The Gains to Considering Fishery Induced Evolution

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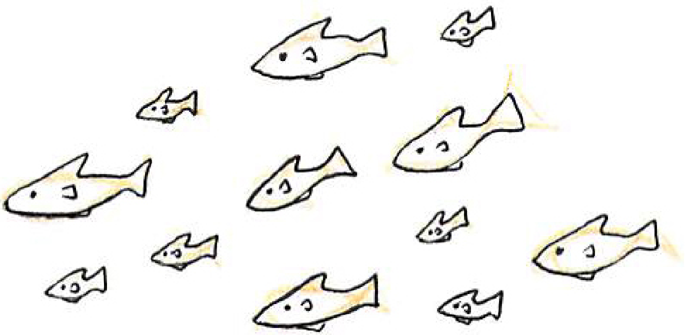
Outline

What is Fishery Induced Evolution?



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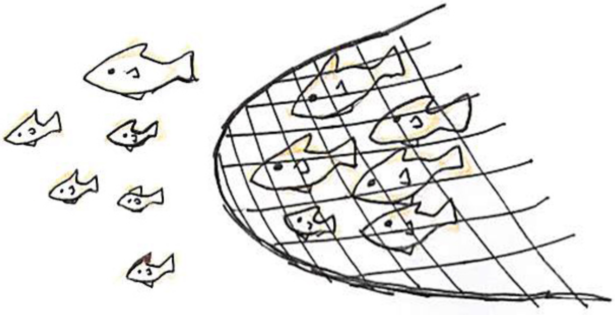
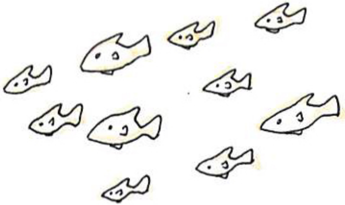


- When a fish population is commercially harvested, large fish are caught more frequently than small fish.

What is Fishery Induced Evolution?

- The mature individuals in the surviving population reproduce.
- Fish that mature early or are small for their age have a reproductive advantage due to harvesting.
- These traits become more and more frequent in the population, changing the characteristics of the population. (i.e. the population evolves)

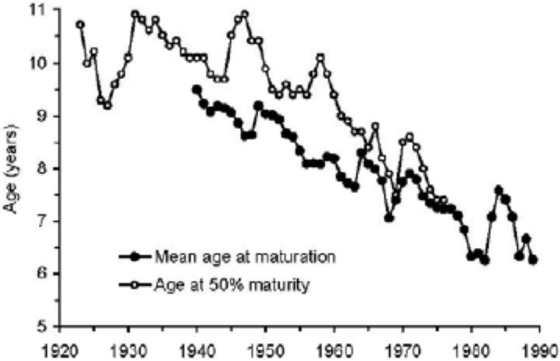


Why does FIE matter?

Economically important traits are evolving in response to fishery effort and selectivity (mesh size).

- population growth rate is linked to maturation rate and individual growth rate
- biomass value is linked to average size at age if there is a price gradient

Why does fishery induced evolution matter?



Age at maturation in Northeast Arctic Cod

Source: Heino *et al.* (2002)

The Question

How much of an increase in fishery profit could we expect to see if fisheries induced evolution was considered by fishery managers?

Literature

- So far, very little economic work has been done regarding fisheries induced evolution. (Eikeset *et al.* 2013, Guttormsen *et al.* 2006)

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- Almost no work has been done to determine the impact of ignoring fisheries induced evolution.
- fit into the larger EBFM literature as a consideration of one of many externalities to fishing.

The model

- comparison of a fishery manager who includes FIE in their management model to the ”status quo”.

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- comparison of a fishery manager who includes FIE in their management model to the "status quo".
- calibrated to North-East Acrtic Cod (NEA Cod)
- multiple controls (mesh and effort)
- real-world gear selectivity pattern (trawler vs. knife edge)
- size-structure population (multiple age classes, and sizes at each age)
- quantitative genetics (which is necessary to model a continuous trait such as maturation rate)

The Model

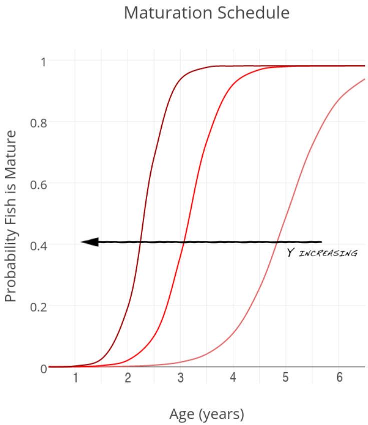
- Compare the steady state reached by a ‘dynamic’ fishery manager to that reached by a ‘myopic’ fishery manager
- Dynamic fishery manager dynamically optimizes the NPV of the fishery, taking evolution into account
- Myopic fishery manager optimizes annual fishery profit, subject to a sustainability constraint, taking population characteristics as given, and assuming they are fixed. (i.e. assuming evolution is not occuring)

Evolution

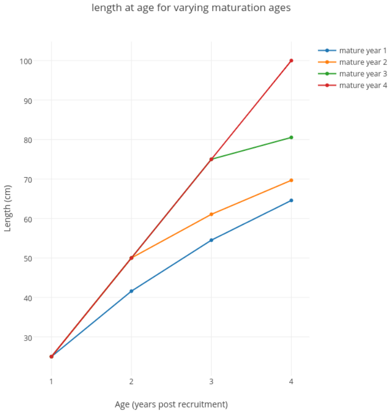
- Evolution is a fitness maximizing process
- The rate of evolution is given by the breeders equation, which is a function of effort, mesh, and the current value of y, the evolving parameter.

The Breeders Equation

What is y?


Maturation Schedule
Probability Fish is Mature
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
Age (years)
Y INCREASING

Size Class Determination



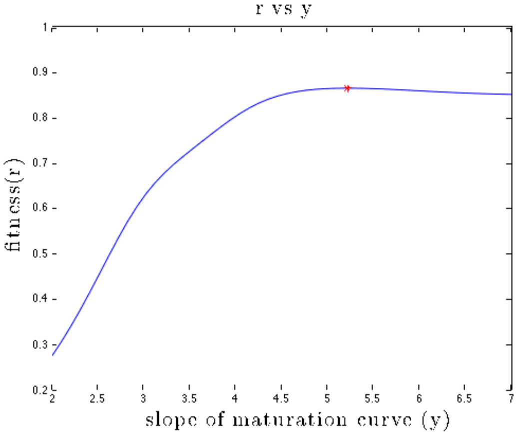
Fitness = population growth rate (r)

$$r(y)$$

if y increases, fish are more likely to mature at a young age. This means they are smaller at any given age, and they:

- produce fewer eggs at any given age
- more likely to escape harvest at any given age
- get a 'head start' on procreating

Fitness


r vs y
fitness(r)
slope of maturation curve (y)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7

Dynamic Fishery Manager

The dynamic fishery manager's Hamiltonian:

$$H = \sum_{k=1}^{K} p_k N_k w_k h_k(E, m) - cE + \lambda_1(\Delta N_1) + \ldots + \lambda_K(\Delta N_K) + \mu(\Delta y_t)$$

k	one of the K size classes
N_k	the number of individuals in size class k
w_k	the weight of individuals in size class k
E	fishery manager's first choice variable: effort
m	fishery manager's second choice variable: mesh
$h_k(E, m)$	annual probability of individuals in size class k being harvested by effort level E and mesh size m
c	cost of effort
λ_k	the shadow price of size class k
μ	the shadow price of the slope maturation curve

Myopic Fishery Manager

The myopic fishery manager solves:

$$\max_{E,m} \qquad \pi = \sum_{k=1}^{K} p_k N_k w_k h_k(E, m) - cE$$

subject to

$$\Delta N_k = 0 \quad \forall \quad k = 1, ..., K$$

Myopic Fishery Manager

Equilibrium characterized by:

$$\{E, m\} = \arg\max_{E,m} \left\{ \pi = \sum_{k=1}^{K} p_k N_k w_k h_k(E, m) - cE \right\}$$

subject to

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Myopic Fishery Manager

Equilibrium characterized by:

$$\{E, m\} = \arg\max_{E,m} \left\{ \pi = \sum_{k=1}^{K} p_k N_k w_k h_k(E, m) - cE \right\}$$

subject to

$$\Delta N_k = 0 \quad \forall \quad k = 1, ..., K$$

and

$$\Delta y = 0$$

Results. Price per pound constant.

Table 1 : Effort, mesh size, and annual profit of the Dynamic fishery's steady state, relative to the Myopic fishery's steady state

	ρ =0.00	ρ =0.01	ρ =0.02	ρ =0.03	ρ =0.04	ρ =0.05
Effort	-25.3%	-3.6%	2.0%	4.6%	6.5%	8.2%
Mesh	-3.4%	-0.2%	-0.8%	-1.4%	-1.8%	-2.2%
Profit	28.9%	19.1%	6.3%	1.6%	-0.1%	-1.1%

Appendix

Table 2 : Steady state biomass by age for myopic and dynamic fisheries at the steady states

Age	ρ =0.00	ρ =0.01	ρ =0.02	ρ =0.03	ρ =0.04	ρ =0.05	Myopic
1	0.10	0.09	0.09	0.09	0.09	0.09	0.09
2	0.65	0.64	0.64	0.64	0.64	0.64	0.64
3	1.45	1.25	1.06	1.00	0.98	0.96	1.00
4	2.18	1.79	1.59	1.50	1.44	1.39	1.63

Table 3 : Steady state maturation rates for myopic and dynamic fisheries at the steady states (price per pound constant)

Age	ρ =0.00	ρ =0.01	ρ =0.02	ρ =0.03	ρ =0.04	ρ =0.05	Myopic
1	0.00	0.00	0.01	0.01	0.01	0.01	0.01
2	0.26	0.53	0.76	0.82	0.85	0.86	0.85
3	0.98	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Results. Price per pound increasing with fish size.

Table 4 : Effort, mesh size, and annual profit of the dynamic fishery's steady state, relative to the myopic fishery's steady state

	ρ =0.00	ρ =0.01	ρ =0.02	ρ =0.03	ρ =0.04	ρ =0.05
Effort	-25.4%	-3.3%	2.5%	4.6%	6.4%	7.9%
Mesh	-4.1%	-0.5%	-1.0%	-1.4%	-1.7%	-2.5%
Profit	33.7%	21.2%	1.3%	-0.7%	-1.6%	-2.7%

More

Results

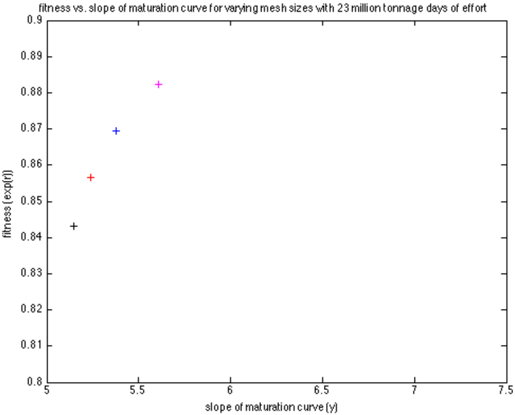
- Ignoring FIE can be very costly to both fishery profit and fishery biomass at the steady state, which gives us good reason to believe it can significantly affect the NPV of the fishery.
- In order to fully understand what ignoring FIE means for the NPV of the fishery, we need a fullly dynamic model to compare to a myopic simulation

Future Directions

- increasing number of age/size classes, to be able to approximate NEA Cod.
- approximating the value function for the full dynamic problem

Appendix

mesh size: 140mm 145mm 150mm 155mm



as the slope of the maturation curve increases, fish are more likely to mature at a young age.

This pattern holds for any effort level

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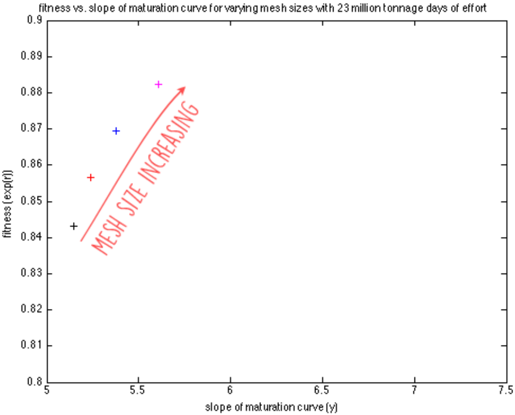

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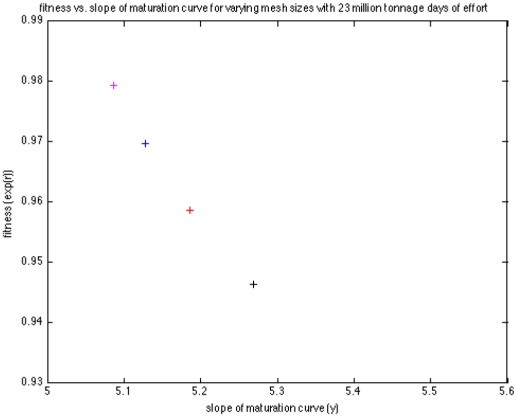
mesh size: 180mm 185mm 190mm 195mm



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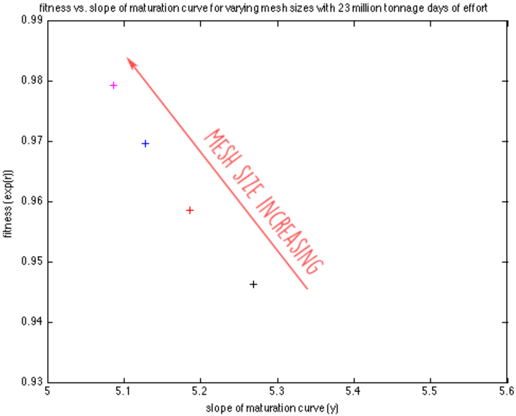

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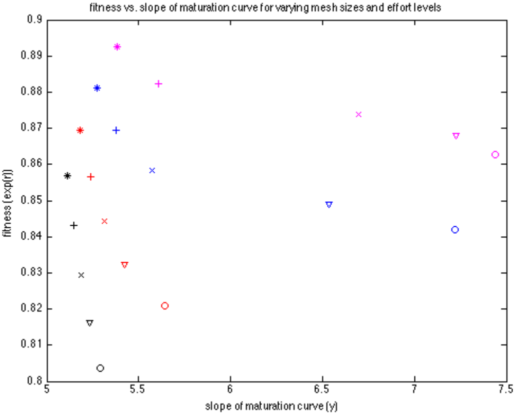

effort level: $* = 21$; $+ = 23$; x = 25; $\nabla = 27$; o = 29 (in million tonnage days)

back

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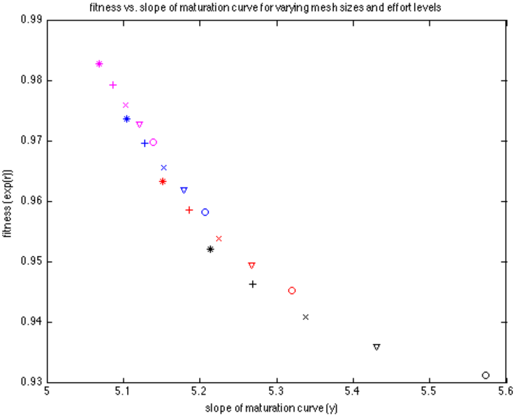

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back

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Table 5 : Steady state maturation rates for myopic and dynamic fisheries at the steady states (price per pound increasing)

Age	ρ =0.00	ρ =0.01	ρ =0.02	ρ =0.03	ρ =0.04	ρ =0.05	Myopic
1	0.00	0.00	0.01	0.01	0.01	0.01	0.01
2	0.26	0.58	0.89	0.91	0.89	0.91	0.90
3	0.98	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6 : Steady state biomass by age for myopic and dynamic fisheries at the steady states

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1	0.10	0.09	0.09	0.09	0.09	0.09	0.09
2	0.65	0.64	0.64	0.64	0.64	0.64	0.64
3	1.46	1.22	0.97	0.95	0.94	0.93	0.97
4	2.25	1.85	1.63	1.57	1.52	1.47	1.72

The Breeders Equation

$$y_{t+1} - y_t = \sigma^2 \cdot \underbrace{\frac{1}{W(y_t)} \cdot \frac{\partial W(y_t)}{\partial y_t}}_{\textit{selection gradient}}$$

Where

$$\underbrace{W(y_t)}_{\textit{average fitness}} = \int_{x=-\infty}^{\infty} Pr(x) \cdot r(x) dx$$

and

$$x \sim N(y, \sigma)$$

so

$$Pr(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\{-\frac{(x-y)^2}{2\sigma^2}\}$$

back