Beyond biomass:
Valuing genetic diversity in natural resource management

WCERE 2018

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Salmon transferring from a truck into the Sacramento River
(CBS, 2015)

funding:

DELTA STEWARDSHIP COUNCIL

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

Salmon collapse in the Central Valley results in unprecedented fishery closures (2008)

San Francisco Chronicle

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It's a hard homecoming for season's fall-run salmon

The numbers of salmon returning to spawn are well below what fishermen expected.

Kim Komenich / *The Chronicle* 2004

By Jane Kay
Chronicle Environment Writer

The Central Valley fall run of chinook salmon apparently has collapsed, portending sharp fishing restrictions and rising prices for consumers while providing further evidence that the state's water demands are causing widespread ecological damage.

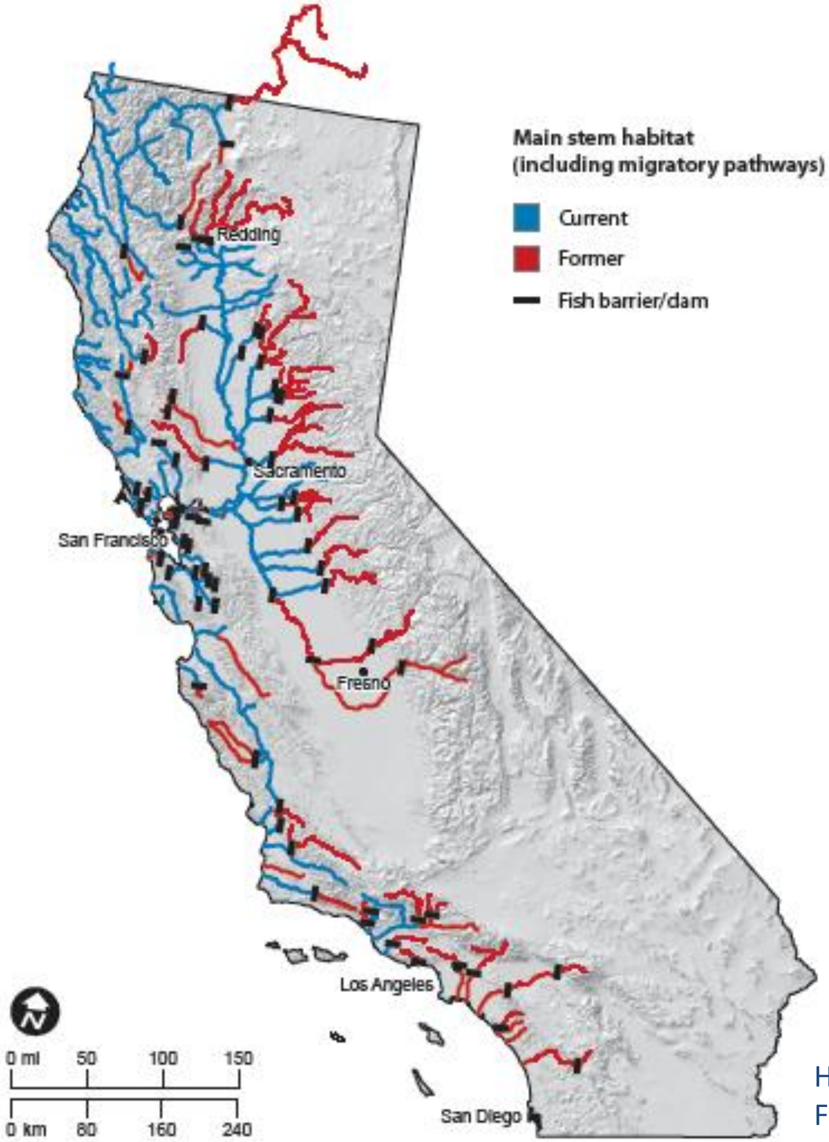
The bad news for commercial and sport fishermen and the salmon-consuming public surfaced Tuesday when a fisheries-management group warned that the numbers of the bay's biggest wild salmon run had plummeted to near record lows.

In April, the Pacific Fishery Management Council will set restrictions on the salmon season, which typically starts in May. A shortage could drive up the price of West Coast wild salmon. The council's leaders said the news is troubling because normally healthy runs of Central Valley chinook salmon are heavily relied upon by fishermen. Runs on the other river systems historically have been smaller.

"The low returns are particularly distressing since this stock has consistently been the healthy

▶ **FISH:** *Page A10*

Physical capital (hatcheries) has been developed to compensate for the loss of natural capital (habitat)



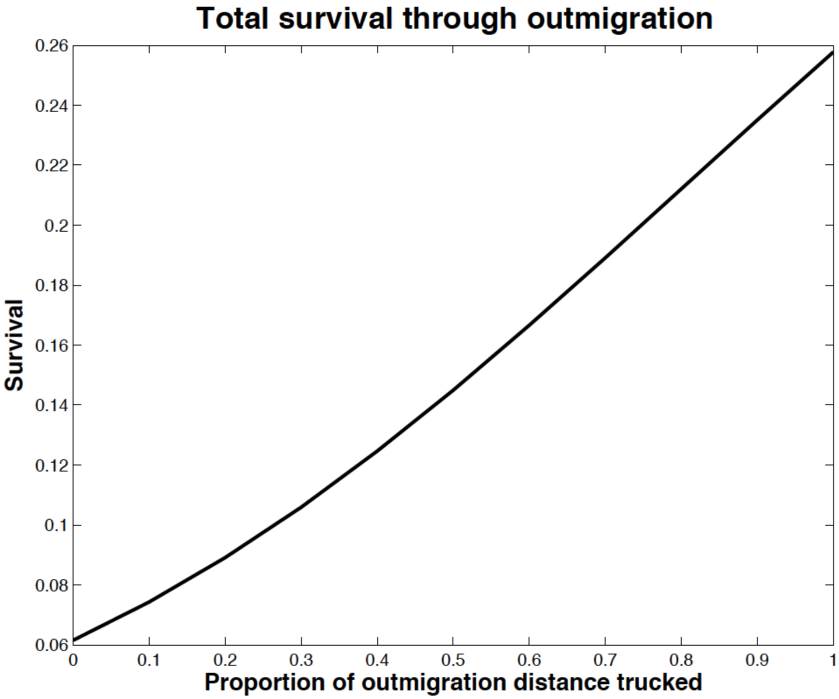
Hanak et al. 2011. Managing California's water: From conflict to reconciliation.

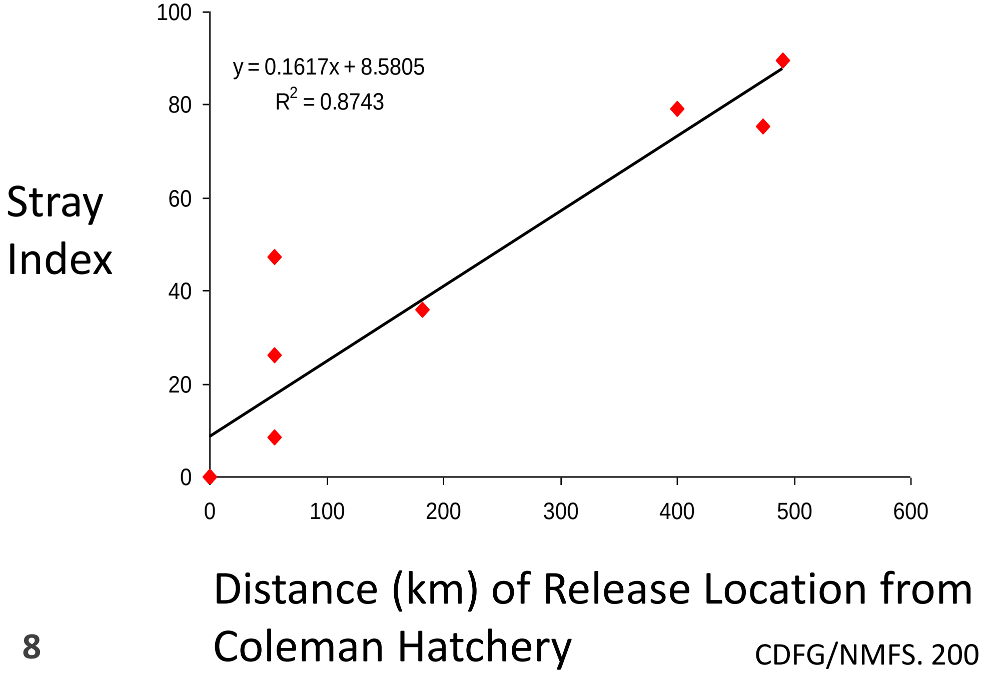
Trend towards off-site releases of hatchery fish

http://www.fisheryfoundation.org/

In 2008, 20.2 million smolts outplanted to San Pablo Bay!

A key management action (trucking) increases juvenile survivorship….





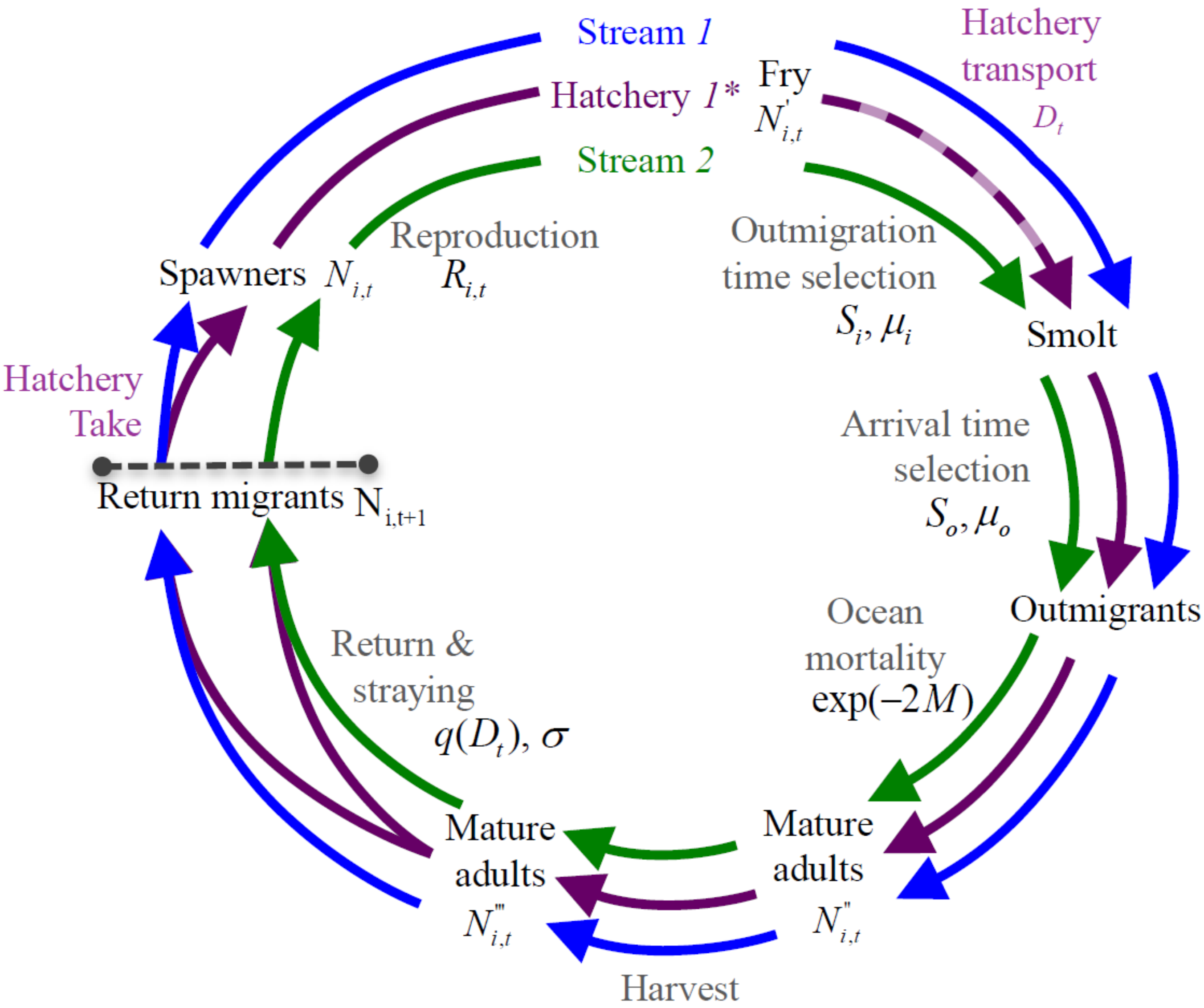
…but also increases straying (failure of adults to return to home stream).

* Homogenization?

* Welfare impacts?

CDFG/NMFS. 2001. Final report on anadromous salmonid fish hatcheries in California.

To capture the portfolio effect within and between rivers we model a two river, one hatchery system



Annual payoffs from the fishery are given by harvest revenue less harvest cost.

$$\pi(X_t, A_t) = \underbrace{p \cdot H_t}_{\text{harvest revenue}} - \underbrace{c \ln\left(\frac{1}{\left(N_t - H_t\right)/N_t}\right)}_{\text{harvest cost}}$$

X – state vector: $\{N, \mu, G\}$

N – stock size

μ – mean genetic value

G – genetic standard deviation

A – action vector, $\{D, H\}$

D – trucking distance

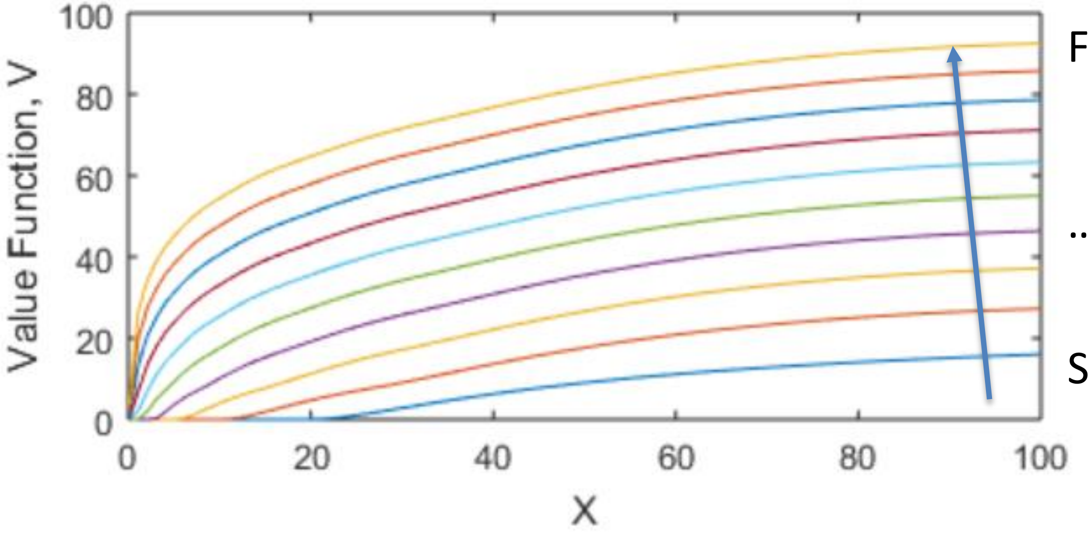
H – harvest (set to PFMC policy)

The state of the system next period (*t*+1) is a function of the current state and chosen actions in period *t.*

$$X_{t+1} = g(X_t \mid A_t)$$

The value function is commonly identified using backwards iteration techniques (“value function iteration”)

$$V(X_t) = \max_{A_t} \left\{ E\pi(X_t, A_t) + \beta EV(X_{t+1}) \right\}$$



Final solution
.
.
…iterating…
.
.
Start: rough guess

Given the challenge of a 6 state variable system we use forward dynamic programming (FDP)

$X -$ state vector: $\{N, \mu, G\}$

N: $\{N_1, N_2\} -$ stock size

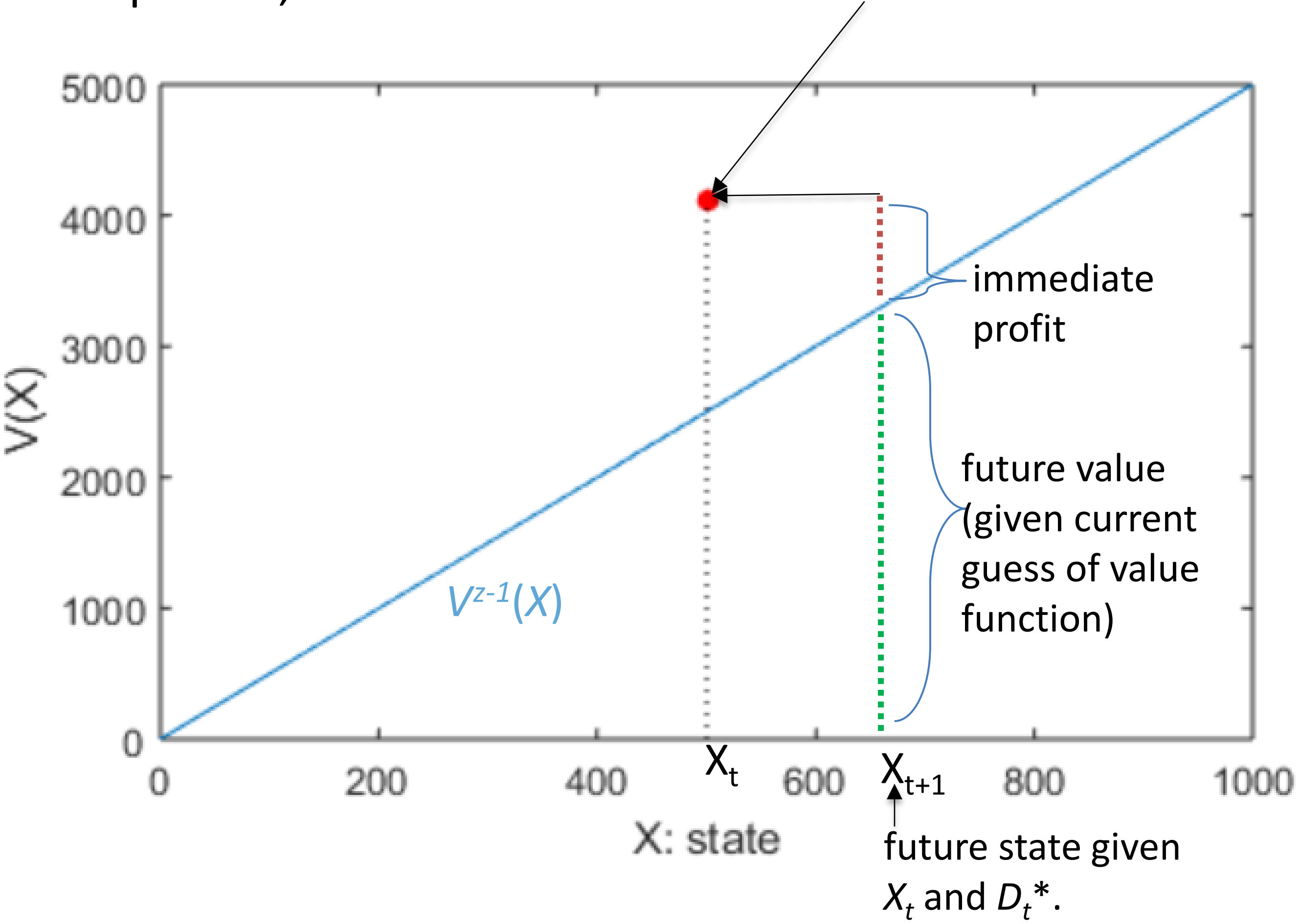
μ: $\{\mu_1, \mu_2\} -$ mean genetic value

G: $\{G_1, G_2\} -$ genetic standard deviation

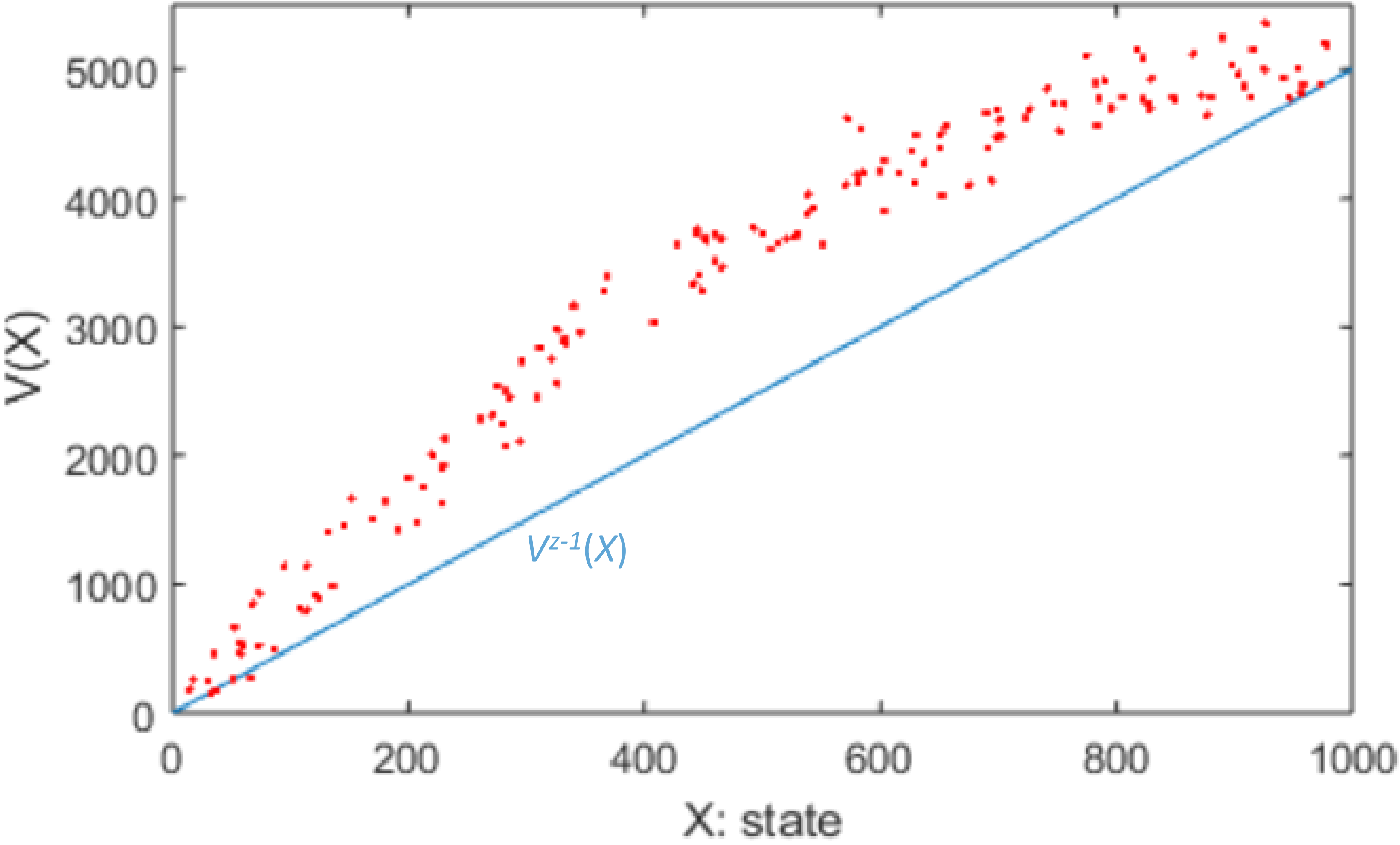
- As the number of stocks and control variables increase, memory becomes a limiting factor.

FDP steps:

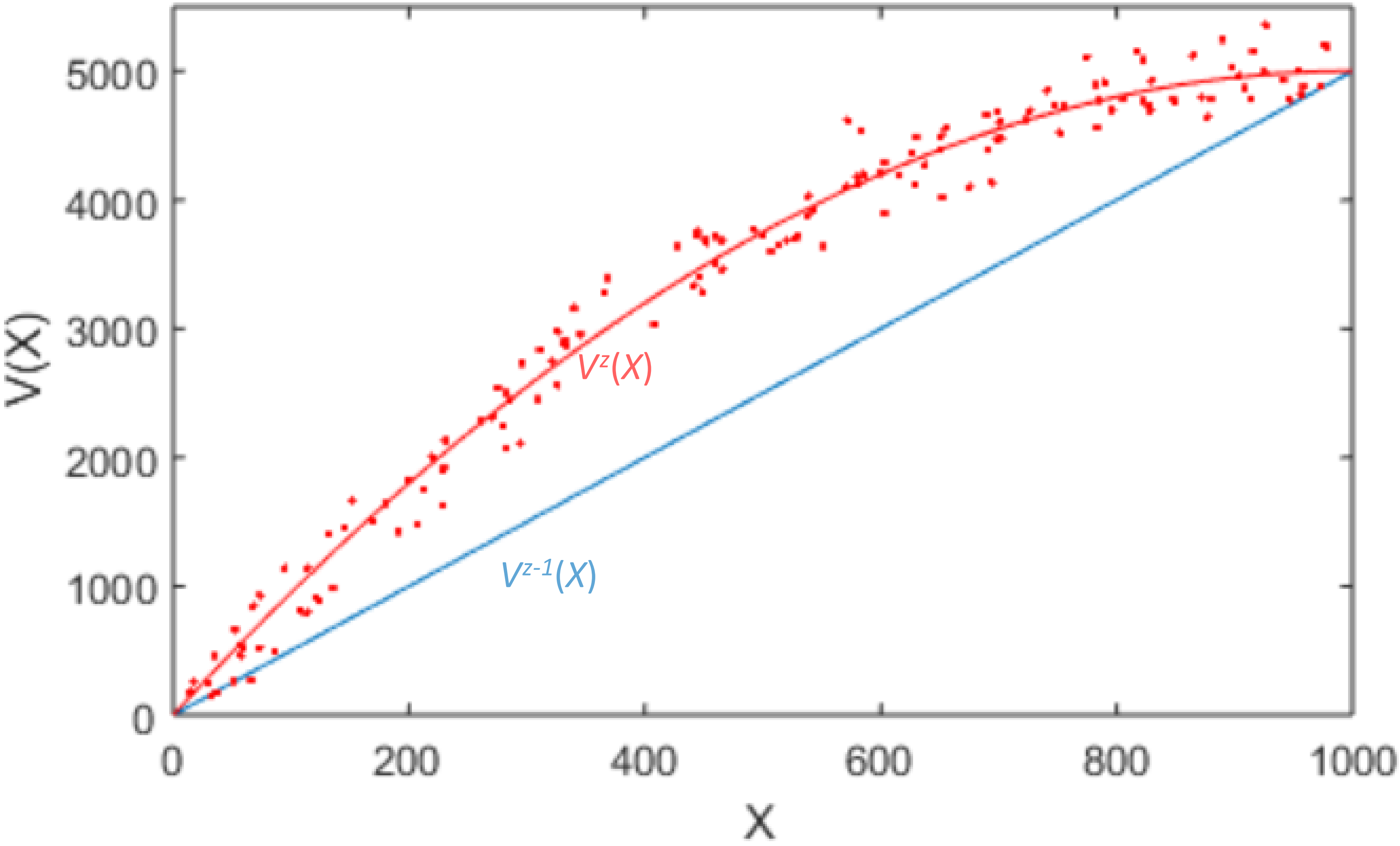
1. You have a guess for value, $V^{z-1}(X)$
2. Randomly choose an initial state, e.g. X_t=500
3. Observe shock, ε_t
4. Choose optimal action D_t*, given immediate profit and discounted future value, $\beta\ V^{z-1}(X_t/D_t^*,\ \varepsilon_\mathrm{t})$
5. Provides an updated, stochastic observation of value.



FDP steps:
Continue to simulate forward in a chain, generating "data" reflecting updated estimates of value



FDP steps: Regress to identify new estimate of the value function.



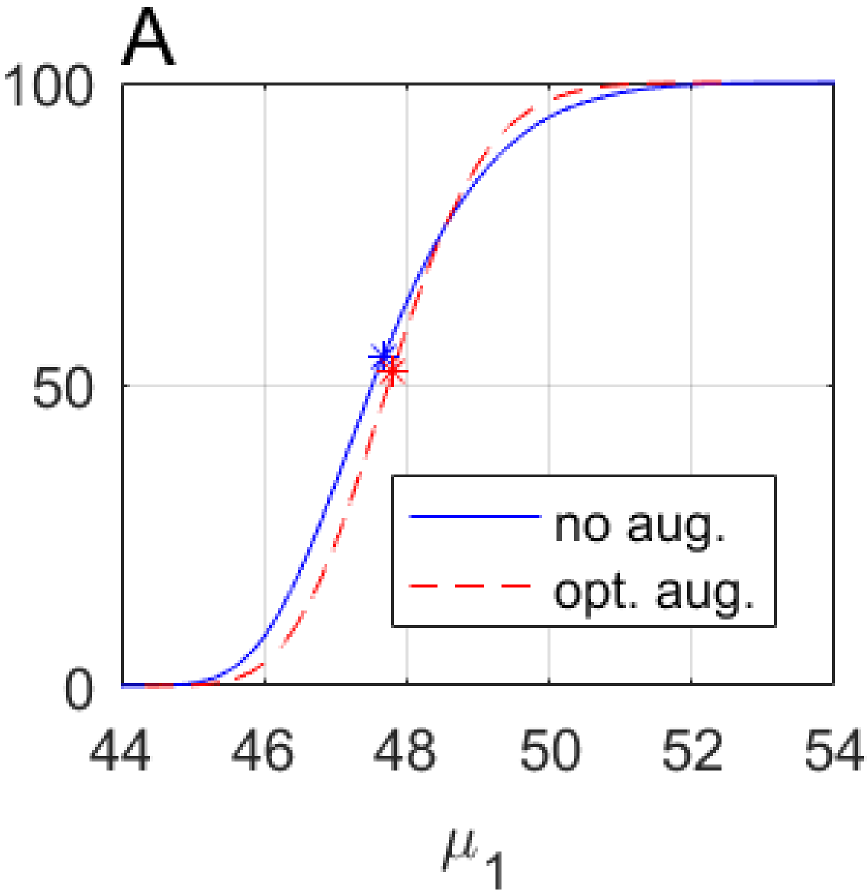
Advantages of FDP

- Simulating forward in time
  - can eliminate (or simplify) integration
  - reduces the need for calculations with very large arrays (e.g. Markov transition matrices used in backwards induction defined across the entire state space)

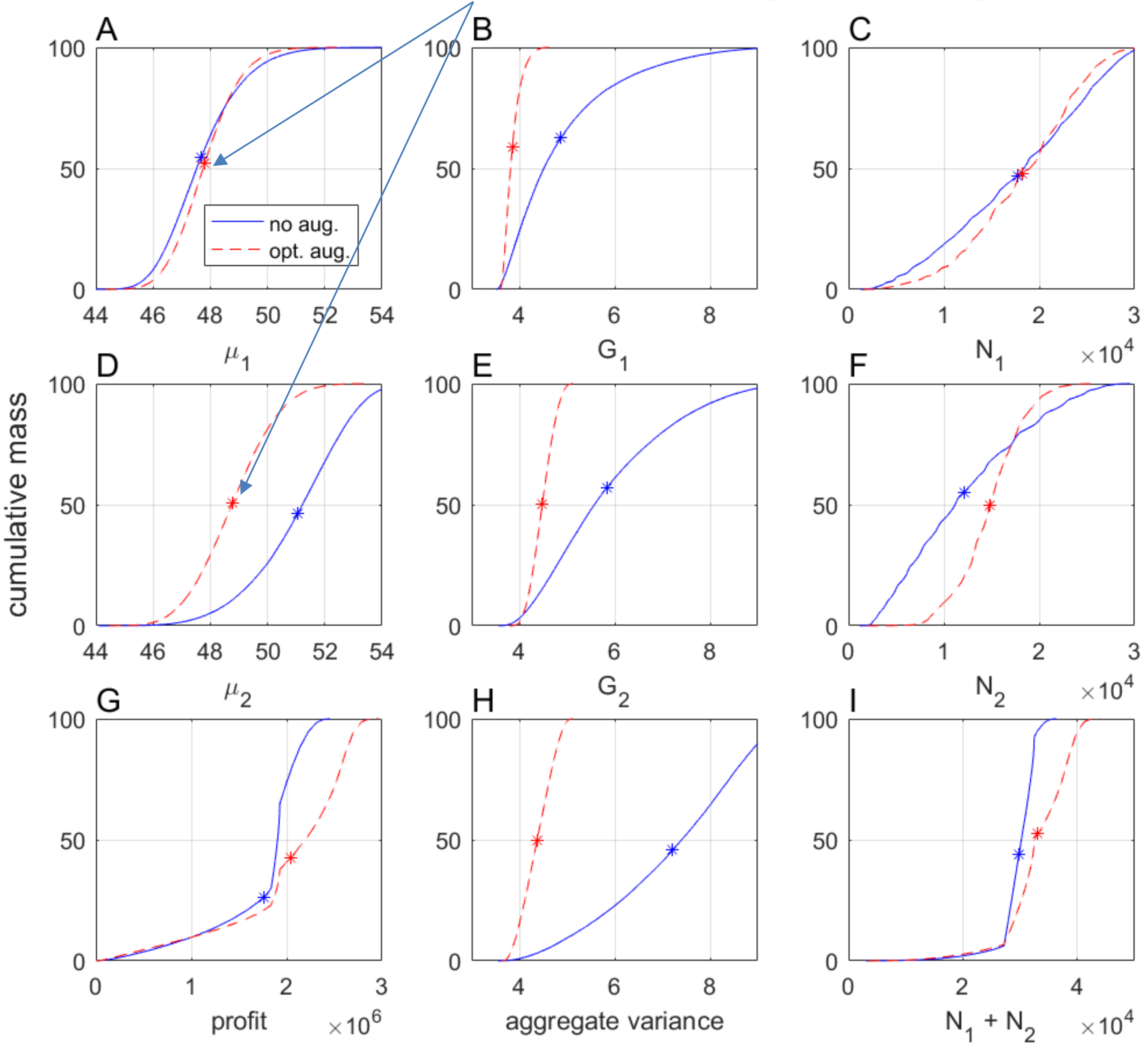
- This makes FDP particularly powerful tool for dynamic optimization with many states and/or controls.

Simulation results:

- 3,000 sims of 50 periods, first 30 periods excluded for burn-in.
- Results presented as cumulative mass functions (CMFs)
- Cases: no augmentation (blue) and optimal augmentation (red)
- *=mean



Simulations show: 1. Optimal trucking (str. 1) pulls trait means together, $\mu_1 \rightarrow\leftarrow \mu_2$ (loss of b/n pop. diversity)

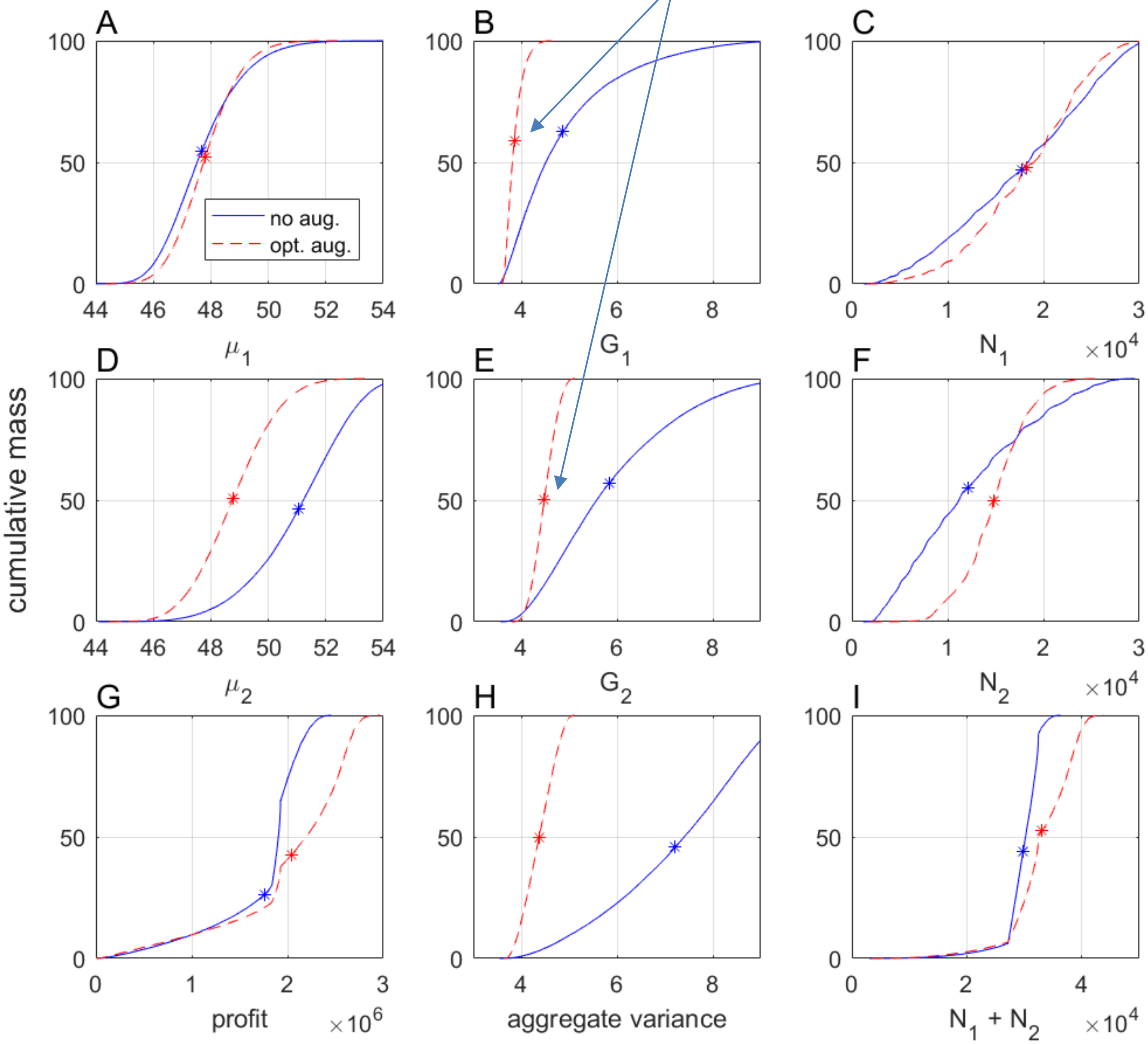


CMFs:

- subpop.1 (top row)
- subpop.2 (middle row)
- aggreg. variables (bottom row)

*=mean outcome

2. Optimal trucking drives down mean G (genetic variance) for both (loss of with subpop. diversity)



CMFs:

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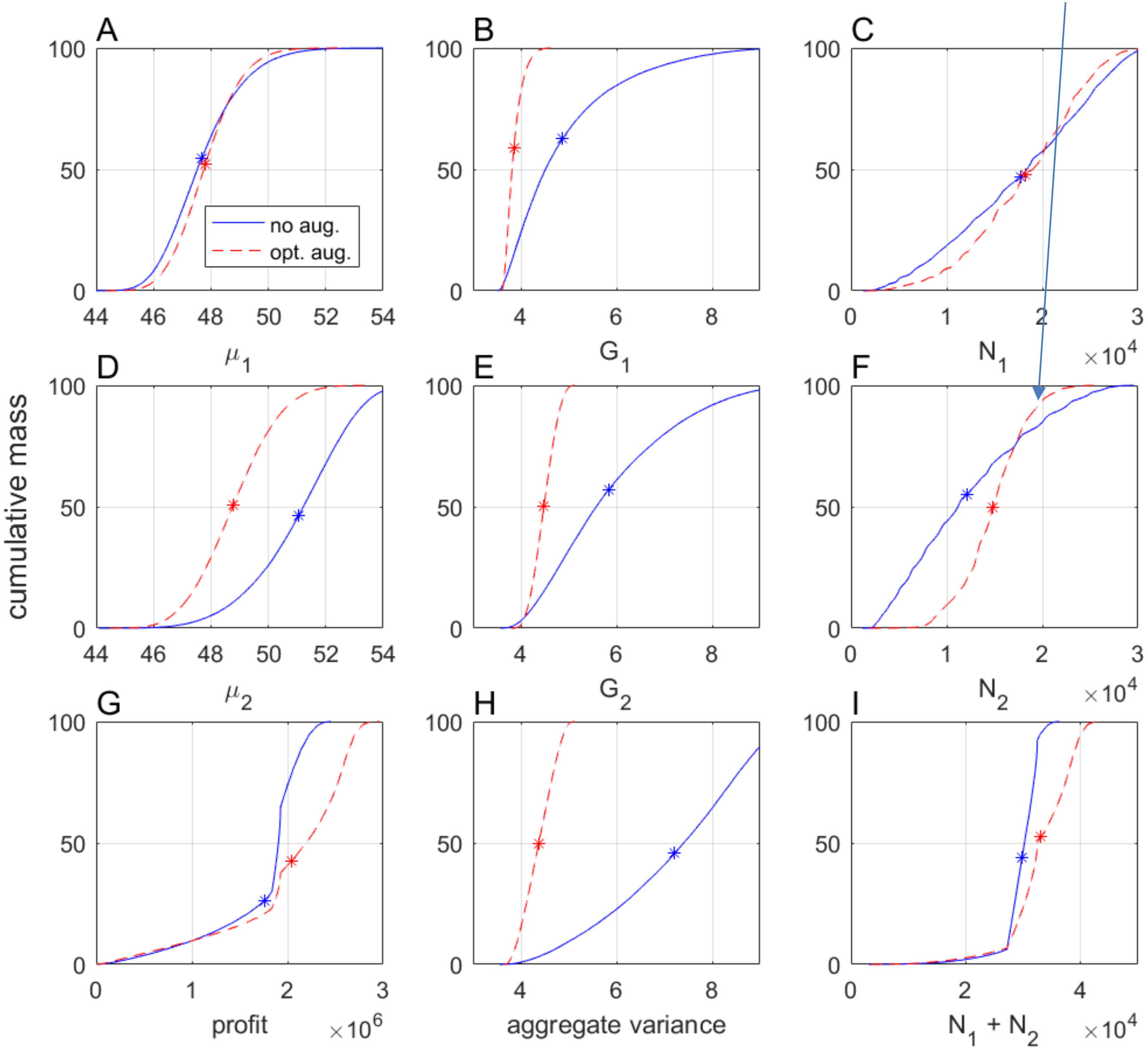
- aggreg. variables (bottom row)

*=mean outcome

Under the optimal policy:

3. Optimal trucking of stream 1 boosts N_2 the most



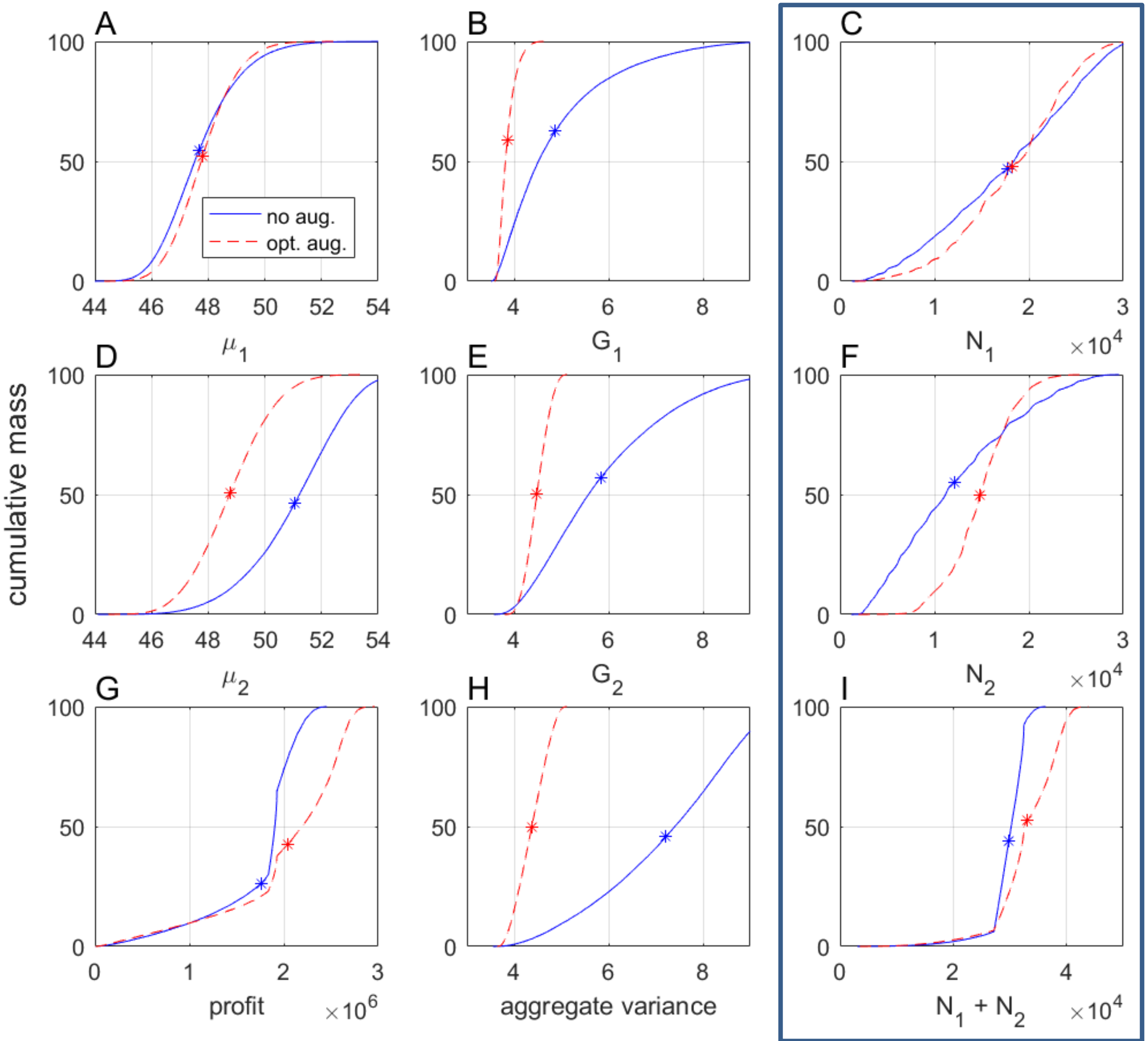
CMFs:

- subpop.1 (top row)
- subpop.2 (middle row)
- aggreg. variables (bottom row)

*=mean outcome

Under the optimal policy:

4. N_1 ,N_2: *less* boom and bust. N_1+N_2: only more boom



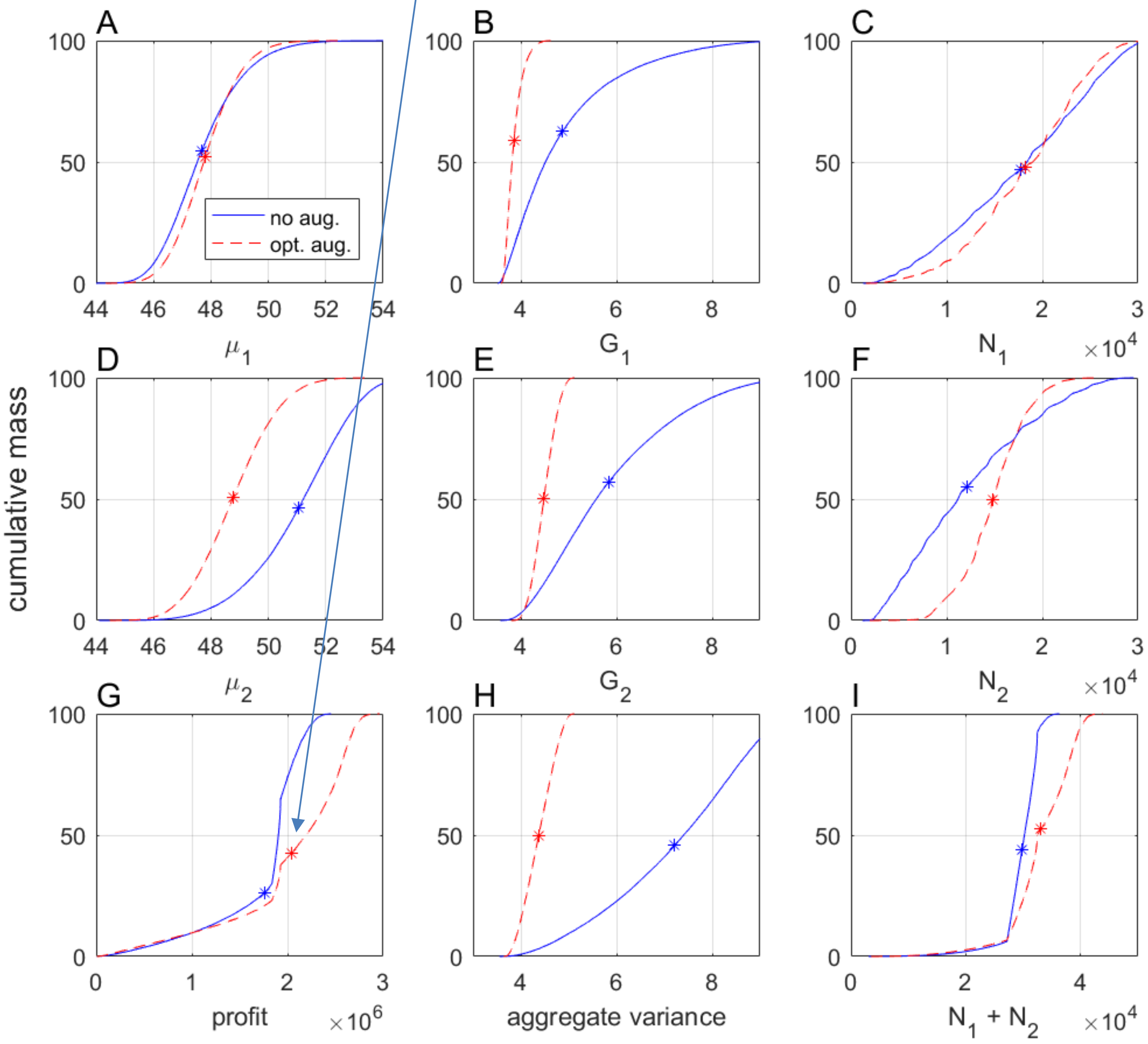
CMFs:

- subpop.1 (top row)
- subpop.2 (middle row)
- aggreg. variables (bottom row)

*=mean outcome

Under the optimal policy:

5. Mean profit up 14%, no change in downside risk, only up



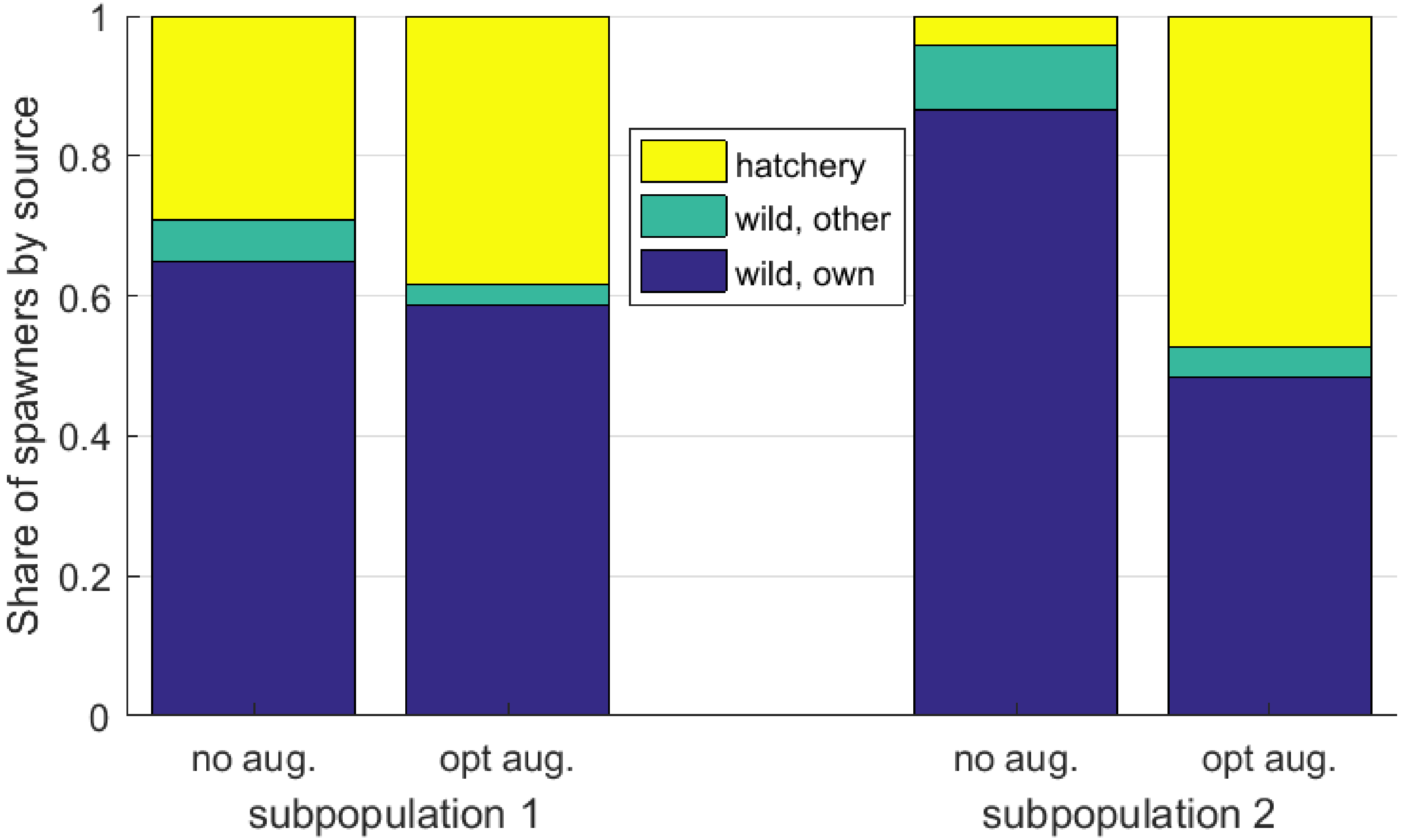
CMFs:

- subpop.1 (top row)
- subpop.2 (middle row)
- aggreg. variables (bottom row)

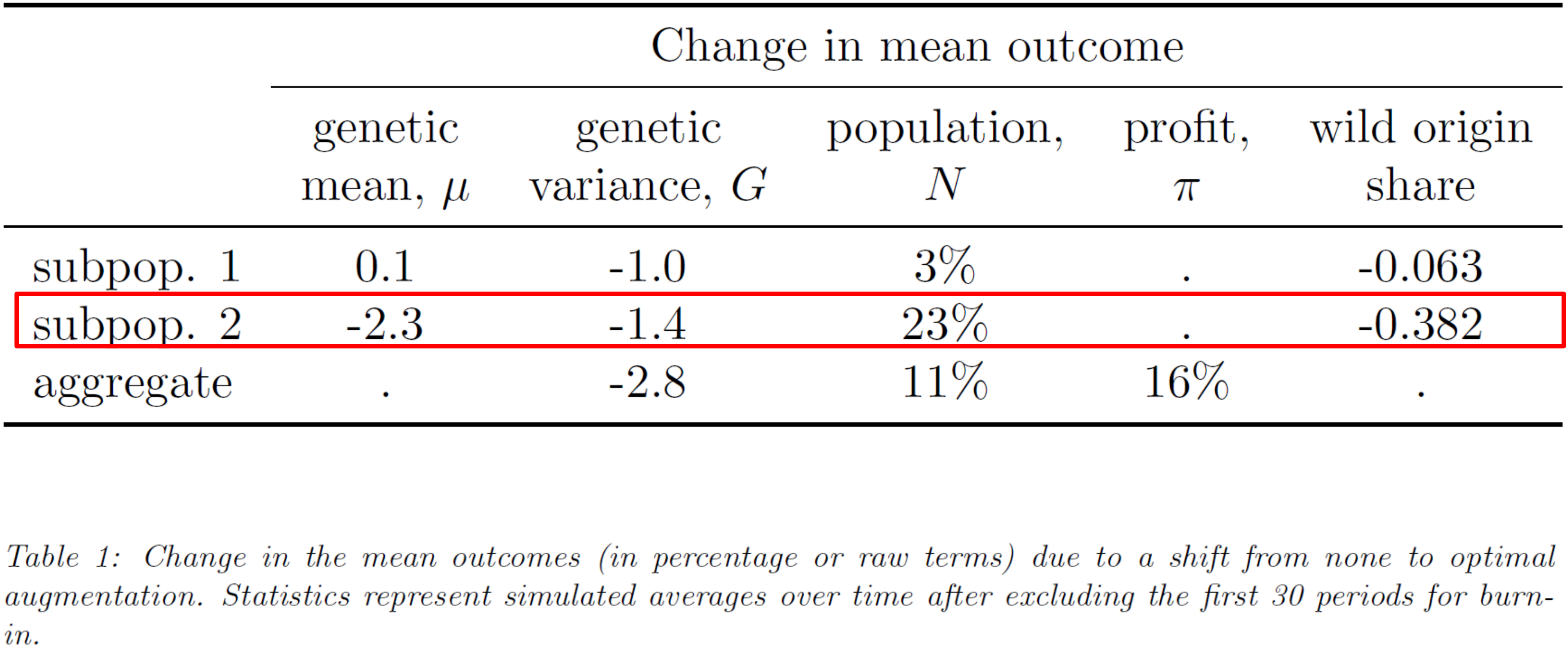
*=mean outcome

Under the optimal policy:

6. Wildness falls, especially for the *non-hatchery* subpop.



Under the optimal augmentation policy:
7. The biggest impacts are on the *non-hatchery* subpop.

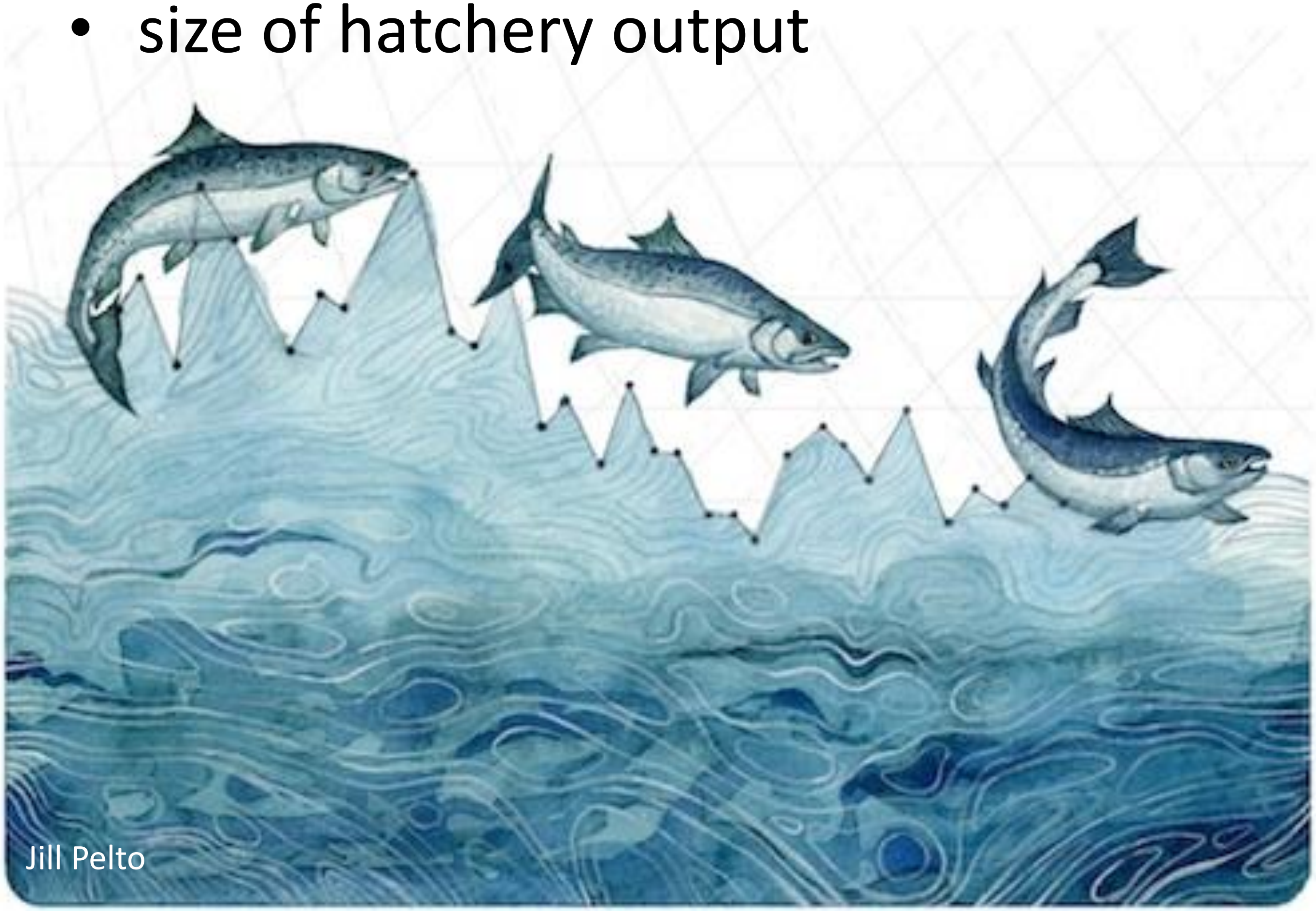


	Change in mean outcome				
	genetic mean, μ	genetic variance, G	population, N	profit, π	wild origin share
subpop. 1	0.1	-1.0	3%	.	-0.063
subpop. 2	-2.3	-1.4	23%	.	-0.382
aggregate	.	-2.8	11%	16%	.

Table 1: Change in the mean outcomes (in percentage or raw terms) due to a shift from none to optimal augmentation. Statistics represent simulated averages over time after excluding the first 30 periods for burn-in.

Future directions

- optimal harvest
- trucking in anticipation of poor environmental conditions
- optimal proportion to truck
- size of hatchery output

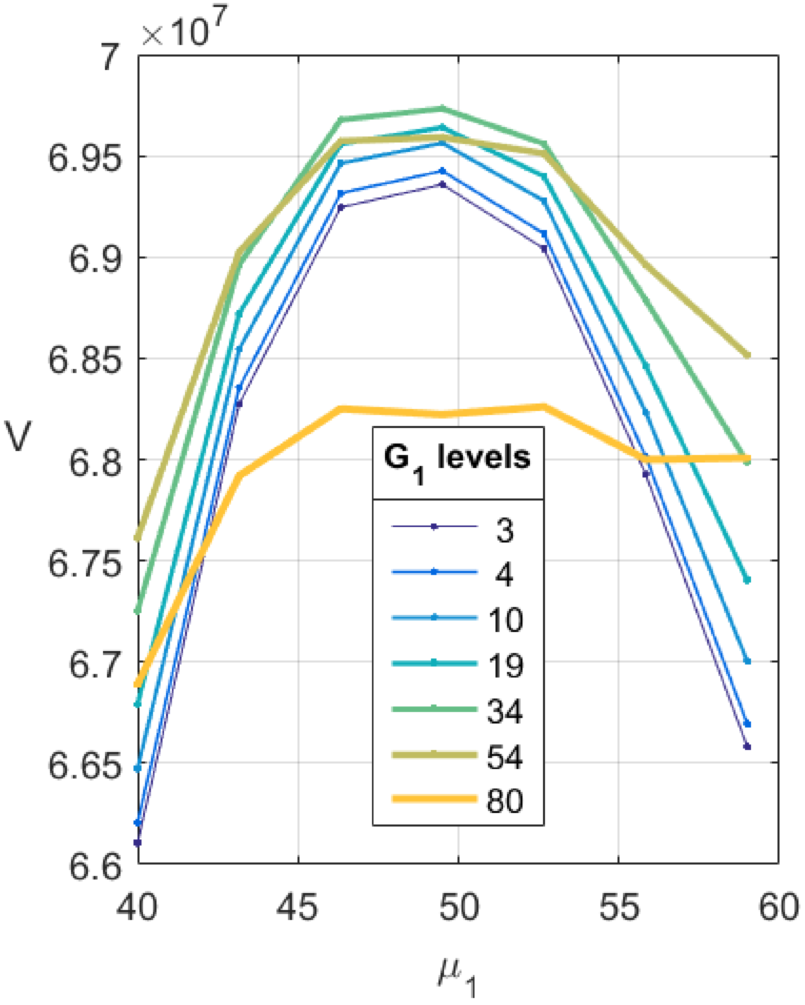


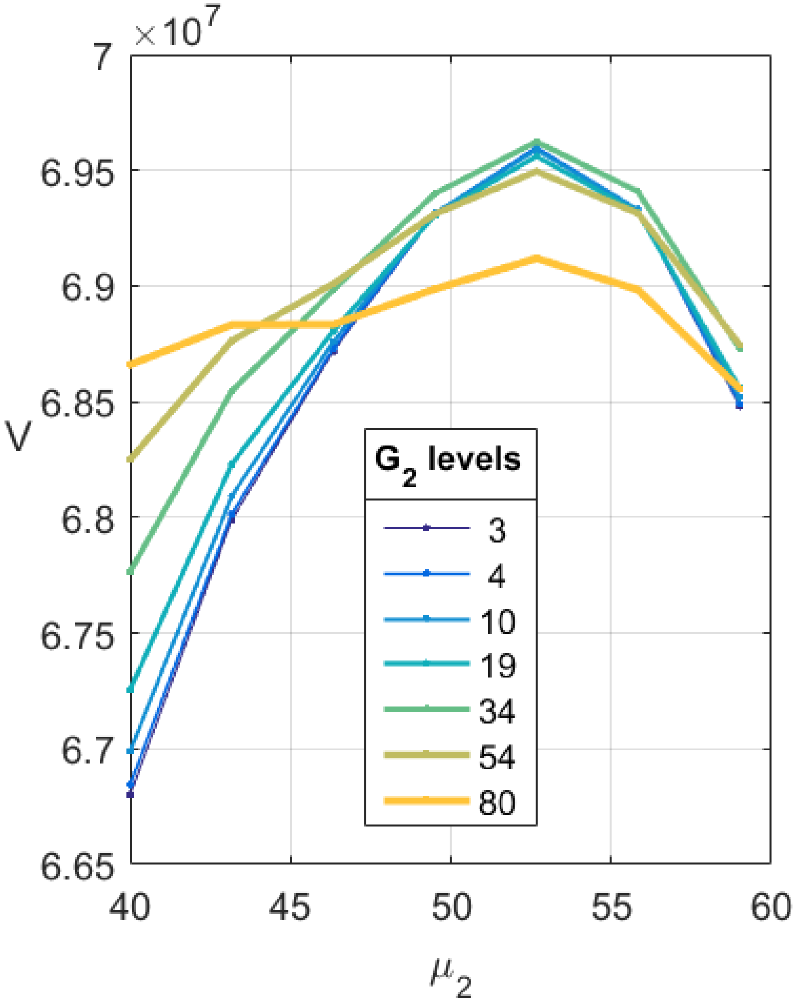
Central findings

- The optimal policy in the vast majority of cases is to fully truck salmon (except: μ_1 near in-stream ideal, N_1 is low)
- Optimal trucking of stream 1 affects stream 2 the most
    - boosts the non-hatchery stock (N_2) the most
    - homogenizes the portfolio:
        - pulls trait means together, $\mu_1 \rightarrow \leftarrow \mu_2$
        - drives down mean G (genetic variance) for both
    - boosts profits by 14%
    - drives loss of wildness
- Weakly sustainable: degraded portfolio leaves system ill-suited for return to fully natural production (recovery eventually occurs unless loss of genetic variance is permanent).
- Value of genetic variance depends on the mean (μ).
    - lowest when μ_i is near its ideal.

Value function plots over the genetic mean show:

1. there is an ideal genetic mean (μ) for streams 1 and 2 (49.5, 52.7)
2. …different from the typical outcomes (47.7, 48.8) under optimal trucking





The optimal policy in the vast majority of cases is to fully truck salmon.

Across a discretization
of the state space:

- D*= 1 -- 82%
- D*= 0 -- 7%
- interior -- 11%

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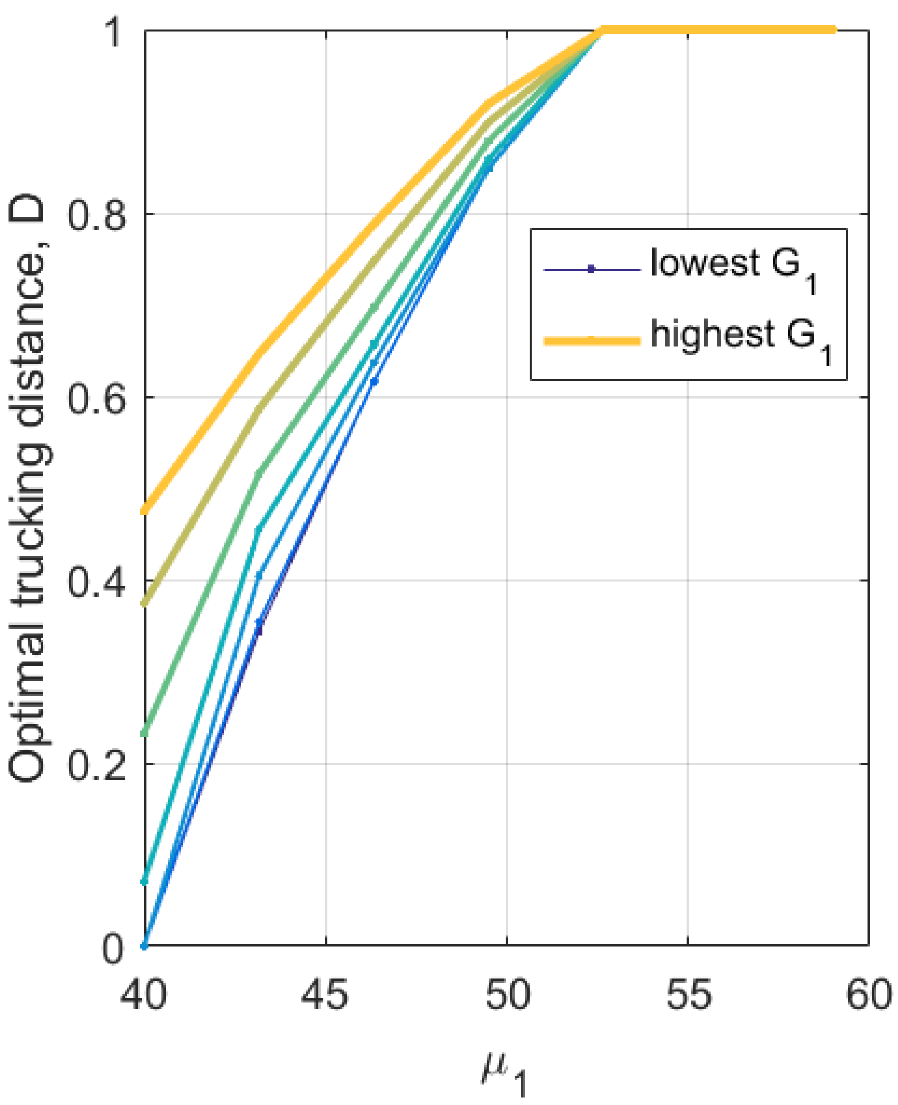
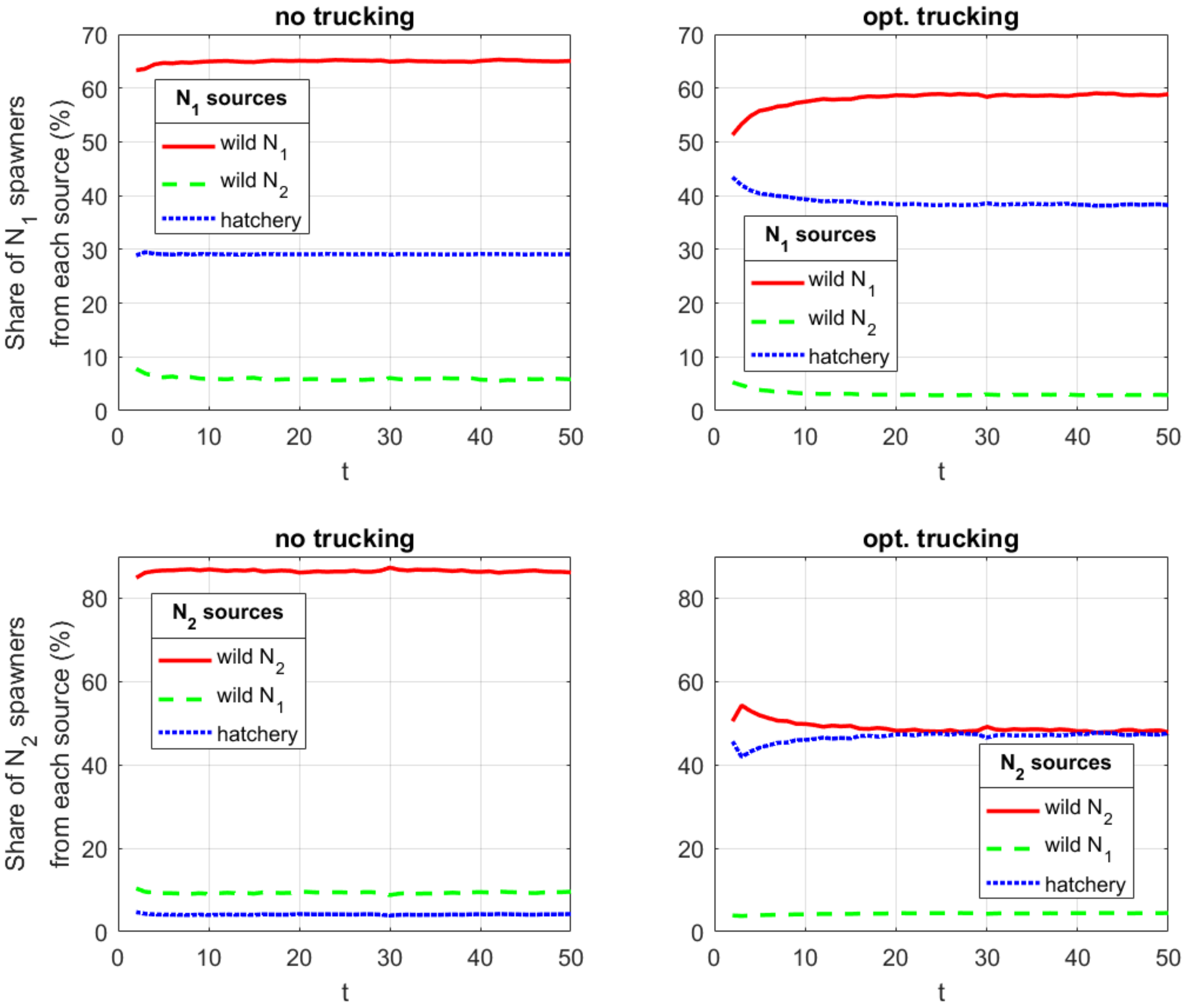


A hatchery management side effect is loss of wildness: replacement of wild with hatchery-reared individuals



Mean percentage share of spawner source for streams 1 (top row) and 2 (bottom row) under no trucking (left column) and optimal trucking (right column) over 3,000 simulation runs across 50 periods.

Appendix

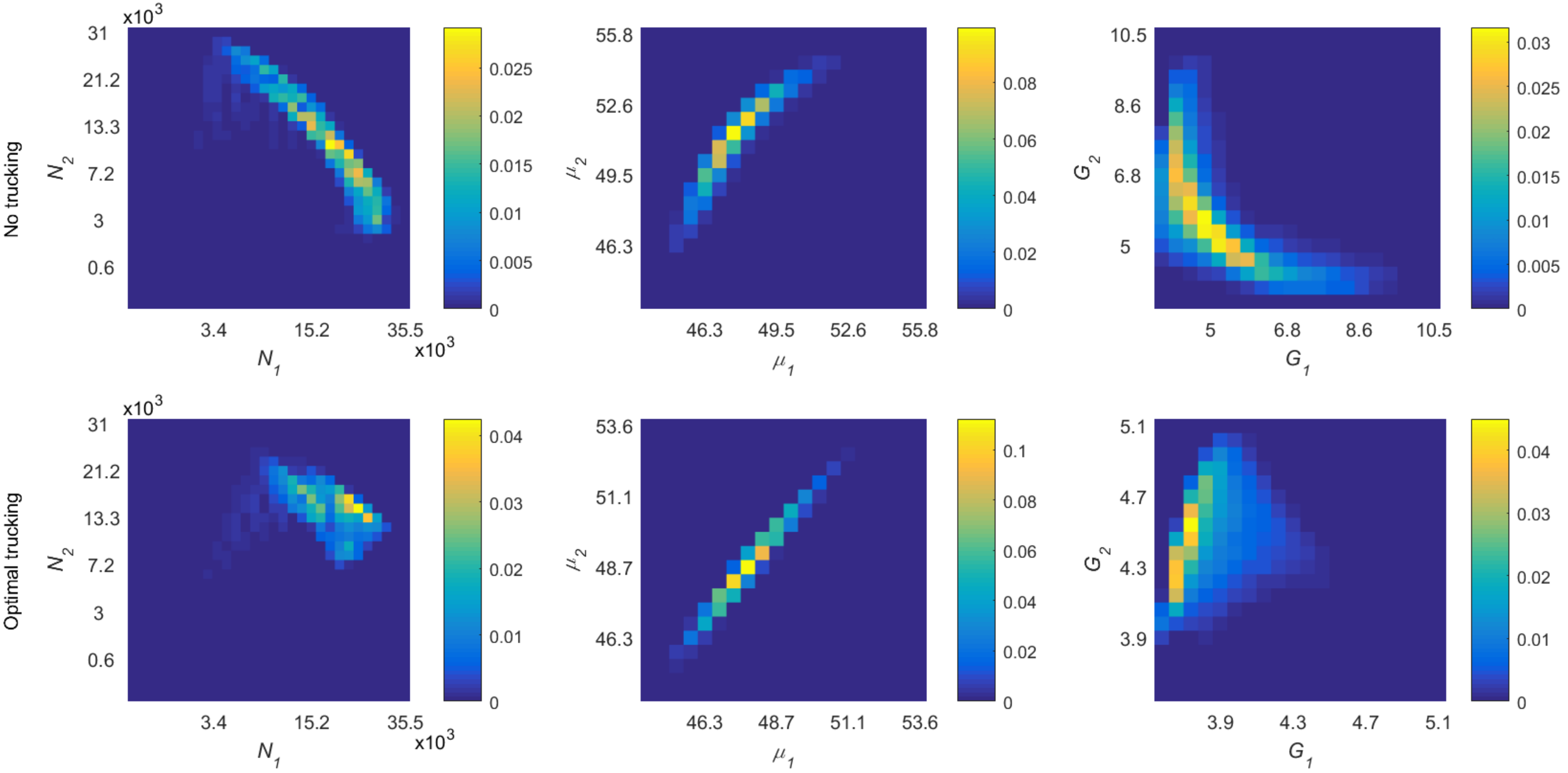
Collaborators

“*Managing natural resources for adaptive capacity: the Central Valley Chinook salmon portfolio*”

With:

Stephanie Carlson (UCB),
Will Satterthwaite (NOAA-Fisheries),
Steve Lindley (NOAA-Fisheries),
Robin Waples (NOAA-Fisheries)

Frequency distributions for each state variable (left to right) show that a shift from no trucking to optimal trucking (top to bottom) alters the distribution of states.



population size

genetic mean

genetic variance