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# Recommendations for a marking, tagging, and recovery program for Central Valley hatchery Chinook salmon

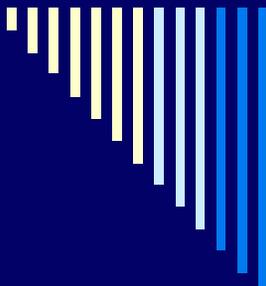
David Hankin, Ken Newman, Allan Hicks\*

August 2005

\***Special thanks!**

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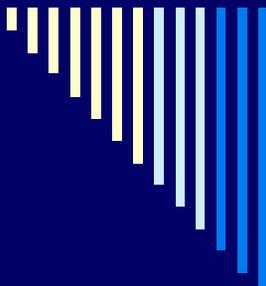
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# History of “Constant Fractional Marking” (CFM) Idea

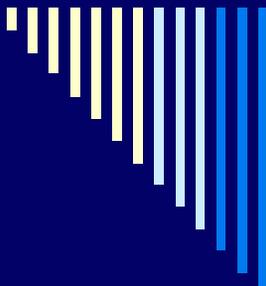
- 1978-1980: Hankin’s work on Klamath chinook.
  - Problem: Low ad+CWT marking rates + variability in marking rates ruled out estimation of the proportion of hatchery fish in the run.
    - Can’t assess hatchery performance;
    - Can’t determine status of wild fish.
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# History of “Constant Fractional Marking” (CFM) Idea (cont.)

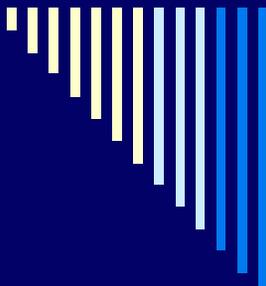
- Hankin’s initial thought: “Mark all the hatchery fish!”
  - CDFG Response: “No way – too expensive!”
  - **CFM = How to mark less than 100% of hatchery fish and still allow accurate estimation of the proportion of hatchery fish.**
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# The original CFM Idea

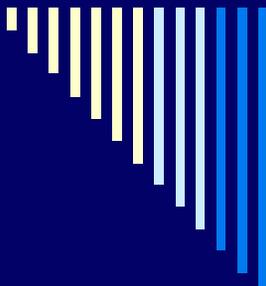
- Allow ad+CWT programs to proceed as they had been.
- Mark a constant fraction of remaining “production” releases with fin clip.

$$\hat{p} = \frac{x_{ad} + c \cdot x_{fc}}{n}$$



# Implementations of CFM

- 1979-1982 BYs: Iron Gate and Trinity River Hatcheries – **fin clip 1/3 of all “production” releases in excess of ad+CWT fish.** (Hankin 1982)
  - 1999 BY-present: Trinity River Hatchery – **25% of all releases receive ad+CWT** (Hankin & Newman 1999)
  - 2001 – present: **Various Locations -100% ad-clipped at federal hatcheries (Mass Marking/selective fisheries), but not all have CWT!** (Federal Legislation)
  - 2005-??: CA CV ?? (Newman/Hicks & Hankin)
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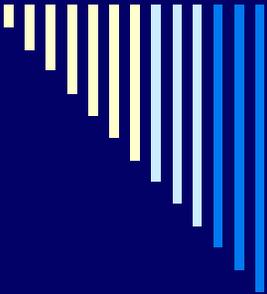
# Uncertainty & CFM Rates

- If  $n$  is small compared to total population size, and a constant fraction of all hatchery fish get ad+CWT, then:

$$\hat{p} = \frac{c \cdot x_{ad}}{n}$$

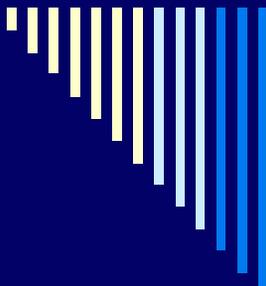
$$\hat{V}(\hat{p}) \approx c^2 \frac{\hat{p}(1 - \hat{p})}{n - 1}$$

<u>% Marked</u>	<u><math>c</math></u>	<u><math>c^2</math></u>
5	20	400
10	10	100
20	5	25
25	4	16
33 1/3	3	9
50	2	4



# What you can get from a CFM program: Chinook Salmon at Willow Creek weir 2004, Trinity R.

<u>Week</u>	<u>Grilse</u>		<u>Adults</u>	
	<u>Total</u>	<u>Ad-Clipped</u>	<u>Total</u>	<u>Ad-clipped</u>
10-Sep	79	16	195	32
17-Sep	105	14	307	63
24-Sep	112	24	506	126
1-Oct	54	10	284	72
8-Oct	24	5	240	63
15-Oct	9	9	145	26
22-Oct	0	0	2	0
29-Oct	2	0	15	7
5-Nov	9	0	30	8
12-Nov	4	0	17	7
<b>Totals:</b>	<b>398</b>	<b>78</b>	<b>1,741</b>	<b>404</b>



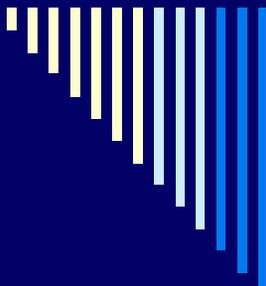
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# Sacramento System Background (Newman, Hicks & Hankin)

Goal is more complicated: to estimate the production of any given wild or hatchery stock of Chinook salmon & to address the CV “Doubling of Natural Production” Mandate.

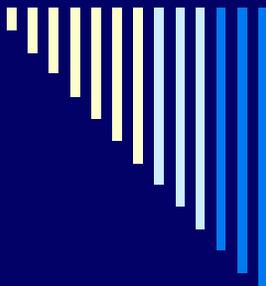
- Production = sum of catches and escapement
    - Catches are made in ocean and freshwater areas
    - Escapement have in-hatchery and in-river components
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# Sacramento System Complications

- Large Number of Stocks, Hatcheries & Agencies
  - High Variability in Marking Rates (Historically from 0% at Nimbus to almost 100% at Merced)
  - High Incidence of “straying” of hatchery fish, **especially** for off-site releases (e.g., fish released in SF Bay).
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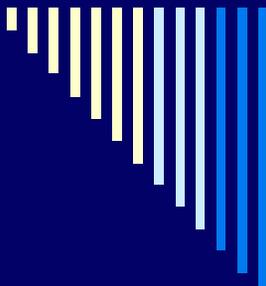


# Proposed CV Tagging & Marking Programs

Tagging = CWT; Marking = AD-clip

## Release Types:

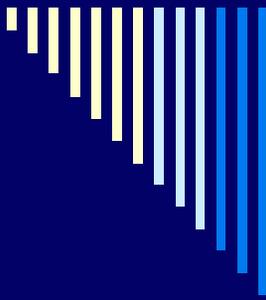
- *Ad hoc* = experimental
    - AD-clip & CWT
  - *Surrogate* = releases meant to mimic a wild stock
    - AD-clip & CWT – **RELEASE ON-SITE!!!**
  - *CFM* = constant % ( $f$ ) of remaining releases
    - AD-clip & CWT
  - *Remainder* =  $(1-f)\%$  of remaining releases
    - No AD-clip & no CWT
    - Externally indistinguishable from wild fish
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# Assumptions

- Non-selective fisheries
  - All recoveries of AD-clipped fish have CWT extracted and are read without error
  - Simple random sampling of catch and escapement; in-hatchery escapement sampled at 100%
  - Wild fish do not stray from watershed, but can enter hatcheries; hatchery fish can stray
  - Surrogate hatchery fish have the same life-history parameters as corresponding wild fish, except for survival from release to ocean age 2.
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# Estimation of Chinook salmon production in the Sacramento system— a complex extension of the simple CFM idea

## Notation

- $n$  = sample size
  - $x$  = # of hatchery stock recoveries in ocean catch sample
  - **LOTS** of subscripts
-

# Estimating hatchery catches

- Ocean Catch from hatchery stock  $i$

$$\hat{C}_{Ohi} = \frac{\hat{C}_O}{n_O} \left( xa_i + xb_i + \frac{xc_i}{f} \right)$$

Estimated Total Ocean Catch  $\hat{C}_O$

# fish sampled from ocean catch  $n_O$

# ad-hoc recoveries from hatchery  $i$   $xa_i$

# surrogate recoveries  $xb_i$

# CFM recoveries  $xc_i$

CFM rate  $f$

- Freshwater catch in each watershed is estimated in a similar manner
- Then sum over watersheds for total freshwater catch from hatchery stock  $i$

# Estimating hatchery escapement

- In-river escapement at age from hatchery stock  $i$

Estimated total in-river escapement in watershed  $j$

$$\hat{E}_{hi,\alpha} = \sum_j \frac{\hat{E}_{j,\alpha}}{n_{E_{j,\alpha}}} \left( za_{ij,\alpha} + zb_{ij,\alpha} + \frac{zc_{ij,\alpha}}{f} \right)$$

# fish sampled from in-river escapement

# ad-hoc recoveries from hatchery  $i$  & watershed  $j$

# surrogate recoveries

# CFM recoveries

CFM rate

- In-hatchery escapement (100% sampled) is estimated in a similar fashion.
- Total escapement = in-hatchery + in-river

# Estimating wild escapement

- In-river escapement at age from wild stock  $i$

Estimated total in-river escapement in watershed  $j$

Estimated in-river escapement of hatchery fish in watershed  $j$

$$\hat{E}_{nj,\alpha} = \hat{E}_{j,\alpha} - \sum_i \hat{E}_{hij,\alpha}$$

- Wild In-hatchery escapement and freshwater catch are estimated in a similar manner
- Total escapement is sum of these two
- Negative estimates are possible

# Estimating wild ocean catch

- Total Ocean catch from wild stock  $i$

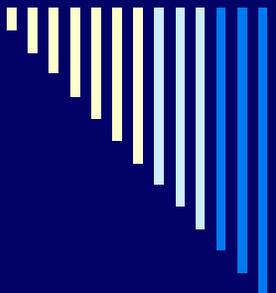
Estimated ocean catch of **surrogates** from hatchery  $i$

Estimated age  $a$  **wild** escapement and freshwater catch for watershed  $j$

$$\hat{C}_{Onj} = \sum_{age} \left( \frac{\hat{C}_o}{n_o} x b_{ia} \right) \frac{\hat{C}_{Tnja} + \hat{E}_{nja}}{\sum_j \left( \frac{\hat{C}_{Tj}}{n_{Tj}} t b_{ija} + \frac{\hat{E}_{j,\alpha}}{n_{Ej,\alpha}} z b_{ija,\alpha} + \frac{\hat{E}_{j,\beta}}{n_{Ej,\beta}} z b_{ija,\beta} \right)}$$

Sum over age

Estimated age  $a$  **surrogate** escapement and freshwater catch for watershed  $j$

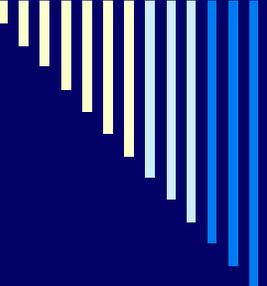


# Estimating wild ocean catch - simplified

- Ocean catch from wild stock  $i$

$$\hat{C}_{Onj} = \sum_{age} \left[ \frac{\text{Estimated age } a \text{ ocean catch of } \mathbf{surrogates} \text{ from hatchery } i}{\text{Estimated age } a \mathbf{surrogate} \text{ escapement and freshwater catch from hatchery } i} \right] \left[ \text{Estimated age } a \mathbf{wild} \text{ escapement and freshwater catch for watershed } j \right]$$

- Basically assume that the ratio of surrogate ocean catch age at age to freshwater catch and escapement at age is the same for the wild stock.

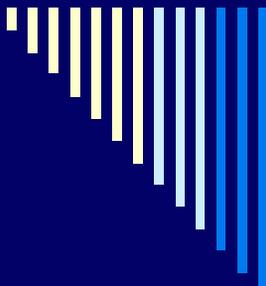


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# Estimating wild ocean catch

## Critical ageing requirements

- Need to age unmarked fish in FW escapement and calculate age-specific estimates of escapement and terminal freshwater catch
  - Use *CFM* fish to calculate age estimates of *Remainder* fish from hatcheries
  - Subtract the *Remainder* estimate from an estimate of all unmarked fish at hatcheries
  - Otolith thermal marking could help distinguish unmarked wild fish from unmarked hatchery fish
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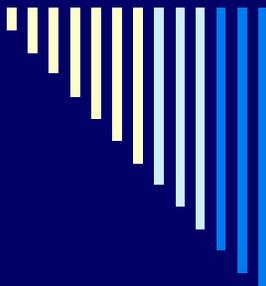


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# CFM Sim (Allan Hicks – MS Thesis w/Ken Newman; more)

A PC program that simulates

- The initial marking and tagging of hatchery fish
  - Natural mortality, fishing mortality, and maturation of hatchery and wild fish
  - The sampling of marine and freshwater catches and escapements
  - The statistical estimation of catches and escapements for each stock separately
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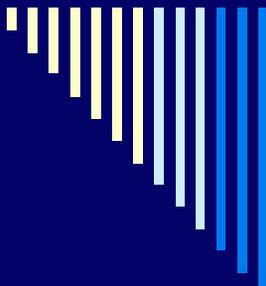


# Design of Simulation Experiments

Varied four factors

- CFM rate:  $f$ 
    - 5%, 10%, 20%, 25%, 33%, 50%, 100%
  - Ocean and freshwater sampling rates:  $CSR$ 
    - 10%, 20%
  - Escapement sampling rate:  $ESR$ 
    - 2.5%, 5%, 10%
  - Coefficient of variation on estimate of escapement:  $ECV$ 
    - 20%, 40%
-

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# Design of Simulation Experiments (Cont.)

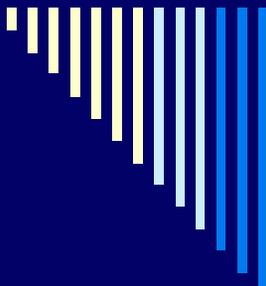
Fixed all other parameters

- Releases, harvest, maturation, etc.
- Chose reasonable values based on available data

3000 simulations of a single year

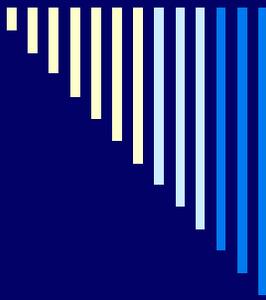
- Includes ages 2 through 5
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# Measures of production

- Hatchery-specific production
  - Watershed-specific natural production
  - Total natural production
  - Total production
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# Performance measures

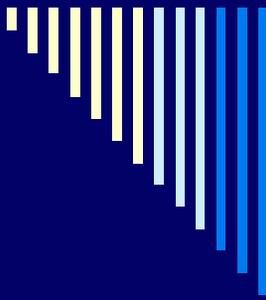
- Relative Mean Estimation Error: *RMEE*

$$RMEE = \frac{\sum_{l=1}^{3000} (\hat{P}_l - P_l) / P_l}{3000}$$

- *RISK*: a measure of risk and bias

$$RISK = 2 \left[ \Pr(\hat{P} > 1.2P) \right] + \Pr(\hat{P} < 0.9P)$$

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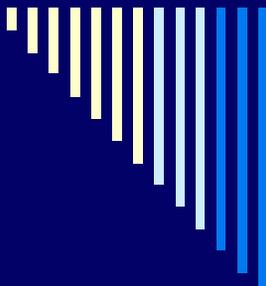
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# Results

## Hatchery-specific production

- *RMEE* effectively zero
    - estimates unbiased
  - A decrease in *ECV* reduced *RISK*
  - Increasing *CFM* rate reduced *RISK* when sampling rates were low
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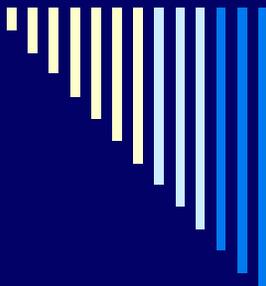
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# Results

## Hatchery-specific production

- *RISK* reduced by different magnitudes for each hatchery
    - different number of releases
    - different straying rates and locations, thus different freshwater harvest rates
    - different percentage of wild fish mixed in with the hatchery fish
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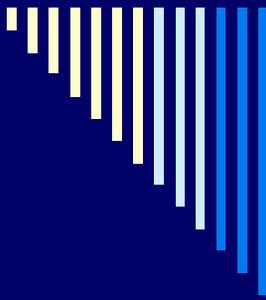


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# Results:

## Hatchery-specific production

- *RISK* near its lowest value when *CFM* rate was greater than 20%
  - *ECV* has a large effect on hatchery-specific escapement estimates and *ESR* has a lesser effect
    - *ESR* and *ECV* are most influential on overall hatchery production because escapement makes up a large amount of the production
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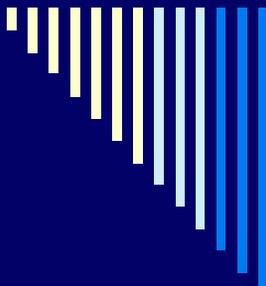


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# Results

## Watershed-specific natural production

- Watersheds can be split into two types:
    - **Those with hatchery fish present**
      - Type m: minority of returns are wild fish
      - Type M: majority of returns are wild fish
    - **Those with no hatchery fish present**
-



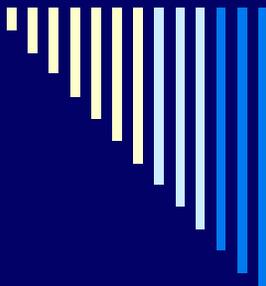
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# Results

## Watershed-specific natural production

No hatchery fish in returns

- Slight bias in ocean catch estimates which decreased with higher *ESR* and lower *ECV*
    - Biased ratio estimator
  - *CFM* rate did not show any influence
    - no hatchery fish to separate out
  - *ESR* and *ECV* most influential
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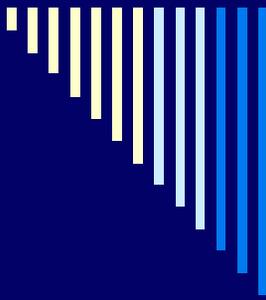
# Results

## Watershed-specific natural production

### Hatchery fish mixed with wild fish

- Type M stocks (majority wild)
    - *CSR, ESR, ECV* lowered *RMEE* and *RISK*
    - *CFM* rate did not have much affect on total production
      - A slight affect on freshwater catch estimates
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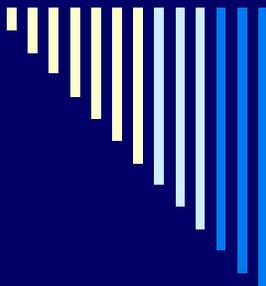


# Results

## Watershed-specific natural production

### Hatchery fish mixed with wild fish

- Type m stocks (minority wild)
    - *CFM* rate a very important factor
    - Negative estimates more frequent when sampling and *CFM* rate were low
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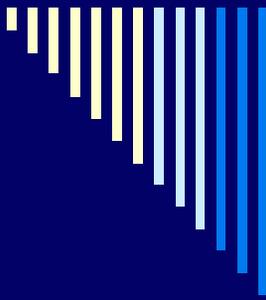
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# Conclusions

## Hatchery fish as surrogates for wild fish

- Surrogate & Stealth Releases are intended to represent experiences of wild fish. Therefore:  
**Rearing & release of these groups must closely mimic wild fish – ALL MUST BE RELEASED ONSITE**
  - We did not study the effects of different numbers of surrogate releases
    - Previous studies indicate that larger surrogate releases can increase the precision of the estimates
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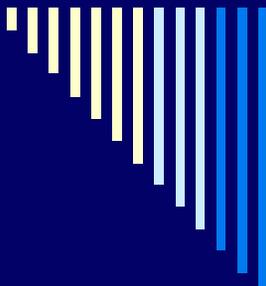
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# Conclusions

## *CFM* rate

- Wild fish mixed with hatchery fish
    - A higher *CFM* rate is important for wild stocks mixed with many hatchery fish in the terminal area
  - Recommendations
    - 33% as a single, consistent system-wide *CFM* rate
    - May need higher value if natural stocks are smaller than simulated here
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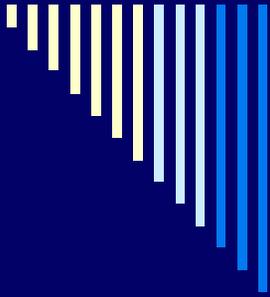


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# Conclusions

## Escapement estimation

- Quality escapement estimates are crucial for quality wild fish production estimates
  - It is critical to verify that ECVs of 20% or 40% are actually achieved.
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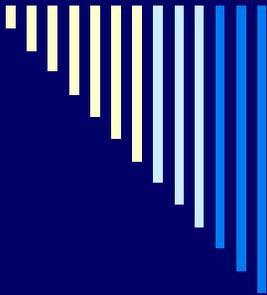


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# Conclusions

## Catch Sampling Rates

- Minor influence on estimation of overall production
    - More important for catch estimation
  - Most important is to implement a consistent freshwater sampling design
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# Primary Conclusions

- **Use CFM rate of at least 33%**
    - 1 in 3 of “remainder” fish are marked and tagged with ad+CWT
  - **Escapement estimation is extremely important for accurate production estimates**
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