Quantifying stream ecosystem resilience to identify thresholds for salmon recovery.

PIs: Adina Merenlender, Vince Resh, G. Matt Kondolf, and Peter Moyle
Contributors: Matt Deitch, Leah Beche, Ted Grantham, David Newburn

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # G4K10732

Significance of thresholds

Identify stream flow thresholds beyond which changes in macroinvertebrate community structure and decline in salmonid survivorship may result using retrospective analysis of existing data.

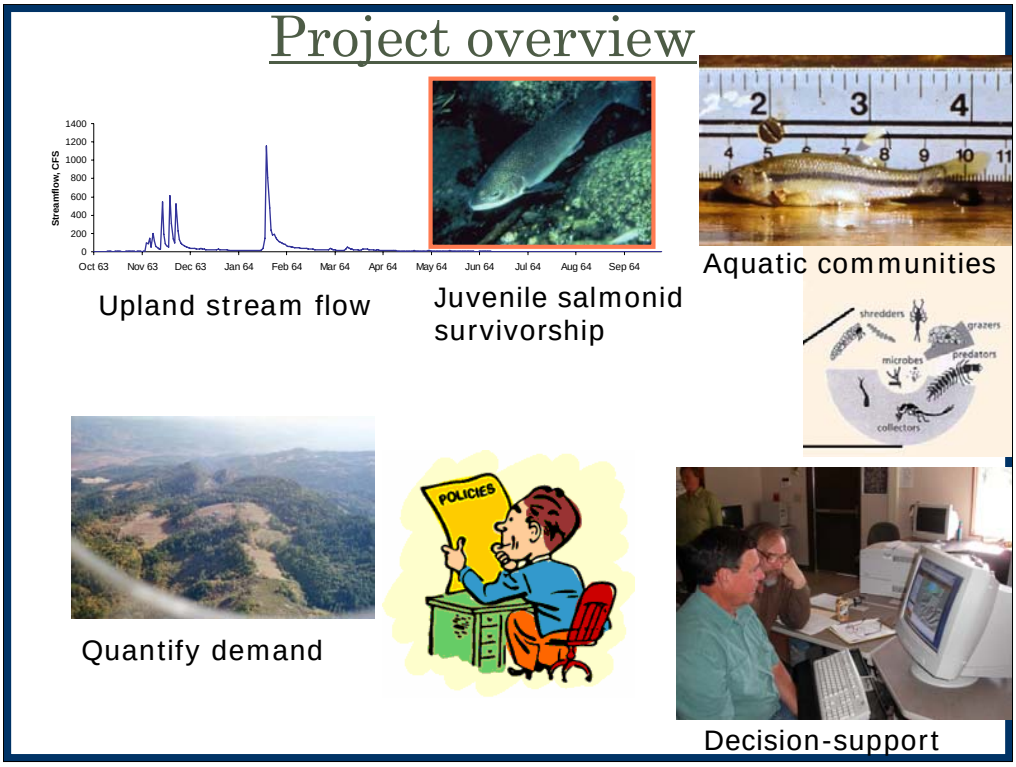
Ecosystem Services Addressed

- Endangered species recovery
- Maintain aquatic biodiversity
- Increase certainty of water supply for wine grape production/economic vitality.

California salmon is an important food source that is culturally significant to some groups.

Overarching Goals

1. Using long-term data sets to examine relationships between flow and aquatic communities and salmonid survivorship and identify thresholds where possible (two studies).
2. Work with stakeholders to collect information on water management and provide science-based information to help prioritize restoration efforts.
3. Develop decision-support tools to examine environmental and economic tradeoffs between winter water storage and dry season pumping and better inform water management and policies to enhance salmon recovery and water security.

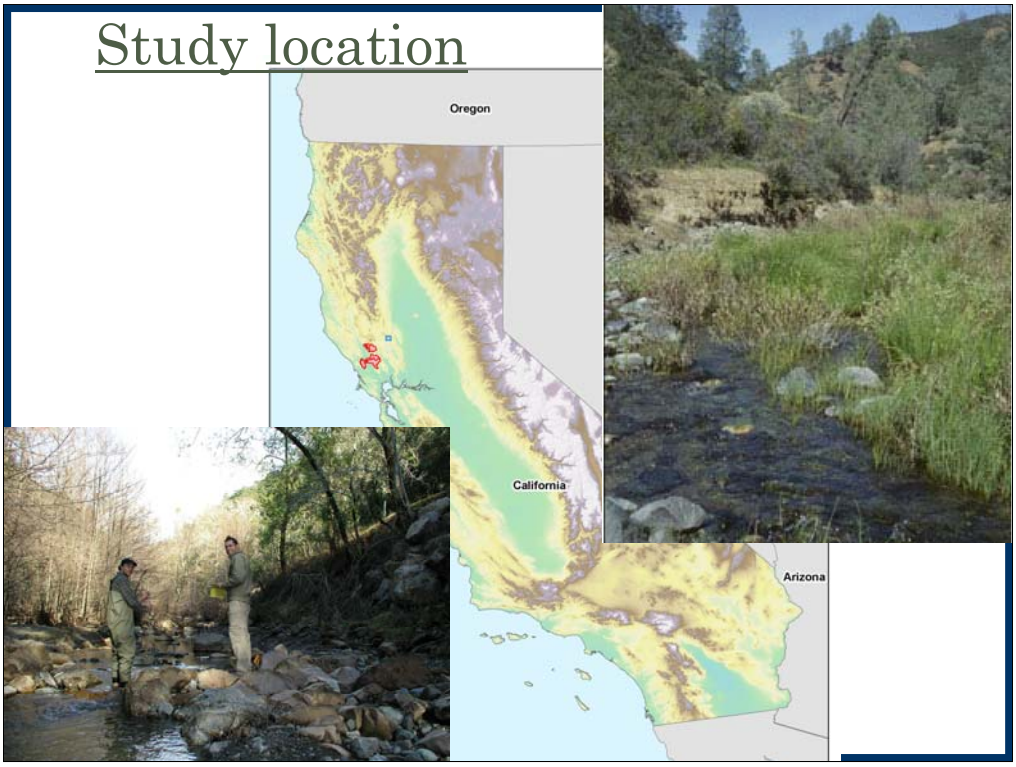


The upland stream flow graph shows data on the upland stream system. Most research conducted to date has focused on the mainstems of large river systems. Thus, there is a major lack of information on upland streams.

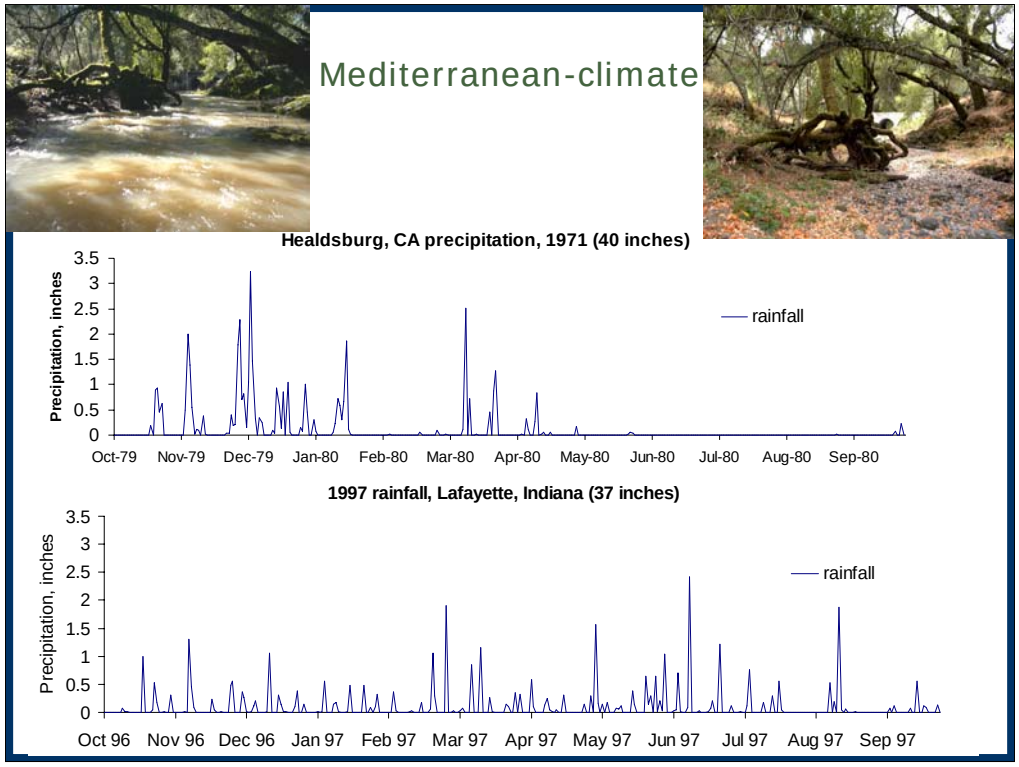
The project has two datasets: one with data on juvenile salmonids, and another with data on other fish populations (both native and exotic).

Increasing amounts of water are being used for agriculture. Thus, the use of water from upland streams has changed rapidly during the past 10-15 years. Some of the work being done on this project will quantify the demands on these upland watersheds.

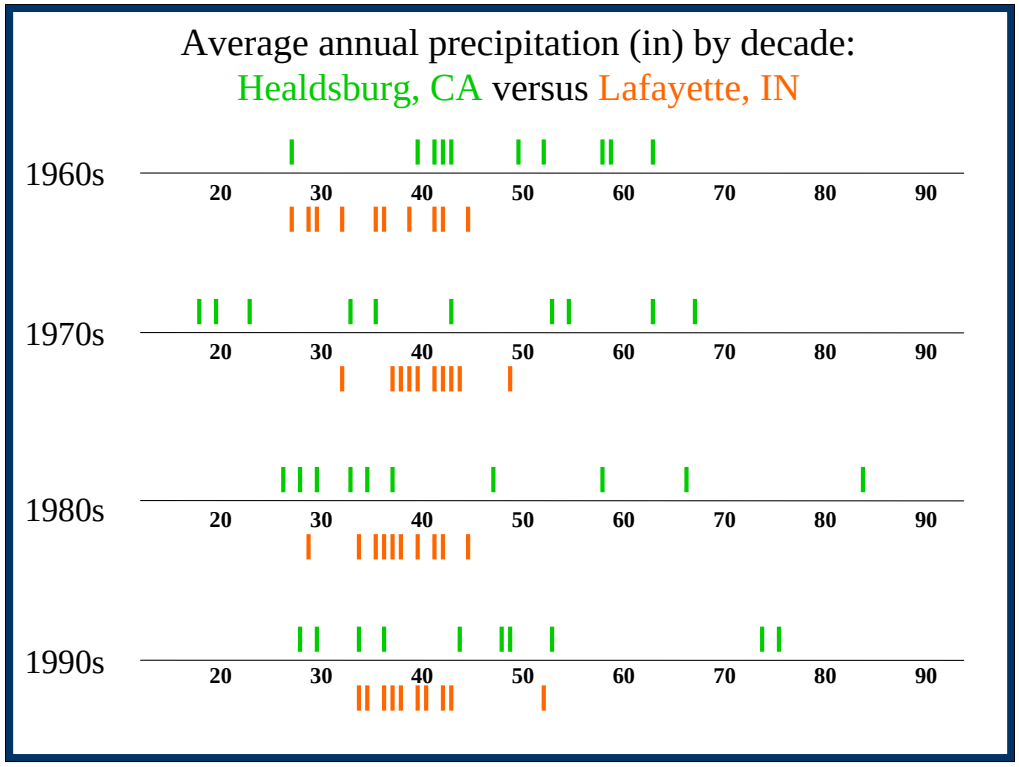
Ultimately, the information gathered will be used to support water policy.



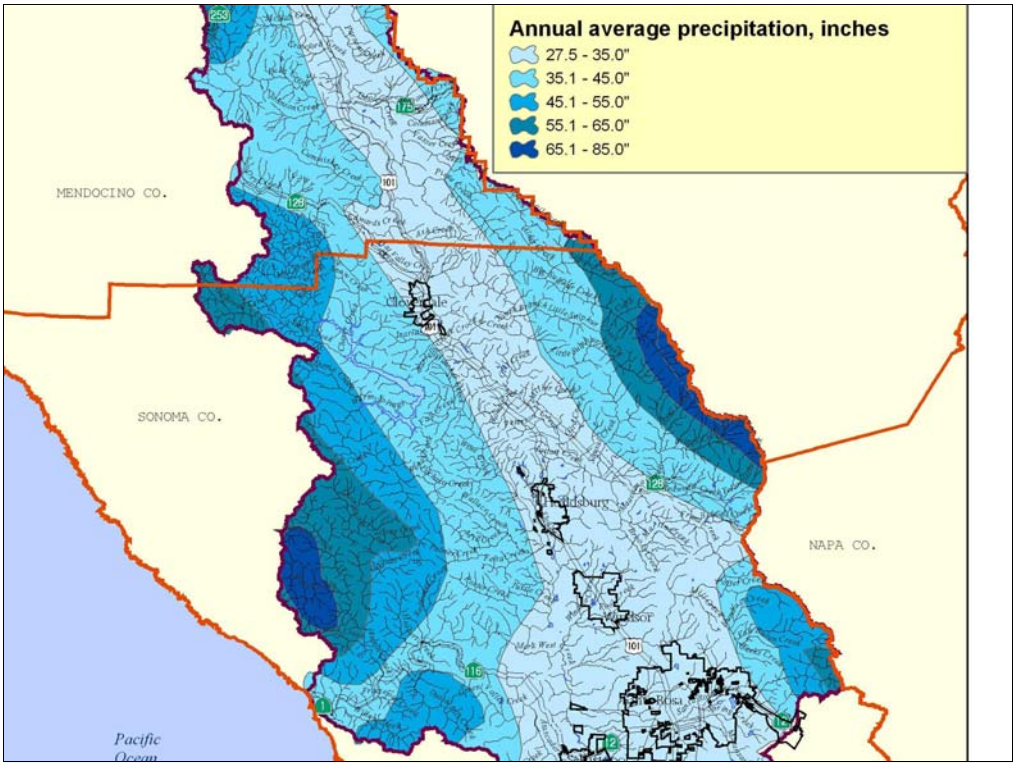
There are two study sites. The red area is the San Francisco Bay Area, which includes the Russian River Basin area. Salmon survivorship is being studied there. The blue area represents creeks in Napa Valley.



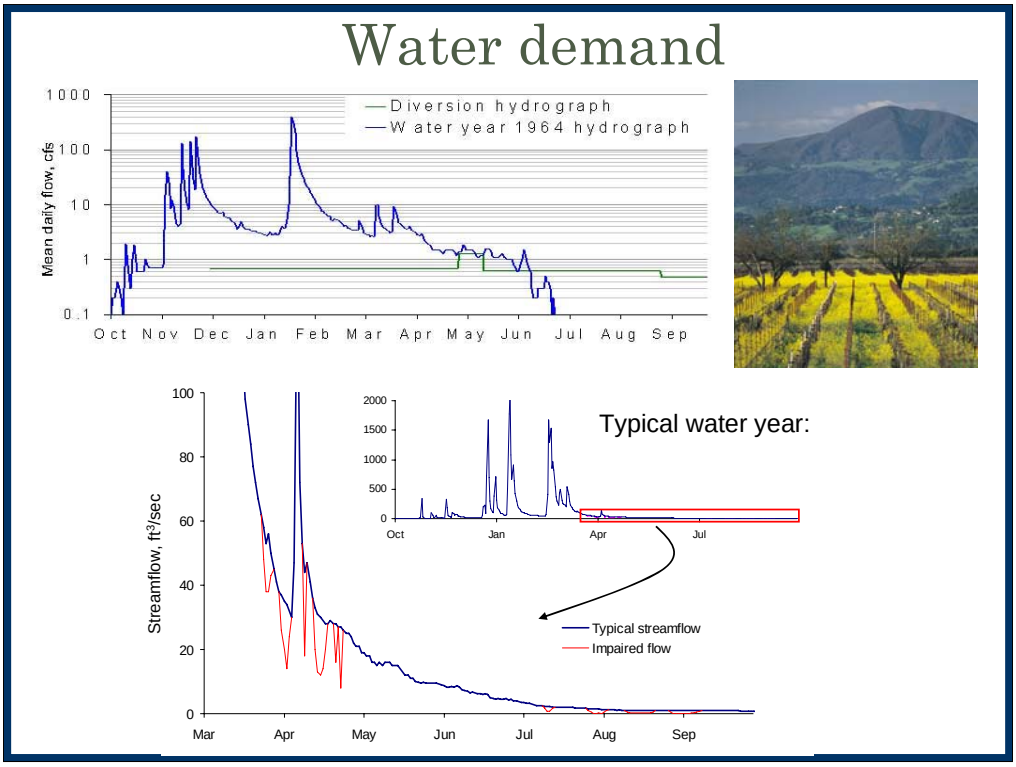
This figure shows high flow in the winter and low flow in the summer in California. The demand for water in California is highest in the summer.



This figure shows that the California Mediterranean climate has more year-to-year variability, which increases uncertainty.

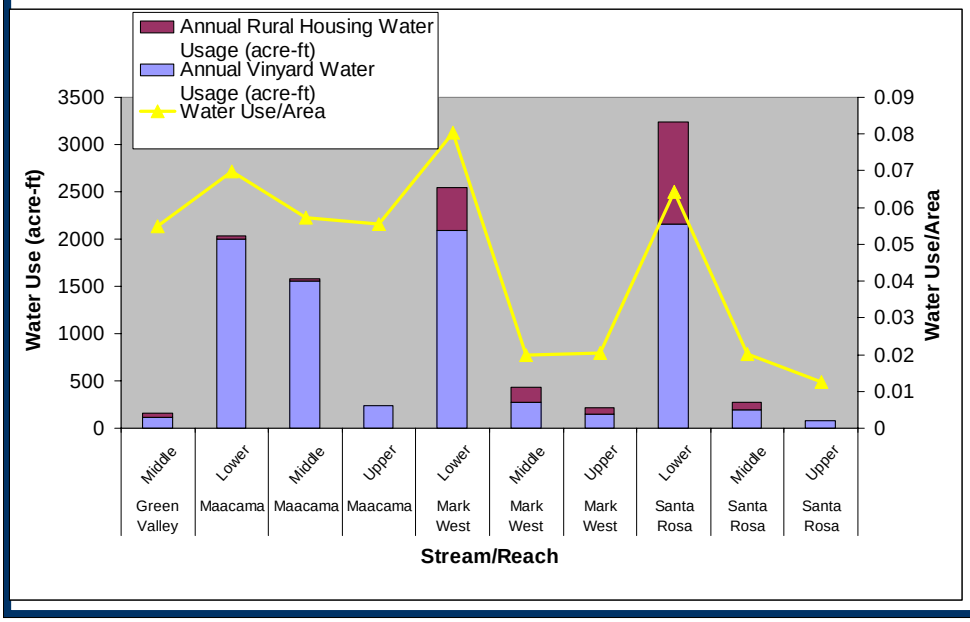


This figure shows high spatial variability in rainfall. It is interesting to note that extremes are seen only miles apart.



Water demand can be met with the amount of winter rainfall. Pumping during the spring and summer can have a cumulative impact on stream flow.

GIS analysis of land use types and estimated water demand in the watershed above each reach.



This is a picture of California wine country. The wine boom in the past 10-15 years has caused complications in the coastal watersheds.

Resilience of fish and macroinvertebrates to drought and flow variability over 20 years in two California streams

- Fish population and macroinvertebrate community responses to flow variability
  - Is there concordance between these "slow" and "fast" variables?
- Hunting and Knoxville Creeks
  - Napa & Lake Counties (CA), University of California McLaughlin Reserve
  - 4 sites on 2 protected streams, 1st-2nd order
  - 1984 to 2002, annual surveys (April)


H1
H2
K1
H3

Data collection

Fish

- Four 100-m reaches sampled per site
- electrofishing, multiple passes per year at each site
- Abundance, length, weight collected for each fish
- 3 “core” species

Macroinvertebrates

- Five Surber samples (1 ft^2 = 0.093 m^2) per site
- Riffle areas
- Identification to genus
- 157 taxa collected

Fish species list

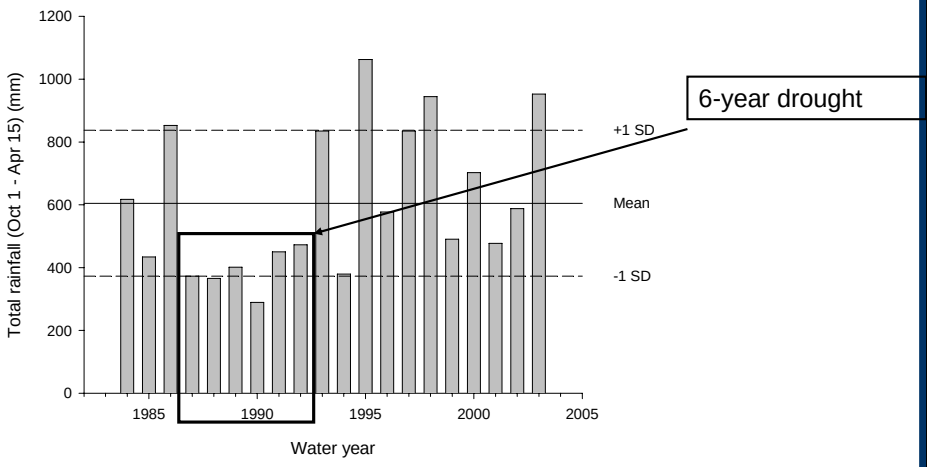
Core species

- California Roach (*Lavinia symmetricus*)
- Green sunfish (*Lepomis cyanellus*) **non-native**
- Sacramento sucker (*Castostomus occidentalis*)

Rare species

Resident rainbow trout (*Oncorhynchus mykiss*)
Sacramento squawfish (*Ptychocheilus grandis*)
Golden shiner (*Notemigonus crysoleucas*) exotic

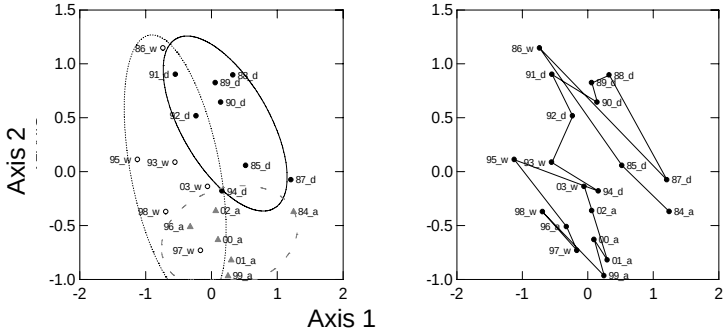
Rainfall during study period



The researchers are studying the effects of the 6-year drought on the system.

Macroinvertebrate results

Site: K1 (1st order)

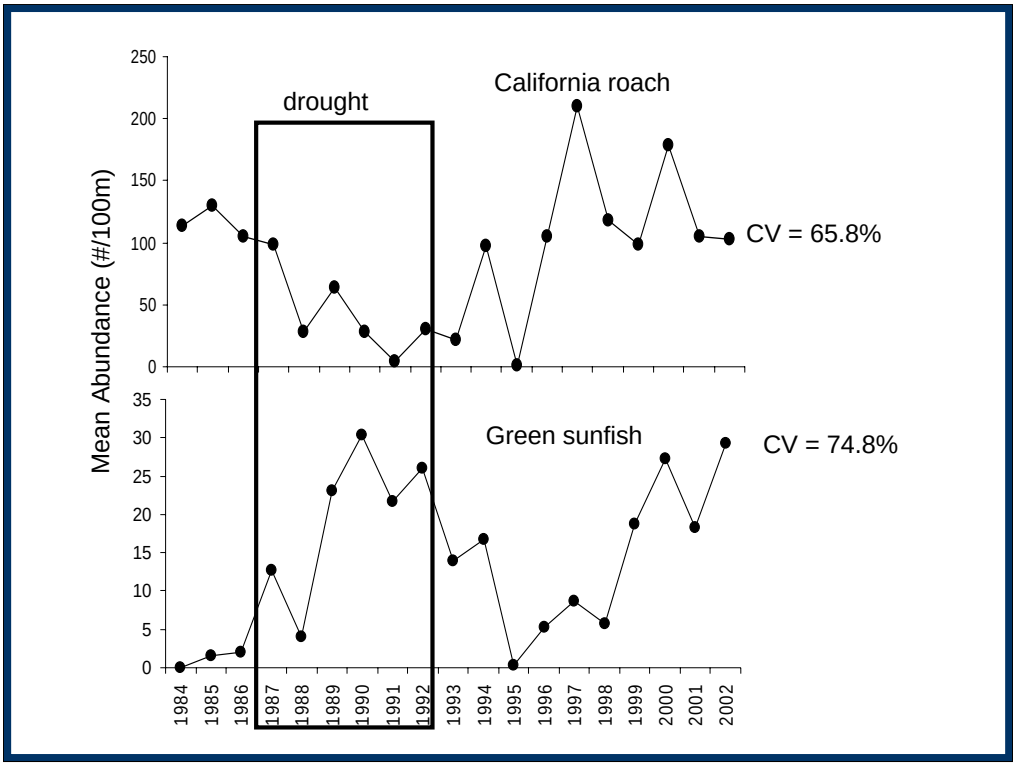


Distinct wet and dry communities

Prolonged drought resulted in long-term community shifts in 1st-order streams

Species recover quickly. In the beginning of the study, the area was a dry community. It then became a wet community. Dragon flies do well in dry periods; beatles and true bugs do well in wet periods (pool pond species). Wet years have few taxa that are characteristic (greater abundance of mayflies and caddisflies in the wet years).

Differences between macroinvertebrate community composition (log10-transformed density) between wet, dry, and average precipitation years were examined using multi-response permutation procedure (MRPP, Bray-Curtis distance). Years were classified as: wet, if precipitation was > 1 standard deviation (SD) above the long-term mean (1938-2004); dry, if < 1 SD below the mean; and average for all other years. Similarly, an MRPP comparing drought years (1985, 1987-1992, 1994) to all other years was performed. Nonmetric multidimensional scaling (NMS) ordination was used to examine temporal patterns in community composition and the influence of flow on these patterns (using Spearman rank correlation). Furthermore, the relationship between fish and macroinvertebrate communities was examined at site H3 using a Mantel test. Analyses were performed using the vegan package (Oksanen, Kindt, Legendre, & O'Hara, 2007) in R 2.4.1 (R Development Core Team, 2006).



This graph shows the averages for the H3 site during the drought period. The native California roach declined during the drought and then recovered after. The invasive green sunfish increased during the drought.

Summary

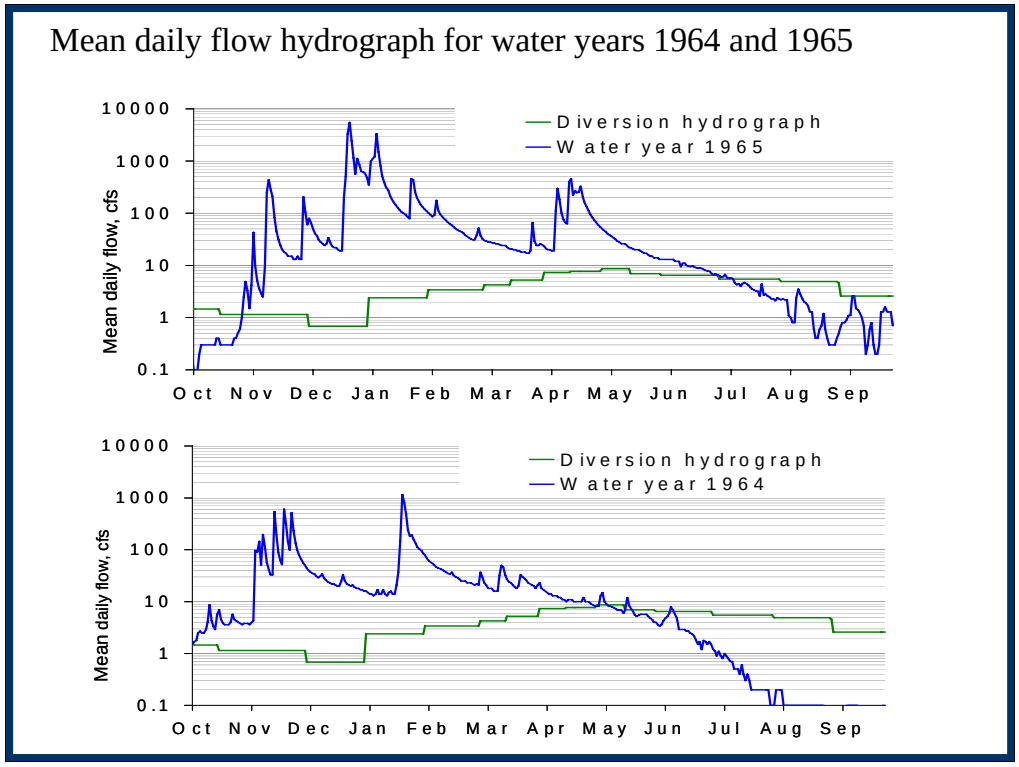
- Macroinvertebrates: distinct "wet" and "dry" communities
- Macroinvertebrates: no lag time in response to flow conditions
- Fish: response lag of 1-3 years to flow
- Fish: prolonged drought → establishment and success of invasive species (Green sunfish)
- Fish and macroinvertebrate communities significantly "concordant" (Mantel test)
  - Reflects influence of flow on both

At one site, the non-native green sunfish flourished during the drought and then became the dominant species. At another site, the native California roach came back as the dominant species.

Flow Variability and Juvenile Steelhead Survivorship in Russian River Tributaries

1) Is stream flow a limiting factor to juvenile steelhead survivorship?
2) How do habitat conditions and land use affect survivorship under different flow regimes?
3) Can we empirically detect a low flow threshold on survivorship?

This is another dataset on salmon from the Russian River tributaries. Water is a factor that is limiting the salmon population in California.



In most areas, the amount of water allocated by the State exceeds the amount available during the spring.

Juvenile Salmonid Surveys

Conducted in summer (June-July) and fall (October) in selected habitat units, from 1994 to 2002

—M. Fawcett and J. Roth (Merritt-Smith Consulting, City of Santa Rosa)

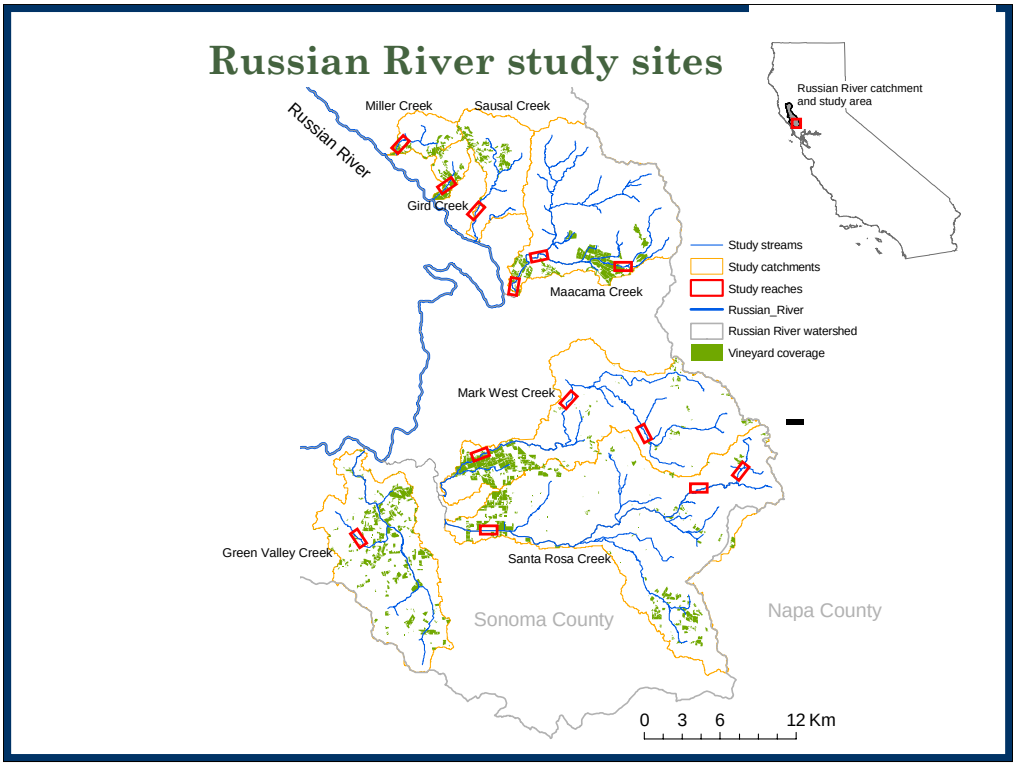
Nine reaches within four streams were sampled (Mark West, Maacama Creek, Santa Rosa, and Green Valley Creeks)

Repeated sampling of "isolated" habitat units

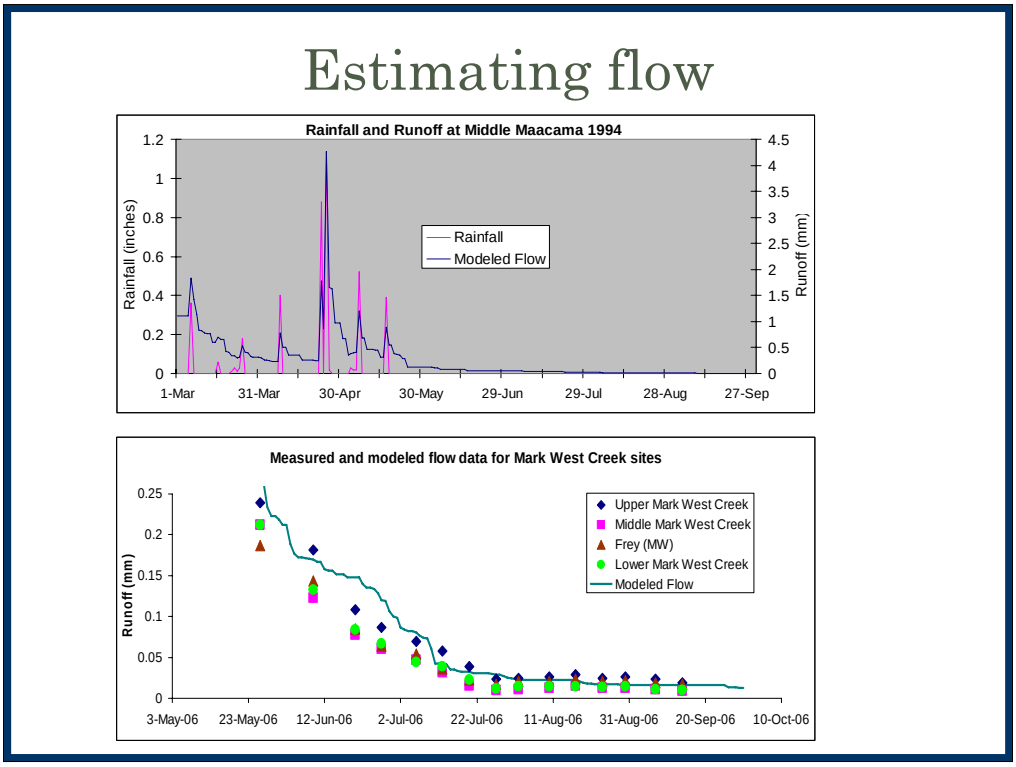
Recruitment = summer spring count

Survivorship = fall/summer count

This is a long-term dataset, with a unique repeated sampling design.



There are three major differences between areas within this site: rainfall amount; lower reach, middle reach, or upper reach; and land use.



In this example, the modeled flow line is fit to Upper Mark West Creek (dark blue dots). The Y axis is reported in units of Runoff (mm) = standardized by area.

For the period when both precipitation and stream flow were monitored, the researchers will derive a statistical model of stream flow as a function of rainfall for the day, as well as rainfall over previous antecedent periods using a multiple regression analysis. Antecedent periods may include rainfall over the previous 3 days (illustrating the extent to which flow may be affected by a storm), the previous 14 days (illustrating the influence of rainfall over a biweekly scale), or the previous 90 days (showing the potential effects of seasonal trends in rainfall). The regression equation derived from the known stream flow and rainfall data will be used at these two sites to estimate stream flow during the previous salmonid assessments, when only rainfall was measured.

Simple flow-scaling techniques will be used to estimate flow at each of the other sites where the stream flow has never been recorded. The middle Santa Rosa flow estimates will be used to predict flow at the other Santa Rosa site and the Mark West sites as well. Flow at each of these sites will be estimated by scaling the predicted middle Santa Rosa site according to a ratio of drainage areas.

The predicted stream flows will be compared to measured stream flows at each of the sites during the course of the proposed study to further test the modeled stream flow, recognizing that land use conversions that have occurred since historical stream flow records were collected could have altered the previous relationship.

Exploratory Analysis

- Start with linear regression to report level of contribution that habitat quality index has on outcomes in addition to flow.
- Move to using fixed effects regression model to account for site effects at each pool that have not been adequately measured and explore low flow threshold.

Outcome Variables
- recruitment
- survivorship

Explanatory Variables
- number of low flow days based on modeled flow
- habitat quality
- land use cover
- stream

Initial habitat assessment at the start of the sampling period (1993-94):

- size and depth of habitat unit (pool, riffle, etc.)
- qualitative habitat suitability rating (1-3 scale)

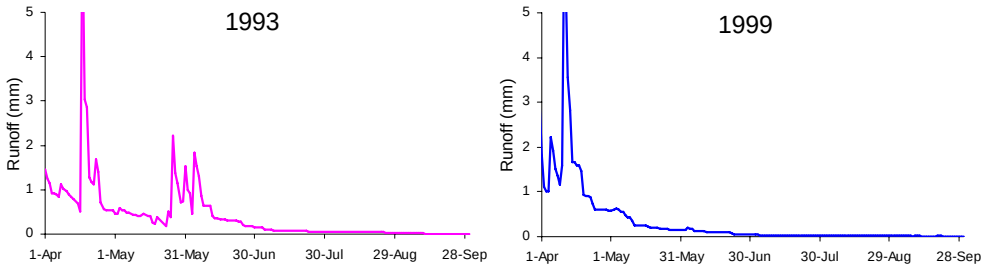
DFG Stream Inventory Data:

- canopy cover
- shelter rating
- embeddedness

Flow model integration

Temporal scale of stream flow conditions is important.

Total seasonal rainfall in 1993 & 1999 was 9.1 inches.



Modeled hydrographs for middle Maacama site

Number of days < 20% = 28

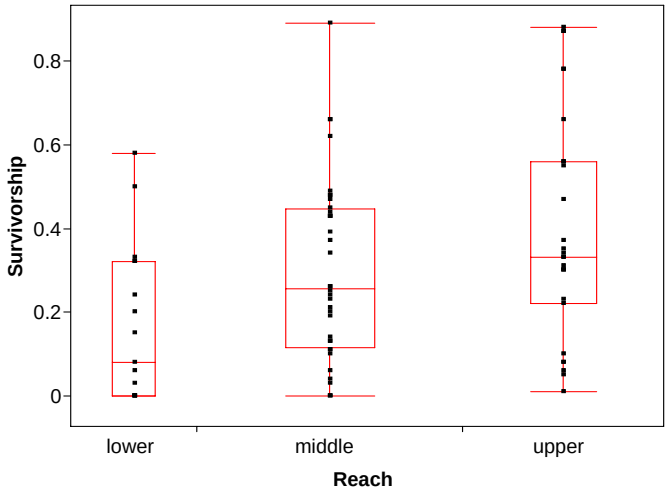
Number of days < 20% = 83

The 20th-percentile flow level was calculated for each stream from all flows for that stream's period of record. The number of days in a season that stream flow fell below the 20th percentile value was considered a measure of dryness or stress that the biological system might be experiencing.

This slide illustrates the importance of looking at periods of dryness as compared to average annual rainfall. Even with the same amount of rain, the number of low flow days can vary dramatically.

Survivorship by reach

Juvenile survivorship within Maacama Creek study reaches

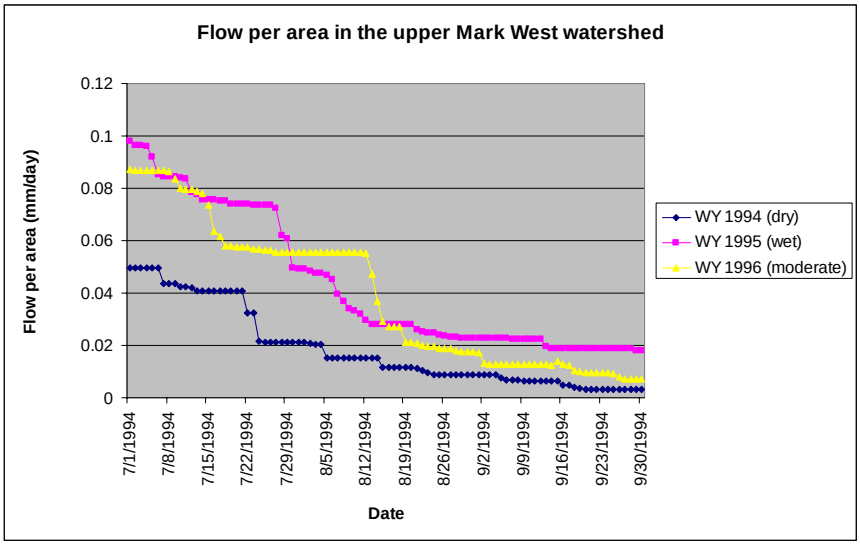


Preliminary analysis results

- Results from OLS on survivorship- Number of low flow days has a significant negative effect on survivorship. Habitat and land use also significant.
- Results from negative binomial on recruitment: Habitat and land use significantly correlated with recruitment. Relationship to rainfall/flow dynamics not clear.
- Survivorship positively correlated with habitat quality and negatively correlated with watershed development.
- Highest survivorship tends to occur in upper reaches and wet years.

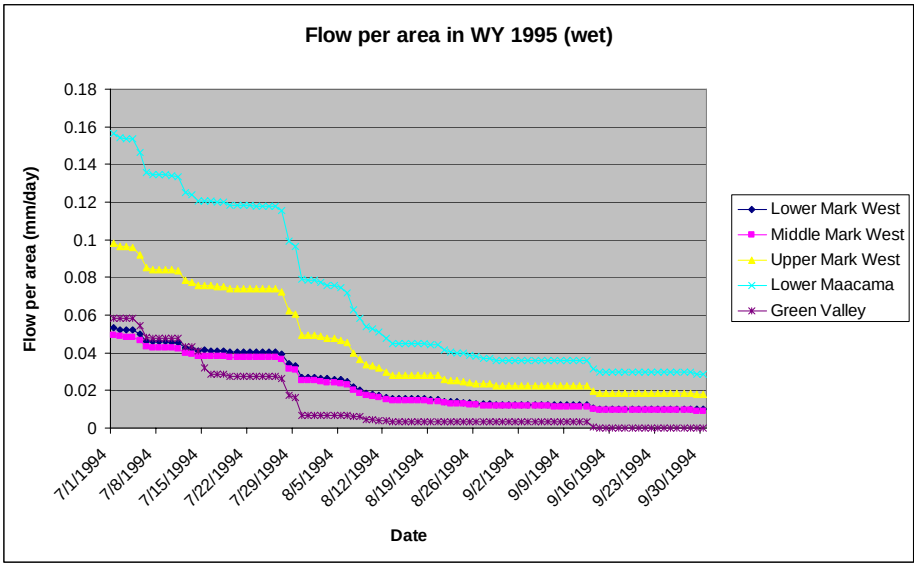
Habitat quality clearly is a fundamental factor affecting juvenile survivorship, but the role that water stress plays is underappreciated. The findings highlight the importance of upper tributaries for recruitment and survivorship; these urban areas also are being threatened by expansion of rural residential and hillslope vineyard uses. Habitat conditions in these upper tributaries generally are good, but increased water competition could have a significant negative effect on reproductive success.

Identifying flow thresholds using fixed effects models



This graph represents different years for the same site. The researchers are working to determine the best metric to use for low flow. Potential metrics include: flow per area, absolute flow, and flow per width for drainage.

Variation between sites – differences in rainfall and location in watershed.



Some of the data limitations

- High inter-annual and site to site variability in steelhead numbers and habitat conditions.
- Habitat conditions difficult to quantify during sampling period (e.g. channel morphology, shelter, embeddedness, thermal regime, food availability).
- Flow models aren't flow measurements.

Lessons learned

- Macroinvertebrate communities do shift with drought but species can recover quickly.
- An alternative stable-state can result with invasive fish becoming dominant due to prolonged drought.
- Concordance was observed between fish and macroinvertebrates because both communities responded to prolonged drought.

- Decline in juvenile salmonid survivorship with decreasing summer flows indicates that water quantity may be an important limiting factor and protecting tributary flows during the dry season is critical to salmon recovery efforts.

To avoid threshold exceedances and regime shifts

- Reduce pumping in dry season by increasing storage of winter rainfall.
- Over 300 appropriative rights requests not approved in the Russian River Basin due to concerns over cumulative effects of reservoirs on winter flow levels required for adult salmonid bypass.
- Need decision-support tools that quantifies cumulative effects in space and over time and addresses trade-offs between winter storage and summer pumping.
- Interest for these tools -- Salmon coalition (stakeholder group), State Water Resources Control Board, Trout Unlimited, local water agencies, NOAA, & CA Dept. Fish and Game.

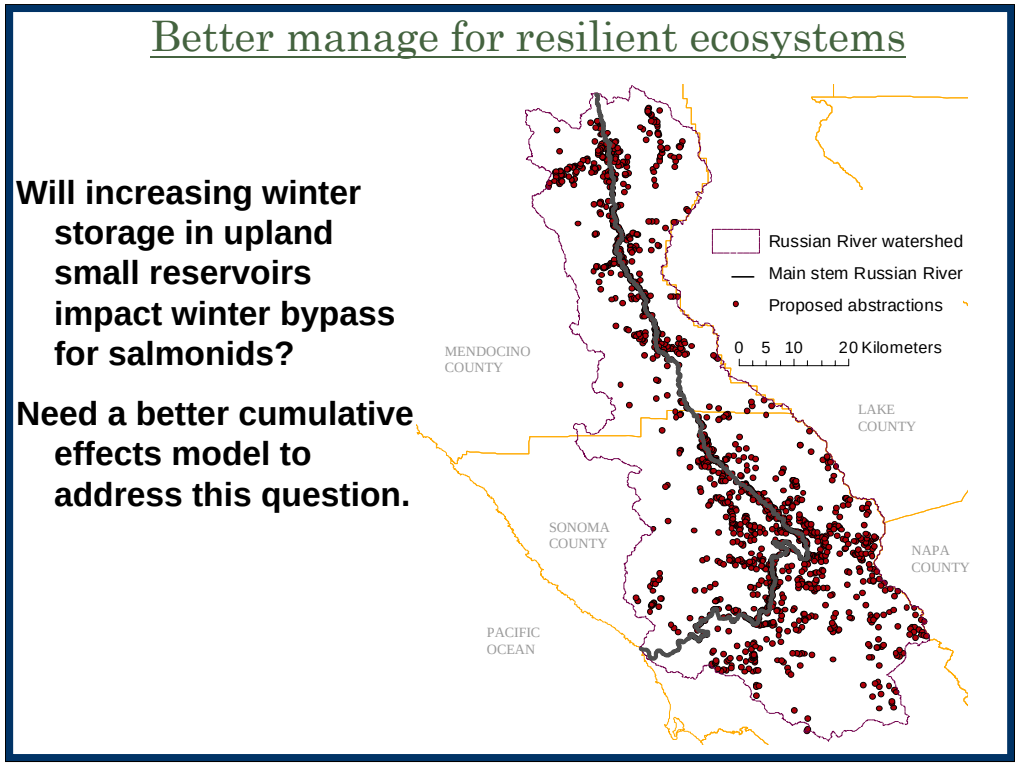
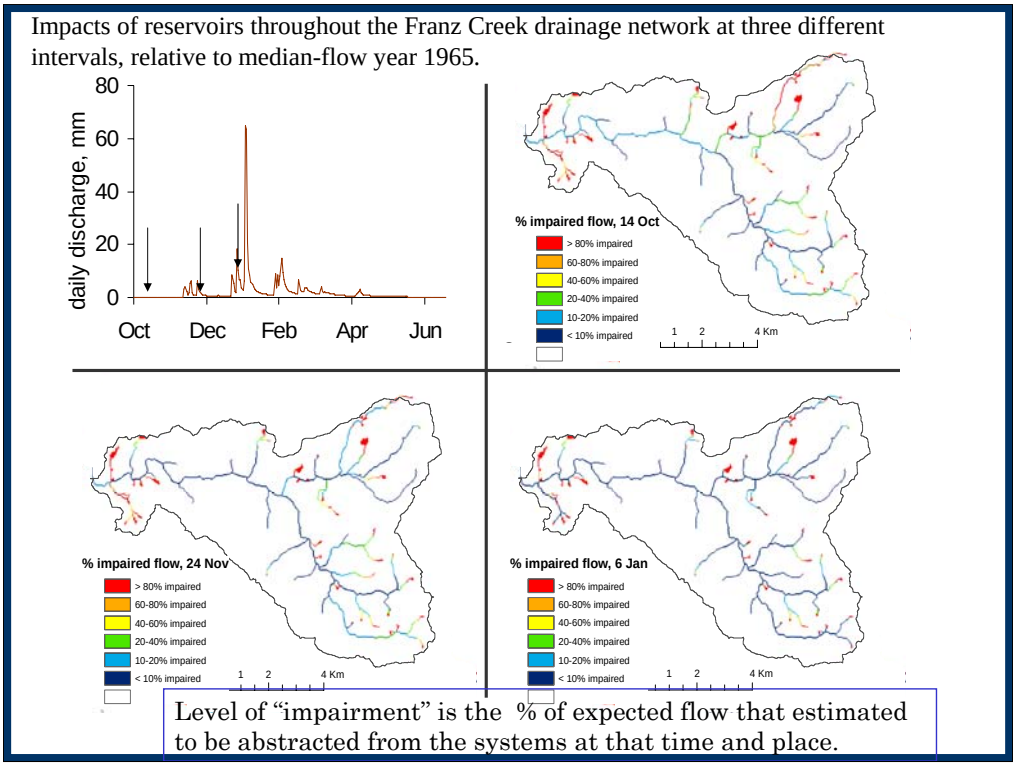


Figure 1. Proposed points of abstraction in the Russian River basin (appropriative and riparian rights), Sonoma and Mendocino Counties, CA, based on the SWRCB WRIMS. (Note: This contains only 1,500 PODs because the WRIMS GIS has not been updated since 2001.)



The level of "impairment" is the percentage of the expected flow that is missing from the system at that time and place. The map in the upper right-hand corner shows significant impairment, the lower left map shows reduced impairment (10% or less), and the lower right map shows virtually no impairment.

Next steps include adding vineyard and residential demand and matching these to reservoir storage. If there is not enough reservoir storage, the demand is being pulled from the system during the dry season. The researchers expect to see a dearth of available storage.

Thank you
http://nature.berkeley.edu/ihrmp

One participant asked Dr. Merenlender about concordance between fish and invertebrates. Specifically, did Dr. Merenlender parcel out the affected space using a partial Mantel test? Dr. Merenlender confirmed that the participant was referring to the space between the different sites. She then explained that the study sites in that particular study are very close to one another.

Another participant asked about the level of impairment that juvenile salmon can survive. Dr. Merelender responded that she and her colleagues currently are working on answering this question. Much more is known about winter bypass issues (such as the amount of water that has to flow down the system to allow adult salmon to migrate up), but very little is known about the amount of water needed for survivorship.

Another participant asked how long the juveniles spend in those regions. Dr. Merenlender responded that it appears to be about 1 year.

Iris Goodman pointed out the parallels between Dr. Merenlender's work and other work being done to develop an optimization system for releases from reservoirs.