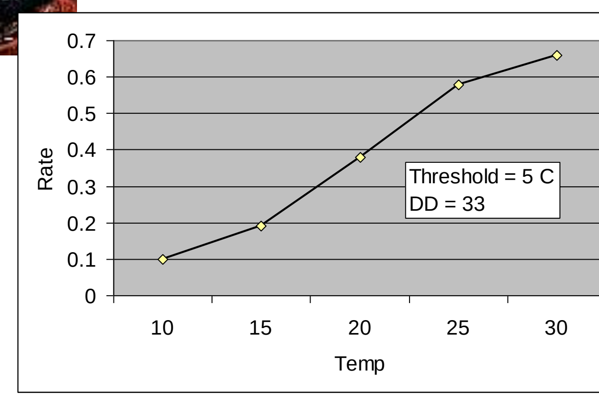


Frequency of host contact

Rate of population growth

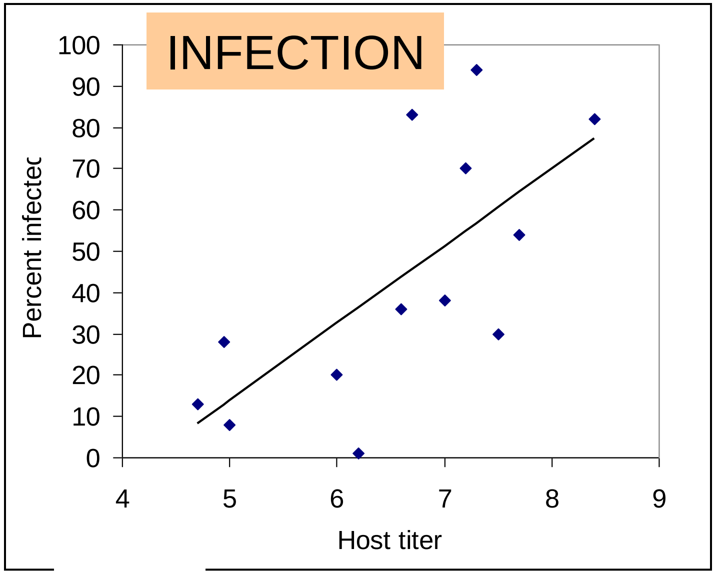


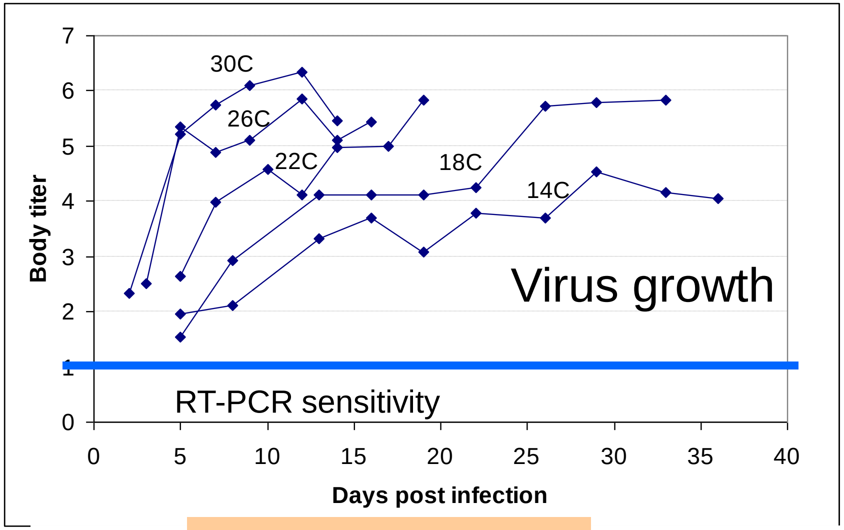


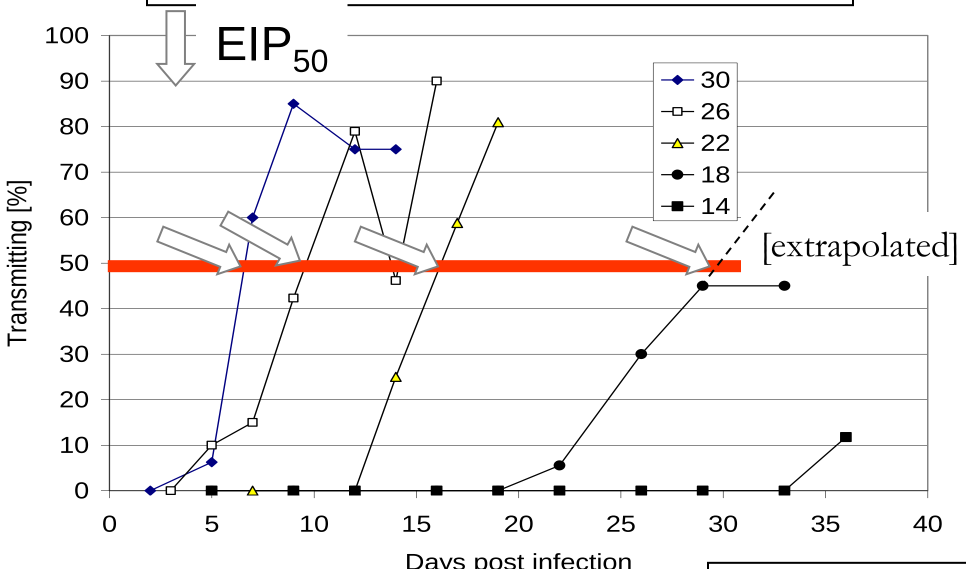


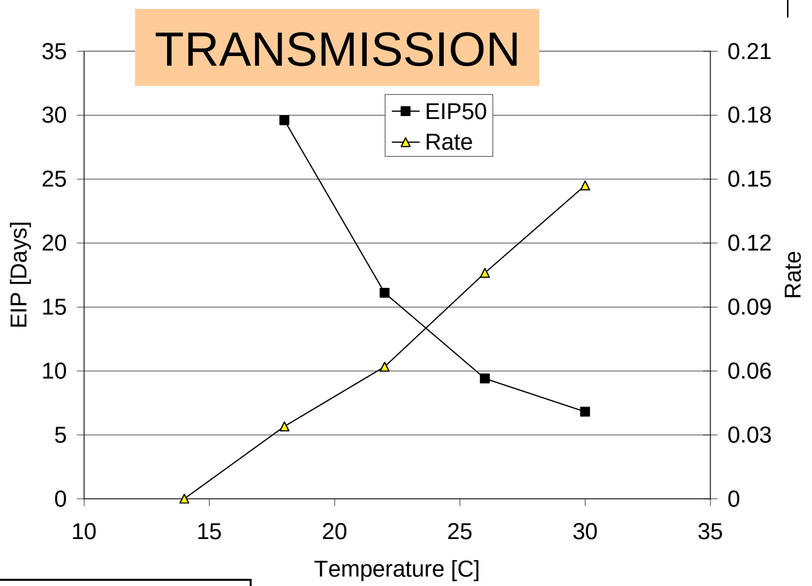
Reisen et al. 1995. JME 32: 636

Effects of host viremia on infection and temperature on transmission









Reisen et al. 2006. JME 43:309

WNV Risk Values

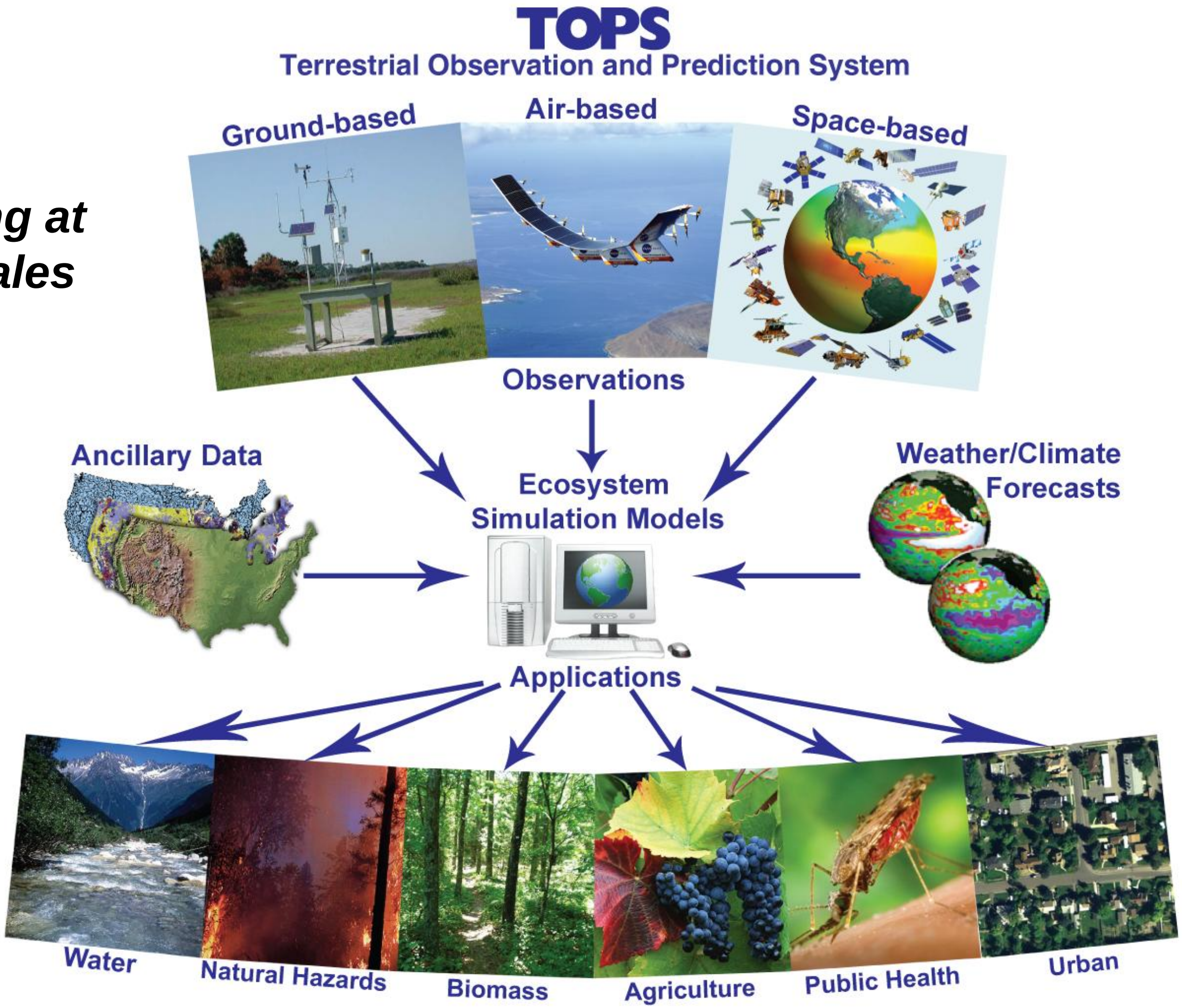
California Mosquito-borne Virus Surveillance and Response Plan

Risk Level	Avg. Daily Temperature	Adult mosquito abundance	Mosquito MIR/1,000	Chicken Seroconversions	Dead Bird Infections	Human Cases
1	<56ºF	< 50% 5-yr. Avg.	0	0 in region	0 in region	
2	57-65ºF	50-90% 5-yr. Avg.	0.1 – 1.0	≥ 1 in region, 0 in agency	≥ 1 in region, 0 in agency	
3	66-72ºF	91-150% 5-yr. Avg.	1.1 – 2.0	1 flock in agency	1 in agency	≥ 1 in region, 0 in agency
4	73-79ºF	151-300% 5-yr. Avg.	2.1 – 5.0	2 flocks in agency	2-5 in agency	1 in agency
5	>79ºF	> 300% 5-yr. Avg.	> 5.0	>2 flocks in agency	>5 in agency	>1 in agency

SCORE	RISK LEVEL
1.0—2.5	Normal season
2.6—4.0	Emergency planning
4.1—5.0	Epidemic

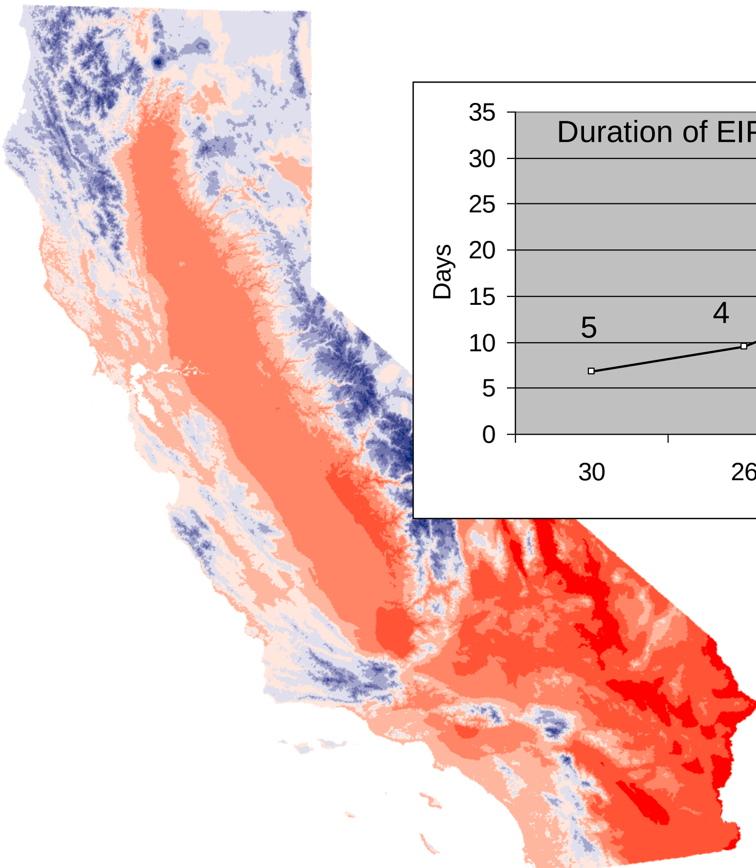
TOPS: Common Modeling Framework

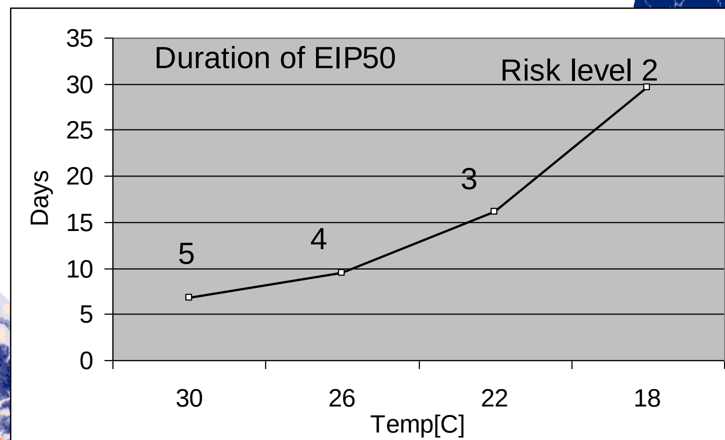
Monitoring,
modeling,
& forecasting at
multiple scales

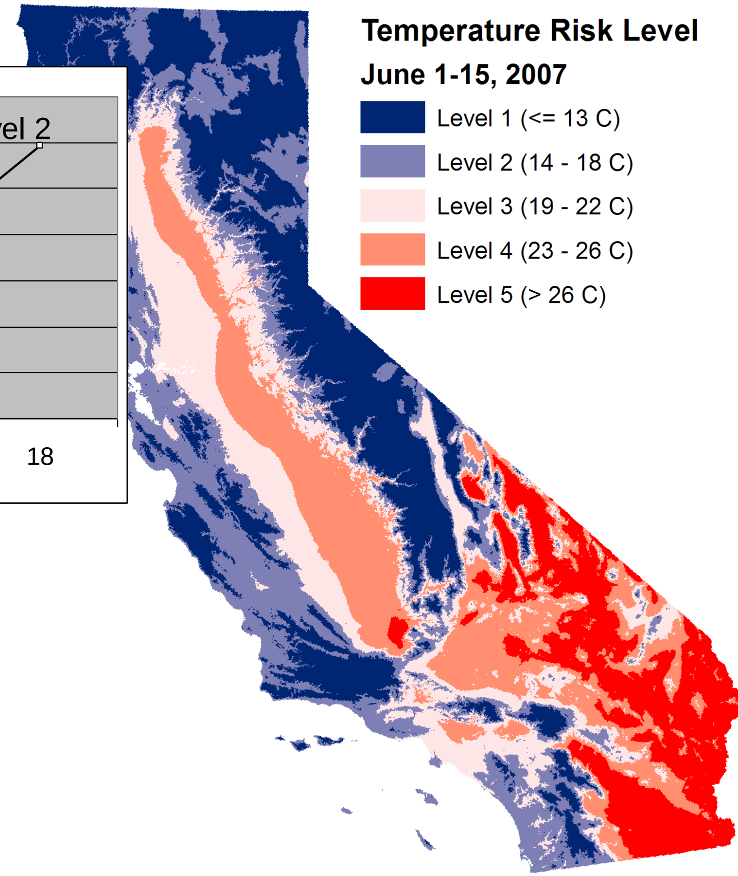


Nemani et al., 2003 and 2007

Assigning WNV risk from TOPS temperature surfaces using the *Cx. tarsalis* WNV EIP model

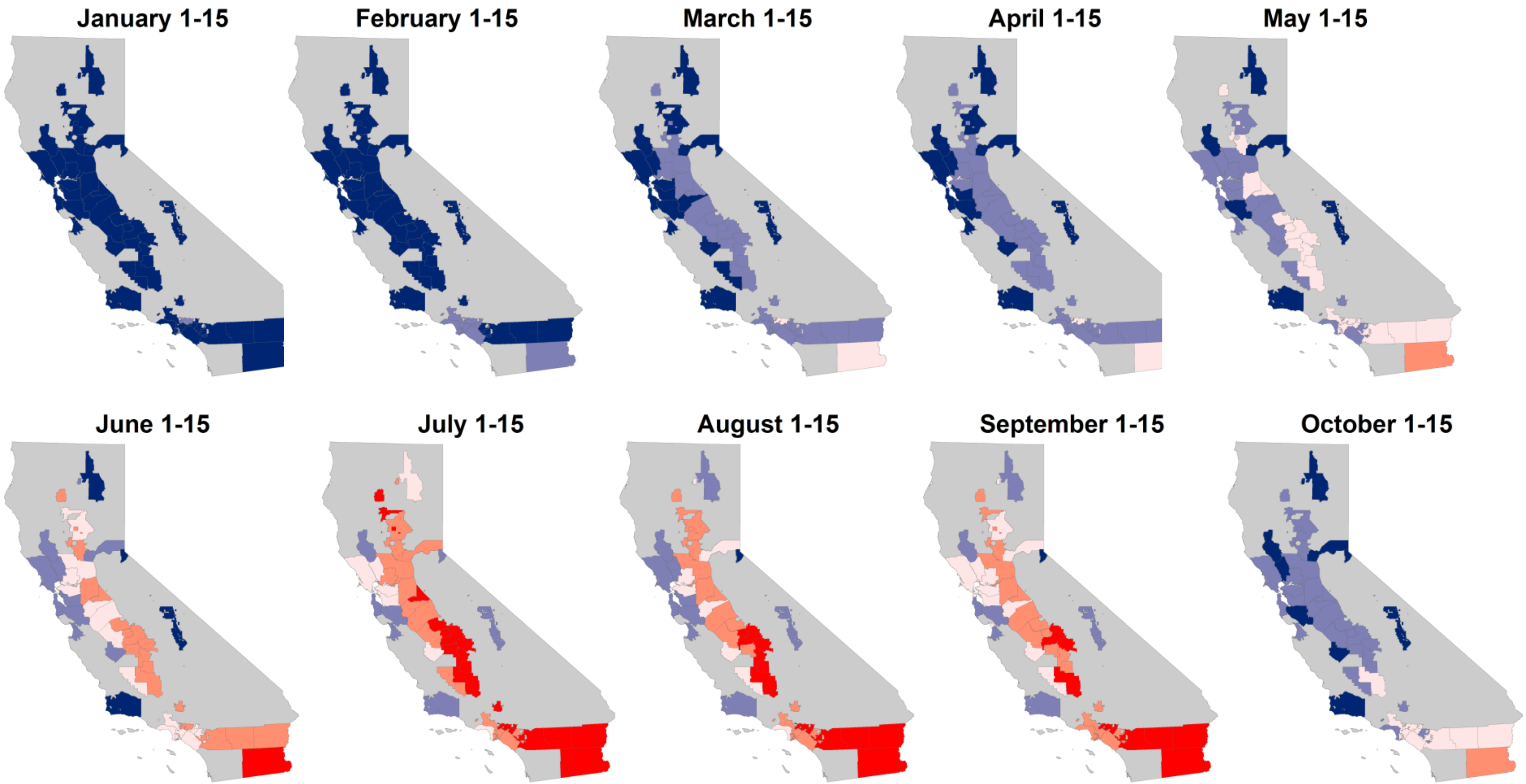


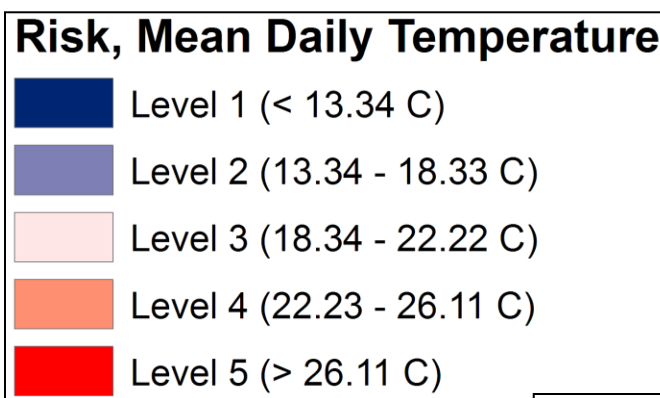


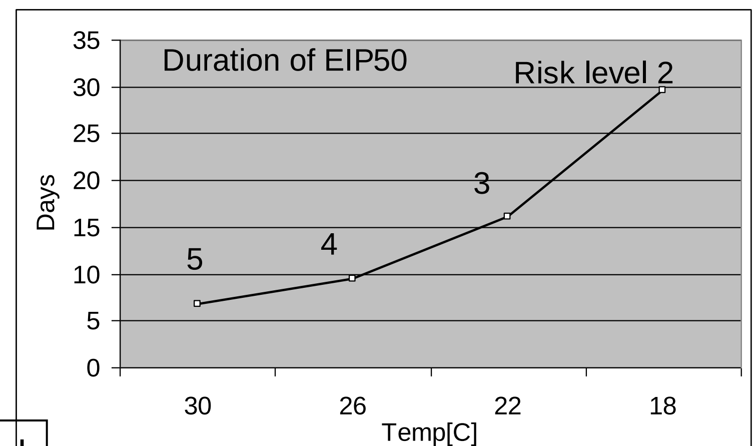


Surface from TOPS for California 1-15 Jun 2007

Assigned risk levels based on average minimum temperature



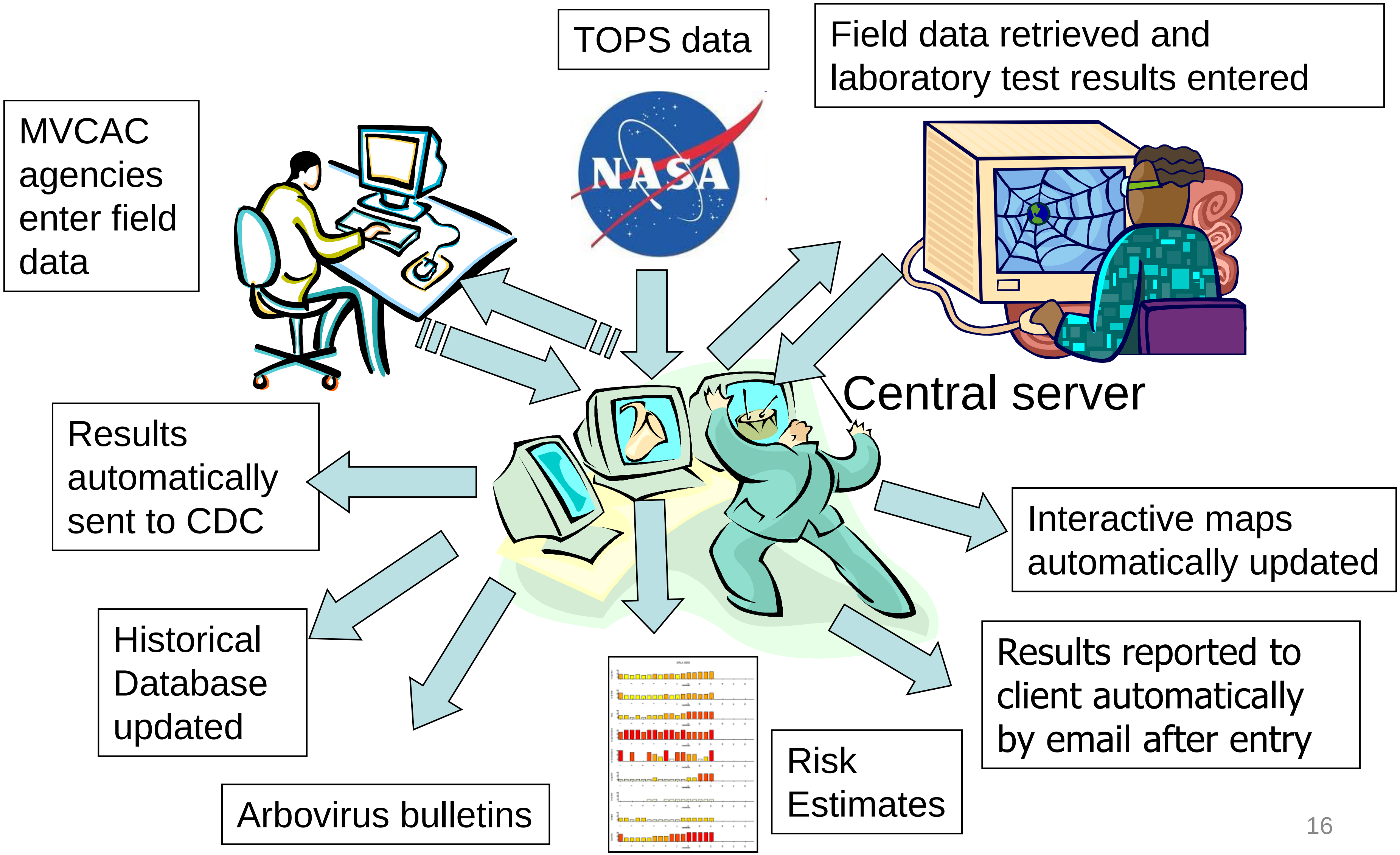


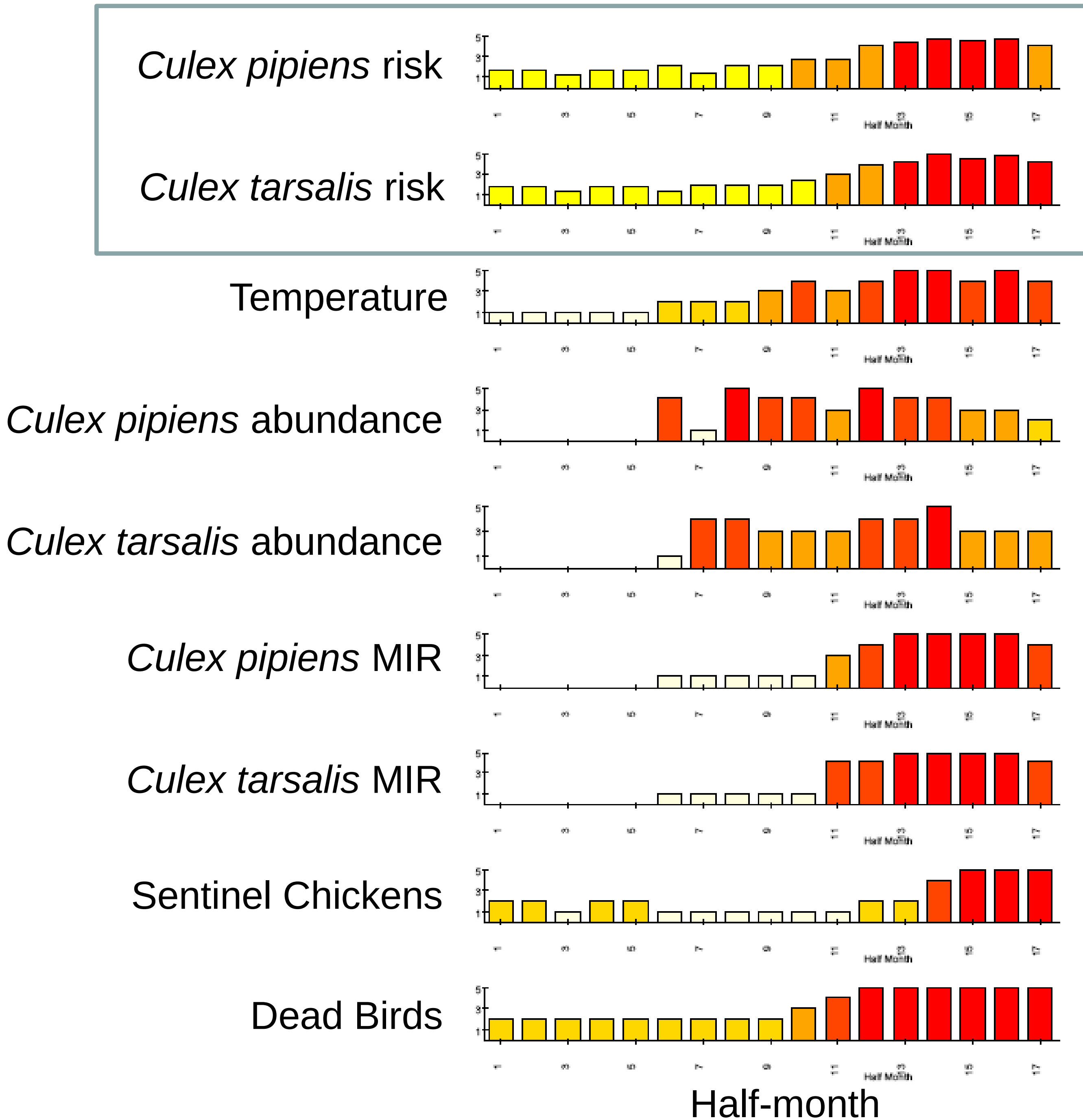


Barker et al. unpublished

CalSurv Surveillance Gateway

Rapid Arbovirus Data Acquisition and Reporting system

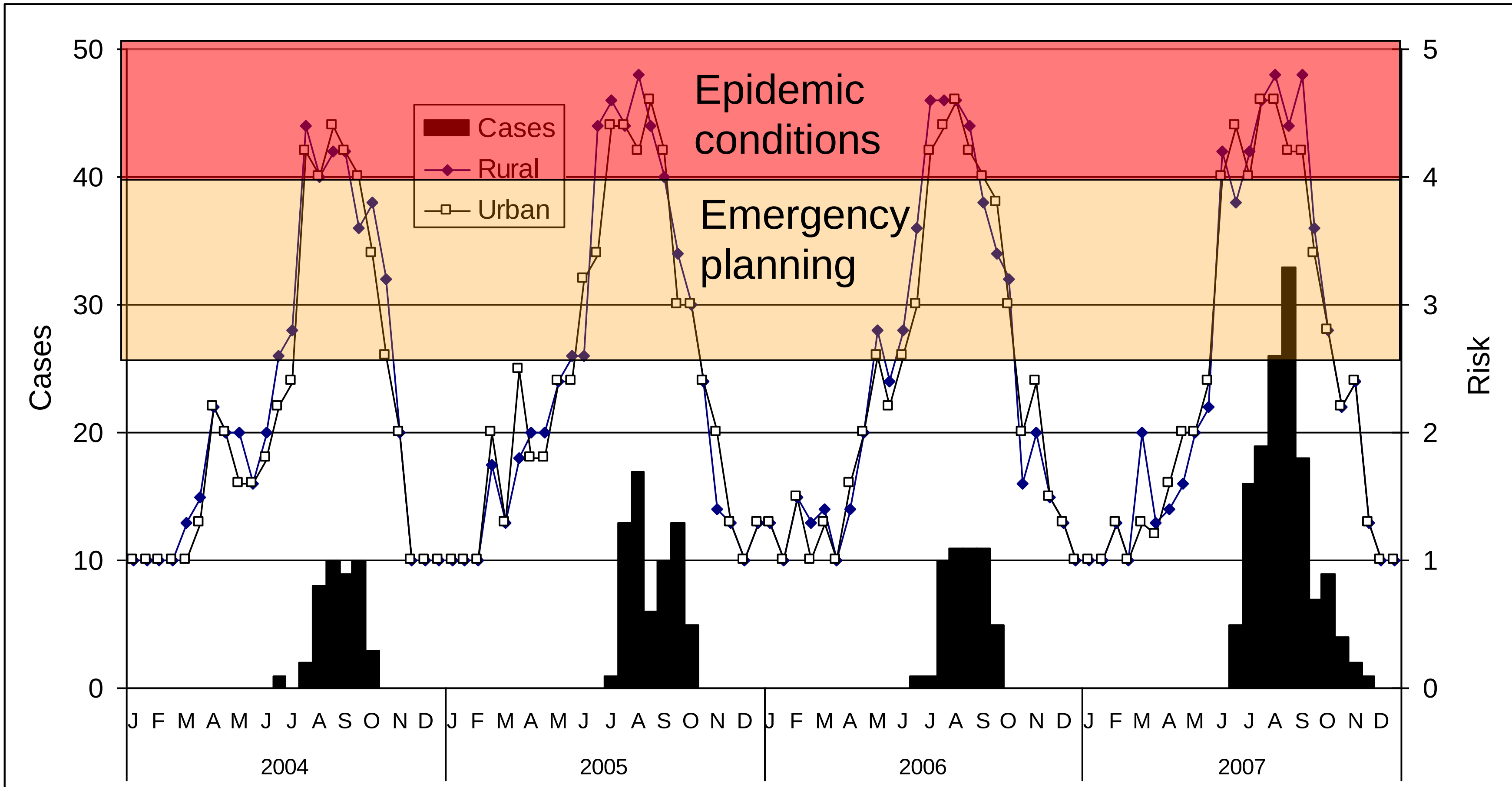




CMVSRP provides nowcasts of WNV transmission risk

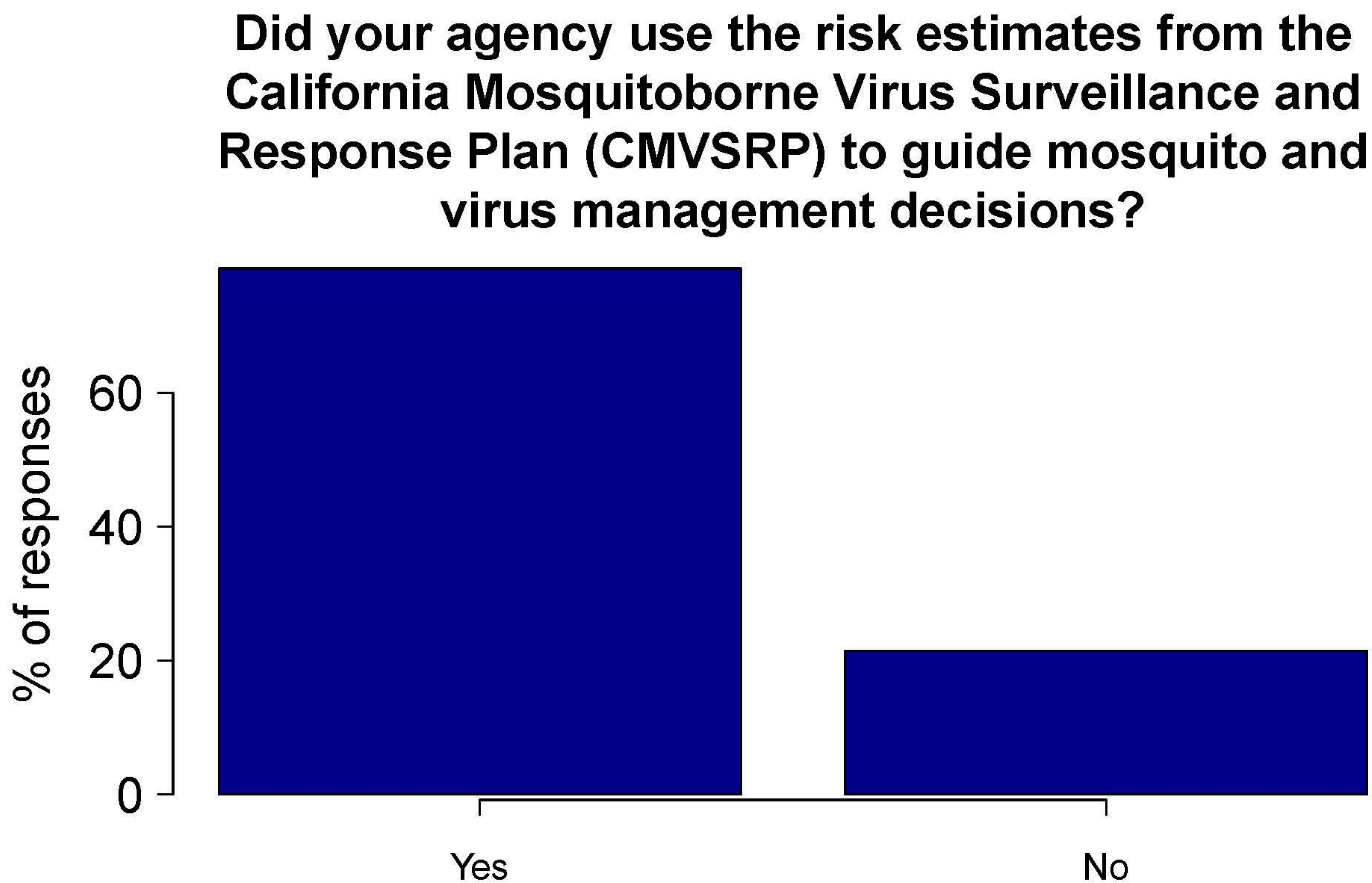
Yellow – normal season
Orange – emergency planning
Red – epidemic

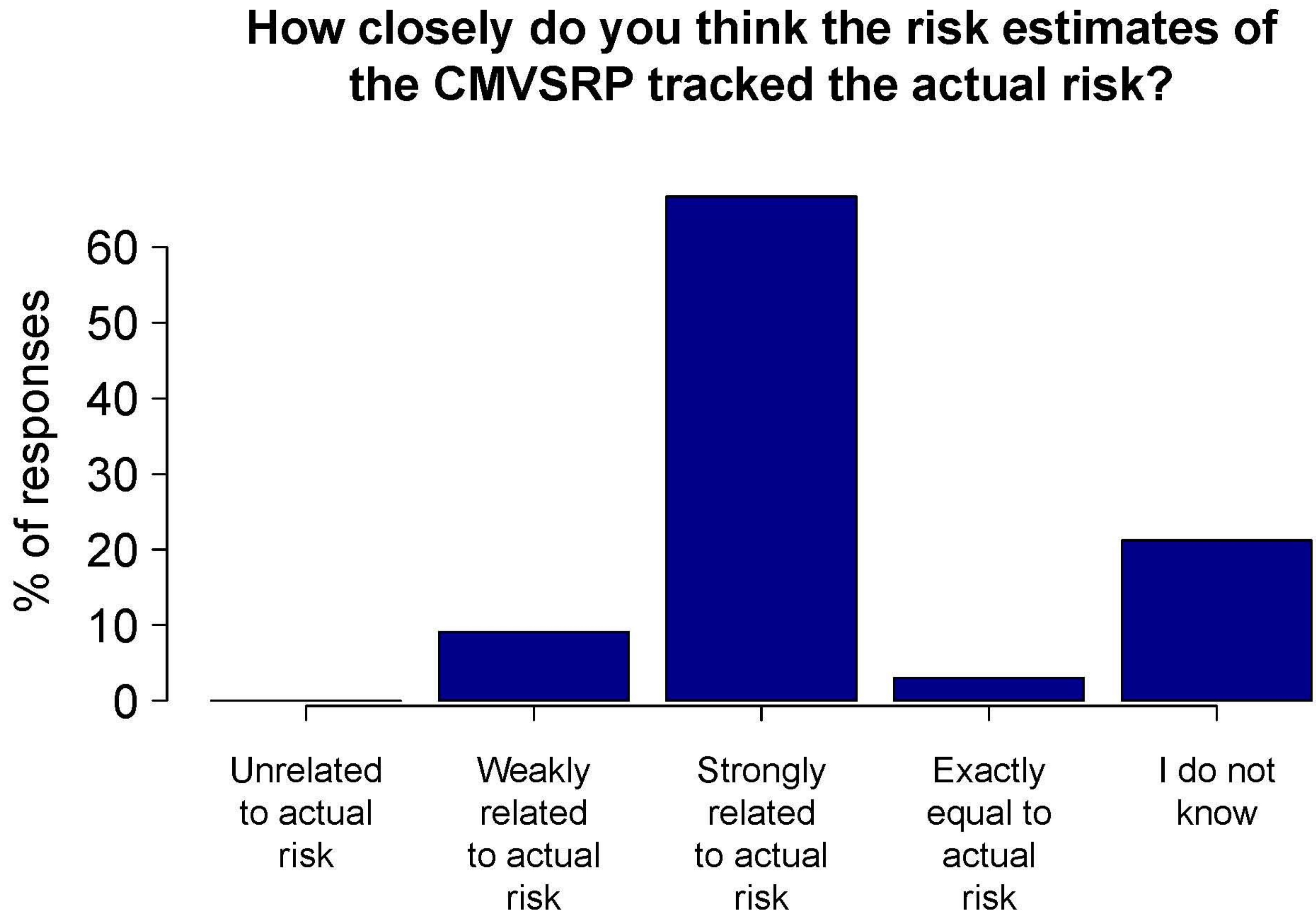
Temporal changes in risk estimated from enzootic surveillance and numbers of human cases, Kern County, California, 2004 – 2007.



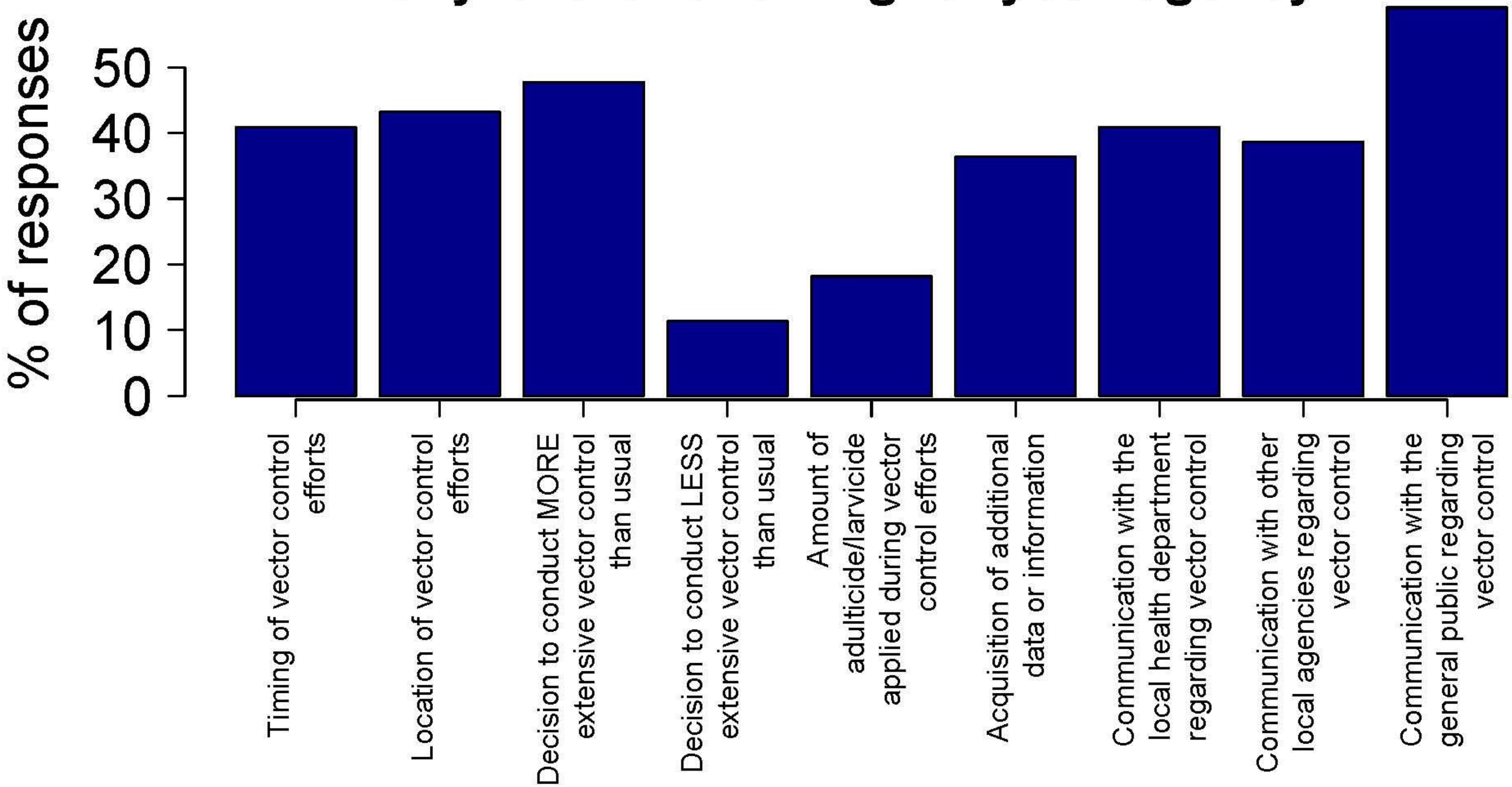
Reisen et al. 2008. JME

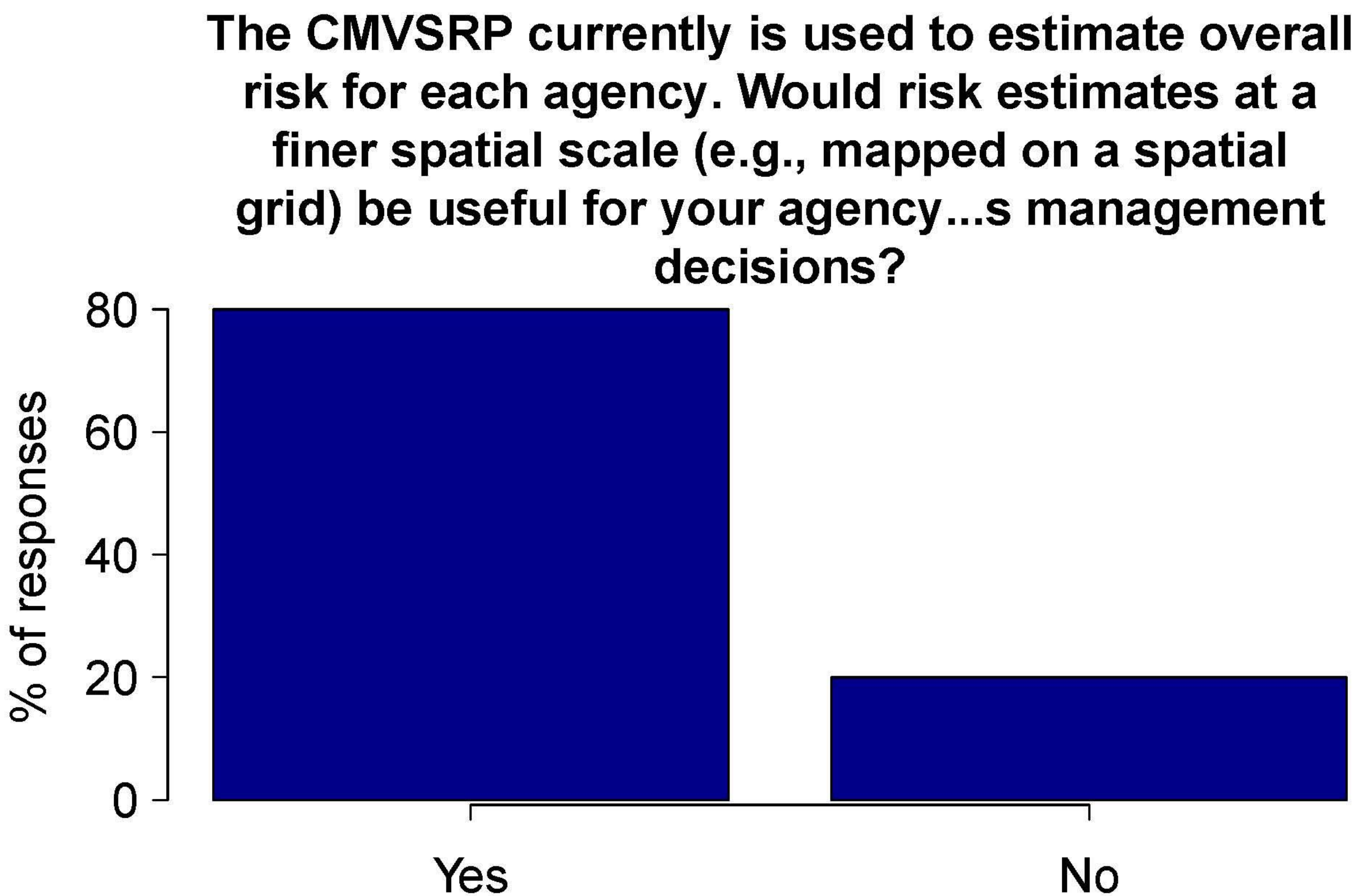
During 2010 surveyed MVCAC clients to determine use of our improved DSS




How closely do you think the risk estimates of the CMVSRP tracked the actual risk?
% of responses
0
10
20
30
40
50
60
Unrelated to actual risk
Weakly related to actual risk
Strongly related to actual risk
Exactly equal to actual risk
I do not know

Did the automated CMVSRP risk assessments (received by email for the 2008 and 2009 surveillance year) or other information from the CalSurv Gateway (e.g., online calculators for mosquito abundance or infection rates) influence any of the following for your agency?





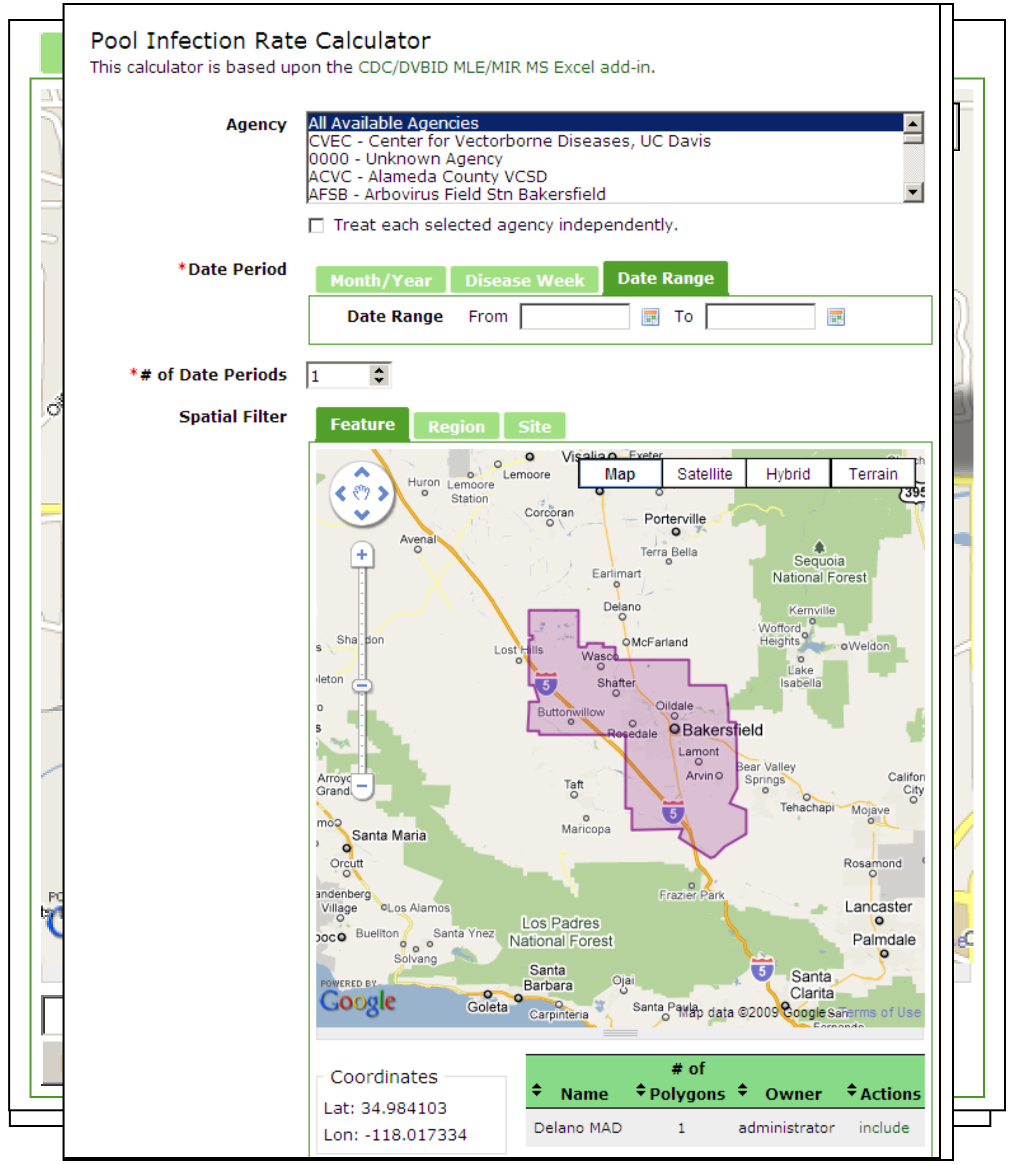
The CMVSRP currently is used to estimate overall risk for each agency. Would risk estimates at a finer spatial scale (e.g., mapped on a spatial grid) be useful for your agency...s management decisions?
80
60
40
20
0
% of responses
Yes
No

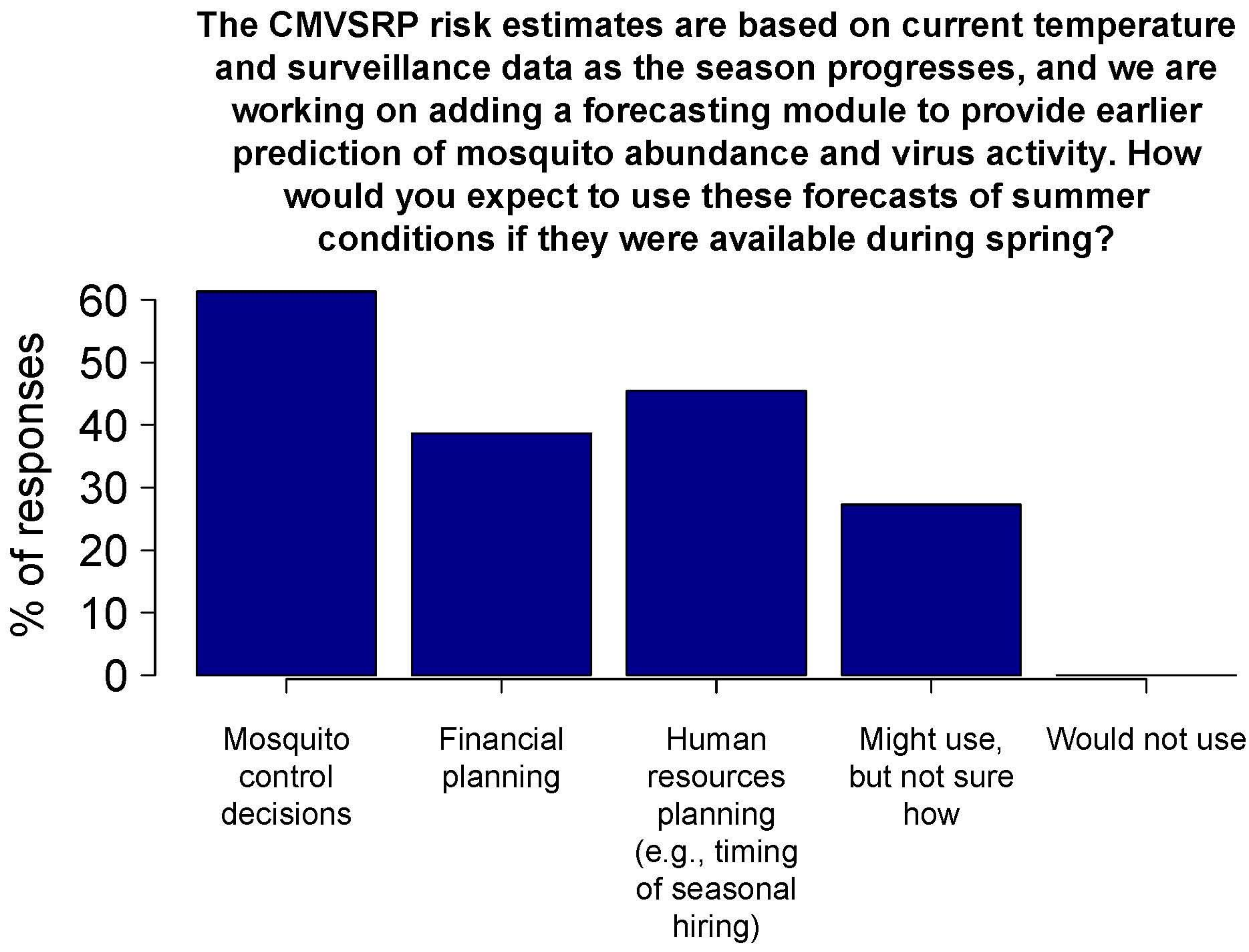
Gateway v2

- Inherent limitations of v1
  - Site codes were fixed once information set
  - Inability to edit/delete existing records
  - Performance issues related to data spatial aggregation
  - Lack of portability
- Inclusion of new software and tools
  - Spatial integration
  - Ease of use
  - Google maps

Spatial Capabilities

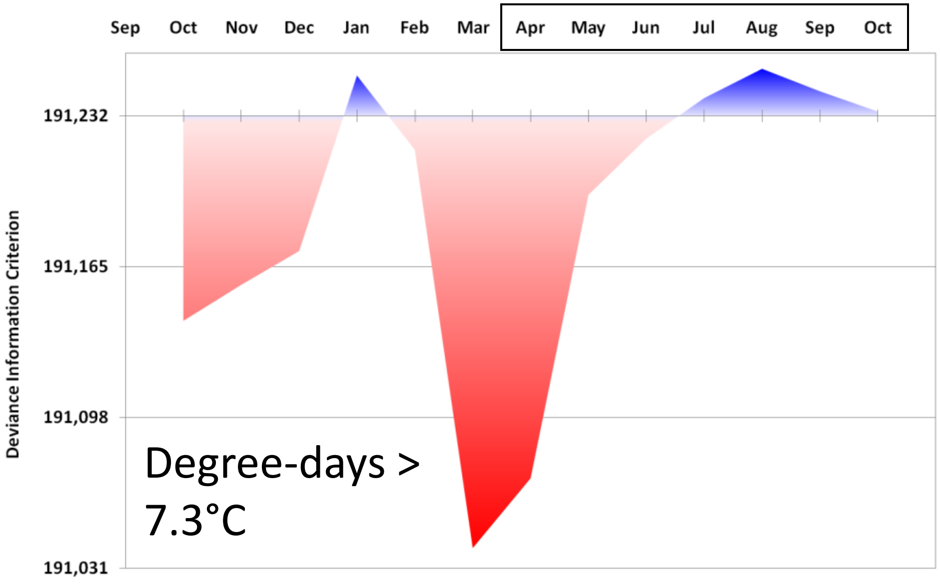
- Use of Google Maps
  - Visualization of site coordinates
  - Placement of trap for arthropod collections
  - Ability to draw, import and export polygons
- Reverse geocoding
- Spatial relationships
  - Calculators use of polygons to filter data to what is appropriate

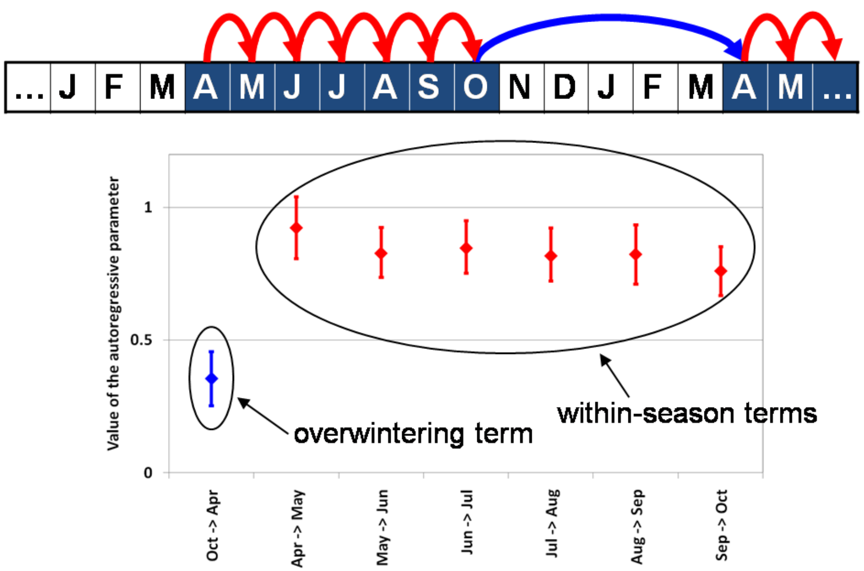



The CMVSRP risk estimates are based on current temperature and surveillance data as the season progresses, and we are working on adding a forecasting module to provide earlier prediction of mosquito abundance and virus activity. How would you expect to use these forecasts of summer conditions if they were available during spring?
% of responses
0
10
20
30
40
50
60
Mosquito control decisions
Financial planning
Human resources planning (e.g., timing of seasonal hiring)
Might use, but not sure how
Would not use

Forecasting Mosquito Abundance and WNV Transmission

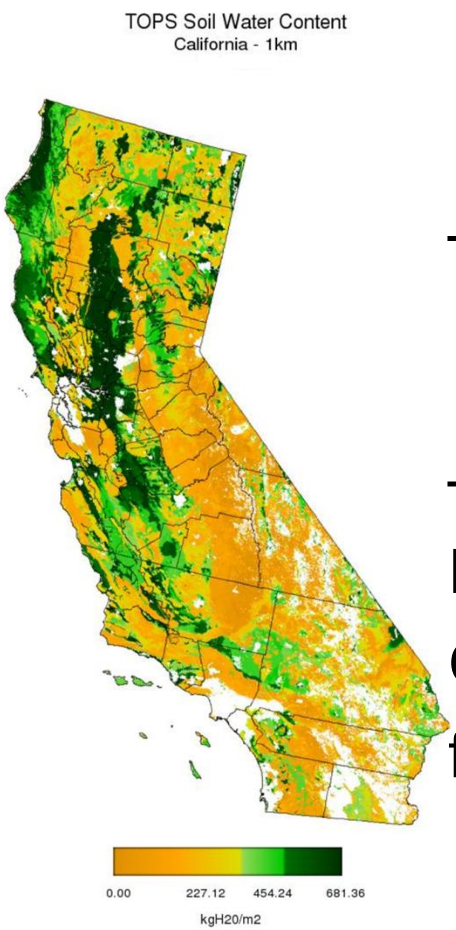
- Key results from earlier models:
  - Mar-Apr climate variables were the best predictors of summer mosquito abundance
  - Mosquito abundance during fall was positively associated with abundance the following spring





Forecasting Mosquito Abundance and WNV Transmission

- Current projects:



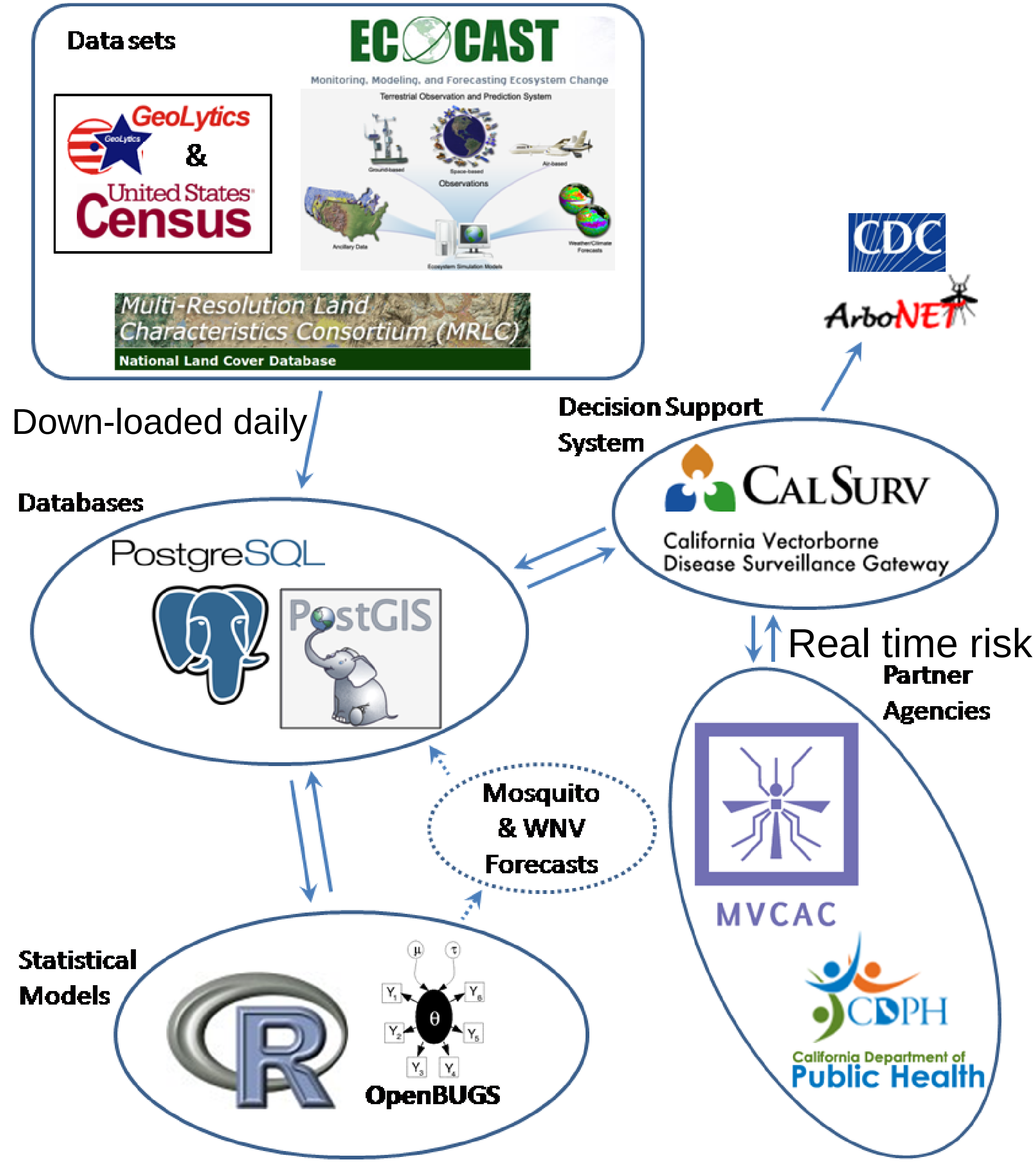
  - Incorporate prior parameter information from our earlier modeling into Bayesian probabilistic forecasts
  - Use prospective surveillance data to evaluate the real-time performance of the forecasts
  - Improve forecasts using additional

MODIS-derived data products (e.g.,

GPP, soil water, and vegetation indices)

from partners at NASA Ames

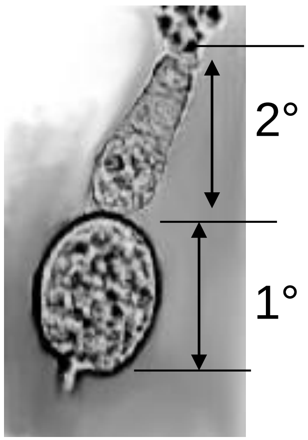
Current Decision Support System Architecture

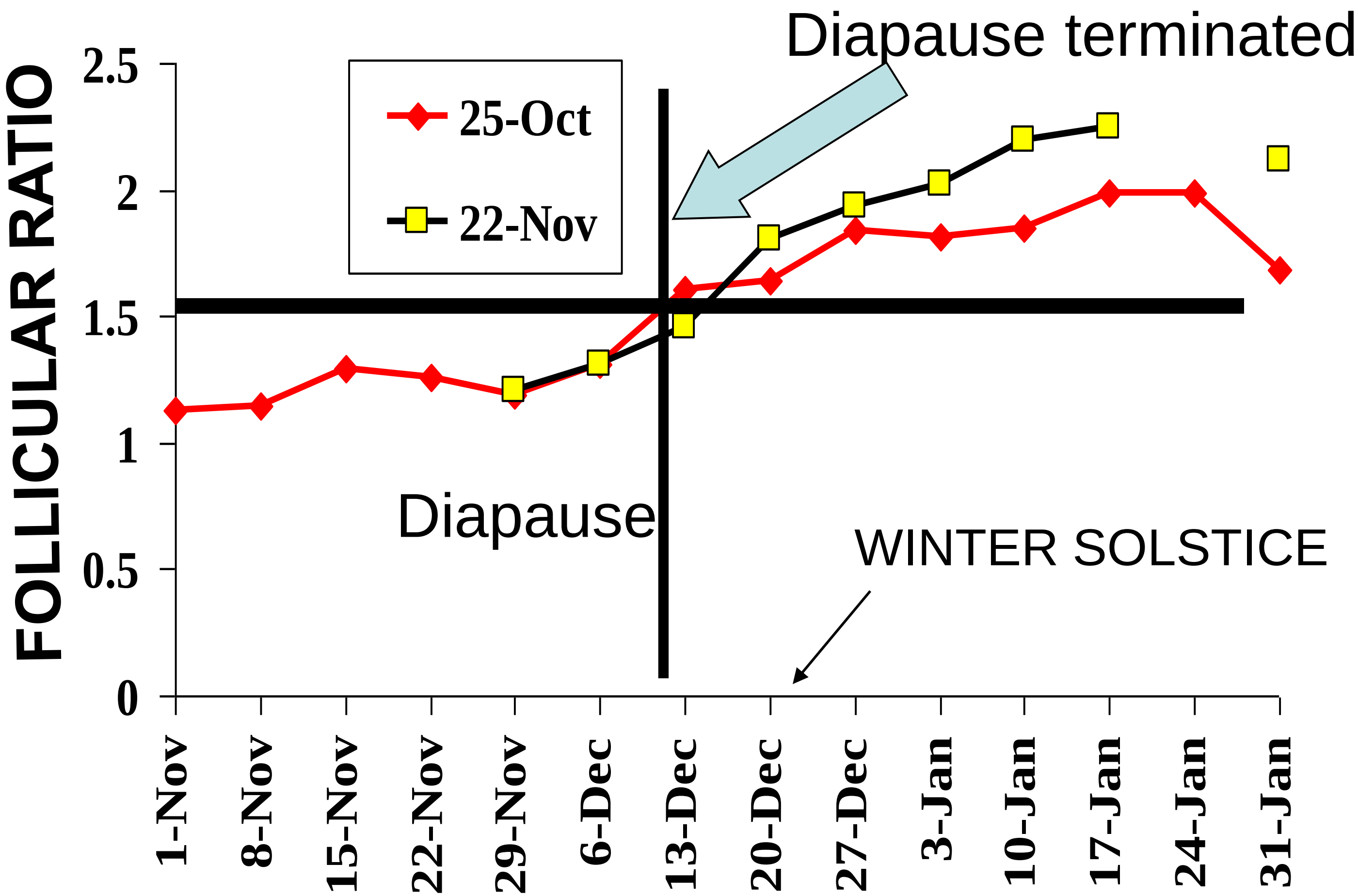


Planned Forecasts

- NIH project: vernal WNV amplification model
  - Start diapause termination date
  - Temperature driven
  - Negative impact of avian herd immunity
- CDC project: climate change seasons in advance forecasts
  - Winter climate
  - Vernal climate and land-cover conditions

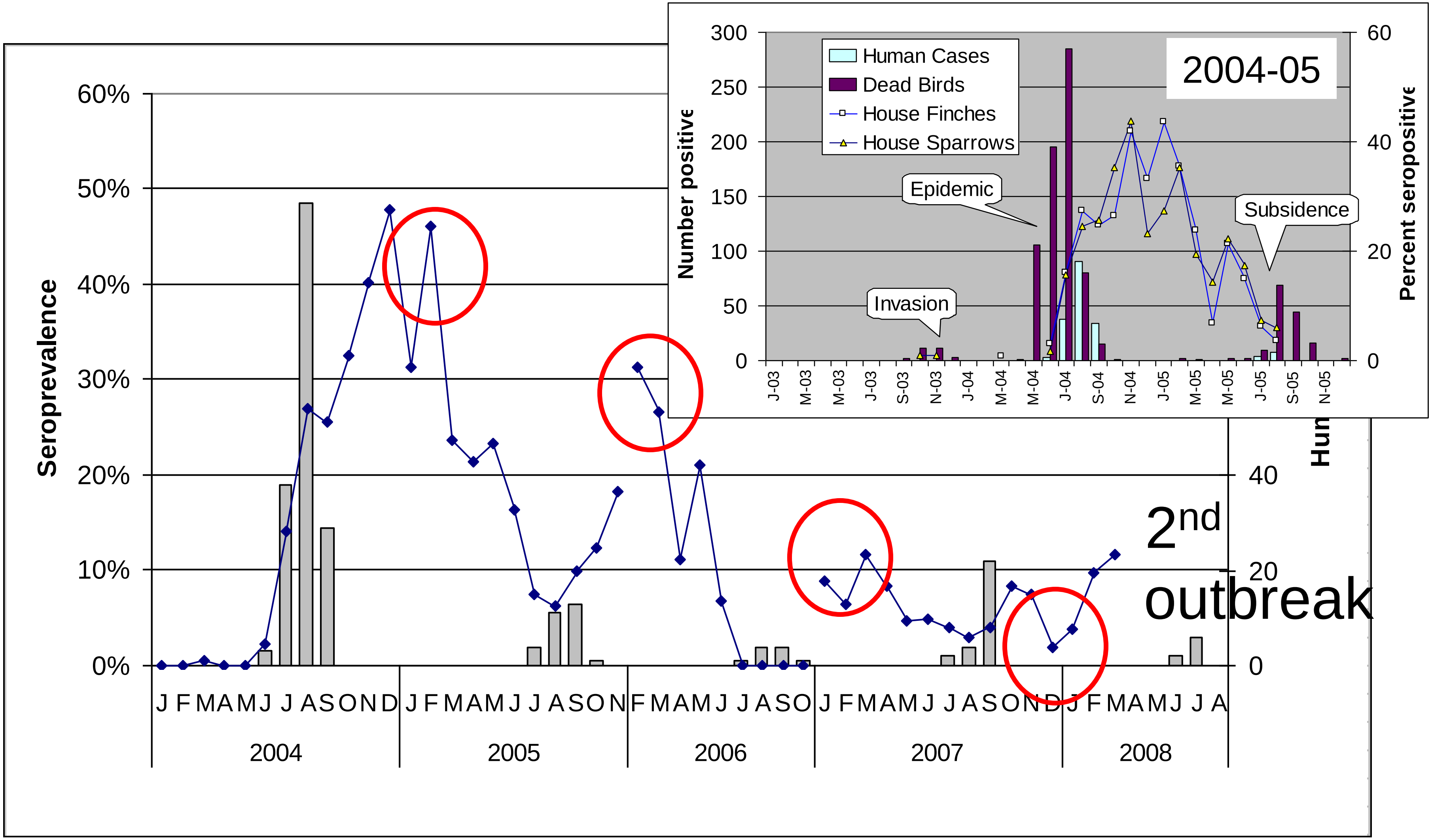
Cx. tarsalis Diapause Maintenance and Termination in Coachella Valley





Reisen et al. 1995. JME 32: 654

AVIAN HERD IMMUNITY: HOFI and HOSP seroprevalence and human cases per month, Los Angeles, 2004 - 2008



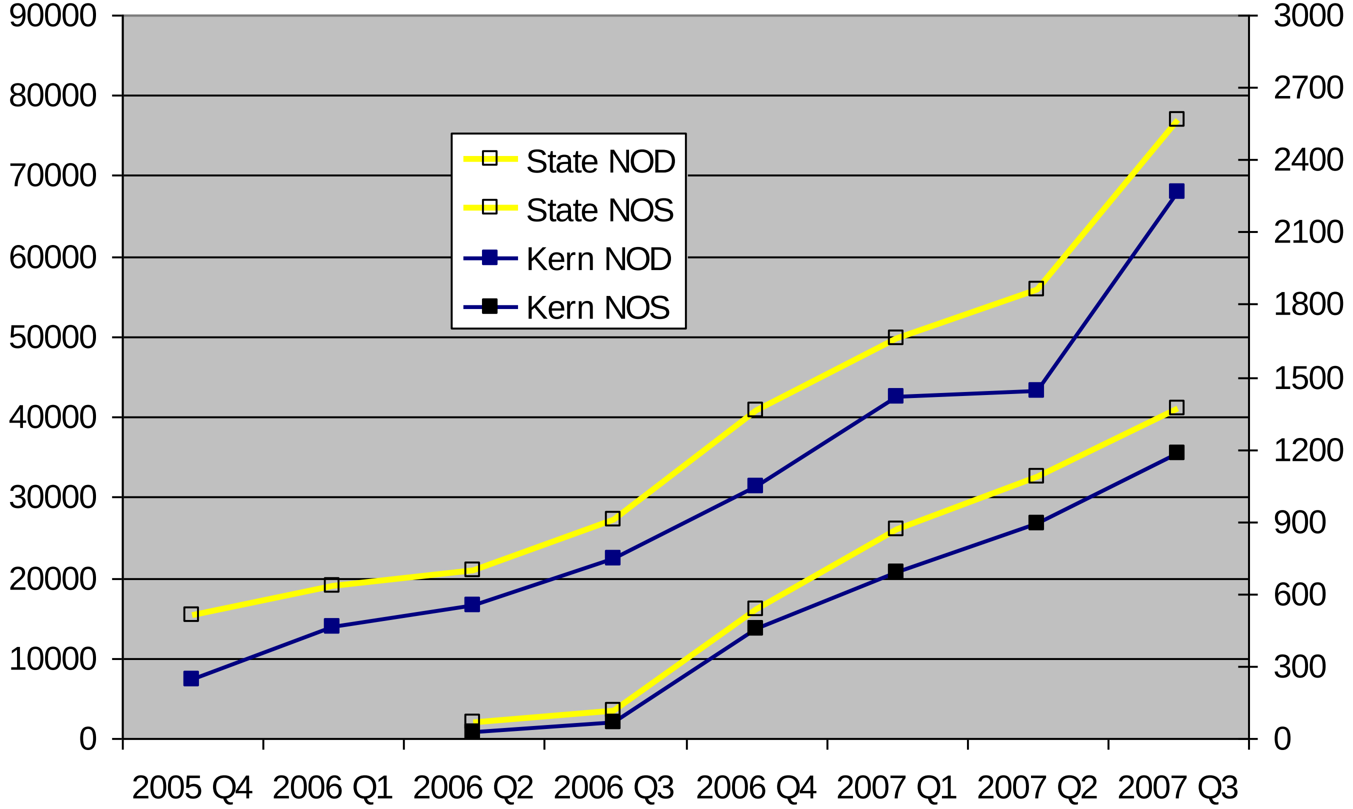
Kwan et al. 2010. AJTMH

Other on-going projects

- Export Surveillance Gateway: Washington State, presentations to Pennsylvania, Florida, Louisiana
- Neglected swimming pools – a new urban risk factor for WNV [F Melton]
- CDC Ft Collins: “Population-based standardized surveillance”
- NIH Research and Policy in Infectious Disease Dynamics (RAPIDD) program, Modeling Mosquito-Borne Diseases Working Group
  – Mathematical models of transmission [D Hartley]
  – WNV dispersal in California [D Hartley]
  – Process based risk assessments [Barker]

California Home Foreclosures:

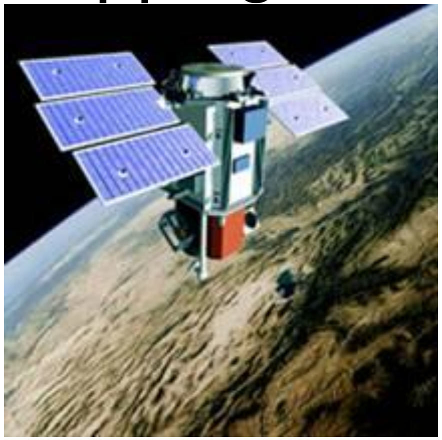
NOD- notice of delinquency; NOS- notice of sale



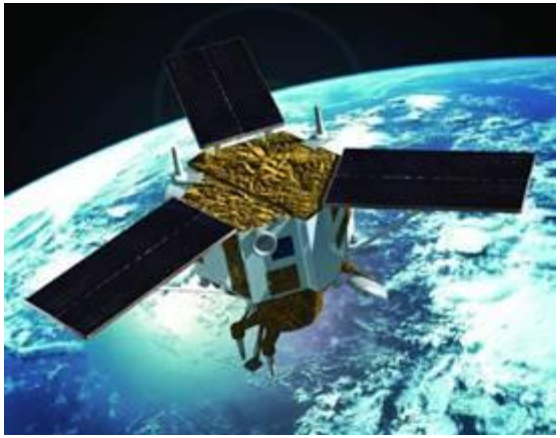
NOD 2007Q3/2006 Q3 = 300%
Increase in WNV cases = 276%

Adjustable rate mortgages, abandoned houses and neglected swimming pools: factors contributing to the 2007 WNV outbreak in Bakersfield [Reisen et al. 2008. EID]

Mapping Green Pools with Satellite Data: Sensors



Quickbird (2)



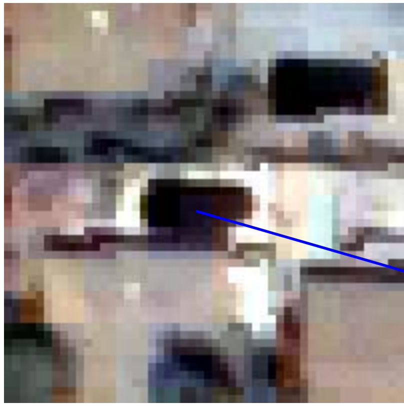
Ikonos

GeoEye

	Pan	Blue	Green	Red	Near-IR
Quickbird	450–900 nm / 0.6m	450-520 nm / 2.4m	520-600 nm / 2.4m	630 – 690nm / 2.4m	760 – 900 nm / 2.4m
Ikonos	526-929 nm / 0.8m	445-516nm / 3.2m	506-595 nm / 3.2	632-698nm / 3.2m	757-893nm / 3.2m
GeoEye	450-800nm / 0.4m	450-510nm / 1.65m	510-580 nm / 1.65	655-690nm / 1.65m	780-920nm /1.65m

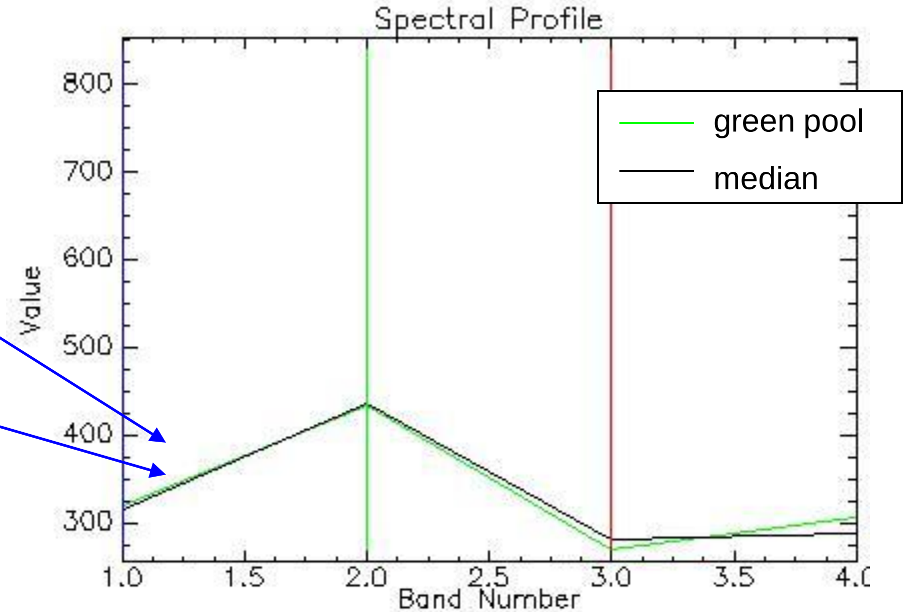
- **Pan-sharpened multispec data with 0.4 - 0.8 m spatial resolution**
- **Data cost of ~$25/km^2 ; $500-$2500 minimum order**

Mapping Green Pools using Spectral Signatures

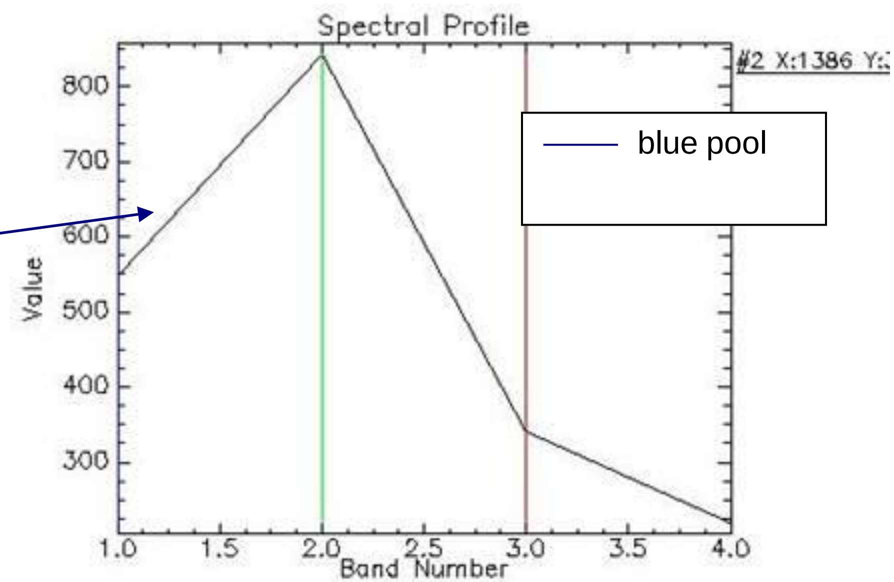


green pool

asphalt / median

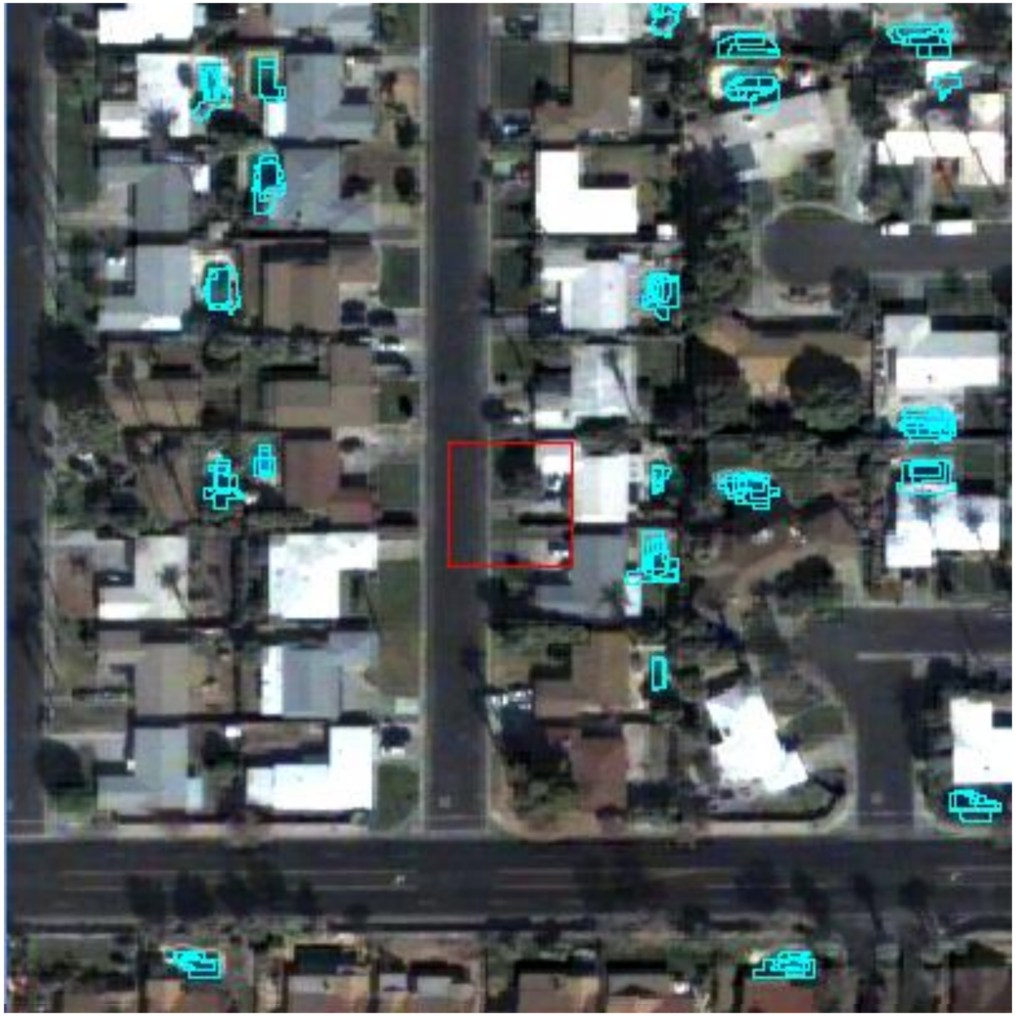


- **Unfortunately, green pools and asphalt / medians are similar spectrally in Quickbird and Ikonos multispectral data**
- **But blue pools are distinct**
- **Change detection approach using mask derived from 2004 imagery**



Mapping Blue Pools

- Results: >500 potential pools mapped in 25km^2 region
- Image segmentation proved to be more accurate in mapping pool boundaries; but spectral thresholds also effective and easier to automate
- Blue pool map based on blue/green band used to filter spectral thresholds for neglected / green pools



Algorithm Performance

- Compared unsupervised classification versus manual identification using twenty 200m x 200m randomly selected image subsets with at least one candidate pool
  - 77 total candidate pools identified manually; 55 pools detected by automated algorithm
  - 71% detection rate for automated algorithm
  - 16 likely false positives (22% of candidates)

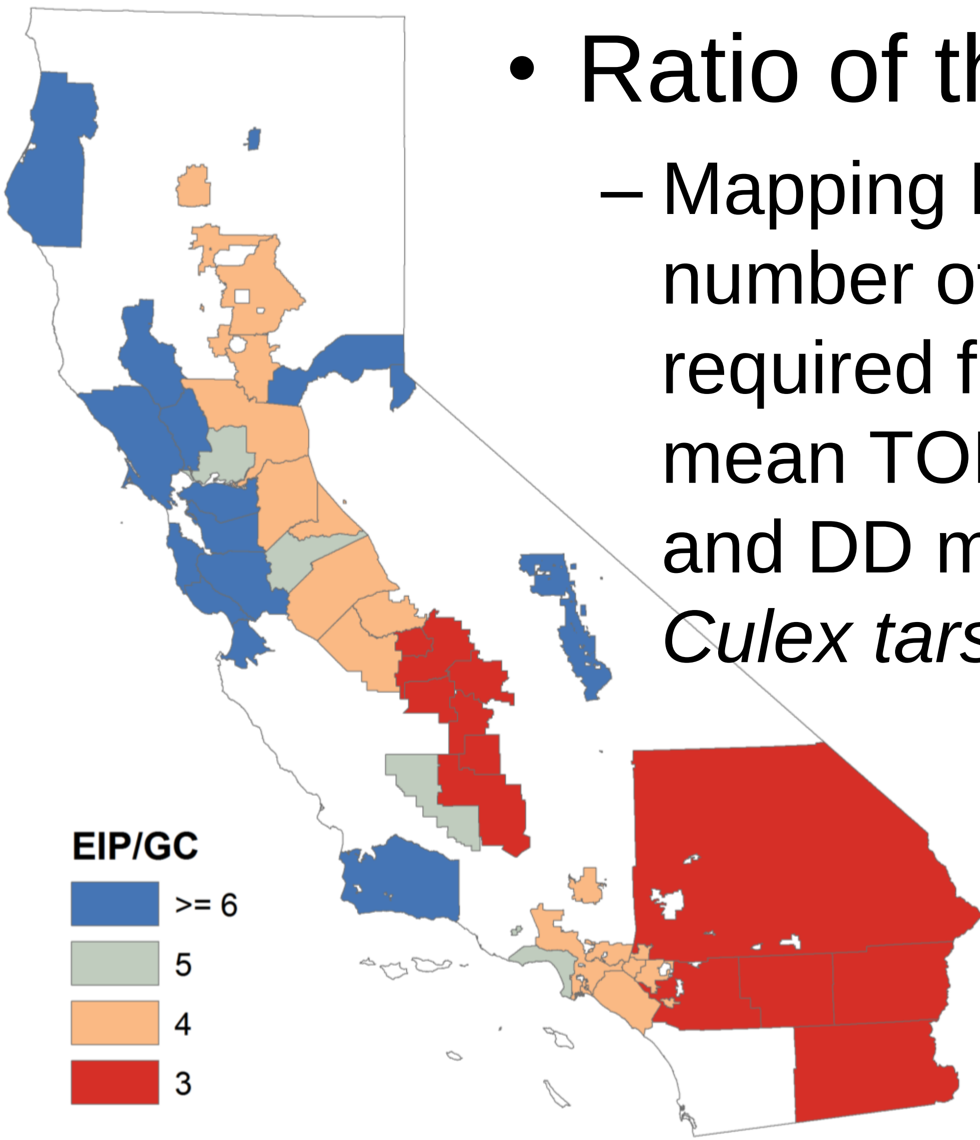
Benefits and Limitations of Approach

May 2008

Oct 2004

- Potentially fully automatable and lower cost than manual classification from aerial data; support initial assessment and mapping
- Difficult to map pools that were empty, dark, covered, shaded, or not yet constructed in baseline imagery
- Will not detect all neglected pools; technique best used as a supplement for aerial mapping or ground surveys
- Update for 2010 currently being prepared for Coachella Valley and Los Angeles

Other measures of risk



- Ratio of the EIP/GC
  - Mapping EIP in terms of the number of gonotrophic cycles required for transmission. Based on mean TOPS temp for August 2003 and DD models for GC and EIP in *Culex tarsalis.*

- Temp -> rate of GC or EIP
- 1/rate = duration in days
- EIP/GC = number of GC required for completion of EIP

Publications in journals, meeting proceedings and book chapters

Papers published on climate variation and decision support systems

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Reisen WK, Martinez VM, Fang Y. 2006. Impact of temperature on the transmission of West Nile virus. Proc Mosq Vector Control Assoc Calif 74:21-22

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Reisen WK, Brault AC. 2007. West Nile virus in North America: perspectives on epidemiology and intervention. Pest Management Sci 63:641-646

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Reisen WK. 2008. How climate affects mosquito biology and arbovirus transmission. Proc Mosq Vector Control Assoc Calif 76:57-63

Reisen WK, Takahashi RM, Carroll BD, Quiring R. 2008. Delinquent mortgages, neglected swimming pools, and West Nile virus, California. Emerg Infect Dis 14:1747-1749.PM:18976560.

Reisen WK, Lothrop HD, Wheeler SS, Kennsington M, Gutierrez A, Fang Y, Garcia S, Lothrop B. 2008. Persistent West Nile virus transmission and the apparent displacement St. Louis encephalitis virus in southeastern California, 2003-2006. J Med Entomol 45:494-508.PM:18533445.

Reisen WK. 2009. Impacts on biological systems: mosquito-borne diseases. Indicators of Climate Change in California. Sacramento, CA: Integrated Risk Assessment Branch, California Environmental Protection Agency.

Reisen WK, Carroll BD, Takahashi R, Fang Y, Garcia S, Martinez VM, Quiring R. 2009. Repeated West Nile virus epidemic transmission in Kern County, California, 2004-2007. J Med Entomol 46:139-157.PM:19198528.

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Reisen WK, Thiemann T, Barker CM, Lu H, Carroll B, Fang Y, Lothrop HD. 2010. Effects of warm winter temperature on the abundance and gonotrophic activity of Culex (Diptera: Culicidae) in California. J Med Entomol 47:230-237.PM:20380305.

Partial listing of presentations at local, national and international meetings

Presentations at State and National Meetings.

2006: WK Reisen. "Impact of temperature on transmission", "Field evidence of vertical transmission", "Conclusions" in Symposium entitled Invasion of California by West Nile virus – year 3 at 74th Annual Conference of the Mosquito and Vector Control Association of California, Reno, NV

2006: WK Reisen. "Overview of West Nile virus in the United State" in symposium entitled West Nile virus at European meeting of the Society of Vector Ecology, Serres, Greece.

2006: WK Reisen "Effects of climate variation of mosquitoes and arboviruses in California", Invited speaker, 3rd Annual Climate Change Conference, Sacramento, CA.

2007: WK Reisen "Is non-viremic transmission of West Nile virus by *Culex* mosquitoes non-viremic?" at American Mosquito Control Association annual meeting in Orlando, FL.

2007: CA Nielsen and WK Reisen "Ecological observations on the West Nile virus outbreak in Davis, California, 2006", Poster at American Society of Tropical Medicine and Hygiene, Philadelphia, PA

2007: WK Reisen "The Use of Satellite-Generated Meteorological Data to Predict Mosquito-Borne Encephalitis Virus Transmission**"** at Institute of Medicine meeting "Global Climate Change and Extreme Weather Events: Understanding the Potential Contributions to the Emergence, Reemergence and Spread of Infectious Disease", Washington, DC

2008: BF Eldridge and B Park. "CalSurv: One-stop shopping for vectorborne disease surveillance information in California", CM Barker. "Dynamics of California mosquito populations",
Symposium: "Improving the use of climate variation in decision support systems":
1. WK Reisen. "How climate affects mosquito biology and arbovirus transmission"
2. M Dettinger, USGS and Scripps Institution, UC San Diego. "Impact of climate change on California spring run-off: importance to mosquito populations"
3. D Cayan, Scripps Institution, UC San Diego. "Correlations between climate variation and mosquito abundance"
4. F Melton, CSU Monterey Bay / NASA Ames Research Center. "Monitoring and modeling environmental conditions with the NASA Terrestrial Observation and Prediction System"
5. CM Barker, Center for Vectorborne Diseases, UC Davis. "Modelling the response of *Culex tarsalis* to climate variation in California"
6. S Kluh, Greater LA Co. VCD, Los Angeles. "Use of the California Response Plan: LA a case study"
7. B Park, Center for Vectorborne Diseases, UC Davis ." Building upon California's Surveillance Gateway"
8. BF Eldridge, Center for Vectorborne Diseases, UC Davis. "Future directions in data management"

at 76th Annual Conference of the Mosquito and Vector Control Association of California, Palm Springs, CA.

2008: WK Reisen "Integration of remote sensing into encephalitis virus intervention decision support systems" Am Soc Trop Med Hyg, New Orleans, LA

2008: WK Reisen "Using climate change to forecast the risk of arbovirus outbreaks", Invited Plenary Lecture, International Research in Infectious Diseases meeting, Division of Microbiology and Infectious Diseases, NIAID, NIH, Bethesda, MD

2009: CM Barker and WK Reisen. Mosquito encephalitis virus integration using remote sensing for intervention decision support systems, Am Soc Trop Med Hyg, Washington, DC

2009: WK Reisen "West Nile virus ecology in temperate areas", National West Nile virus conference, Savannah, GA.

2009: WK Reisen "West Nile virus in California, USA: introduction, amplification and persistence", 2nd NIAID Research Conference on Emerging Diseases, Sofia, Bulgaria

Sunset at the N Shore of the Salton Sea