Size selectivity under noncooperative harvest: when does management improve the value of the fishery?

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Why does size matter?

Management controls catch in terms of weight (e.g. kilograms or pounds).

- But are all pounds equal, or are some pounds more equal than others?

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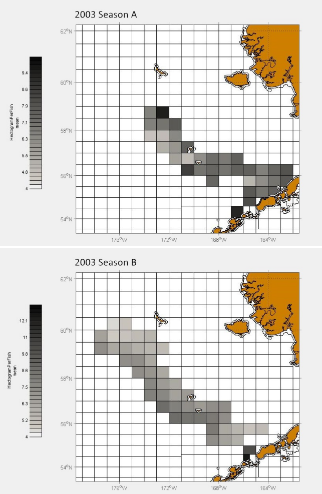
- But are all pounds equal, or are some pounds more equal than others?

Different pathways that influence size selectivity:

- Economics
  - Are larger fish worth more?
  - What is the cost of being selective?
- Biology
  - How does growth rate change at age?
- Management
  - How do bycatch policies influence selectivity decisions?

Costly selectivity

1. It is costly to be selective.



- Fish swim, changing locations across time, and fish school by size.
- If you want a particular size of fish, you need to spend effort and time searching.

[1] Maps created in FishSET

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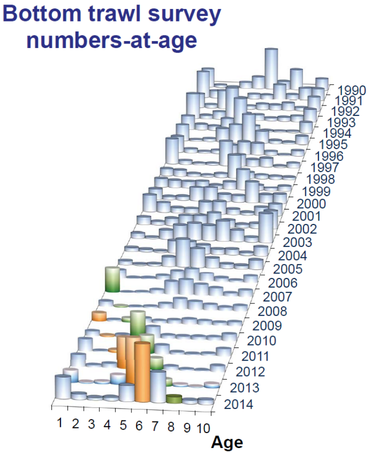

- Abundance of fish also changes across age. Catch per unit effort decreases as we select scarce sizes.
- There is an incentive to fish on large year classes, because it is less expensive.

[2] Ianelli et al. Pollock Assessment 2014

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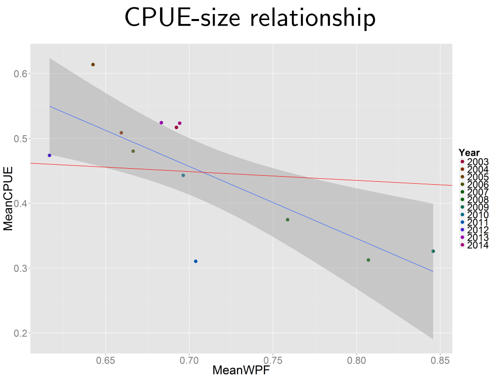
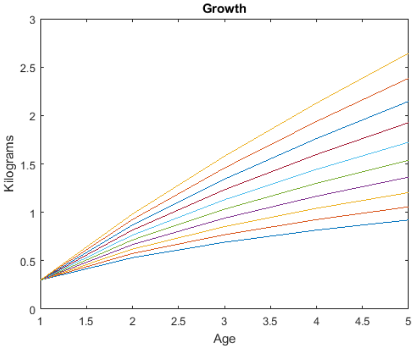


- It can be more efficient to target smaller sizes; catch per unit effort increases, as larger abundances are targeted.

2 But younger fish tend to grow at a faster rate than older fish.

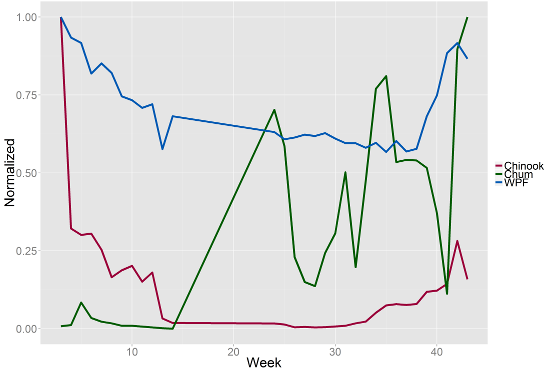
- Larger size fish at older ages.
- Our model uses a strictly concave size at age function.
- Examining about 80% by weight of harvested pollock age classes.

- Slowest growth corresponds to the yearly average pollock assessment weight at age (Ianelli et al.).



3. And by being selective harvesters can avoid costly bycatch.

Bycatch by week

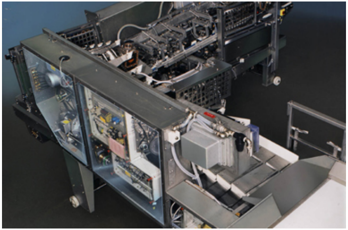


- Bycatch is important because of the timing during the season.
- Do fish school by size across species, and do larger pollock mix with returning salmon?

4. As well as catch larger, more valuable fish.

Price per produced metric ton, 2003-2013, 2014$

	1st Quartile	Mean	3rd Quartile
Fillet	3,095.3	3,478.7	3,855.9
Surimi	2,070.0	2,820.0	3,425.0



- Equipment used to process higher-valued products may require larger fish (e.g. equipment may be more productive or require a minimum size to transform to fillet).

- Noncooperative decision making leads to inefficient selectivity.

- Model noncooperative harvest in a size- and time-differentiated system.
  - Results are consistent with and support the findings in a static game (Diekert ERE 2012), where decreasing selectivity is due to incentives to lower own costs.
  - Externality occurs because fishing younger fish reduces the steady-state biomass and future harvests.
  - Heterogeneous harvesters and use of a bycatch policy can give unintuititve results.

- Certain pathways (rate of growth) impact net present value of the fishery more than others.

Each harvester may face a different price-at-age curve.

$$\pi = \sum_{t=1}^{\infty} \delta^t \left(\sum_{a=1}^{A} \left(p_{i,a} s_{i,a,t} - c(f_{i,t}) \right) \right) \tag{1}$$

The harvester chooses a minimum age $\underline{a}$ as well as a maximum age $\bar{a}$.

- Then a constant fishing mortality rate is applied to all age classes chosen, such that:

$$f_{i,t}(\sum_{a=\underline{a}}^{\bar{a}} N_{a,t}\omega_a) \leqslant \frac{TAC_t}{V} \quad \forall i,t$$

$$s_{a,i,t} = \begin{cases} f_{i,t}(N_{a,t}\omega_a) & \underline{a} \leqslant a \leqslant \bar{a} \\ 0 & o.w. \end{cases}$$

$N_{a,t}$ = numbers at age.
ω_a = weight at age.

- Costly to be selective
- Need to search for or avoid sizes, increases effort.

The individual harvester chooses smallest age and largest age to target.

$$\max_{\substack{\underline{a}_L, \bar{a}_L \\ \underline{a}_H, \bar{a}_H}} \pi = \sum_{t=1}^{\infty} \delta^t \left(\sum_{a=1}^{A} \left(p_{i,a} s_{i,a,t} - c(f_{i,t}) \right) \right) \tag{1}$$

The model

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$$N_{1,t} = \Omega_t \quad \text{(Stock dynamics 1)}$$

$$N_{a+1,t+1} = (N_{a,t} - \frac{1}{\omega_a} \sum_{i=1}^{\eta} s_{i,a,t})\mu_t \quad \text{(Stock dynamics 2)}$$

$$N_{A,t+1} = (N_{A,t} - \frac{1}{\omega_A} \sum_{i=1}^{\eta} s_{i,A,t})\mu_t + (N_{A-1,t} - \frac{1}{\omega_{A-1}} \sum_{i=1}^{\eta} s_{i,A-1,t})\mu_t \quad \text{(Stock dynamics 3)}$$

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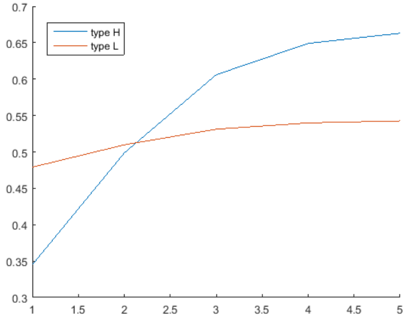
$$\sum_{i=1}^{V} s_{i,a,t} \leqslant N_{a,t} \omega_a \quad \text{(Stock constraint)}$$

- Harvesters derive different values from size.
- Larger fish can be made into more valuable products (e.g. fillet vs. surimi).
- Production technology is different across vessels.



The value of the fishery for the i^{th} harvester can be expressed as a Bellman:

$$V_i(\hat{N}) = \max_{0<s_{i,a}<N_a*\omega_a} \left(\sum_{a=1}^{A} \left(p_{i,a}s_{i,a,t} - c(f_{i,t}) - prob_S\left(\sum_{i=1}^{V} f_{i,\hat{a},t}\right) * S \right) + \delta E[V_i(\hat{g}(s_{i,a}, s_{-i,a}, N_a))] \right)$$

Or for the fishery manager:

$$V(\hat{N}) = \max_{0<s_{i,a}<N_a*\omega_a} \left(\sum_{a=1}^{A} \left(p_{H,a}s_{H,a,t} - c(f_{i,t}) - prob_S\left(\sum_{i=1}^{V} f_{i,\hat{a},t}\right) * S \right) + \sum_{a=1}^{A} \left(p_{L,a}s_{L,a,t} - c(f_{i,t}) - prob_S\left(\sum_{i=1}^{V} f_{i,\hat{a},t}\right) * S \right) \right) + \delta E[V(\hat{\hat{g}}(s_{i,a}, s_{-i,a}, N_a))] \Big)$$

Selected results, simulated over 50 years

	Manager less noncoop. cost (billions $)	Manager less noncoop. harvest (billions kg)	Manager less noncoop. NPV (billions $)
Homogeneous cost $\alpha = 6$ growth $\beta = 9$	0.85	1.49	0.10

- Even though noncooperative harvesters reduce own costs, the manager increases biomass and harvest, and therefore the value of the fishery.

Selected results, simulated over 50 years

	Manager less noncoop. cost (billions \$)	Manager less noncoop. harvest (billions kg)	Manager less noncoop. NPV (billions \$)
Homogeneous cost $\alpha = 6$ growth $\beta = 9$	0.85	1.49	0.10
Heterogeneous cost $\alpha = 6$ growth $\beta = 9$	0.54	1.05	0.05

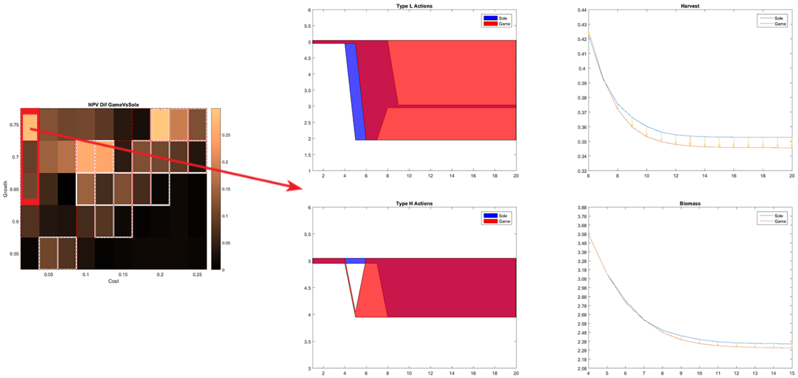
- Including a heterogeneous harvester who values large fish more decreases the selectivity externality, as there is less incentive to fish smaller faster growing fish.

Selected results, simulated over 50 years

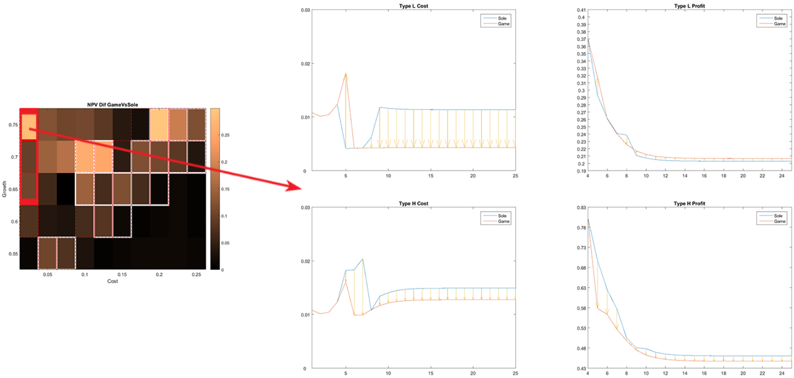
	Manager less noncoop. cost (billions $)	Manager less noncoop. harvest (billions kg)	Manager less noncoop. NPV (billions $)
Homogeneous cost $\alpha = 6$ growth $\beta = 9$	0.85	1.49	0.10
Heterogeneous cost $\alpha = 1$ growth $\beta = 10$	0.41	0.61	0.28

- When biological growth is fast enough, and costs are low enough, the manager would prefer to segregate harvesters.

- Because the harvester that is indifferent towards size has no incentive to avoid larger fish, there is a larger difference in welfare and an improvement for the fisher manager to make.



- These indifferent non-responsive harvesters will end up capturing a greater share of rents under noncooperative harvesting.



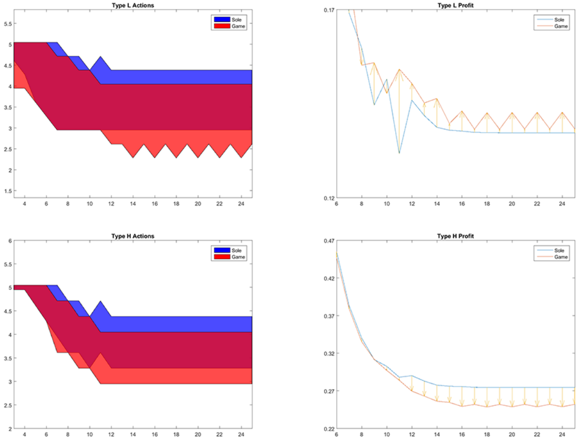
Selected results, simulated over 50 years

	Manager less noncoop. cost (billions \$)	Manager less noncoop. harvest (billions kg)	Manager less noncoop. NPV (billions \$)
Homogeneous cost $\alpha = 6$ growth $\beta = 9$	0.85	1.49	0.10
Bycatch cost $\alpha = 6$ growth $\beta = 9$	2.29	1.54	0.22

- Or when bycatch cost is sufficiently small, it can be worthwhile for the manager to fish on the bycatch age, rather than harvest small, fast-growing fish.

Bycatch

- The fishery manager would prefer to select more of the bycatch age, instead of fishing down the age structure.



- We find:
  1. Harvesters end up with fewer costs than the fishery manager during noncooperative harvesting (by decreasing their selectivity).
  2. But, fishing younger fish reduces the steady-state biomass and future harvests (because overall fishery rate of growth has decreased).
  3. Decreased future harvest, and higher prices per kilogram for larger fish, generally outweigh benefits from fewer costs, for the types of fisheries with the parameter assumptions we have made.