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

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August 2005

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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.

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.

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)

Uncertainty & CFM Rates

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

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

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

% Marked	c	c^2
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.

	Grilse		Adults	
Week	Total	Ad-Clipped	Total	Ad-clipped
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
Totals:	398	78	1,741	404

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

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).

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

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.

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*

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

Estimated Total Ocean Catch

ad-hoc recoveries from hatchery *i*

CFM recoveries

CFM rate

fish sampled from ocean catch

surrogate recoveries

- 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*

ad-hoc recoveries from hatchery *i* & watershed *j*

CFM recoveries

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

CFM rate

fish sampled from in-river escapement

surrogate recoveries

- 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*

$$\hat{C}_{Onj} = \sum_{age} \left(\frac{\hat{C}_O}{n_O} xb_{ia} \right) \frac{\hat{C}_{T_{nja}} + \hat{E}_{nja}}{\sum_j \left(\frac{\hat{C}_{Tj}}{n_{Tj}} tb_{ija} + \frac{\hat{E}_{j,\alpha}}{n_{Ej,\alpha}} zb_{ija,\alpha} + \frac{\hat{E}_{j,\beta}}{n_{Ej,\beta}} zb_{ija,\beta} \right)}$$

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*

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

- 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.

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

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

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%

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

Measures of production

- Hatchery-specific production
- Watershed-specific natural production
- Total natural production
- Total production

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

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

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

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

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

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

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

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

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

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

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

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.

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

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