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Balanced harvesting implications for fishing yields, conservation and fish size evolution

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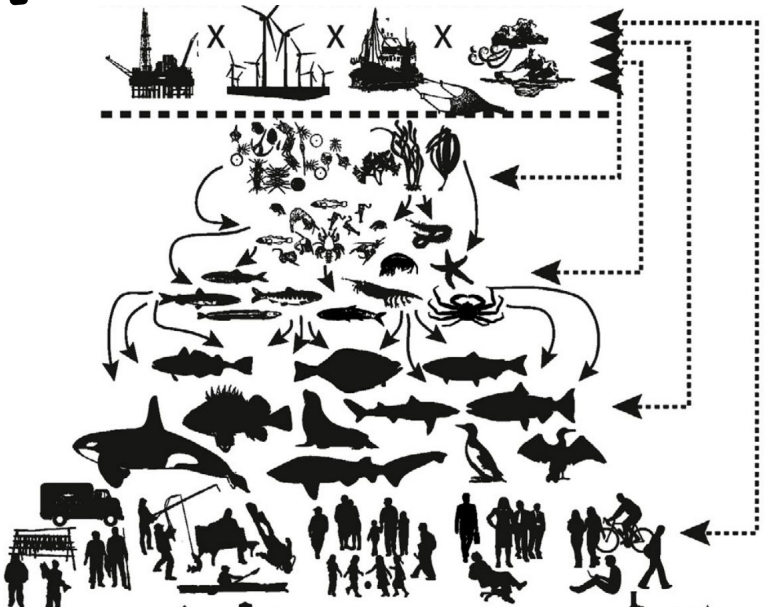
Ecosystem based fisheries management

- avoiding ecosystem **degradation**
- minimizing the risk of irreversible **change**
- obtaining long-term socio-economic **benefits** from fishing
- precautionary approach to **uncertainties**

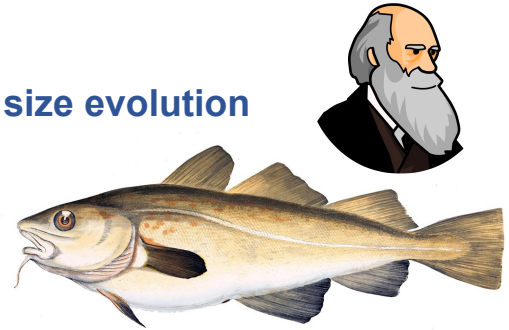
Pikkitch et al. 2004, Bennett et al. 2009

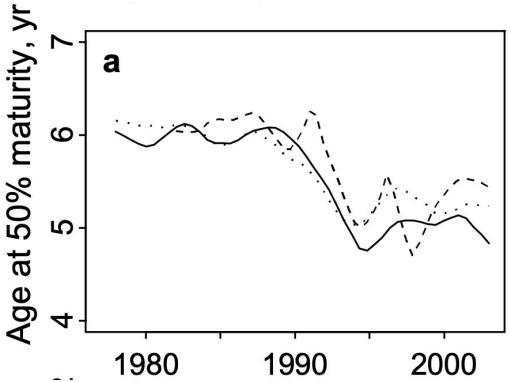
taking into account species interactions

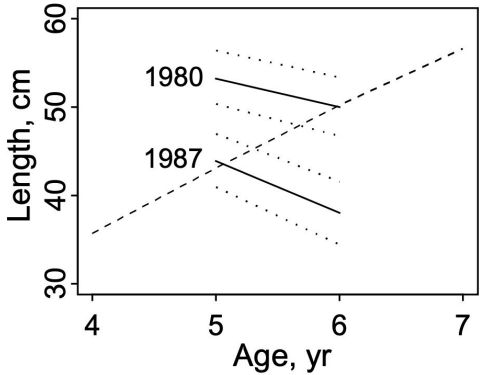


Modified from Holsman et al. 2017

Fish size evolution





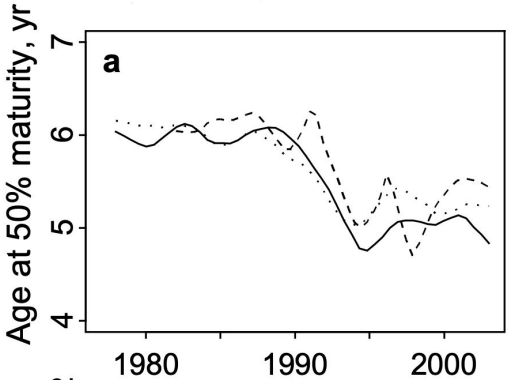


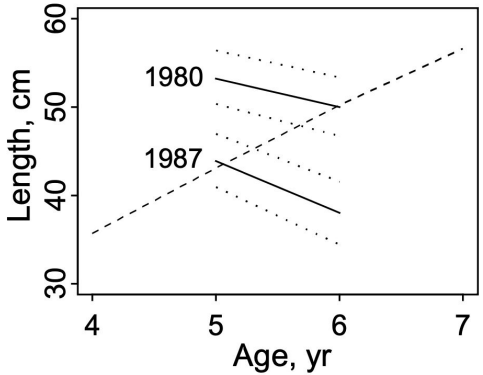
Maturation trends suggestive of rapid evolution preceded the collapse of northern cod

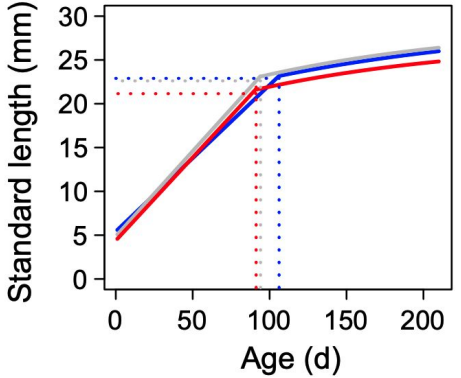
Olsen et al. 2004

Fish size evolution

5 generations of size-selected zebra fishes







large-selected

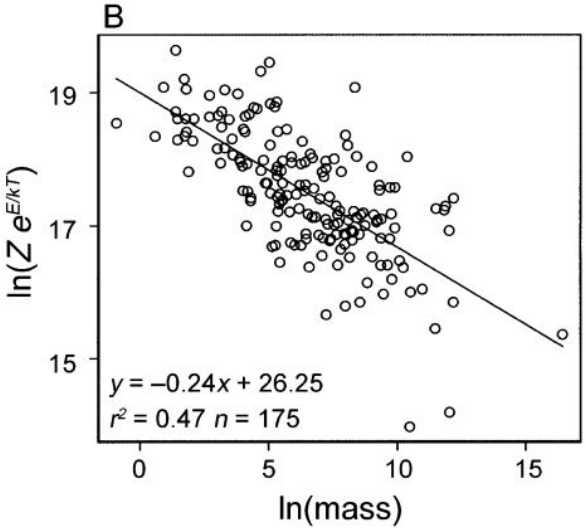
small-selected

Maturation trends suggestive of rapid evolution preceded the collapse of northern cod

Olsen et al. 2004

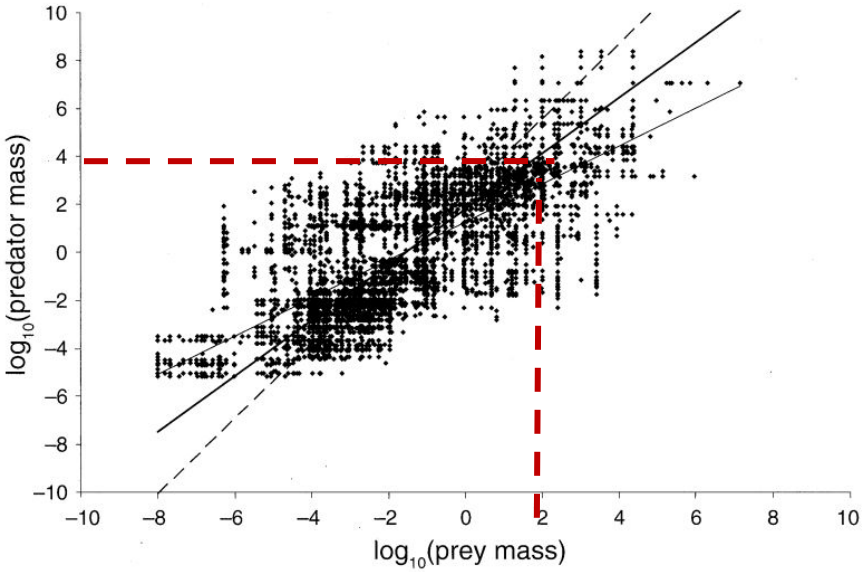
Uusi-Heikkilä et al. 2015

Metabolic theory of ecology



Brown et al, 2004

fish size

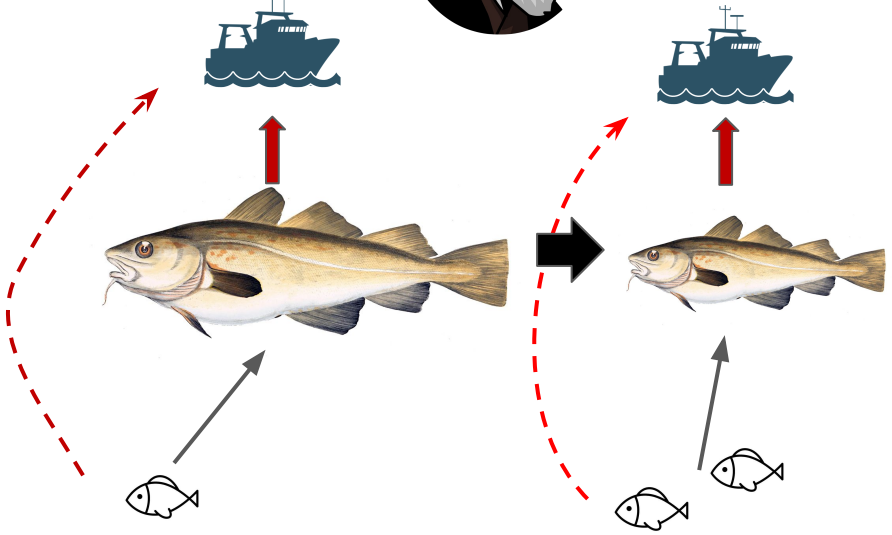


Brose et al, 2006

metabolic processes

ecological interactions

Fish size evolution



direct effect of harvesting on evolution

indirect eco-evolutionary feedback loops

Most of the studies link size evolution in response to size selective fishing : what about **indirect community effects** ?

Densities estimation uncertainties

- **Illegal** and **unreported** fishing (FAO 2022, Agnew et al. 2009)
- **Densities estimations** based on catches

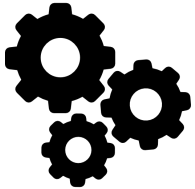
errors

Some stocks under management programs have collapsed

(Lauck et al. 1998, Olsen et al. 2004..)

Region	2000–2003
Northwest Atlantic	9%
Northeast Atlantic	9%
Western Central Atlantic	10%
Eastern Central Atlantic	37%
Southwest Atlantic	32%
Southeast Atlantic	7%
Western Indian	18%
Eastern Indian	32%
Northwest Pacific	33%
Northeast Pacific	3%
Western Central Pacific	34%
Eastern Central Pacific	15%
Southwest Pacific	4%
Southeast Pacific	19%
Antarctic	7%
Average	**18%**

Agnew et al. 2009



EBFM approaches and species interactions

Evolution of size in exploited stocks

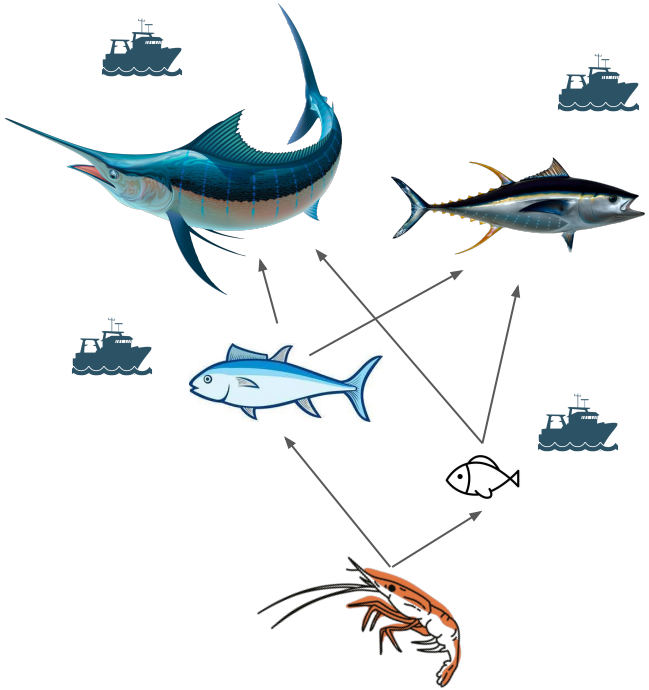
Uncertainties in density estimations

Balanced Harvesting

Balanced Harvesting as a ecosystem-based management tool

Applying a moderate fishing intensity across as much of the ecosystem as possible : **spreading the load in proportion to each taxa's production** instead of putting pressure on particular selected taxa or sizes

Zhou et al. 2019, Garcia et al. 2012



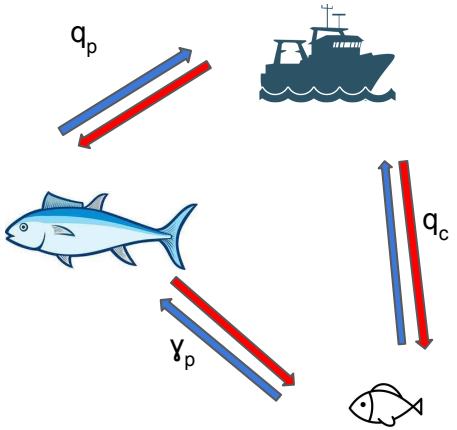
What implications of balanced harvesting approaches for fishing yields, conservation and fish size evolution ?

What implications of balanced harvesting approaches for fishing yields, conservation and fish size evolution ?

1- How the repartition of fishing effort affects the socio-ecological sustainability of fisheries ?

2- What impact of BH on size evolution ?

$$\frac{dC}{dt} = C(\gamma_c \lambda_c R - c_0 C - \gamma_p P - \mu_c - q_c E)$$
$$\frac{dP}{dt} = P(\gamma_p \lambda_p C - c_p P - \mu_p - q_p E)$$



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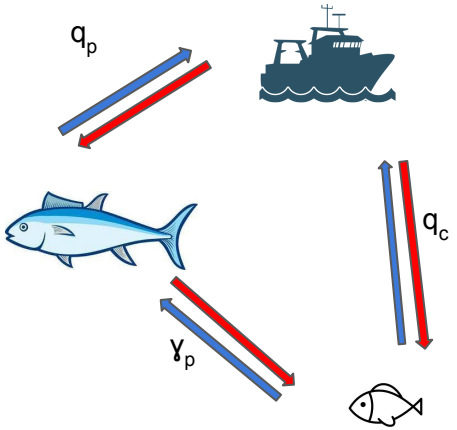
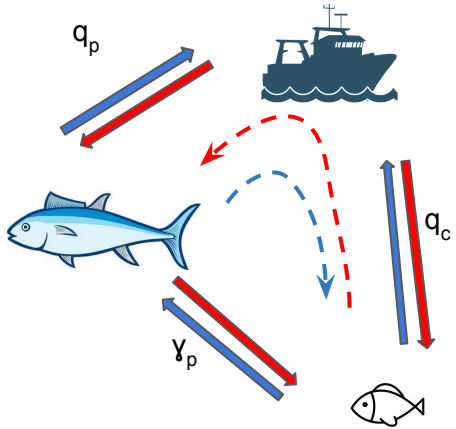
$$Y^* = E(q_c s_c C^* e^{z_c} + q_p s_p P^* e^{z_p} - cost)$$

$h^* = -\sum p_i \mathrm{Log}(p_i)$



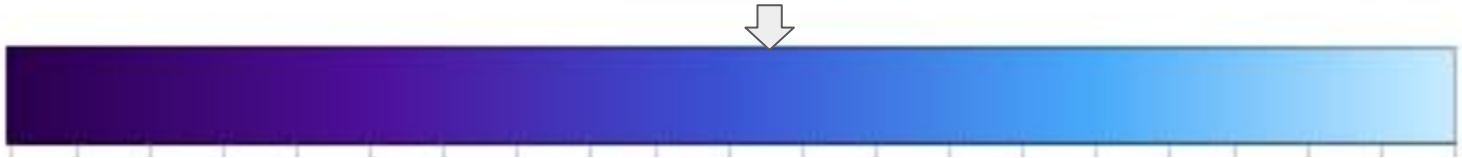
$q_c + q_p = q_{tot}$

Constant global pressure



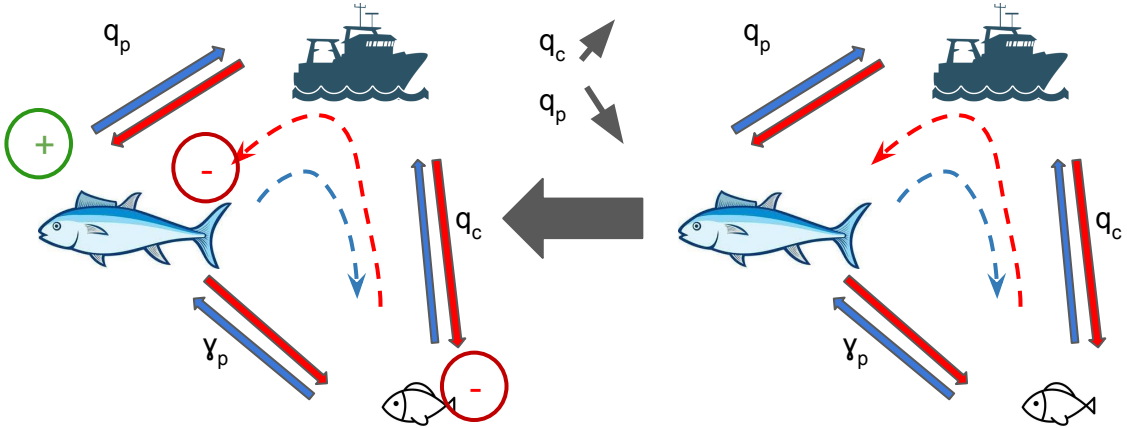
Balanced Harvesting

$q_c = q_p$



competition effects

$q_c + q_p = q_{tot}$

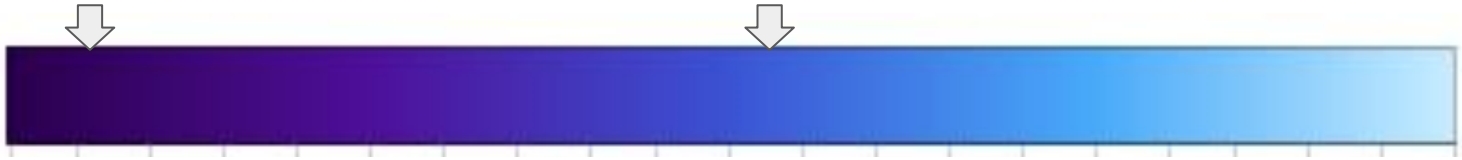


Unbalanced Harvesting

$q_c >> q_p$

Balanced Harvesting

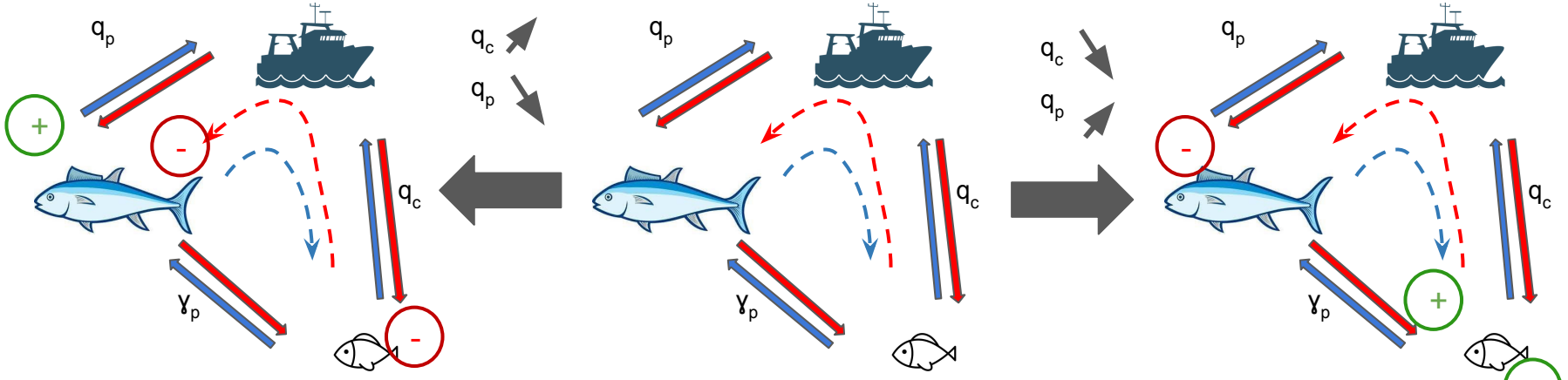
$q_c = q_p$



competition effects

$q_c + q_p = q_{tot}$

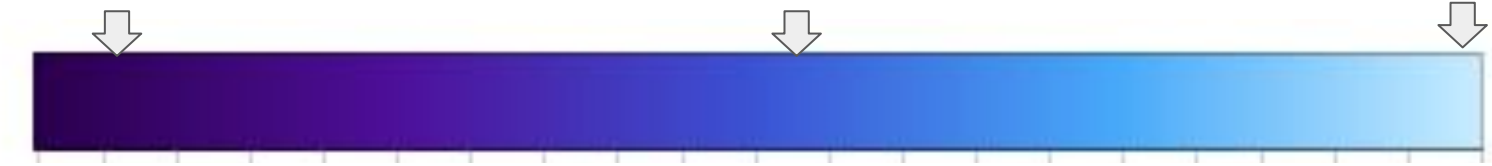
trophic chain effects

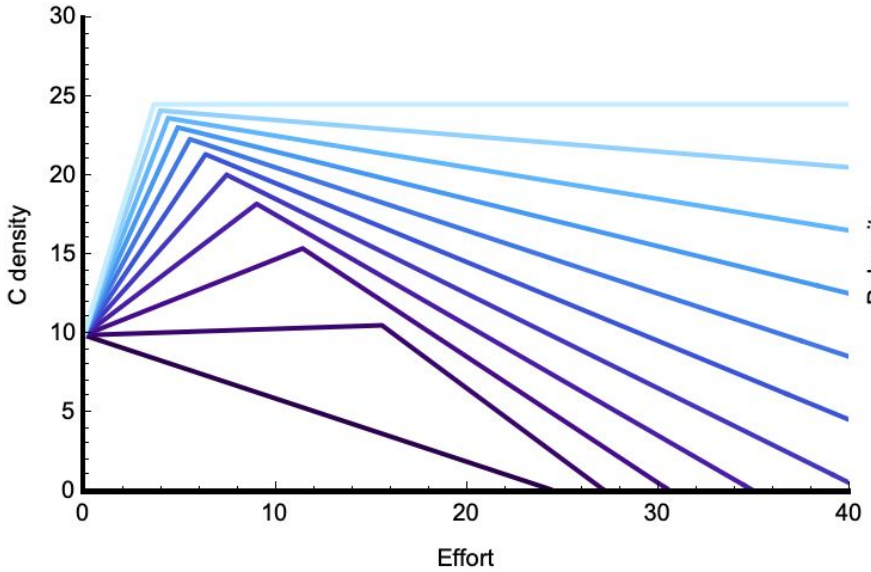


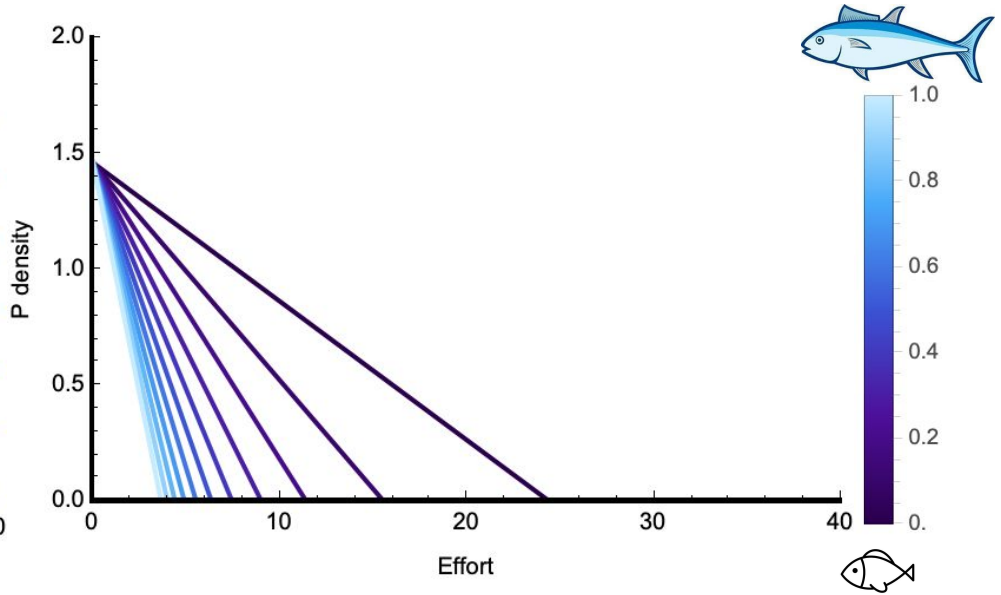
Unbalanced Harvesting
$q_c >> q_p$

Balanced Harvesting
$q_c = q_p$

Unbalanced Harvesting
$q_c << q_p$

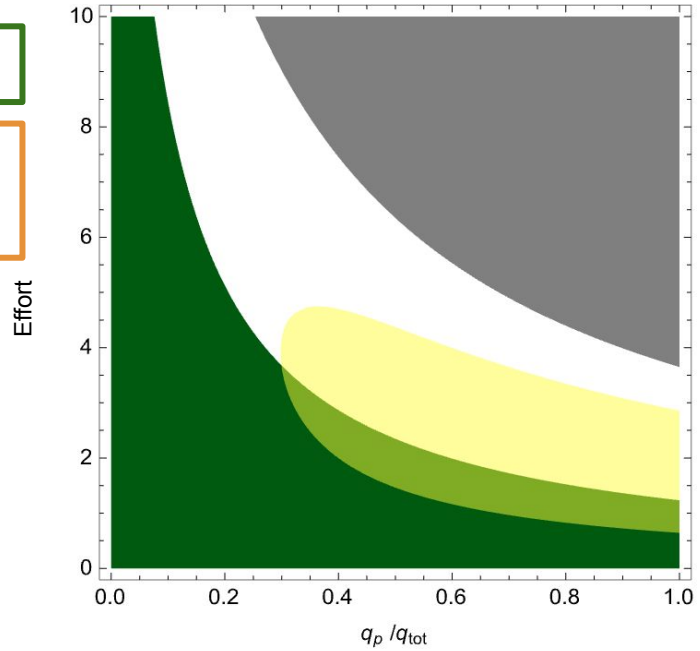



C density
Effort
0
5
10
15
20
25
30
0
10
20
30
40


P density
Effort
0.0
0.5
1.0
1.5
2.0
0
10
20
30
40
1.0
0.8
0.6
0.4
0.2
0.

Constrained fleets

1. **40% best Shannon scores**
2. **40% best multi-species economic yields scores**



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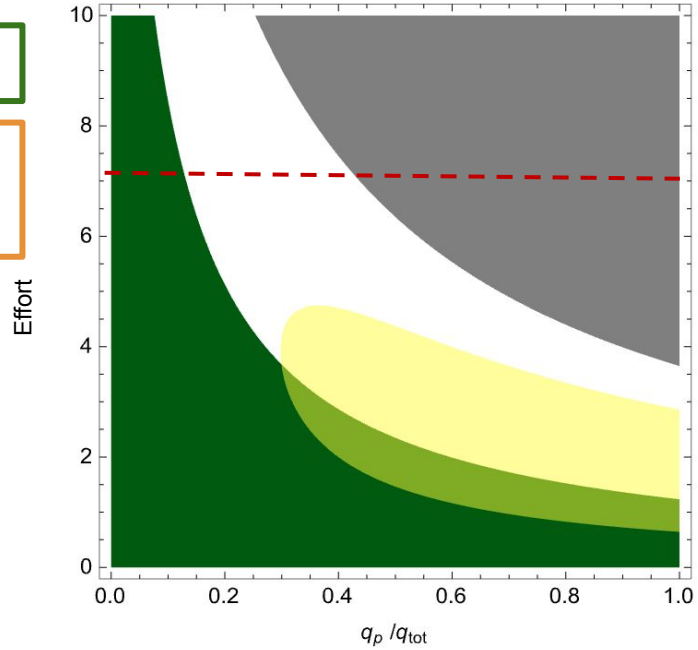

High effort :
small pelagics fishing allows 1

Constrained fleets

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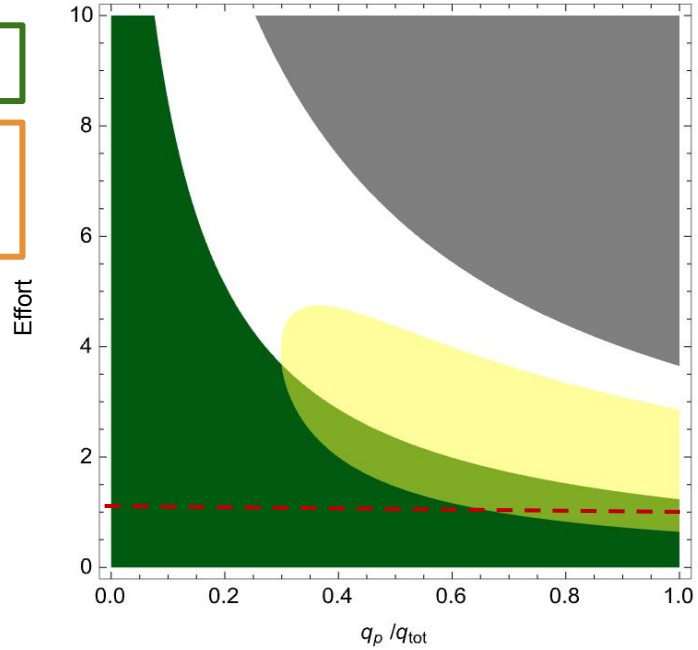

High effort :
small pelagics fishing allows 1

Low effort :
multiple strategies allow 1 2

Constrained fleets

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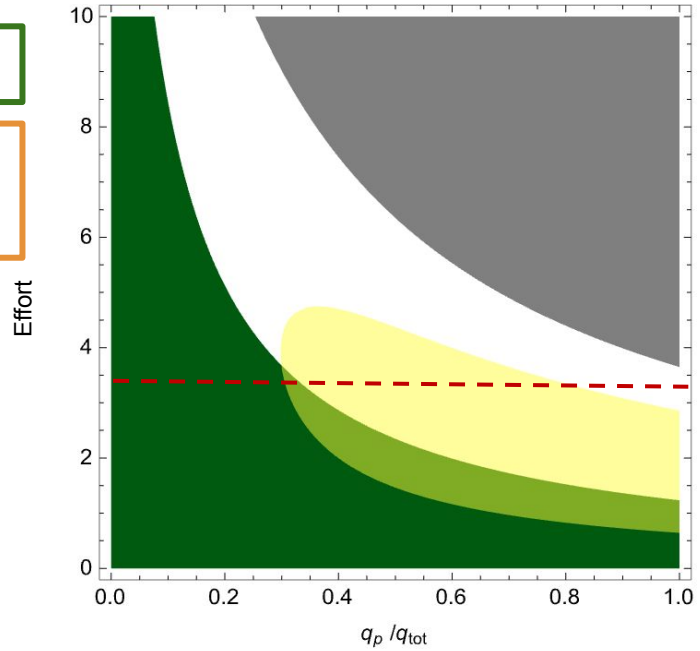
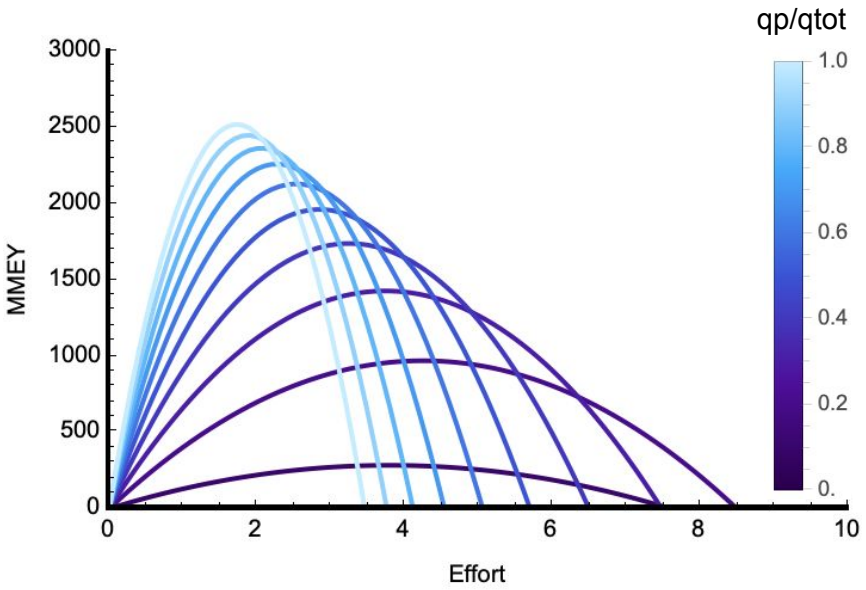


High effort :
small pelagics fishing allows (1)

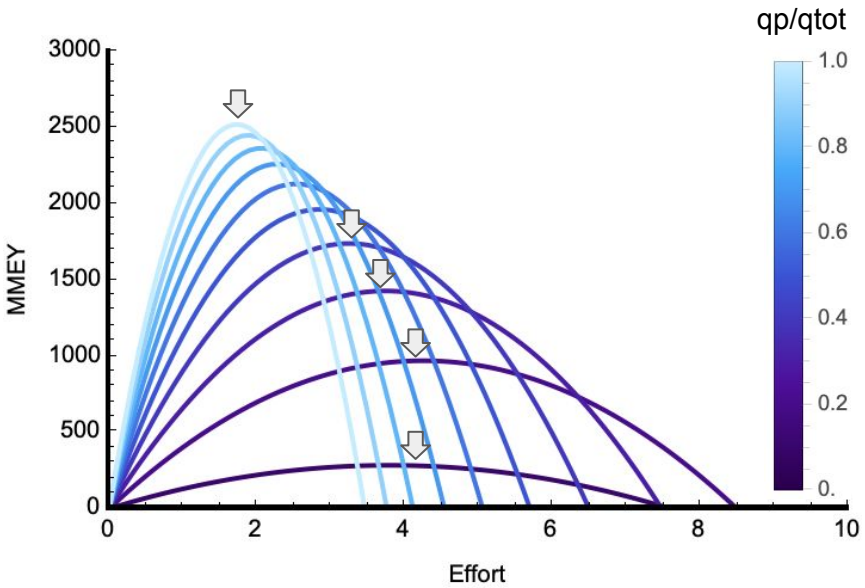
Intermediate effort :
BH allows (1) (2)

Low effort :
multiple strategies allow (1) (2)

Controlled fleets : MMEY fishing

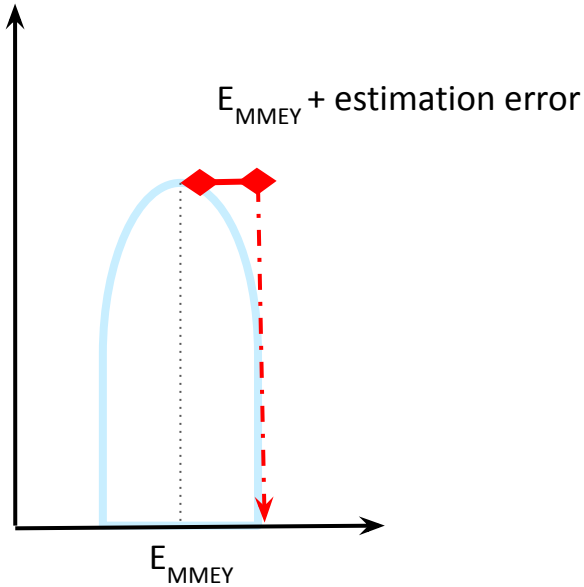


Controlled fleets : MMEY fishing



Economic yield at E_{MMEY} increases when focusing on predators

Impacts of estimation errors



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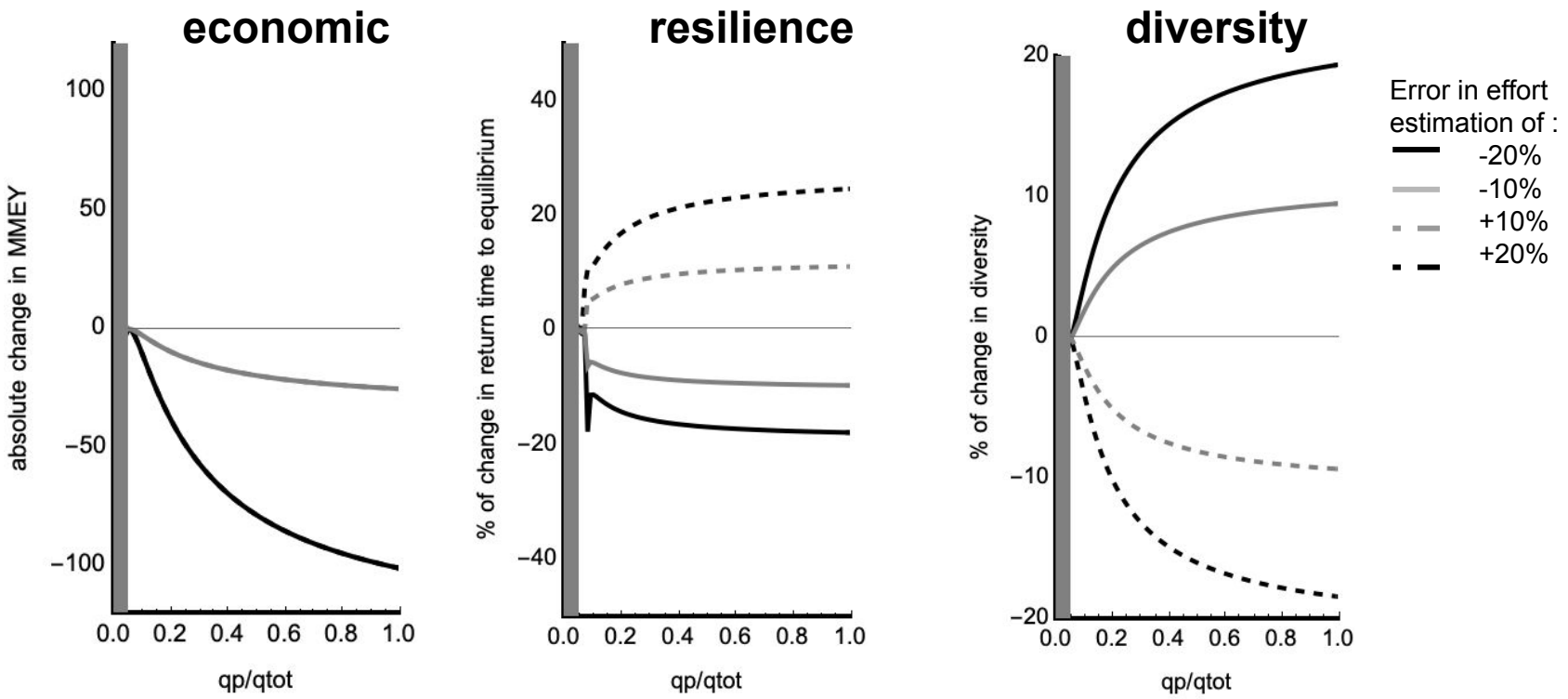
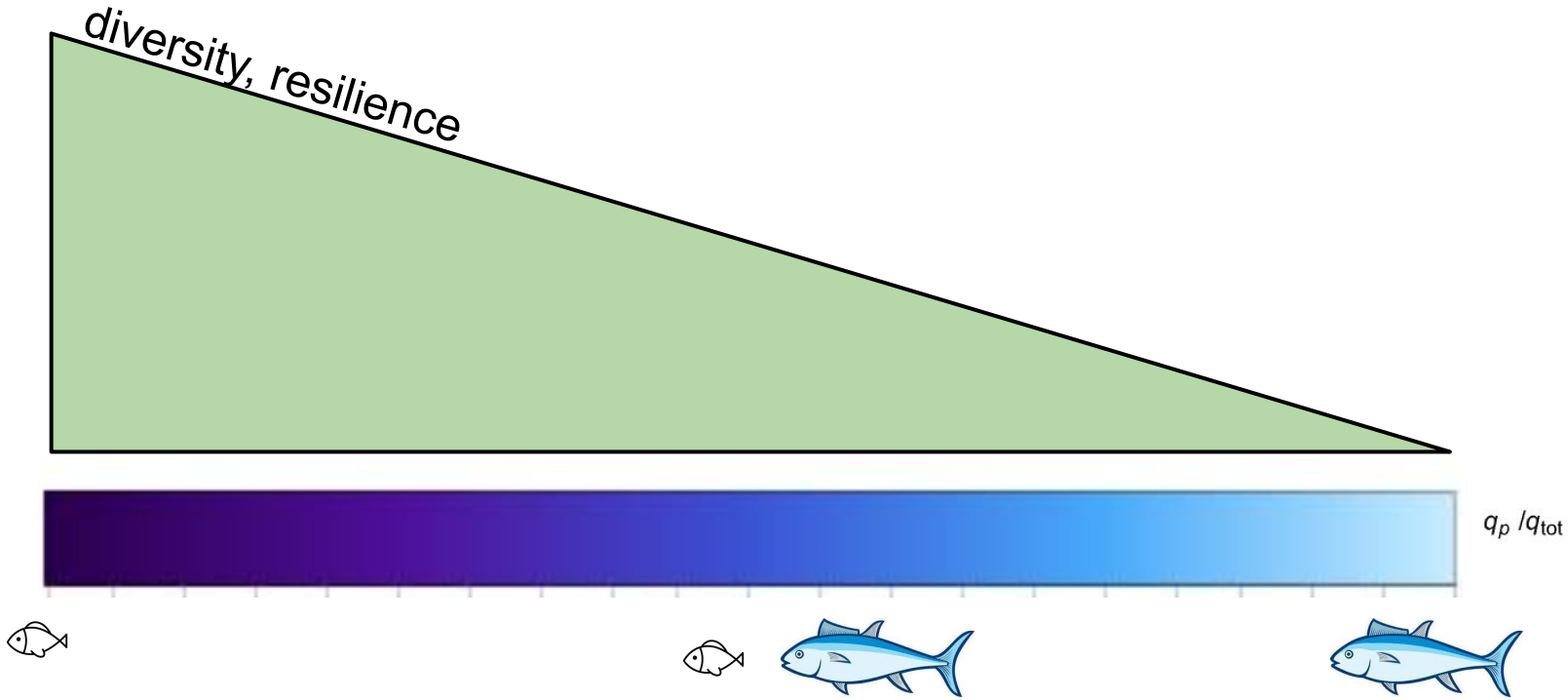
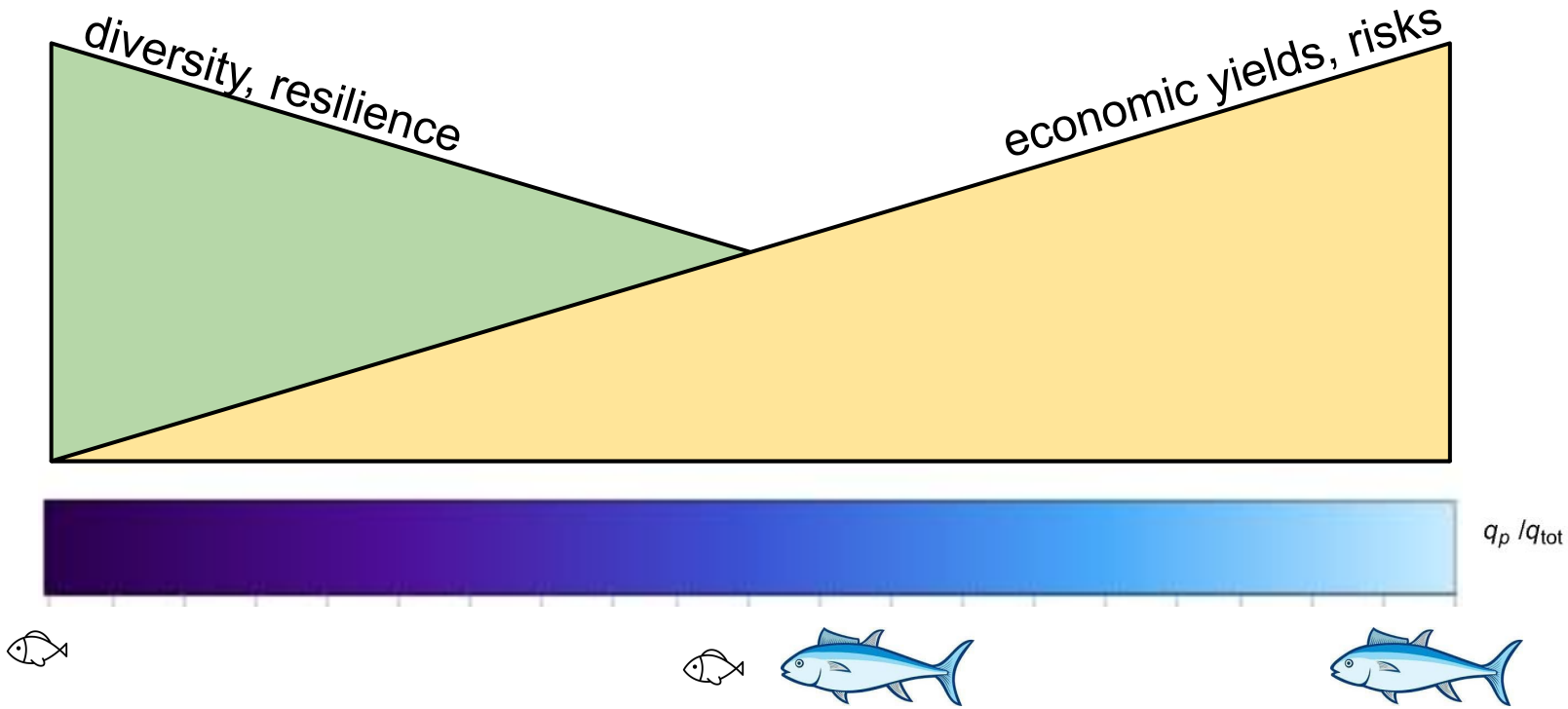



diversity, resilience
q_p /q_{tot}


diversity, resilience
economic yields, risks
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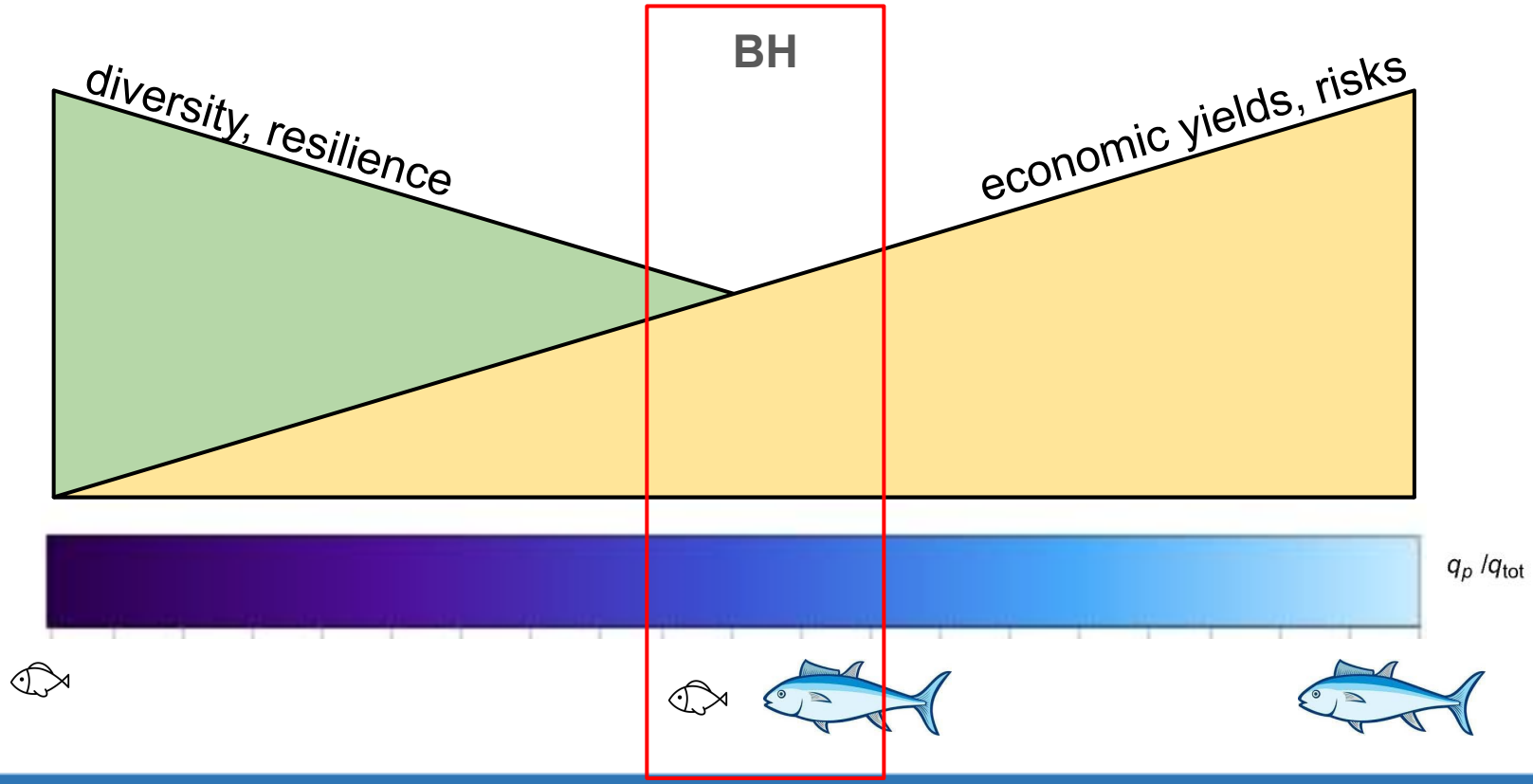
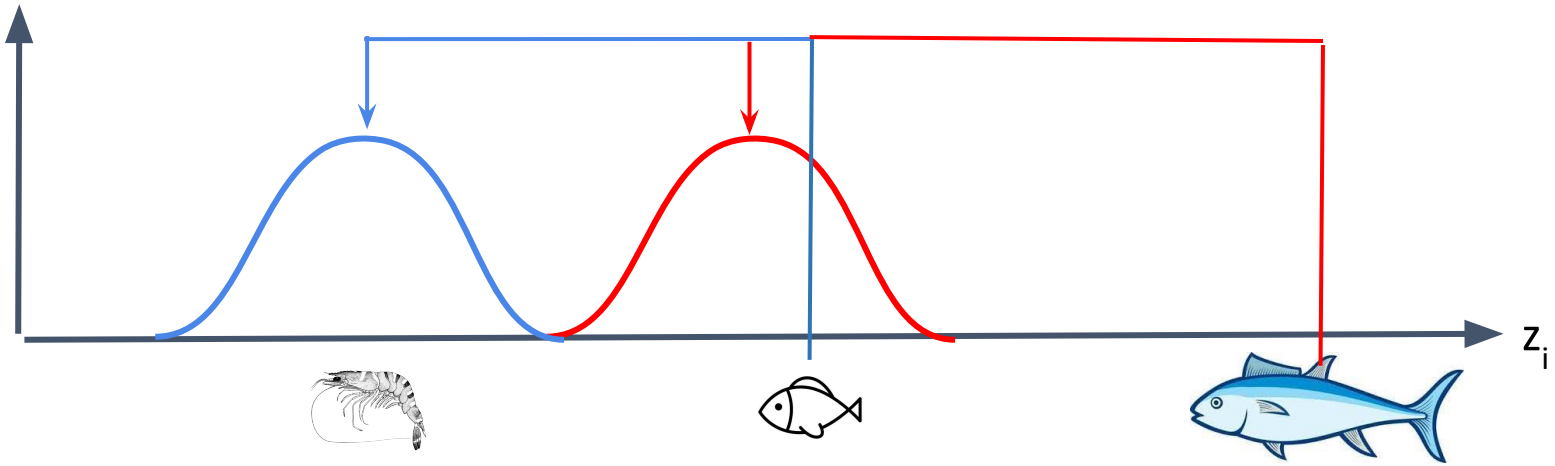

BH
diversity, resilience
economic yields, risks
q_p /q_{tot}

Allometric models
Evolution of size according to **adaptive dynamics**



How size evolves ?

$$\frac{dz_i}{dt} = \frac{1}{2}\eta_i \sigma^2_i N^*_i \left(\frac{\partial\ \omega(z_{im}, z_i)}{\partial\ z_{im}} \right)_{z_{im} \to z_i}$$

fitness gradient of rare mutant

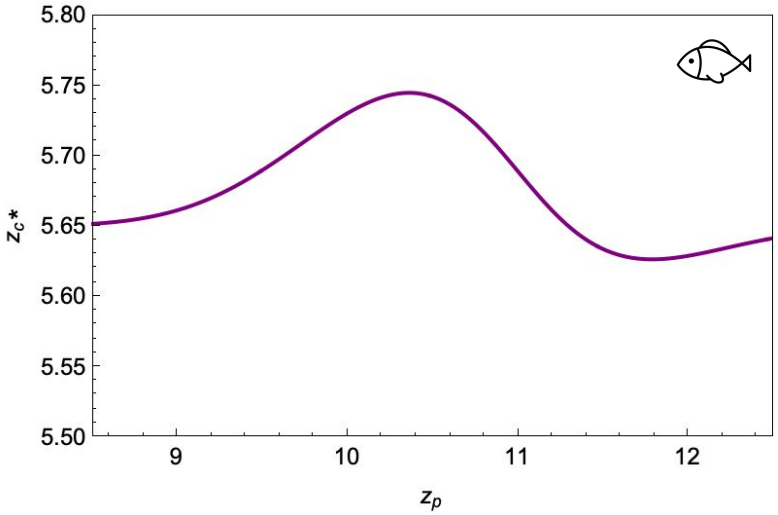
mutation magnitude

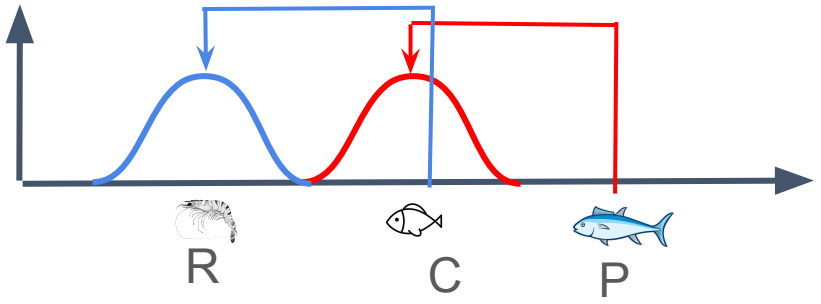
mutation probability

No direct size selective effects of harvesting

How size evolve ?

$$\left(\frac{\partial \omega(z_{cm}, z_c)}{\partial z_{cm}}\right)_{z_{cm} \to z_c} = \alpha_1 \gamma_c \lambda_c R - \gamma_p' P^* - \mu_c'$$





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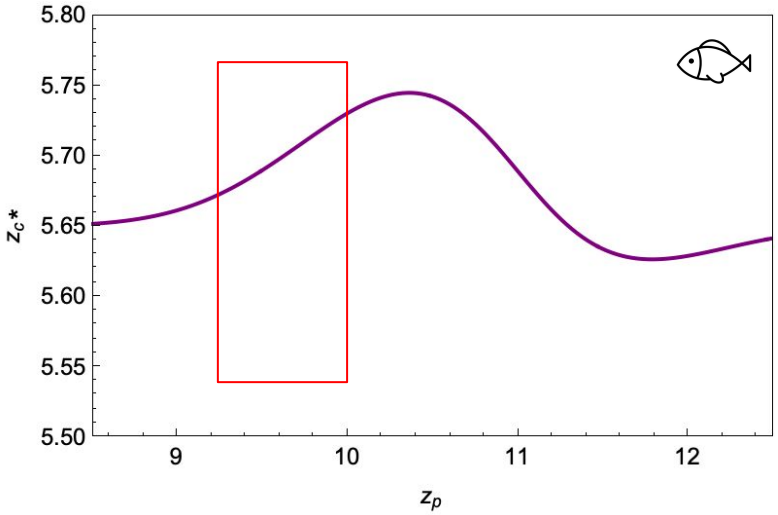

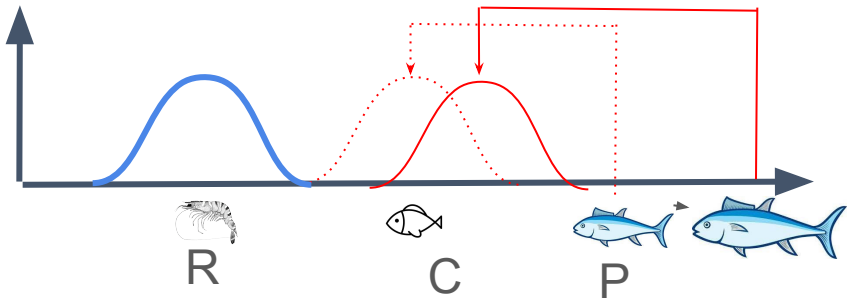

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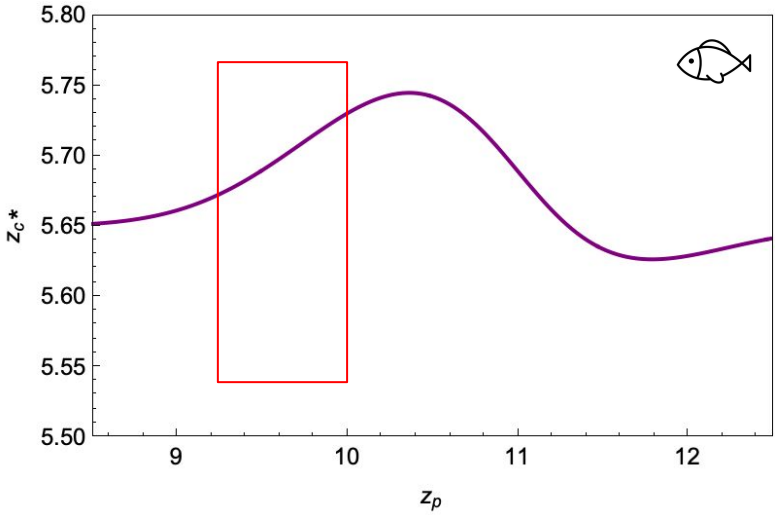

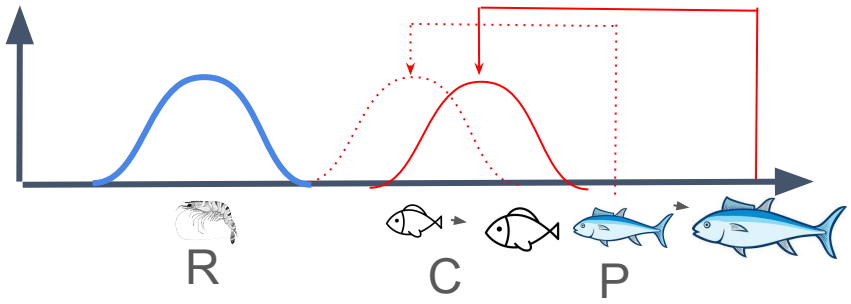

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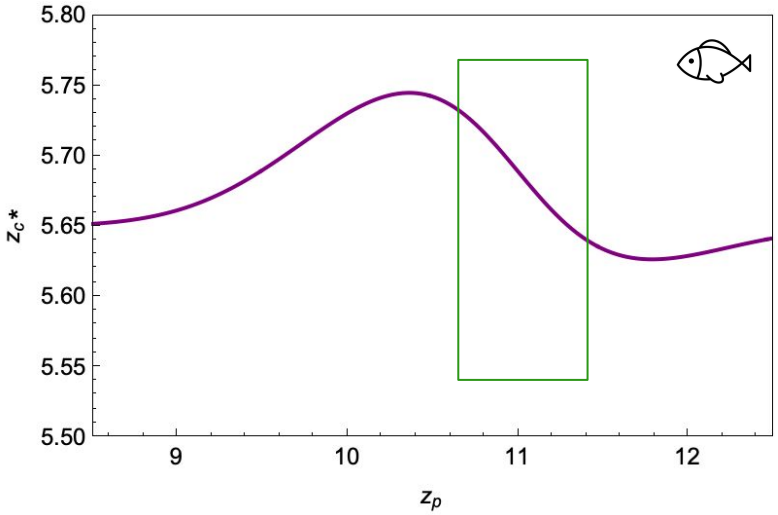
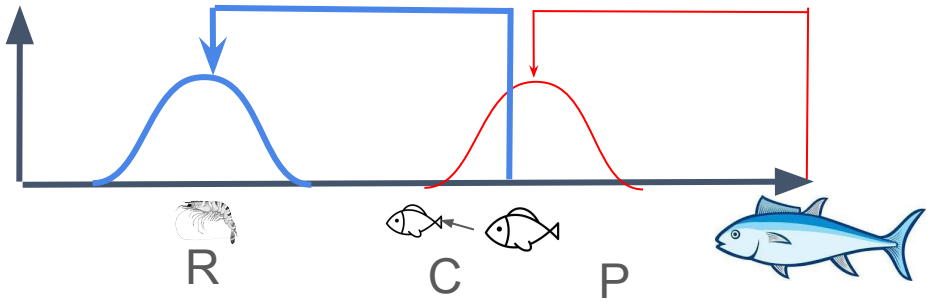
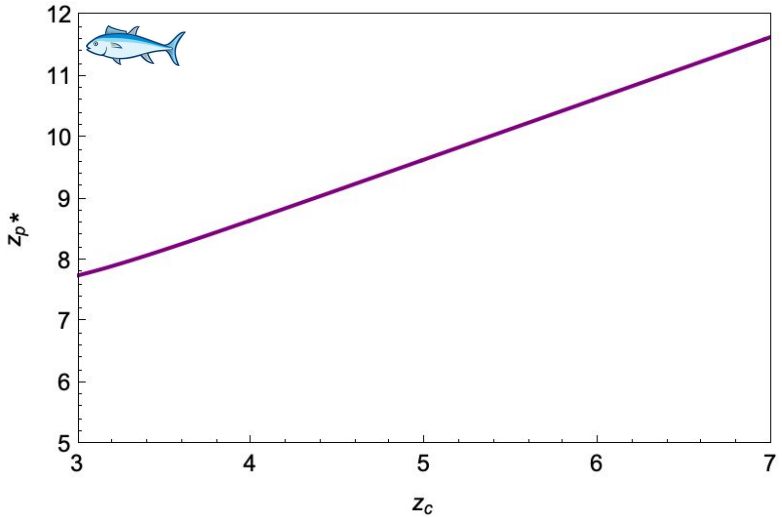
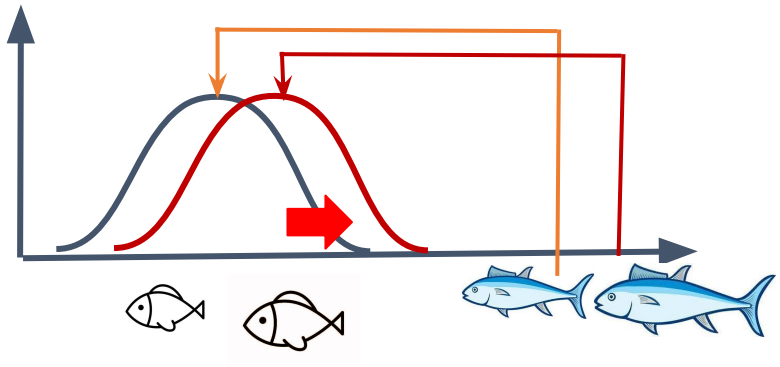




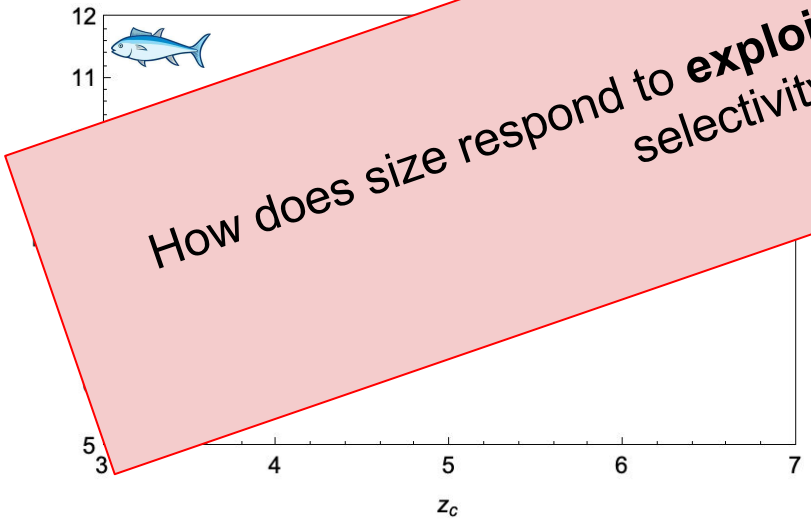
$$\left(\frac{\partial \omega(z_{pm}, z_p)}{\partial z_{pm}}\right)_{z_{pm} \to z_p} = \alpha_2 \gamma_p \lambda_p C^* - \mu_p'$$

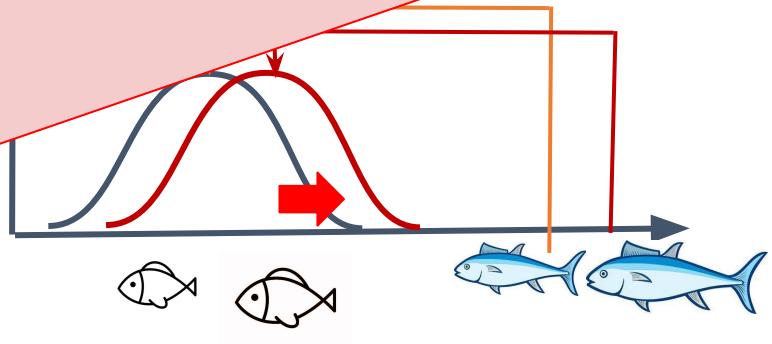


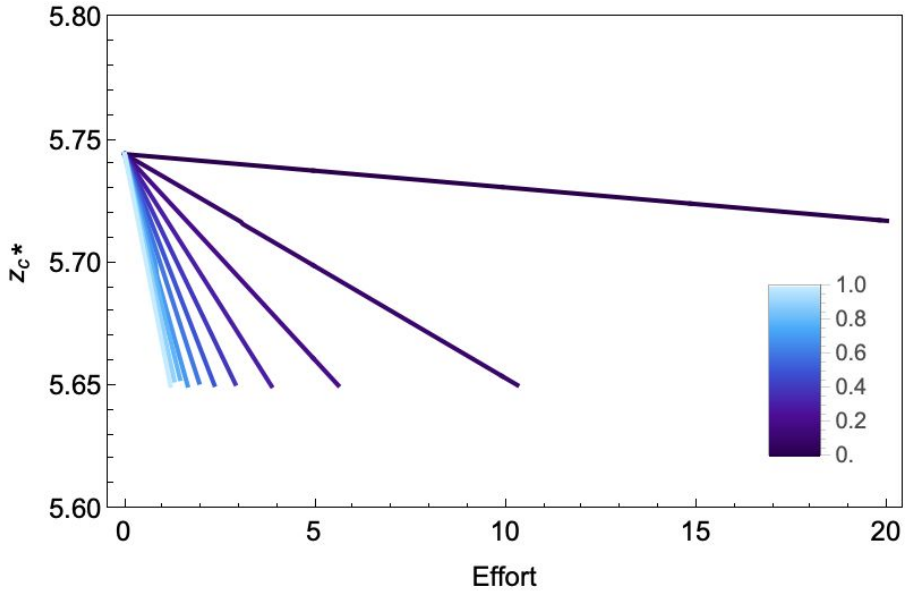


$$\left(\frac{\partial \omega(z_{pm}, z_p)}{\partial z_{pm}}\right)_{z_{pm} \to z_p} = \alpha_2 \gamma_p \lambda_p C^* - \mu'_p$$

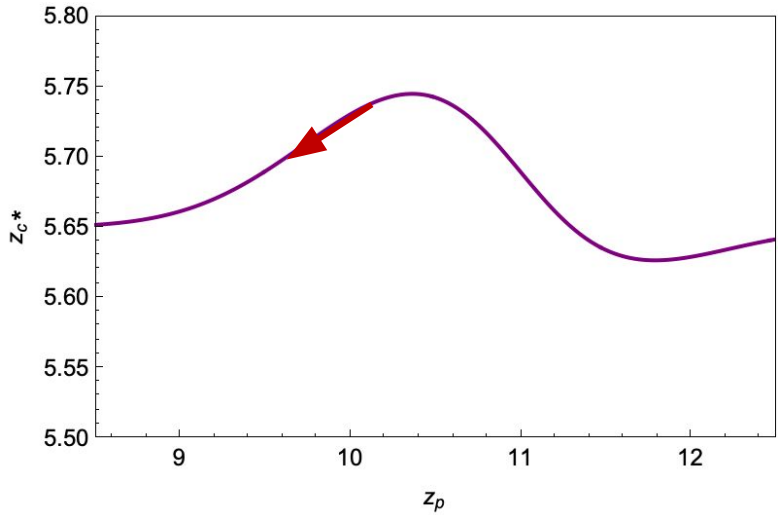
How does size respond to **exploitation** (without direct size selectivity) ?





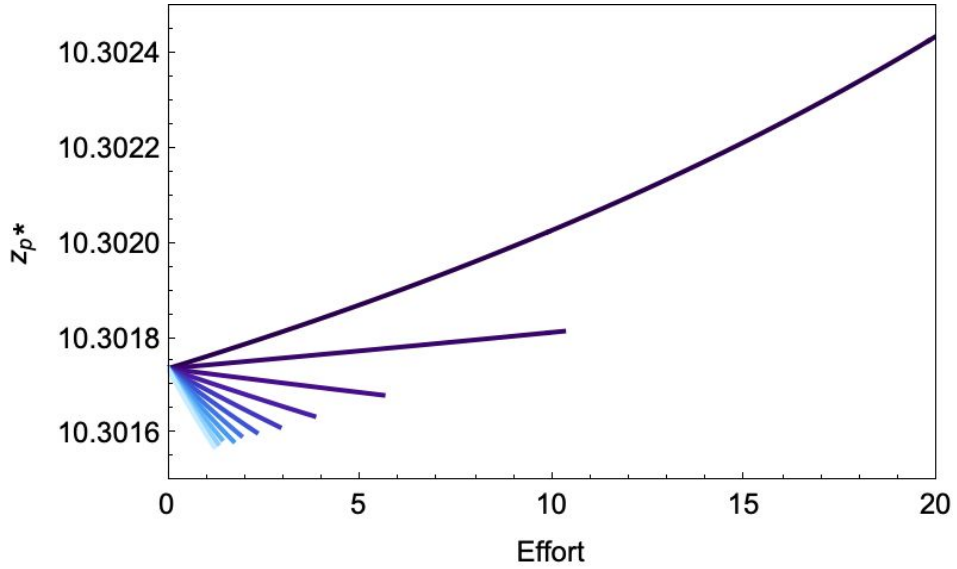


$$\left(\frac{\partial \omega(z_{cm}, z_c)}{\partial z_{cm}}\right)_{z_{cm} \to z_c} = \alpha_1 \gamma_c \lambda_c R - \gamma_p' P^*(E, q_p) - \mu_c'$$



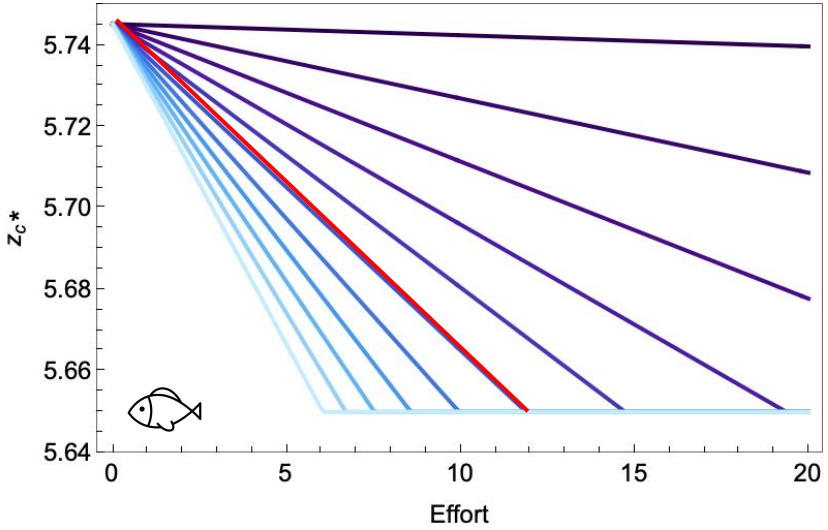
Consumer size decreasing is all the more important that fishing focuses on predators

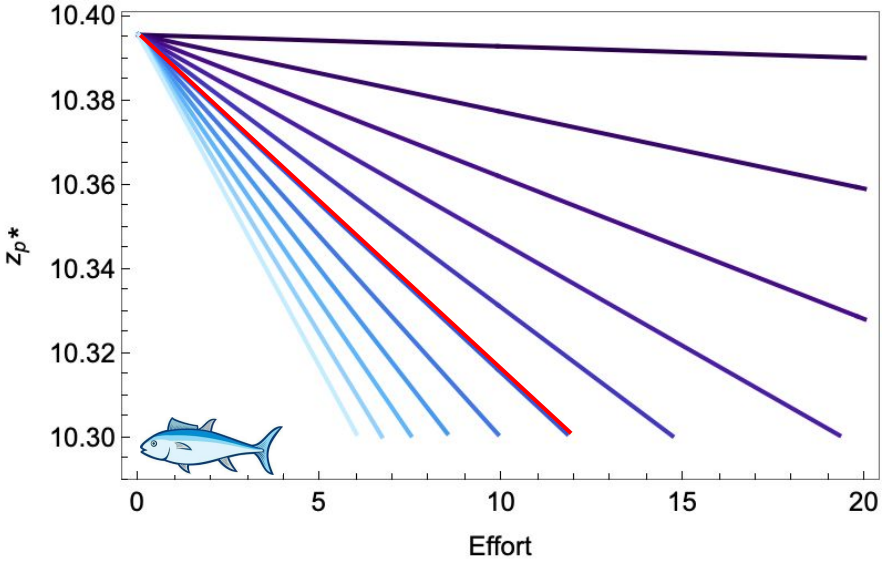
$$\left(\frac{\partial \omega(z_{pm}, z_p)}{\partial z_{pm}}\right)_{z_{pm} \to z_p} = \alpha_2 \gamma_p \lambda_p C^*(E, q_p) - \mu_p'$$



Predator size may **increase** or **decrease** depending on fishing strategies

Co-evolutionary patterns





Predator size does not increase
Red queen eco-evolutionary pattern

BH strategies mitigate the evolution of size

Discussion

- BH **optimizes** economic returns *vs* impact on diversity

Zhou et al.2017, Jacobsen et al., 2014; Kolding et al., 2016; Law et al., 2012

- BH **limits** the risks of estimation errors on economic returns and diversity

- Exploitation reduces the size of exploited and non-exploited fishes due to **density variations within the network**

Edeline & Loeuille 2021

- BH strategies **mitigate** the evolution of size

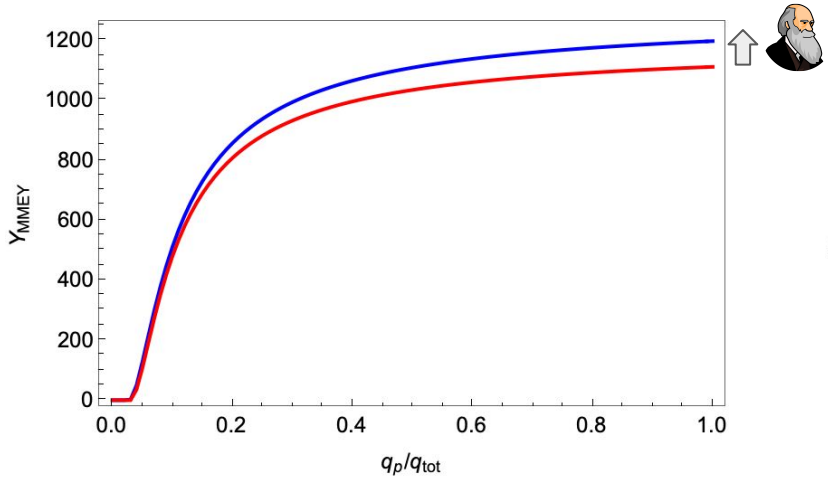
Perspectives

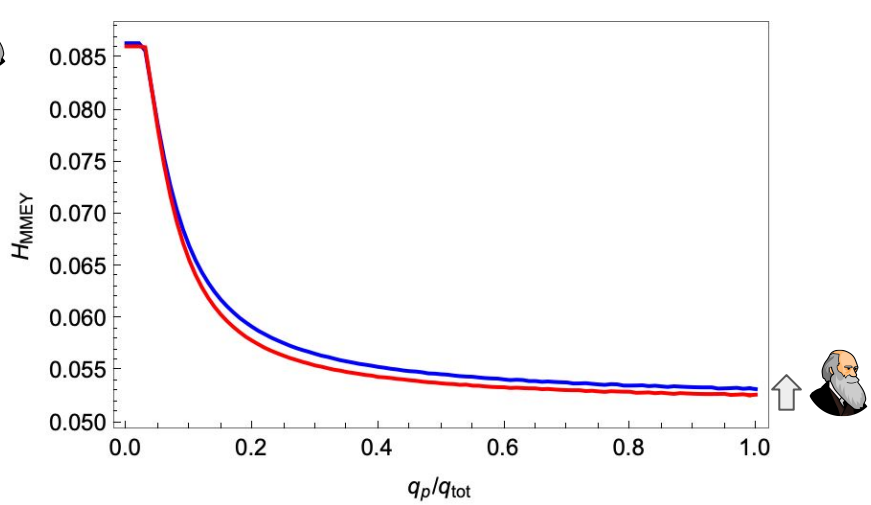
Size evolution with direct size selectivity

Socio-economic implications of evolution

Large networks simulations

Thank you for your attention !

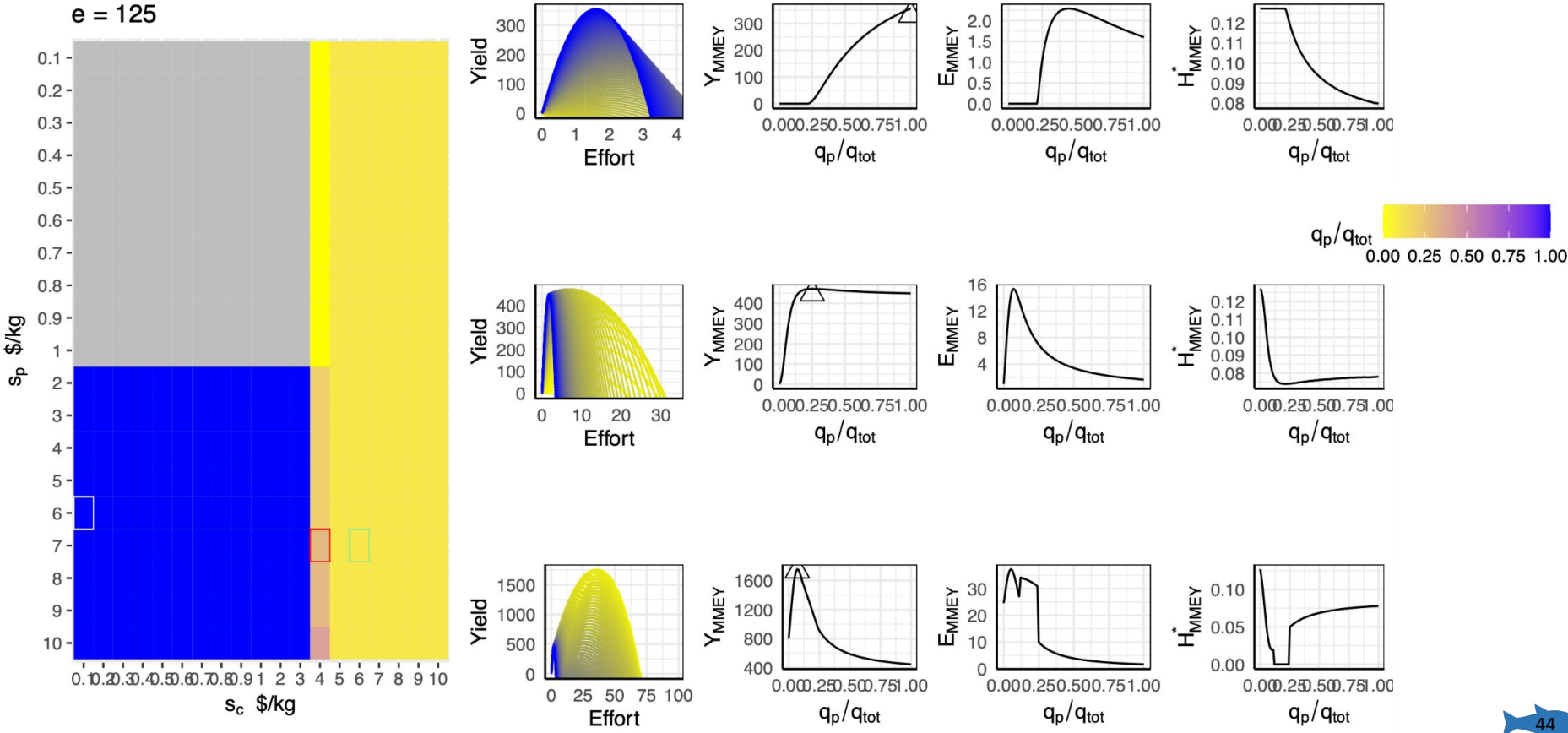




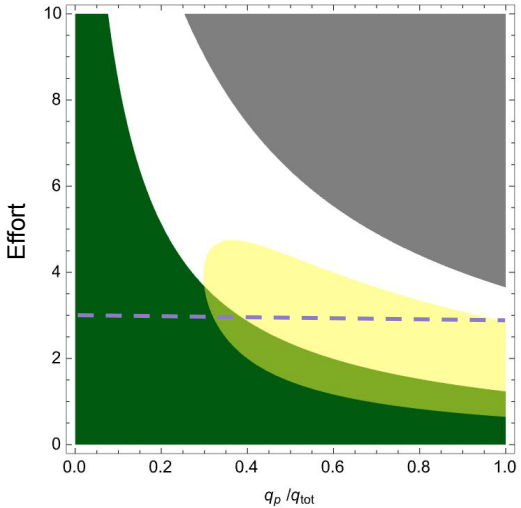
Evolution increases both economic returns and ecological diversity

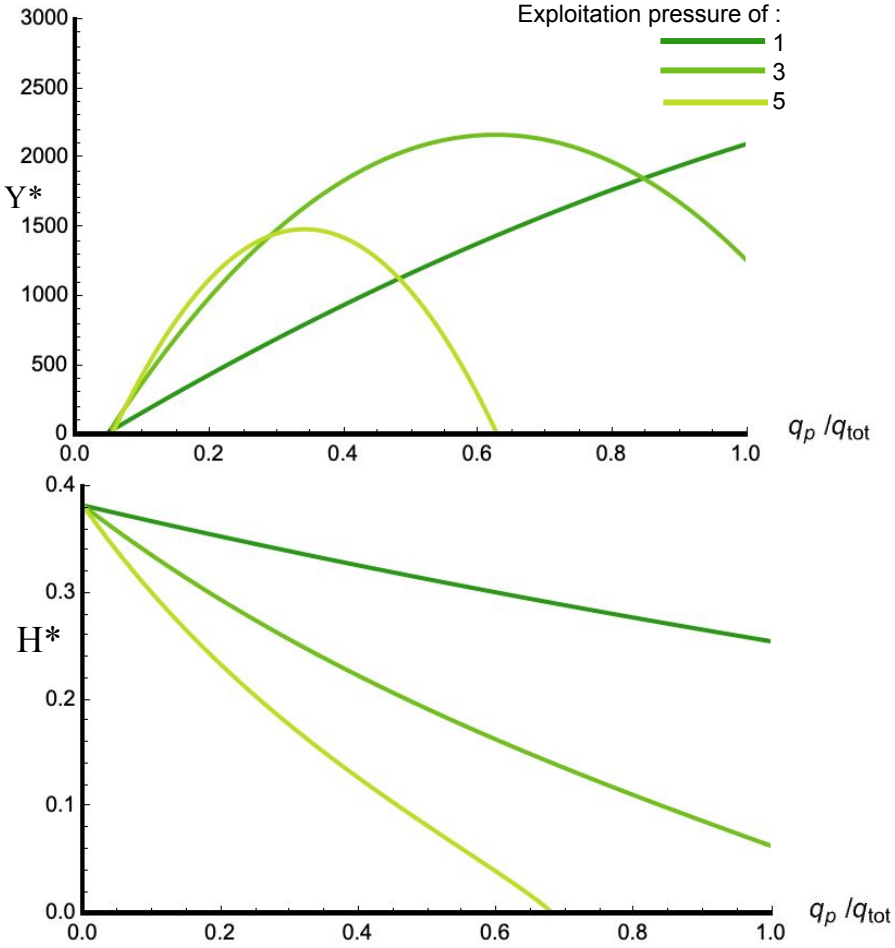
Same trade-off calling for BH

Prices globalisation

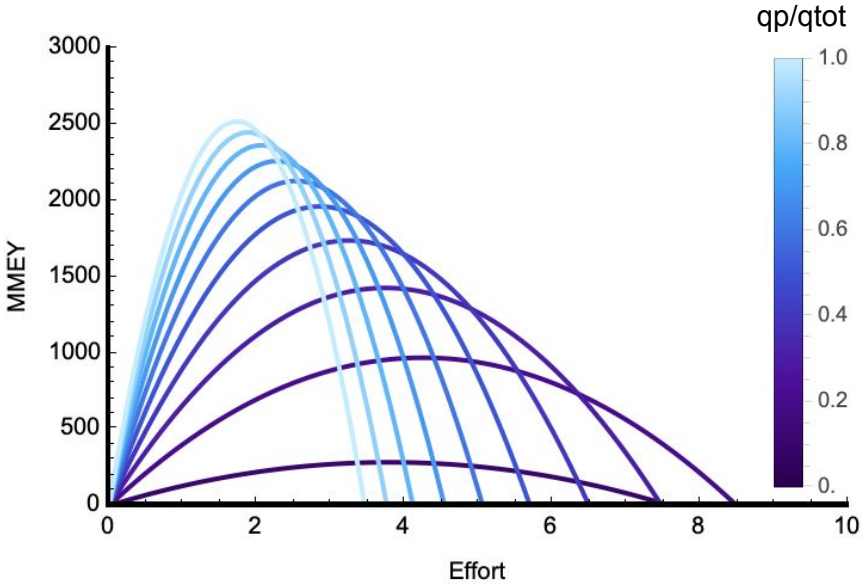


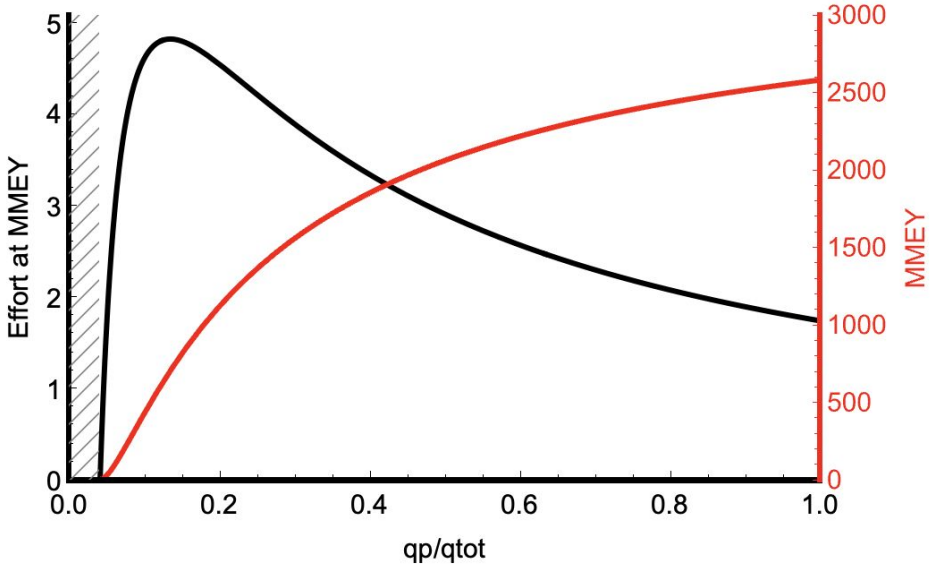
Constrained fleets

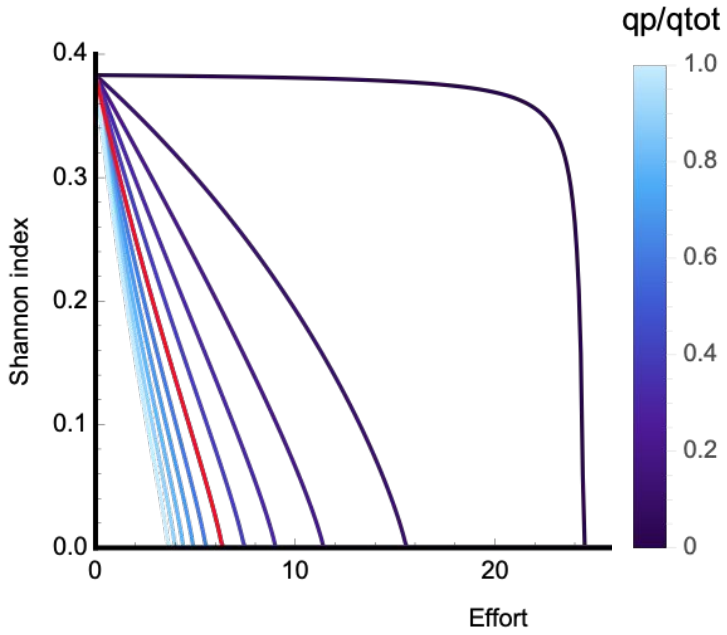




Controlled fleets : MMEY fishing






qp/qtot
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0.8
0.6
0.4
0.2
0
0.4
0.3
0.2
0.1
0.0
Shannon index
0
10
20
Effort