Will innovation in Bluefin tuna aquaculture improve conservation of wild-caught Bluefin tuna stocks?

IIFET 2018

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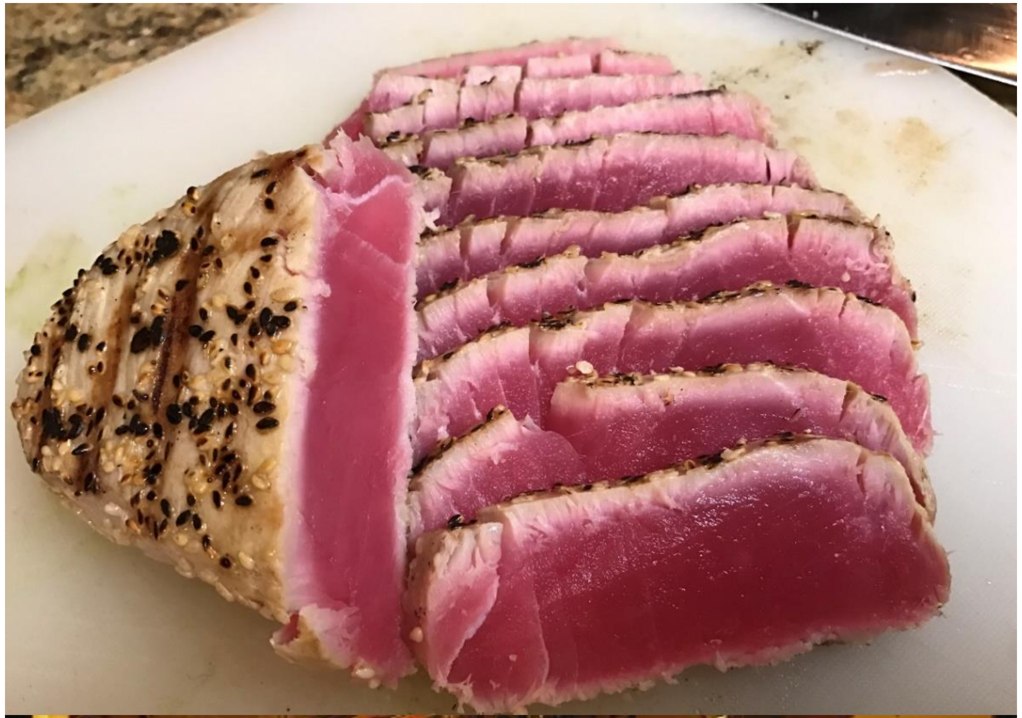
Depends on:
1) the nature of innovations in aquaculture
2) key bioeconomic parameters (especially recruitment)

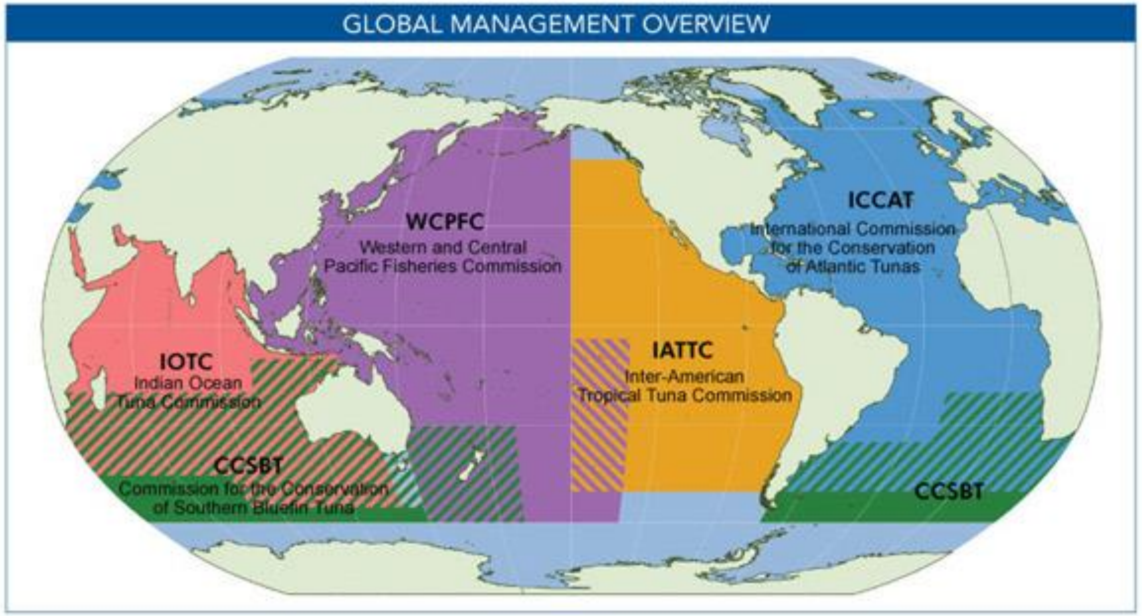
Bluefin Tuna – global & luxury item

- Global harvest & market
- Generated between $2 and $2.5 billion in 2014
- ~$13/kg
- Overfished

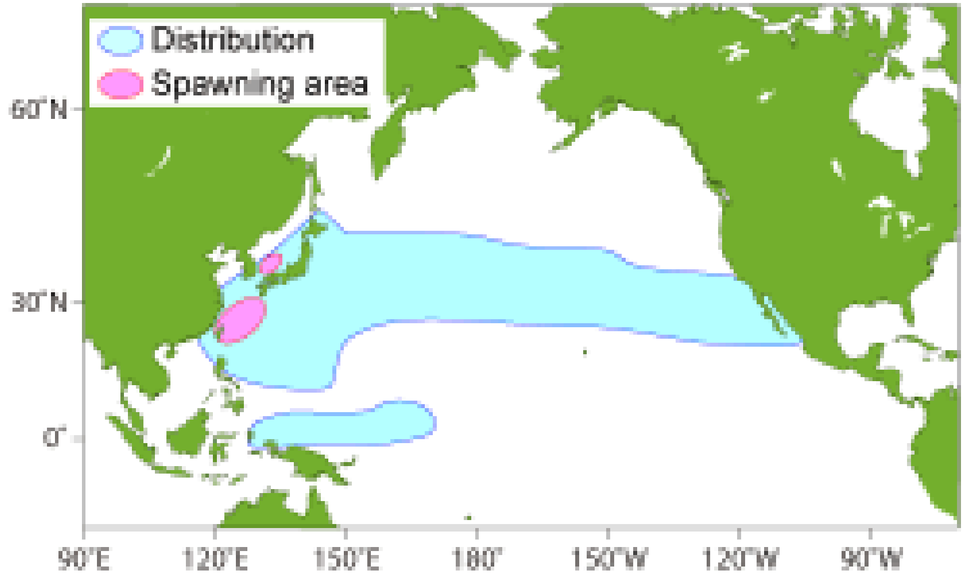


Open Access Incentives Despite Governance

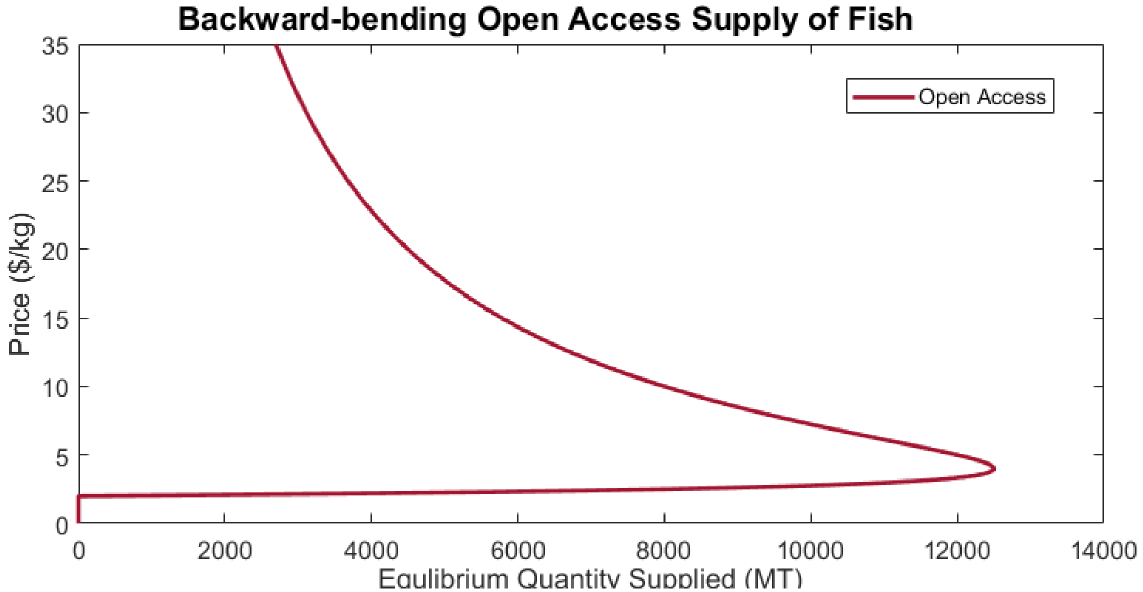
- Mismatch of state authority and ecosystem scale
- Heterogeneity in quota setting and enforcement
- High estimates of IUU

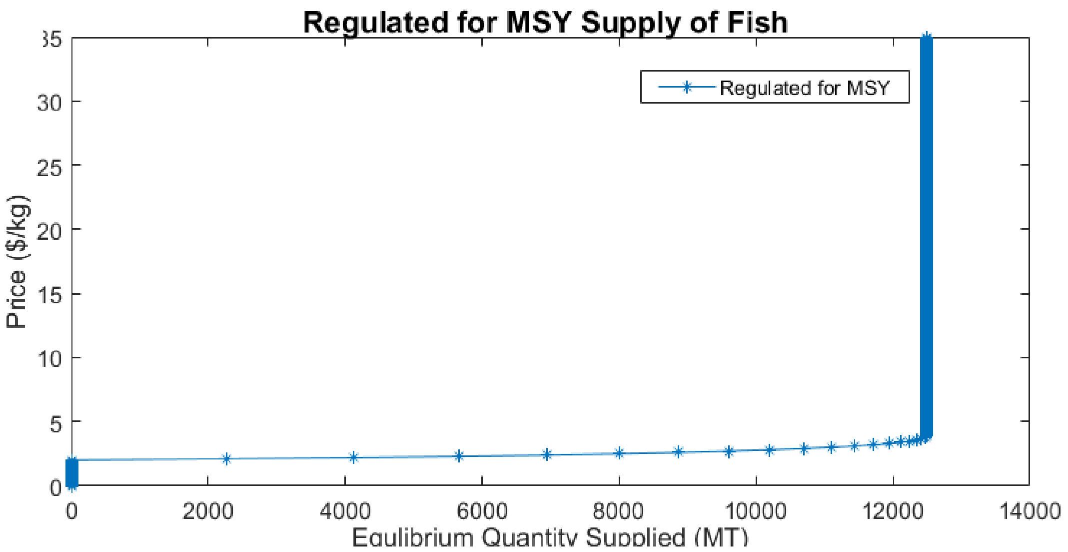


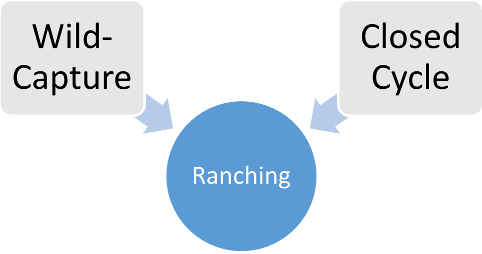
Spatial Scale of the Pacific Bluefin Tuna Stock



So our supply curve looks more like this…



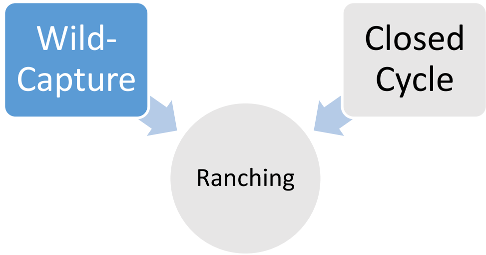




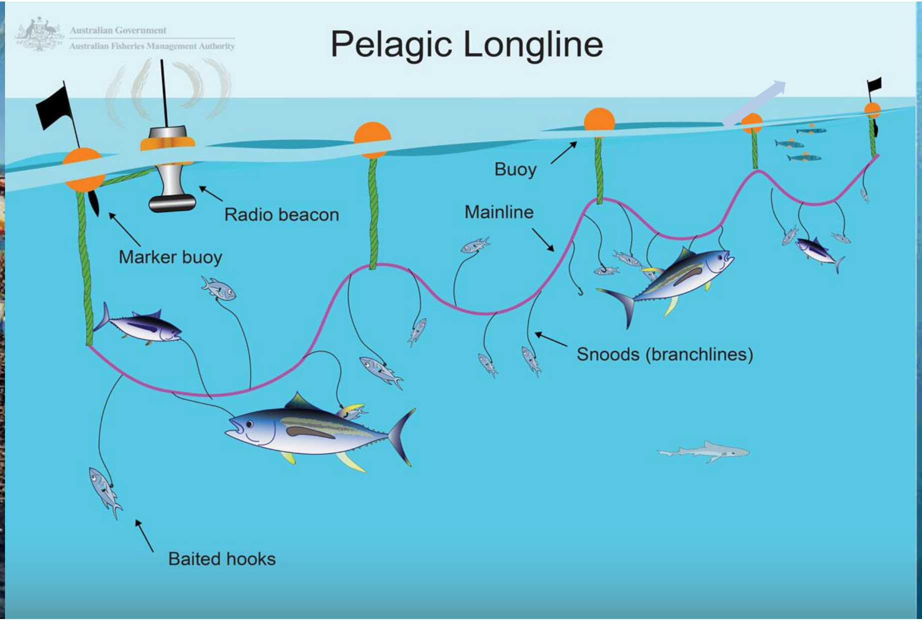
Ranching

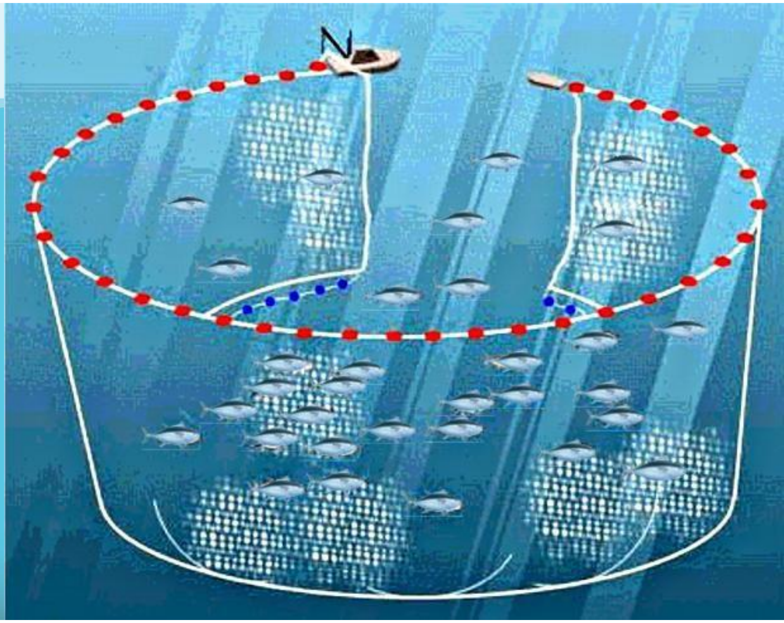
- ~ 35000 MT produced in 2014 (FishStat J)
- Known as ‘farming’ or ‘ranching’ or ‘aquaculture’

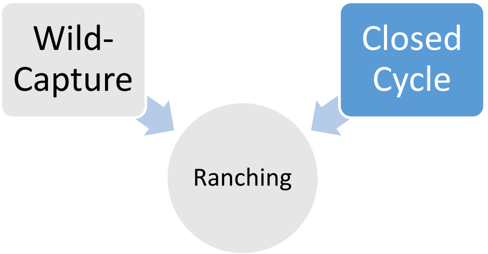
Wild-Capture



- ~ 85,000 MT from wild capture
- Traditional mode of harvesting BFT
- Some goes to ranching







Closed Cycle

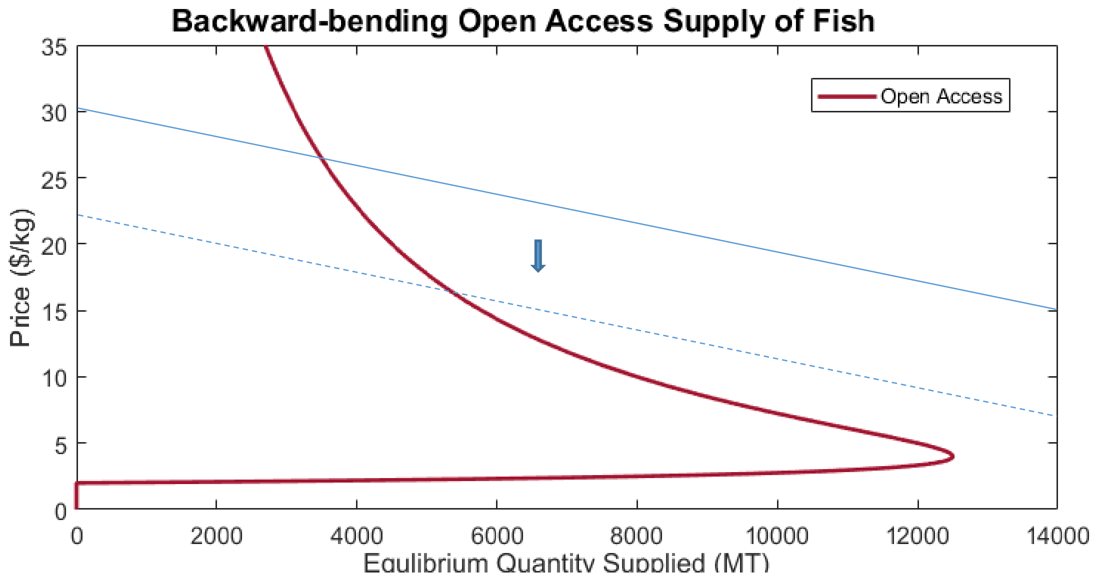
- 1000 MT expected for 2017
- Creating BFT with reproductive capacity in controlled environments
- Successful with PBT in Japan and ABT in Spain
- High rates of mortality during breeding and early-life
- 100% goes to ranching

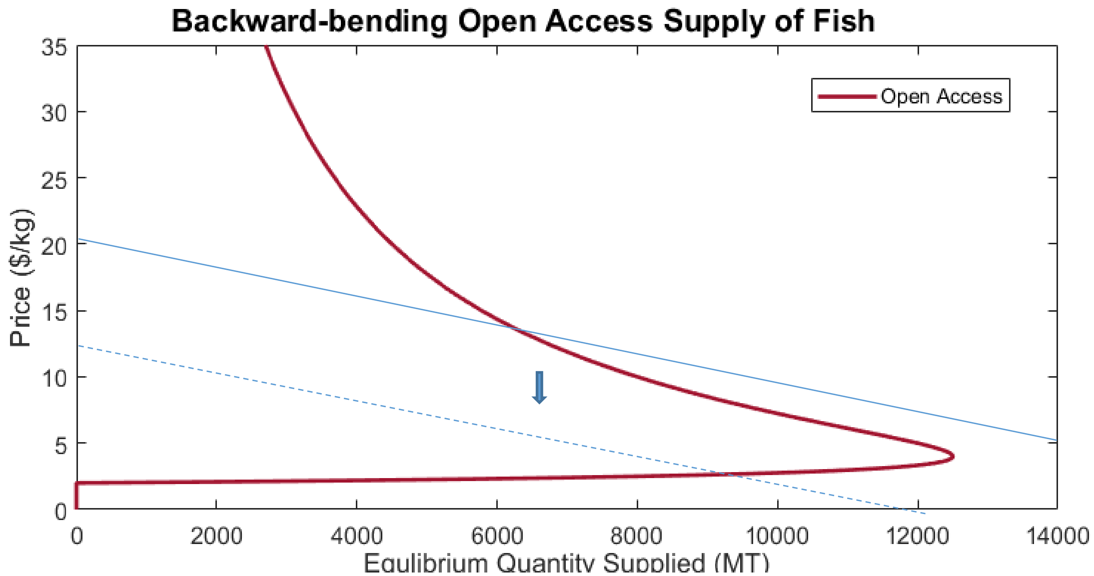
Aquaculture innovation, residual demand for wild, and conservation outcomes

In theory and practice

In theory,

Aquaculture Innovation ↑
Residual Demand for Wild ↓





High Baseline Demand	Low Baseline Demand
High Relevance for Conservation	Low Relevance for Conservation

In practice,

what can we learn from other fisheries?

The Salmon Case

Salmon Cost and Price Changes (Norwegian farmed Atlantic)

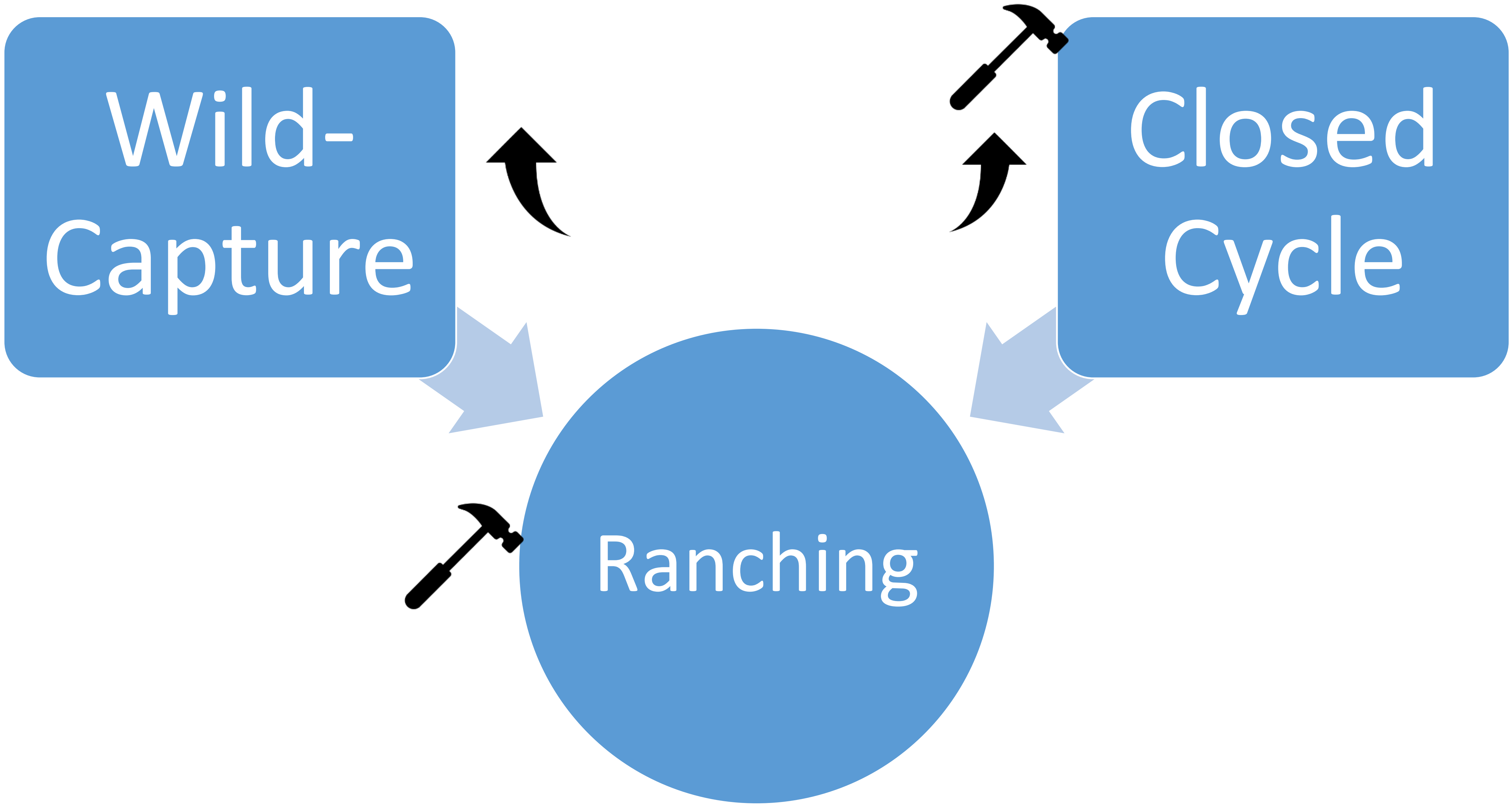
	Average Cost (2013 $/kg)	Price (2013 $/kg)
1985	5.32	7.43
1986	6.93	6.93
1987	6.89	8.32
Mean 1985-87	**6.38**	**7.56**
2000	1.52	2.93
2001	1.42	2.32
2002	1.74	2.39
Mean 2000-02	**1.56**	**2.55**
Percent Decrease	**75.5%**	**66.3%**
Annual Percent Decrease	**9.0%**	**7.0%**

Source: Asche (2008); Norwegian Directorate of Fisheries; Norwegian Seafood Export Council

Market development and innovation

A middle class US consumer in the middle of the country can plan to buy fresh salmon for a dinner party at the supermarket any day of the year

Not All Innovations are Created Equally in BFT



Aquaculture innovation may not lower residual demand for wild BFT

Level of Innovation	Impacts supply of wild, ranched, closed-cycle?	Impact of increased innovation on cost of ranched/wild	Impact of increased innovation on residual demand of ranched/wild
Breeding	Closed-cycle	None	Decrease
Early Life	Closed-cycle	None	Decrease
Transfer	Wild, ranched, closed-cycle	Decrease	Increase
Grow-Out	Ranched, closed-cycle	Decrease	Increase
Supply Chain	Wild, ranched, closed-cycle	Decrease	Increase

At what price does the BFT supply curve bend backward?

Backward-bending supply curve for age-structured populations for BFT

$$w(a)=\omega L(a)^{\eta}$$ Weight

Survival $$N_{a+1,t+1}=e^{-(f_t(a)+m(a))}N_{a,t}$$

$$L(a)=L_{\infty}(1-e^{-\delta(a+\mu)})$$ Length (von Bertallanfy)

Harvest $$H_t=\sum_{a=1}^{50}\frac{f_t(a)}{f_t(a)+m(a)}\left(1-e^{-(f_t(a)+m(a))}\right)w(a)N_{a,t}$$

$$B_t=\sum_{a=a_{\min}}^{50}w(a)N_{a,t}$$ Spawning Stock Biomass

Endogenous fishing mortality $$f_t(a)=qE_t$$

$$N_{0,t}=\frac{\alpha B_t}{1+B_t/k}e^{\sigma v_t}$$ Recruitment (B-H)

Open Access $$E_{t+1}=E_t+\gamma\left(P_tH_t-cE_t\right)$$

Empirical approach

1. Back out fishing mortality from biomass data and landings f_t
2. Estimate recruitment parameter from biomass, recruitment, and landings data by simulating the age-structured model to generate estimated biomass and landings k
3. Use number of active vessels as effort proxy to estimate catchability from fishing mortality q
4. Use effort proxies, catchability, real prices, and landings to estimate Vernon Smith open access model to obtain cost of effort and speed of adjustment c, γ

Backward-bending supply curve for age-structured populations for BFT

$$w(a) = \omega L(a)^{\eta}$$ Weight

Survival $$N_{a+1,t+1} = e^{-(f_t(a)+m(a))} N_{a,t}$$

$$L(a) = L_{\infty}(1 - e^{-\delta(a+\mu)})$$ Length (von Bertallanfy)

Harvest $$H_t = \sum_{a=1}^{50} \frac{f_t(a)}{f_t(a)+m(a)} \left(1 - e^{-(f_t(a)+m(a))}\right) w(a) N_{a,t}$$

$$B_t = \sum_{a=a_{\min}}^{50} w(a) N_{a,t}$$ Spawning Stock Biomass

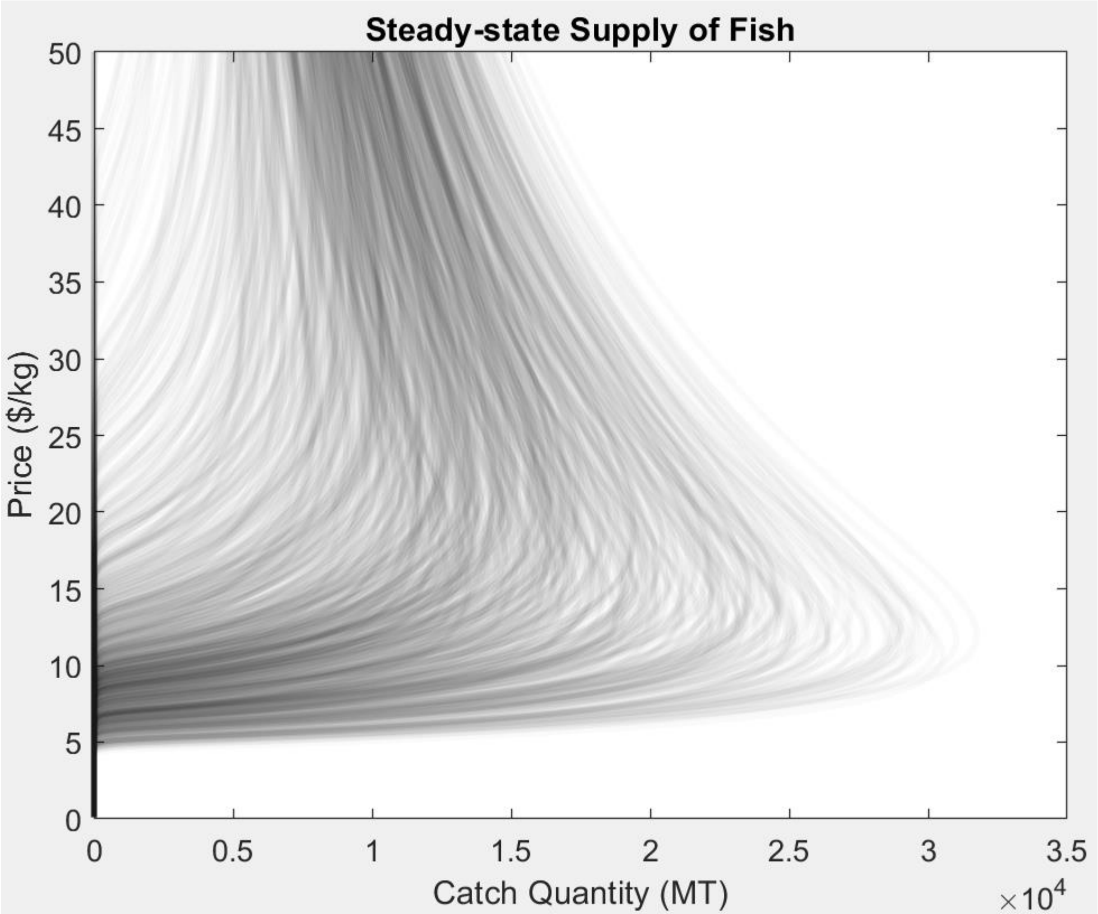
Endogenous fishing mortality $$f_t(a) = qE_t$$

$$N_{0,t} = \frac{\alpha B_t}{1 + B_t / \boxed{k}} e^{\sigma v_t}$$ Recruitment (B-H)

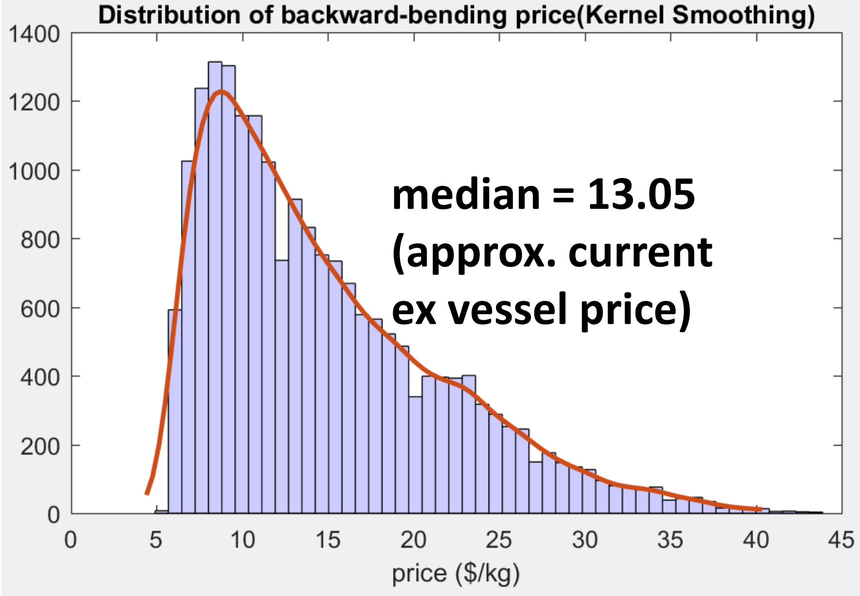
Open Access $$E_{t+1} = E_t + \gamma\left(P_t H_t - cE_t\right)$$

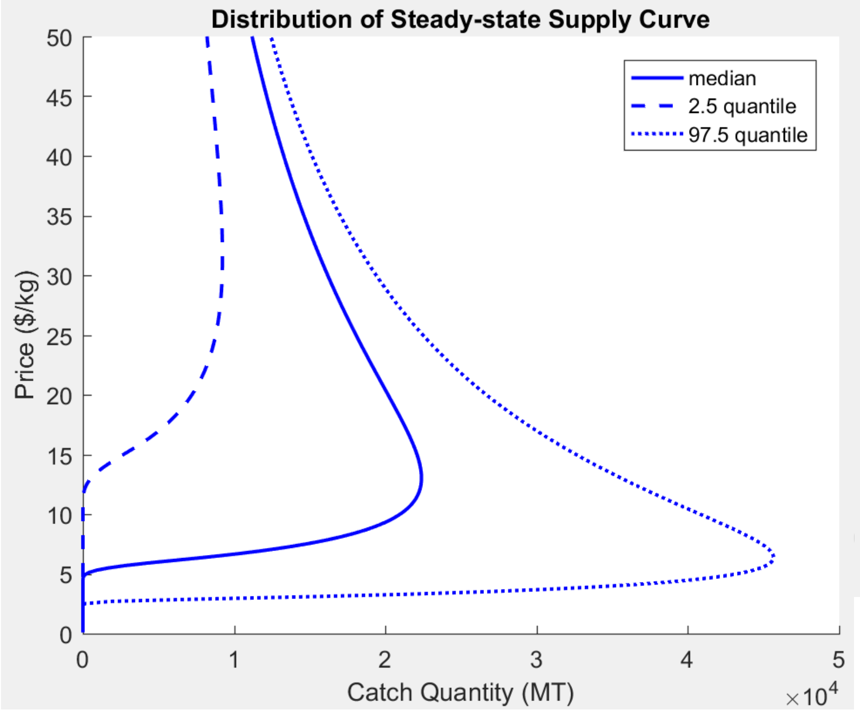
k = estimated recruitment parameter

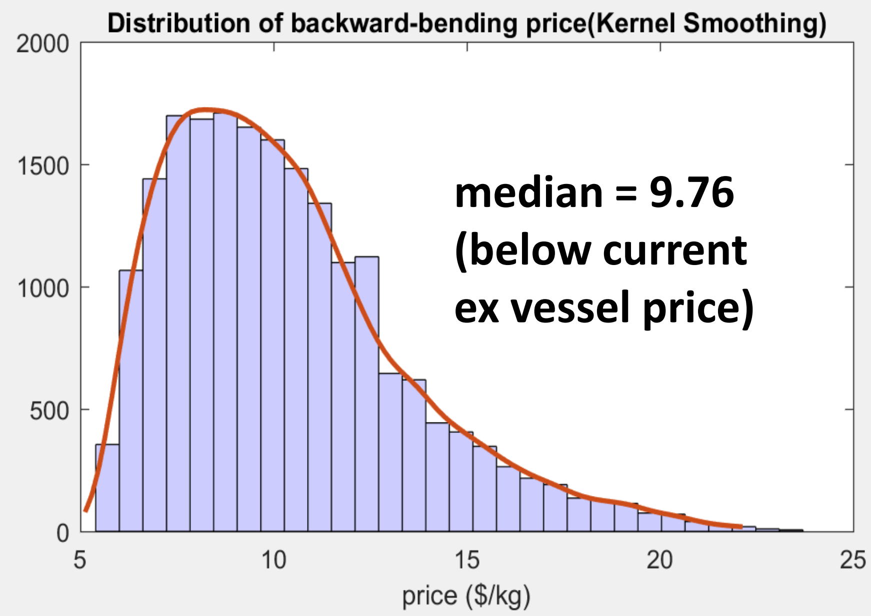
Monte Carlo Simulation w/ Variable Recruitment

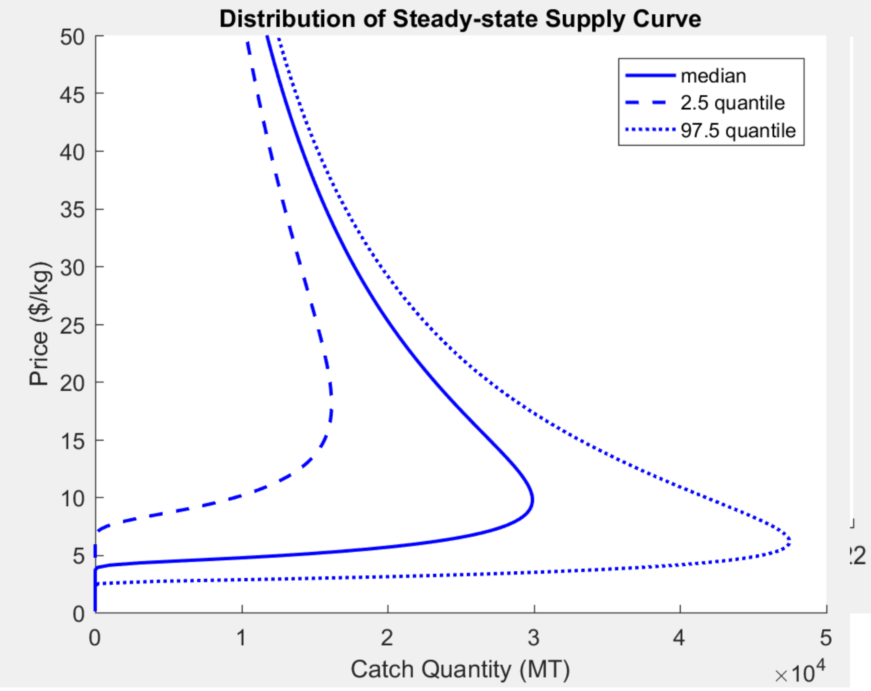


The backward-bending point of the supply curve is very sensitive to the recruitment scale parameter



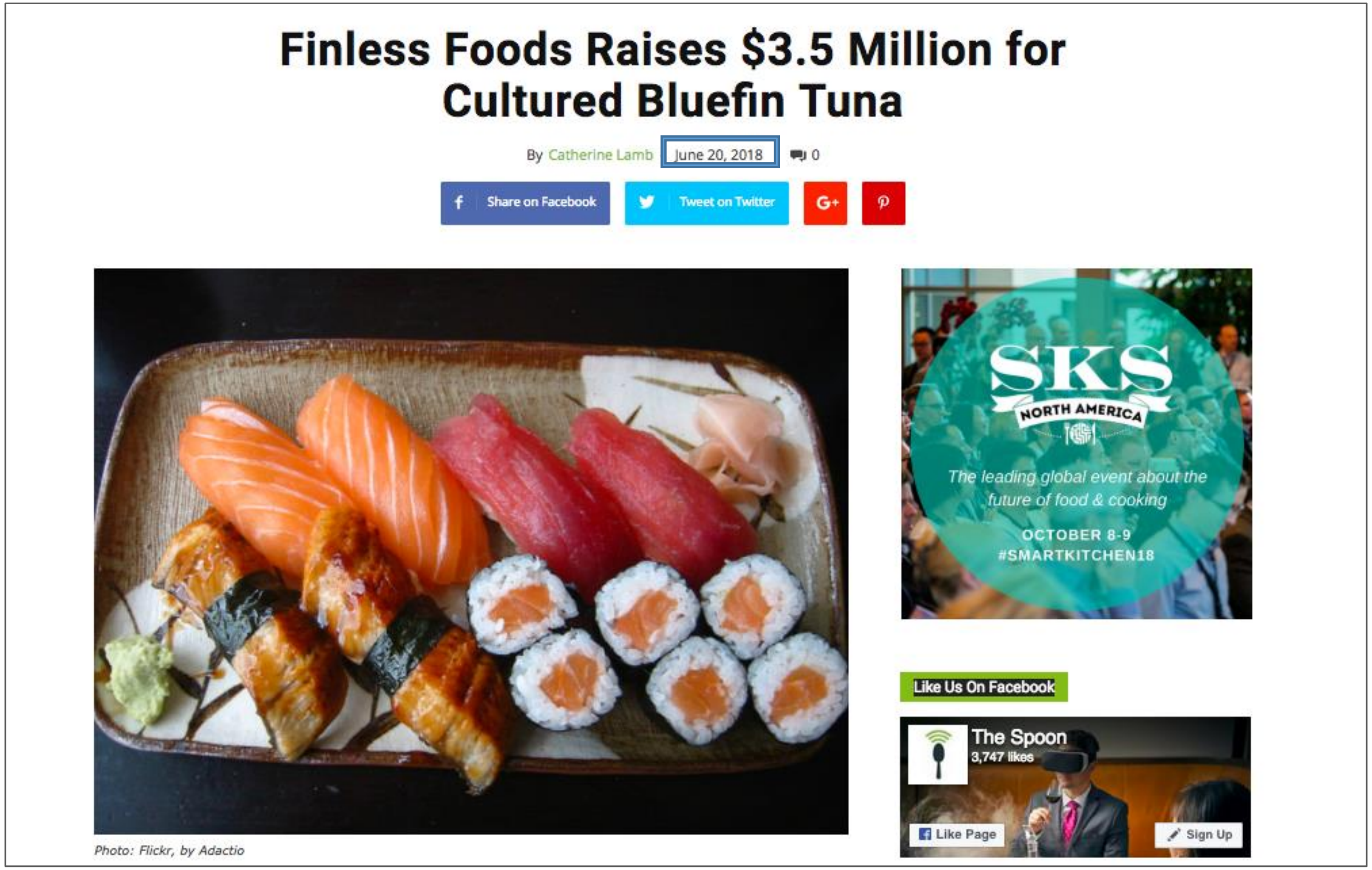






Anticipated Market Development & Policy Changes

Changes in innovation & technology happening fast & now!



Finless Foods Raises $3.5 Million for Cultured Bluefin Tuna

By Catherine Lamb June 20, 2018 0

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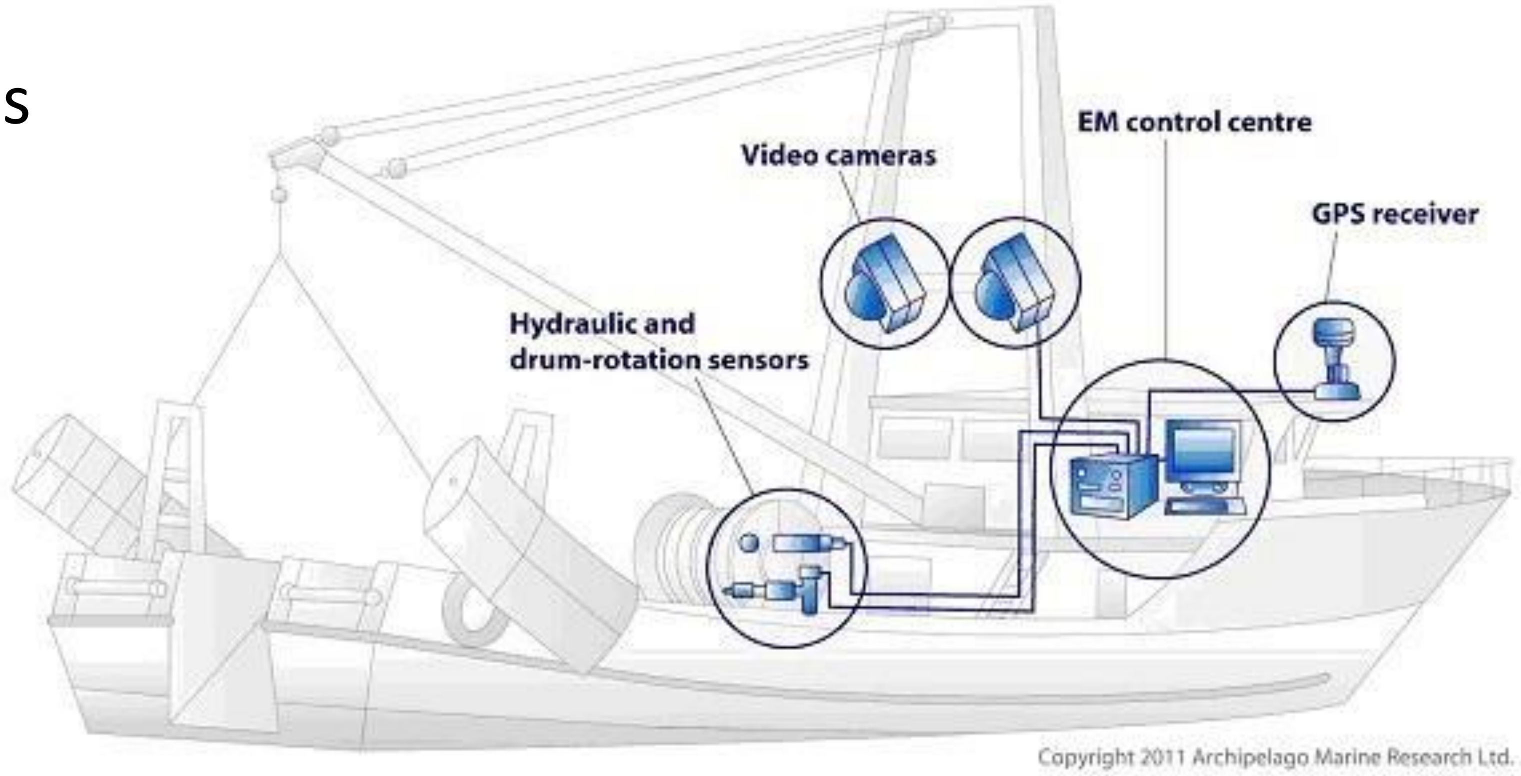
Photo: Flickr, by Adactio

Governance Interventions

- ICCAT Electronic Bluefin Tuna Catch Document (eBCD)
- Port State Measures Agreement
- Electronic Monitoring
- Rebuilding plans by RFMOs



Aquaculture innovation could improve conservation outcomes on wild stocks

- Need better data on critical bioeconomic parameters that we don’t know well (e.g. recruitment)
- Innovation that does not spill over and increase incentives to ranch
  - Survival of closed-cycle breeding
  - Tech only for early life stages
  - Market innovation specific to closed-cycle (e.g. branding)

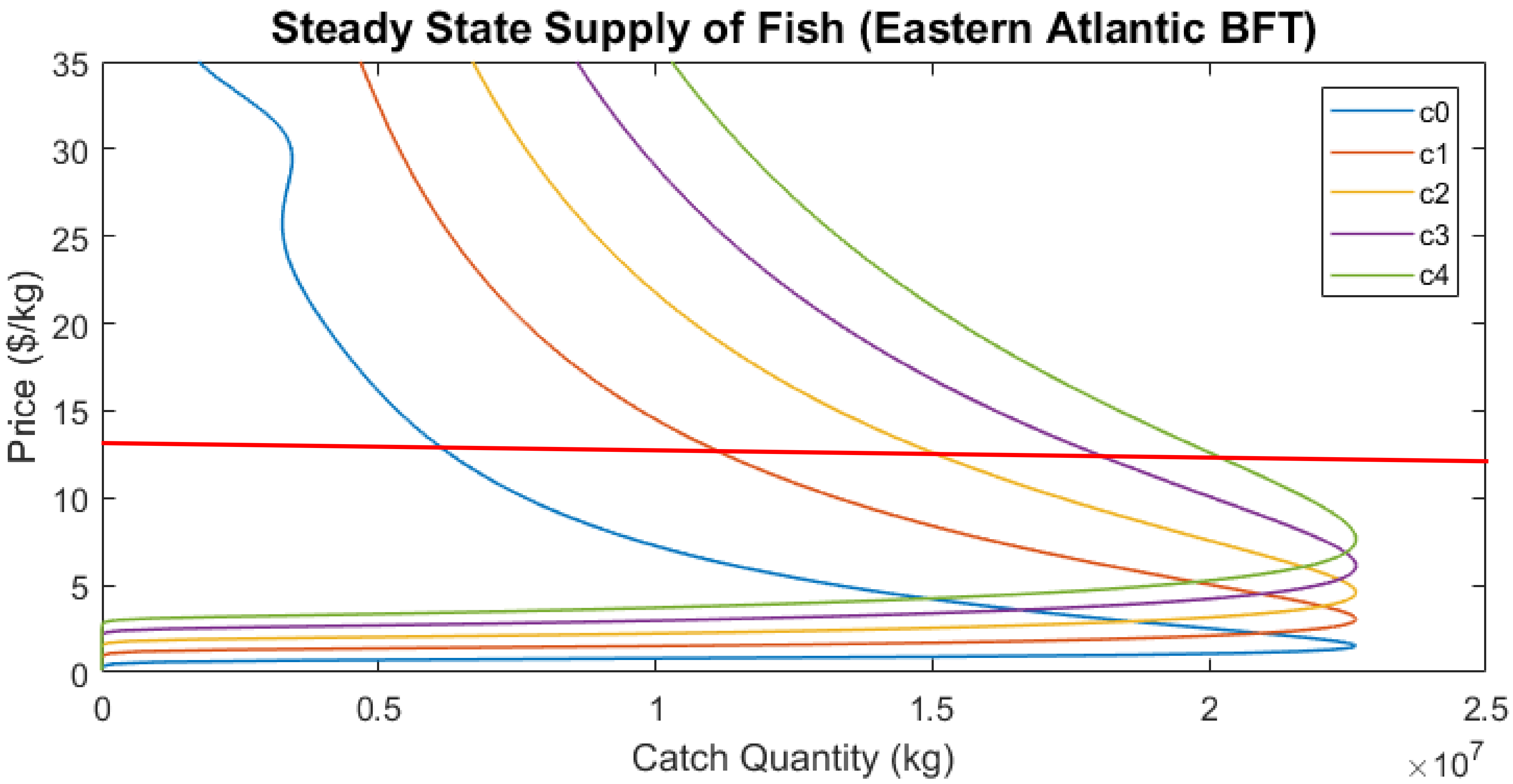
Strong Governance is Always Key

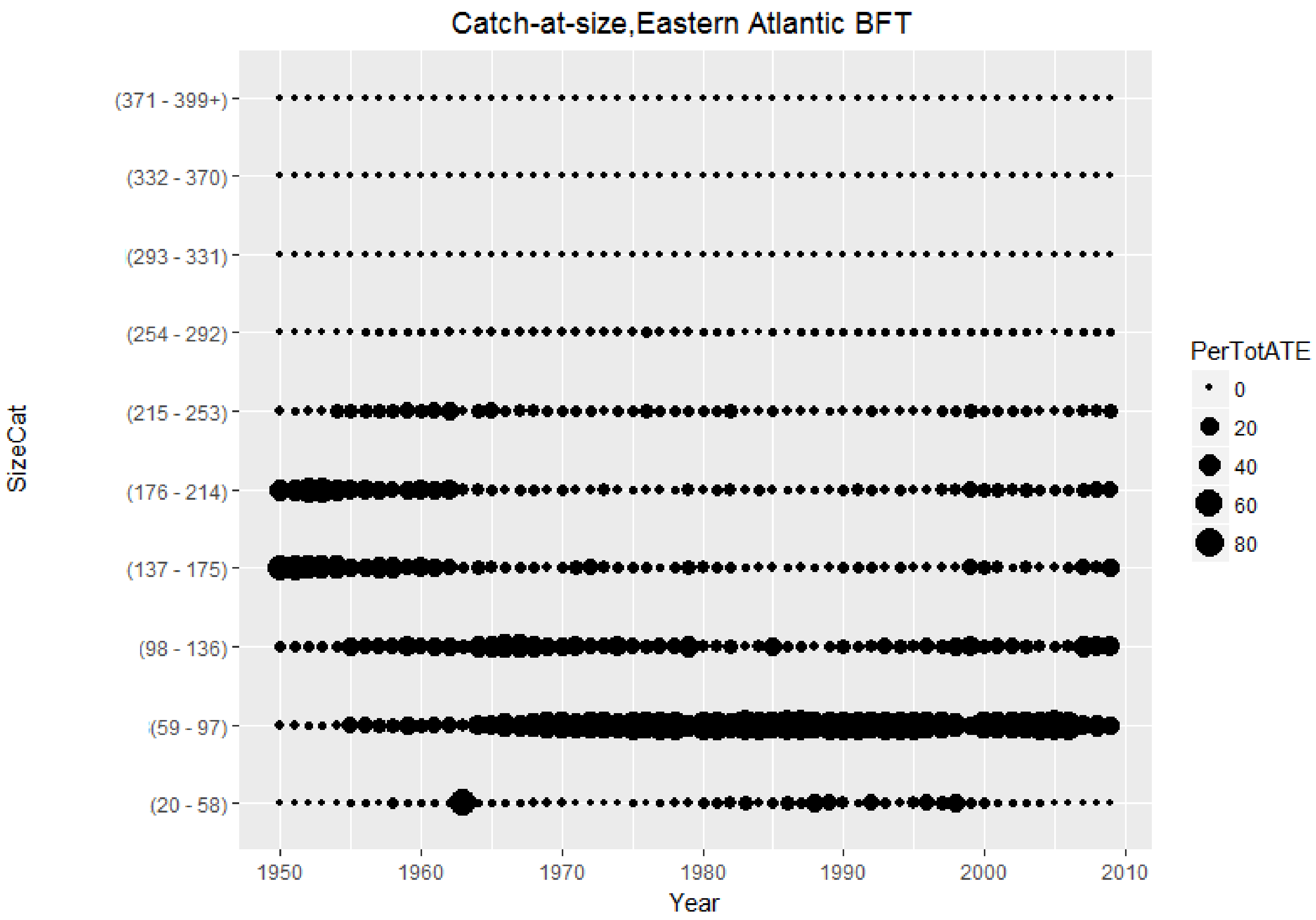
- Hold quota against total production/mortality
- More regulation and documentation for aquaculture
- Provide long-term assistance to private sector, focus on closed-cycle R&D
- Goal: incentivize production/access to/demand for closed-cycle BFT

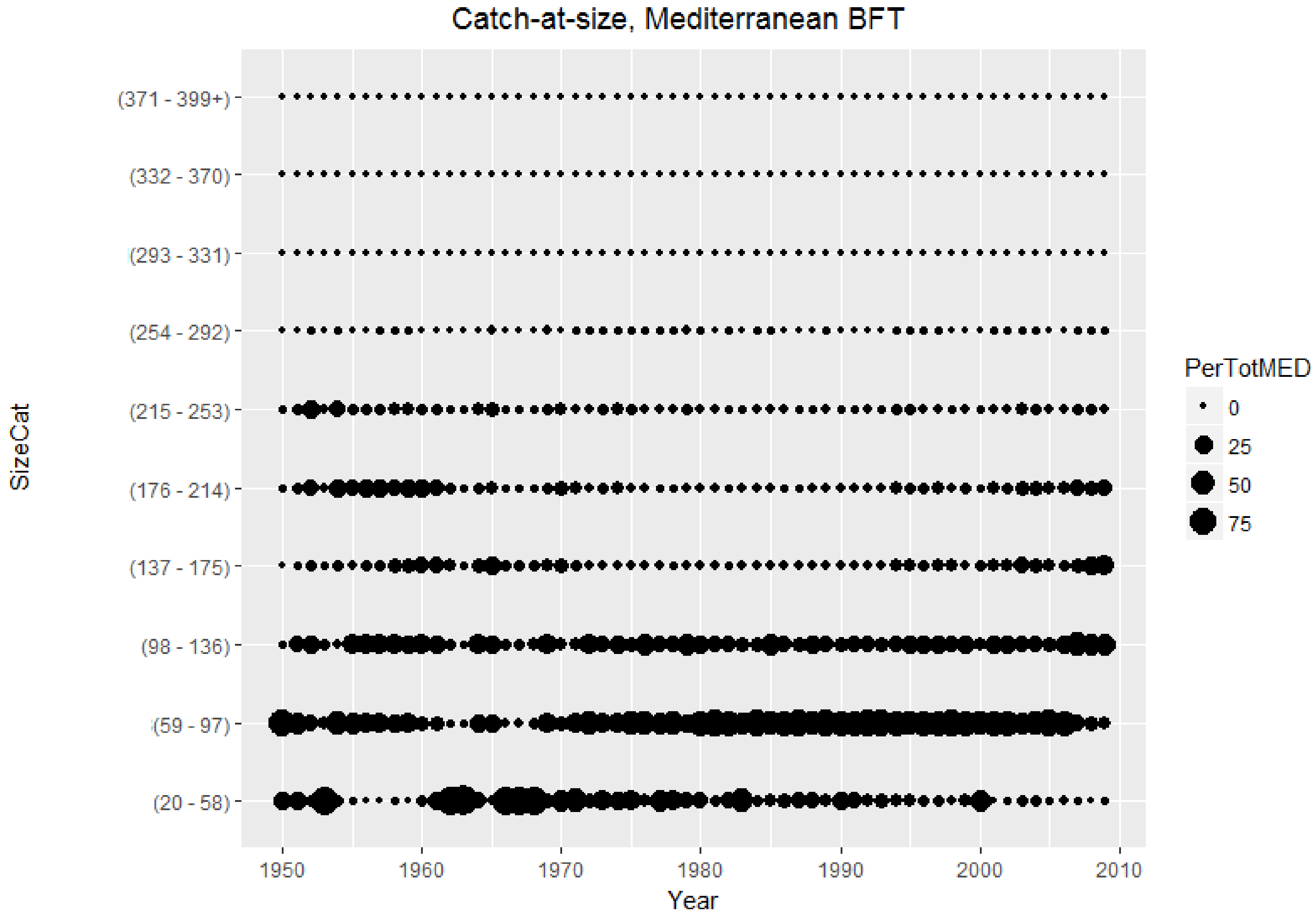
Thanks to:
Dr. Martin Smith & lab
The Pew Charitable Trusts

Email: Rachel.Karasik@duke.edu

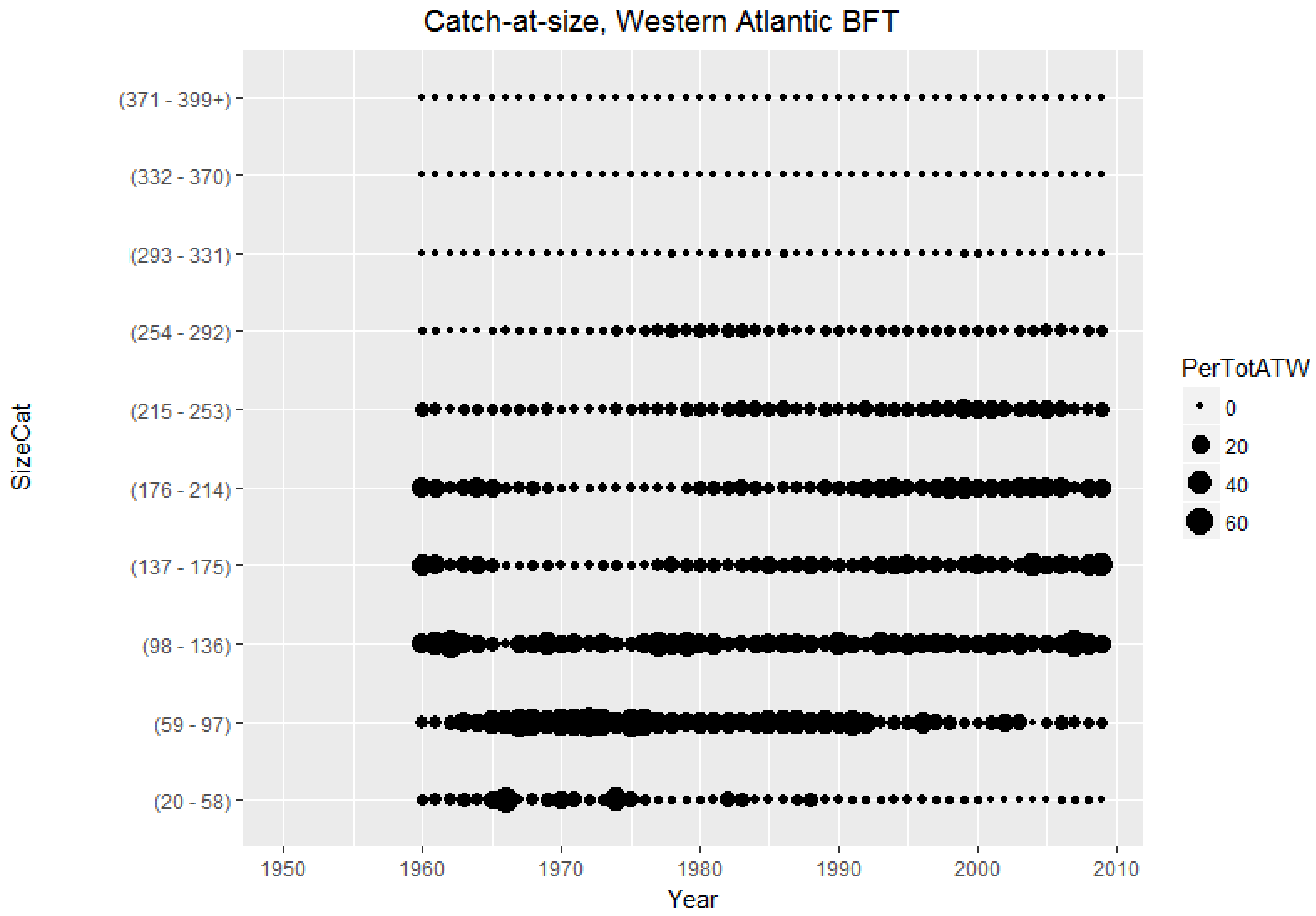
Extra Stuff

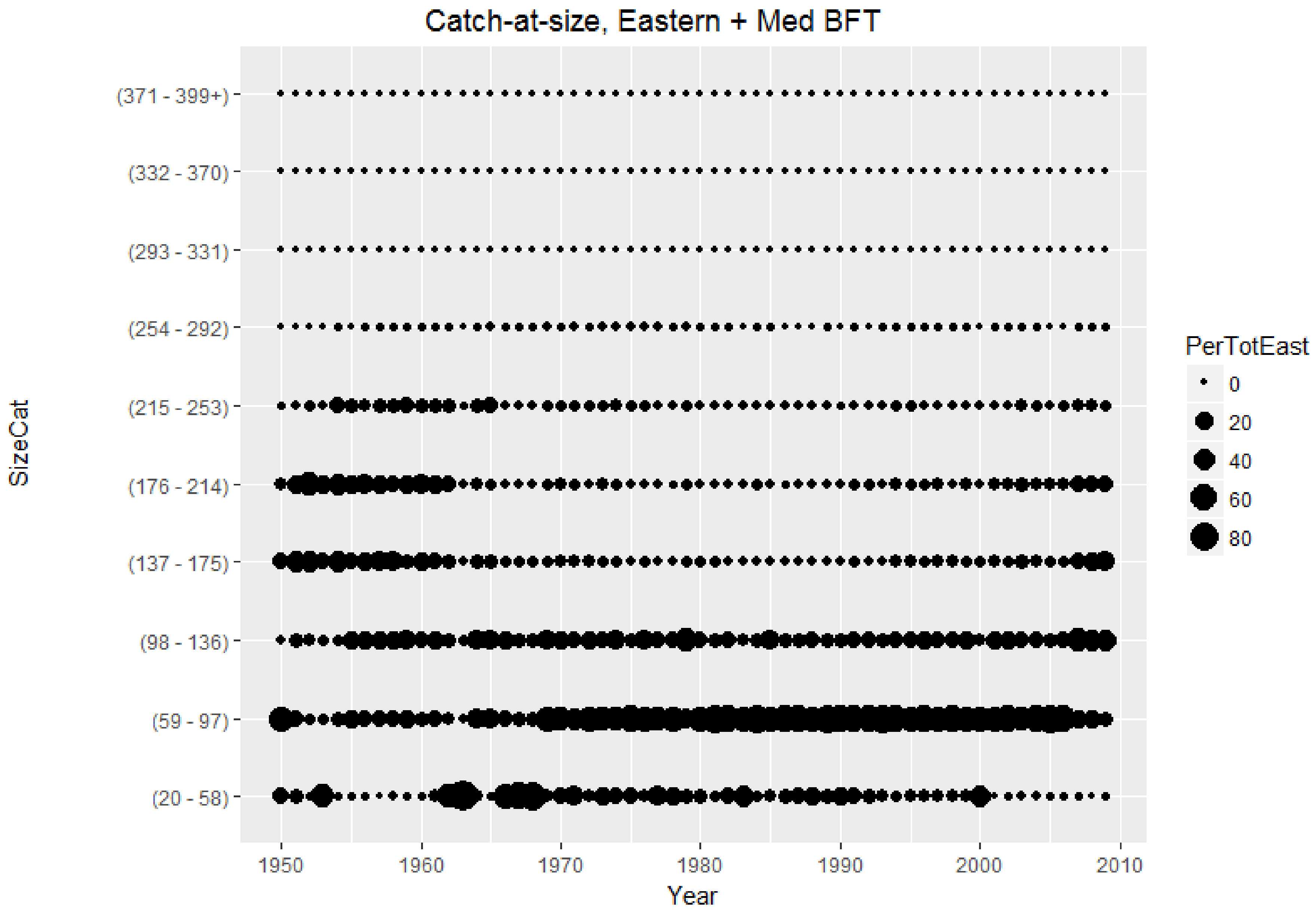

Steady State Supply of Fish (Eastern Atlantic BFT)
c0
c1
c2
c3
c4
Price ($/kg)
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
Catch Quantity (kg)
×10^7

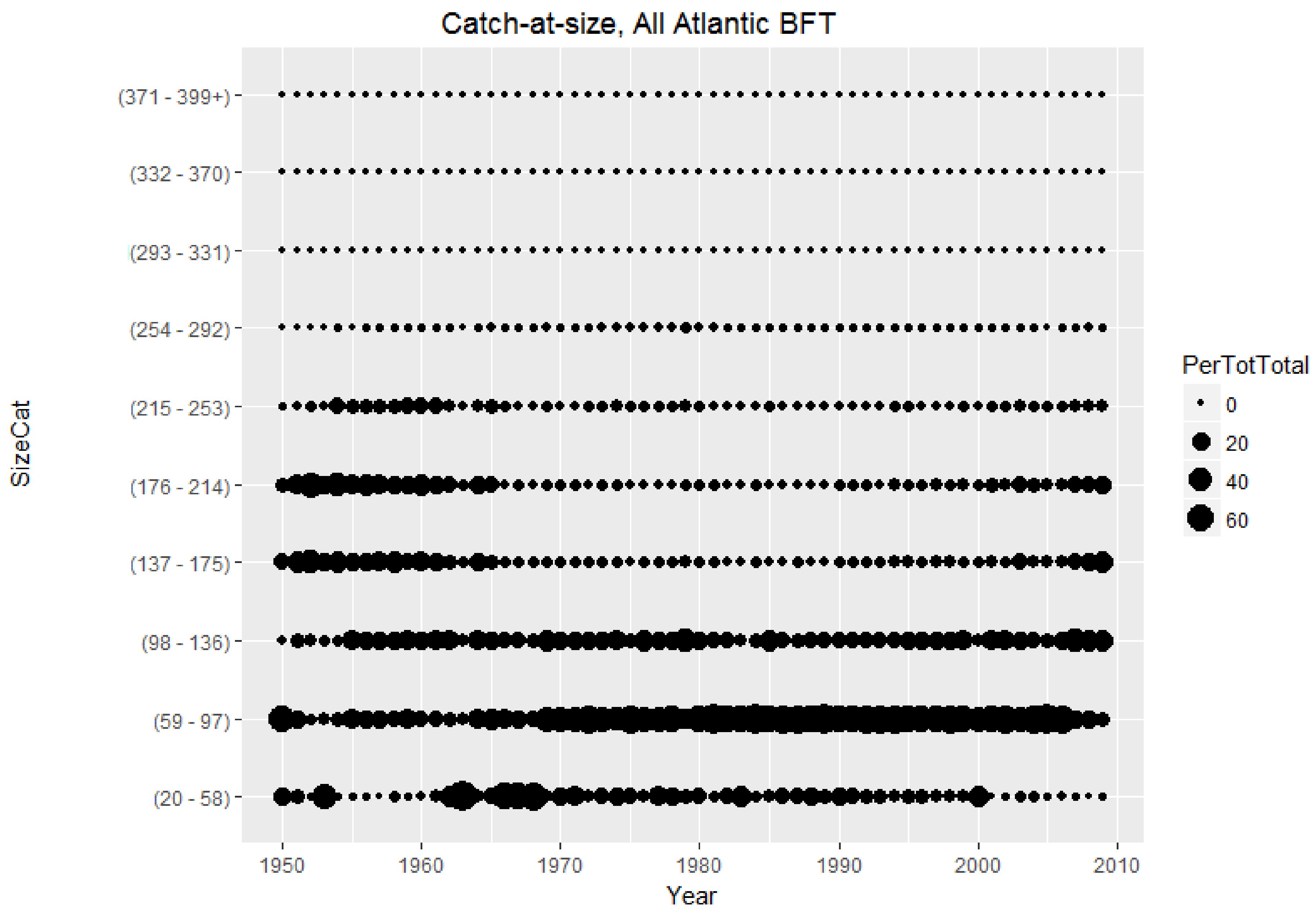

Catch-at-size,Eastern Atlantic BFT
SizeCat
(371 - 399+)
(332 - 370)
(293 - 331)
(254 - 292)
(215 - 253)
(176 - 214)
(137 - 175)
(98 - 136)
(59 - 97)
(20 - 58)
1950
1960
1970
1980
1990
2000
2010
Year
PerTotATE
0
20
40
60
80



Catch-at-size, Mediterranean BFT
SizeCat
(371 - 399+)
(332 - 370)
(293 - 331)
(254 - 292)
(215 - 253)
(176 - 214)
(137 - 175)
(98 - 136)
(59 - 97)
(20 - 58)
1950
1960
1970
1980
1990
2000
2010
Year
PerTotMED
0
25
50
75


Catch-at-size, Western Atlantic BFT
(371 - 399+)
(332 - 370)
(293 - 331)
(254 - 292)
(215 - 253)
(176 - 214)
(137 - 175)
(98 - 136)
(59 - 97)
(20 - 58)
SizeCat
1950
1960
1970
1980
1990
2000
2010
Year
PerTotATW
0
20
40
60


Catch-at-size, Eastern + Med BFT
SizeCat
(371 - 399+)
(332 - 370)
(293 - 331)
(254 - 292)
(215 - 253)
(176 - 214)
(137 - 175)
(98 - 136)
(59 - 97)
(20 - 58)
1950
1960
1970
1980
1990
2000
2010
Year
PerTotEast
0
20
40
60
80


Catch-at-size, All Atlantic BFT
SizeCat
(371 - 399+)
(332 - 370)
(293 - 331)
(254 - 292)
(215 - 253)
(176 - 214)
(137 - 175)
(98 - 136)
(59 - 97)
(20 - 58)
1950
1960
1970
1980
1990
2000
2010
Year
PerTotTotal
0
20
40
60

Target Questions

1) What will the anticipated effects of increased BFT aquaculture be on prices of wild caught, farm raised, and ranched BFT?

2) How would changes in price, and other market conditions, due to increased aquaculture (from ranching to fully closed cycle) affect wild BFT stocks? In other words, has/will increased aquaculture relieve pressure on wild BFT stocks?

3) Are these effects different across different age classes, regions, ocean basins, product types?

4) In what ways could management/regulations - related to ranching and farming of BFT, or capture fisheries - be changed to reduce pressure on the wild stocks or to reduce the negative effects of ranching/farming?

5) Can you provide a short summary of where existing research stands on this topic (for BFT or for other species), and how this project adds to that understanding? What future research would be needed to better answer, or clarify, the above questions, past what's already been done here?

Overview

- 3 species – Atlantic BFT (endangered), Pacific BFT (vulnerable), Southern BFT (critically endangered)
- Feeds global sashimi/sushi market (Japan, USA, Spain, Italy)
- Wild caught: purse-seine, handline, longline
- Ranched: Farmed and fattened (seacages, nets)
- Closed-cycle: Entire lifecycle is part of controlled production (land-based lab, seacages)

	ABT			PBT			SBT		
	Catch (million metric tons)	Dock value (billion USD)	End value (billion USD)	Catch (million metric tons)	Dock value (billion USD)	End value (billion USD)	Catch (million metric tons)	Dock value (billion USD)	End value (billion USD)
2012	0.013	$0.17	$0.87	0.014	$0.36	$0.90	0.01	$0.13	$0.49
2014	0.015	$0.19	$0.81	0.017	$0.28	$0.77	0.012	$0.14	$0.45
Source:	Netting Billions: A Global Valuation of Tuna								

What will the anticipated effects of increased BFT aquaculture be on prices of wild caught, farm raised, and ranched BFT?

Increase: Closed-Cycle → Wild Caught: → Closed-Cycle: → Ranched:

Increase: Ranching → Wild- Caught: → Closed-Cycle: → Ranched:

Current research: existing

- Growing food in labs
- Price Elasticity/substitutability
- Reducing early-age mortality

Current research: non-existing

- Shifts/changes in demand over time
- Product differentiation between farmed/ranched/closed cycle
- Age distributed backward bending supply curves

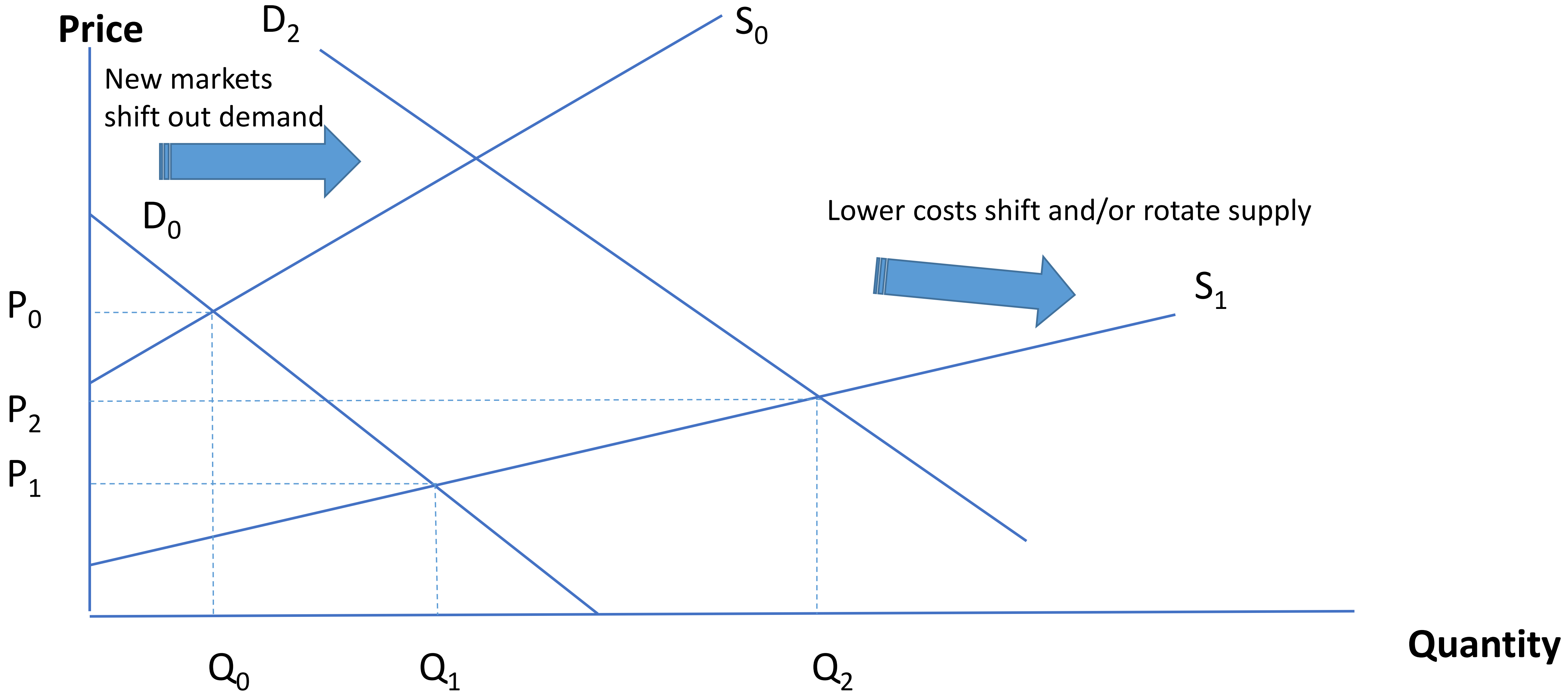
Outline

1. Market interactions
   - Lessons from shrimp
   - Lessons from salmon
2. Backward-bending supply
   - Basic (classic) model with logistic growth
   - Generalize to age-structured population with bluefin parameterization
   - Key uncertainties – harvest/ranching cost, speed of adjustment, recruitment
3. Bluefin institutions
4. Anticipated market development
5. Bluefin innovation and effects on bioeconomic parameters
6. Ongoing/future work
   - Empirical bioeconomic modeling
   - Age/size-dependent fishing mortality (and incentives in ranching)
7. Conclusions

1. Market interactions

What will the anticipated effects of increased BFT aquaculture be on prices of wild caught, farm raised, and ranched BFT?

Simple economics of decreasing costs and new market development



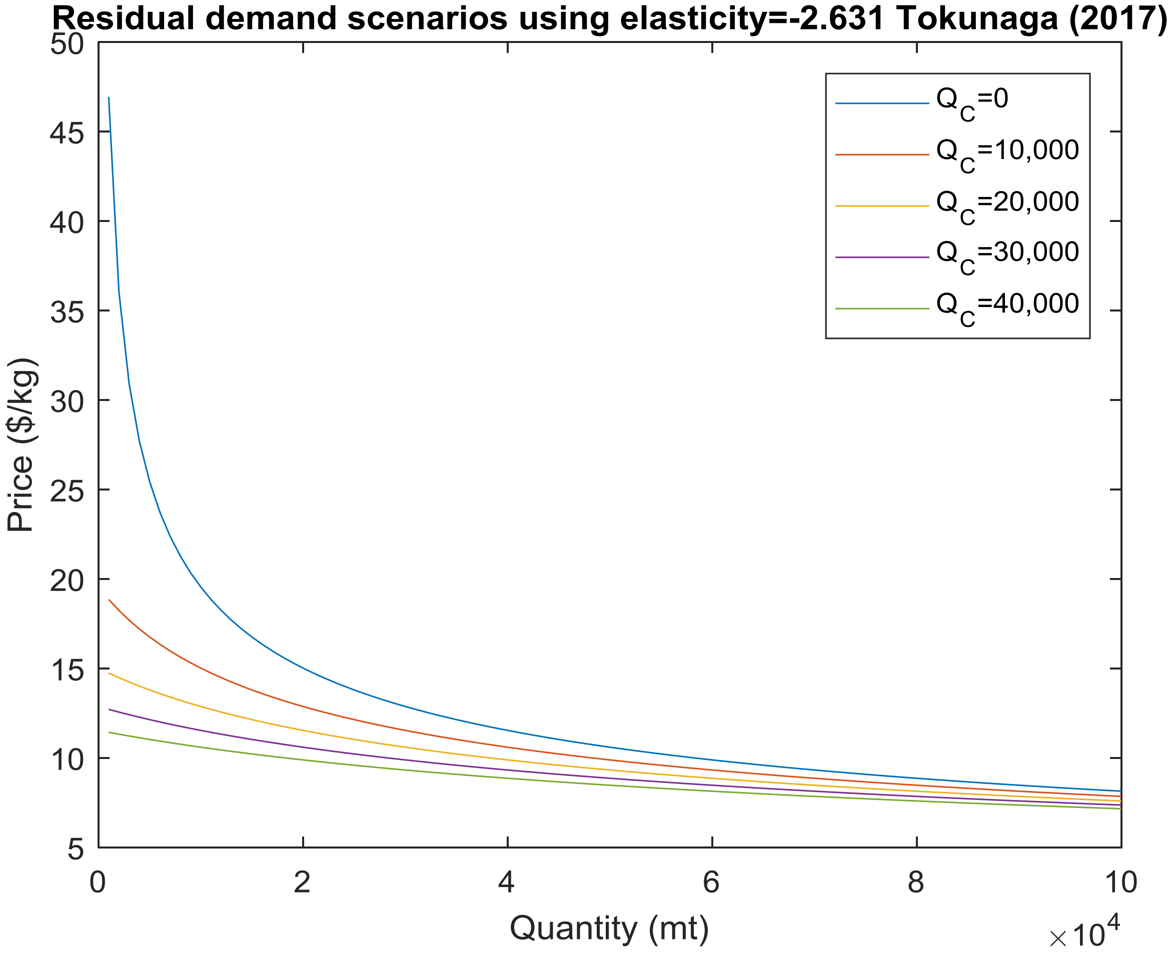
Residual demand and substitutability

$$Q^{D,wild} = Q^{D} - Q^{S,cylcle}$$

$$Q^{D} = \alpha P^{\theta}$$

$$P = \left(\frac{1}{\alpha} \left(Q^{D,wild} + Q^{S,cycle} \right) \right)^{\frac{1}{\theta}}$$

$$Q^{D,wild} = Q^{S,wild}$$



Abstract (for reference)

- Abstract: Scarcity of wild-caught seafood has incentivized innovation and growth in aquaculture, especially for species that compete directly with wild alternatives. In the global tuna industry, the most pronounced scarcity is associated with bluefin tuna species (Atlantic, Pacific, and Southern, which serve similar markets). Supply-side factors including overfishing and governance challenges together with high demand for bluefin as an ultra-premium sushi product have contributed to bluefin scarcity with associated high prices and considerable environmental concerns about the sustainability of the fish stocks. The lucrative bluefin market and limited availability of these tuna from capture fisheries have triggered substantial investment in technologies to farm bluefin tuna. Will technological advances in bluefin tuna farming and market penetration from these operations ultimately alleviate pressure on wild stocks? This paper develops a numerical bioeconomic model of Atlantic bluefin tuna harvest and links the outcomes to developments in the aquaculture industry. We derive a backward-bending supply curve for fish in an age-structured population and show conditions under which technological advances in aquaculture will steer the fishery back to the upward-sloping region of supply.

About BFT

- Beloved (few charismatic megafauna)
- Overfished
- Delicious
- Historic
- Aquaculture?

Backward-bending supply curve for fisheries – analytics of the simple model

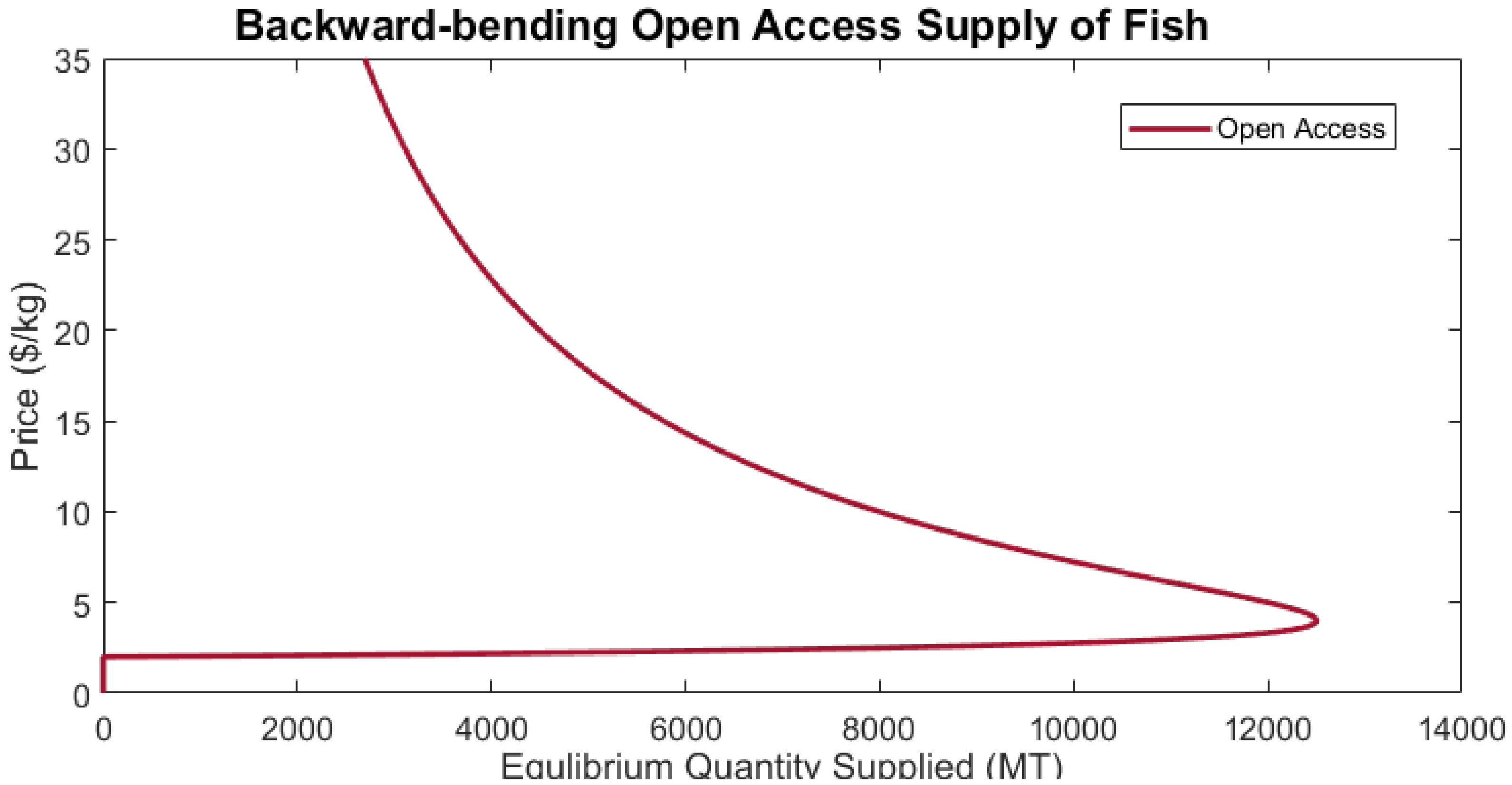
$$Y(t) = qE(t)X(t)$$

$$\frac{dX(t)}{dt} = rX(t)\left(1 - \frac{X(t)}{K}\right) - Y(t)$$

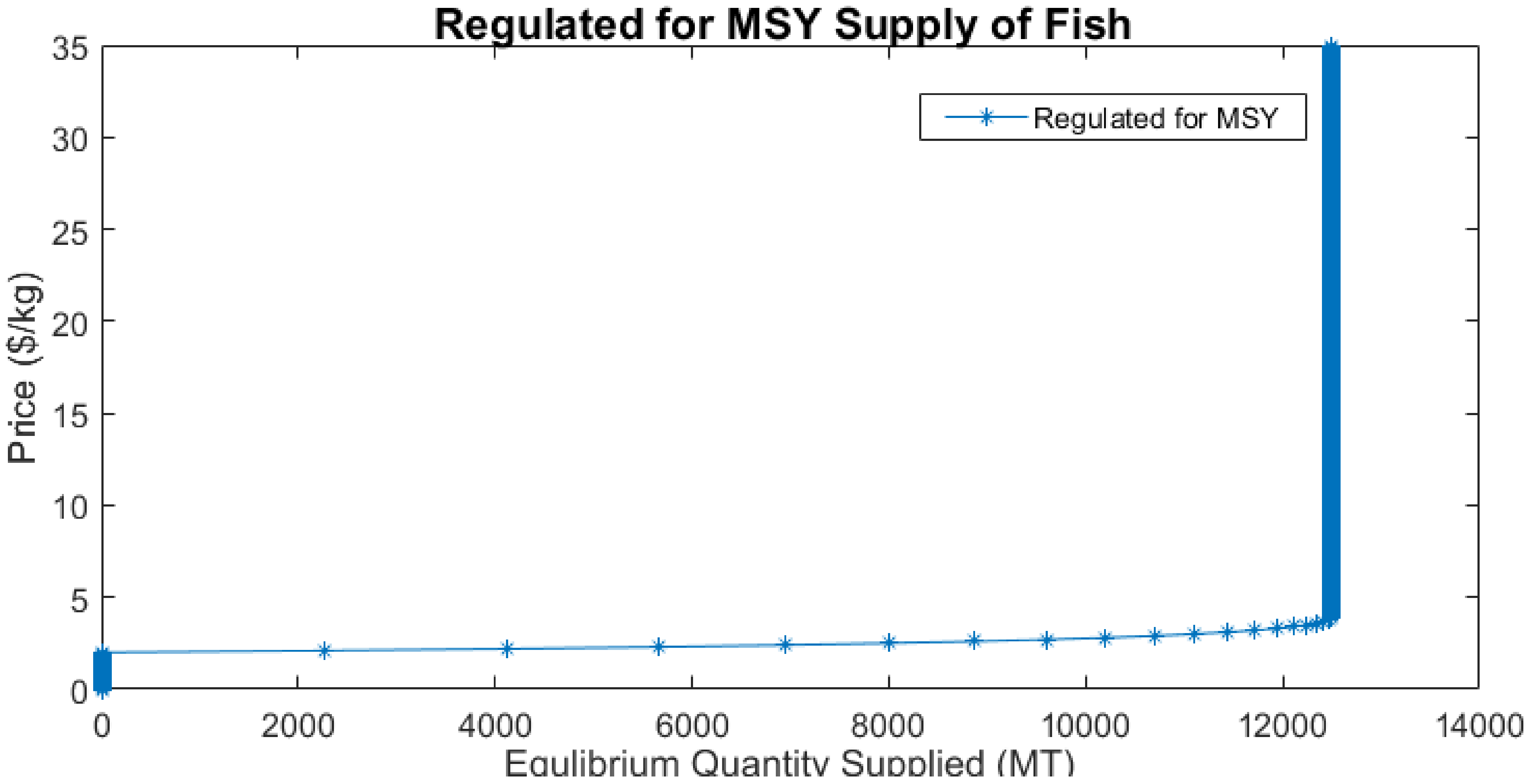
$$PY^{SS} - cE^{SS} = 0$$

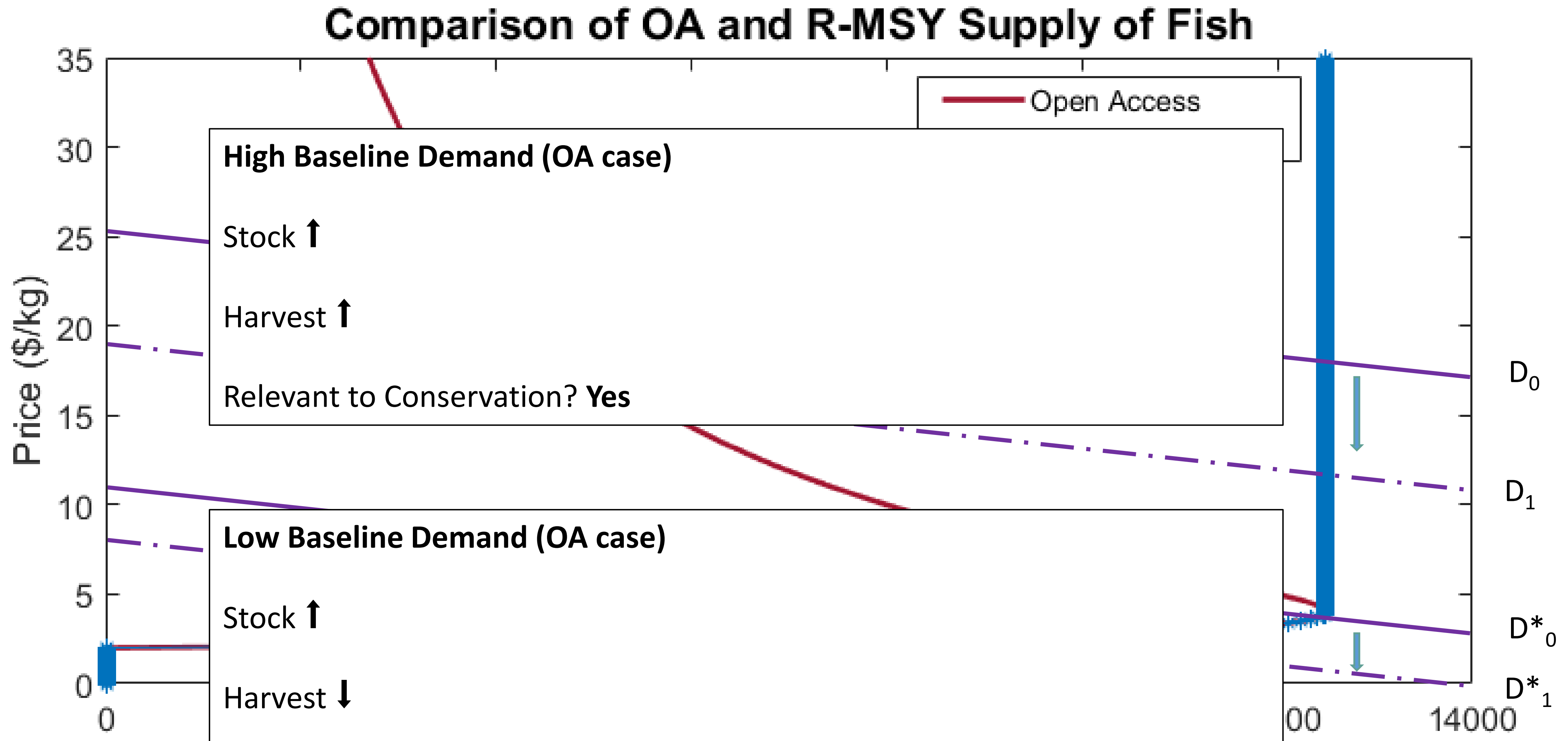
$$X^{SS} = \frac{c}{pq}$$

$$Y^{SS} = r\frac{c}{pq}\left(1 - \frac{c}{pqK}\right)$$



Very important to note that backward-bending supply does not apply to fisheries with binding regulations!





High Baseline Demand (OA case)

Stock ⬆

Harvest ⬆

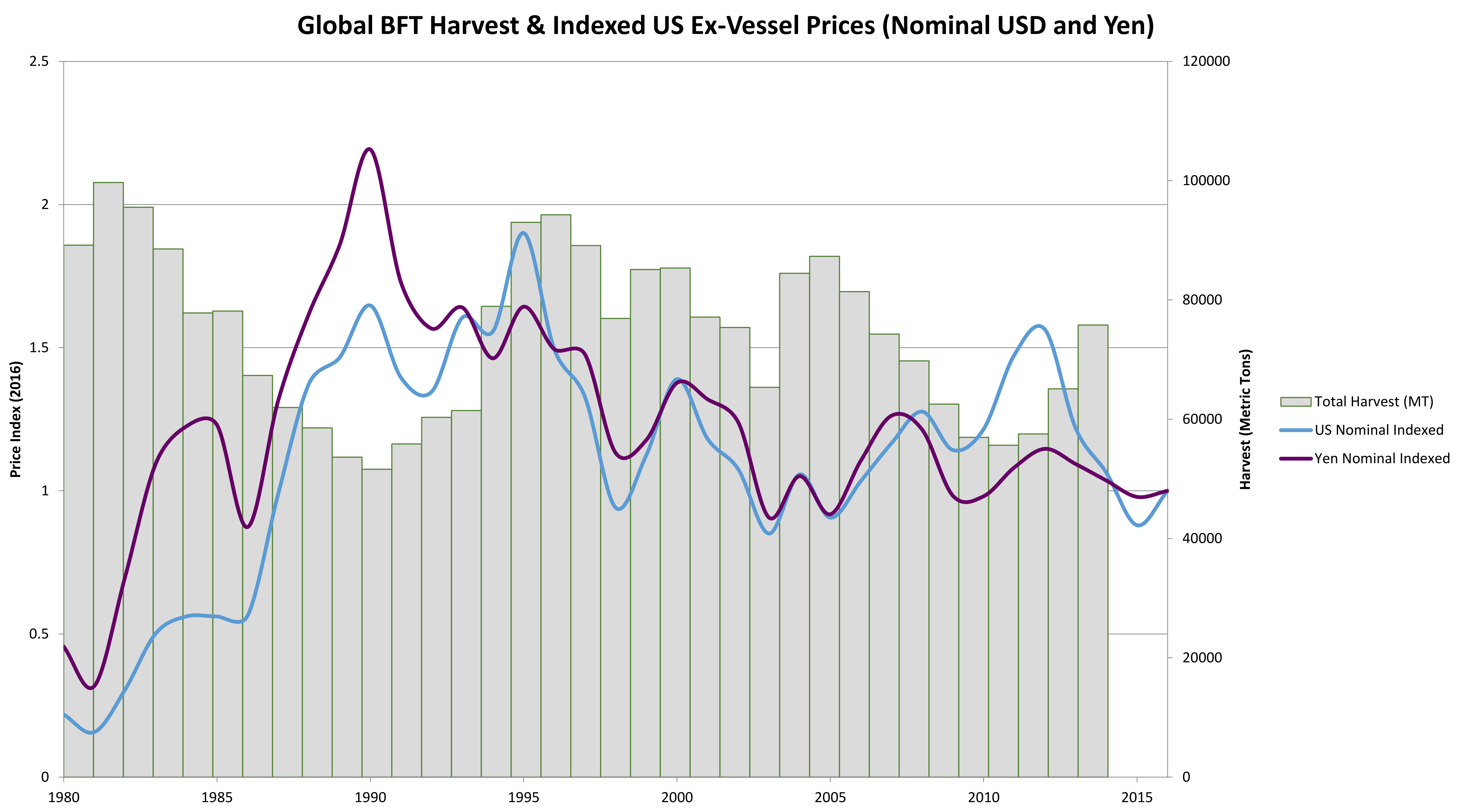
Relevant to Conservation? **Yes**

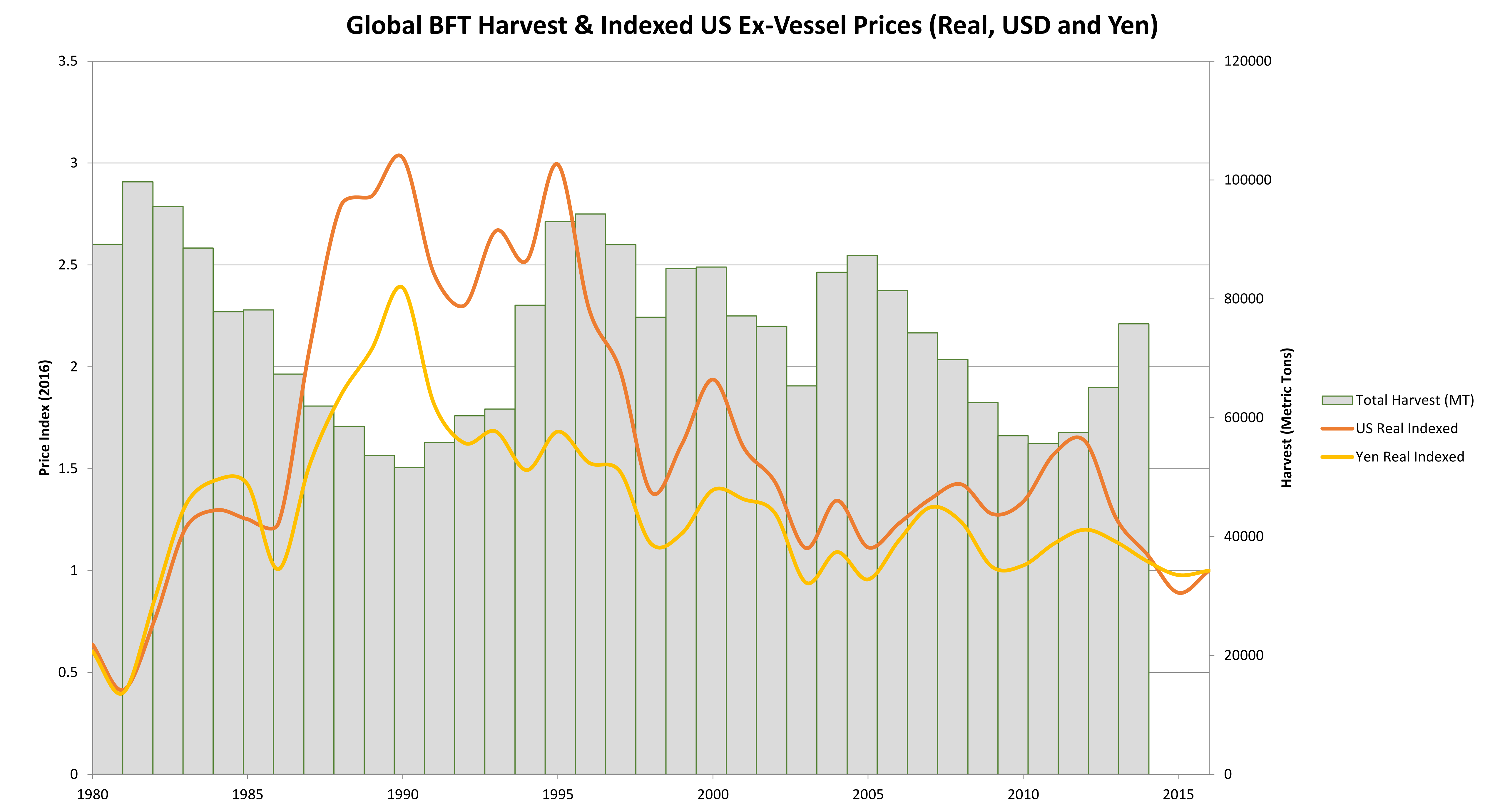
Low Baseline Demand (OA case)

Stock ⬆

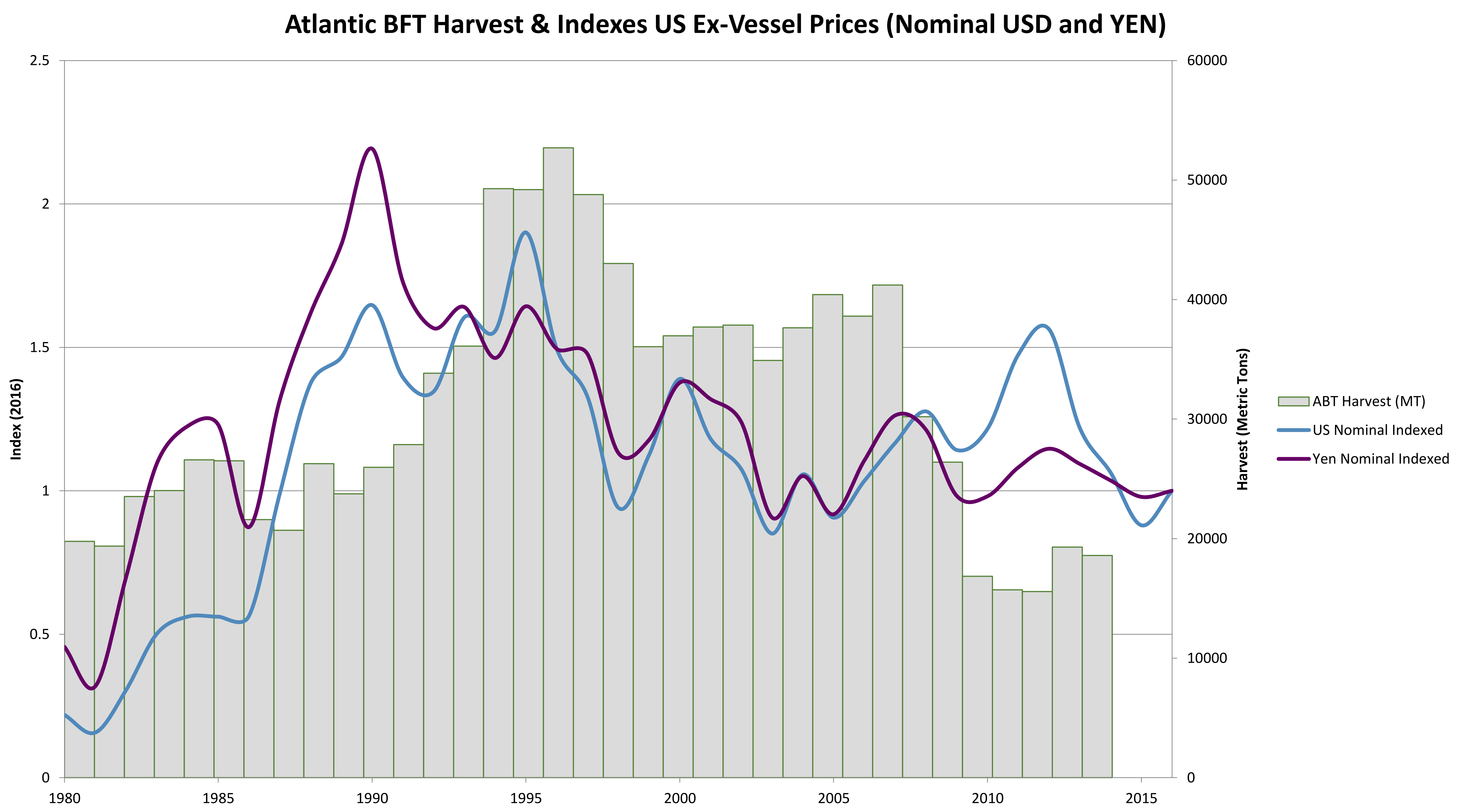
Harvest ⬇

Relevant to Conservation? **No**

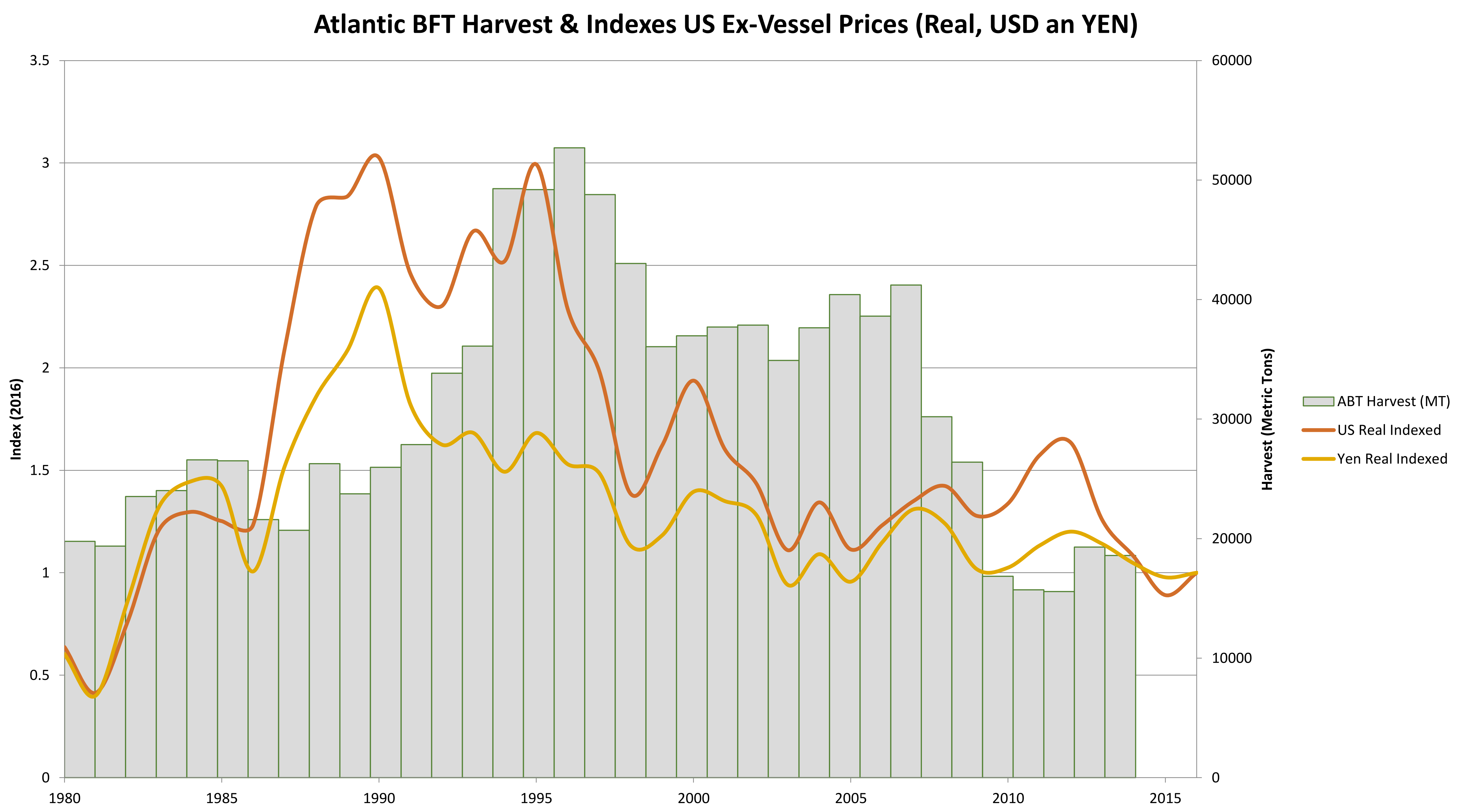

Global BFT Harvest & Indexed US Ex-Vessel Prices (Nominal USD and Yen)
Price Index (2016)
Harvest (Metric Tons)
0
0.5
1
1.5
2
2.5
0
20000
40000
60000
80000
100000
120000
1980
1985
1990
1995
2000
2005
2010
2015
Total Harvest (MT)
US Nominal Indexed
Yen Nominal Indexed



Global BFT Harvest & Indexed US Ex-Vessel Prices (Real, USD and Yen)
Price Index (2016)
Harvest (Metric Tons)
3.5
3
2.5
2
1.5
1
0.5
0
120000
100000
80000
60000
40000
20000
0
1980
1985
1990
1995
2000
2005
2010
2015
Total Harvest (MT)
US Real Indexed
Yen Real Indexed



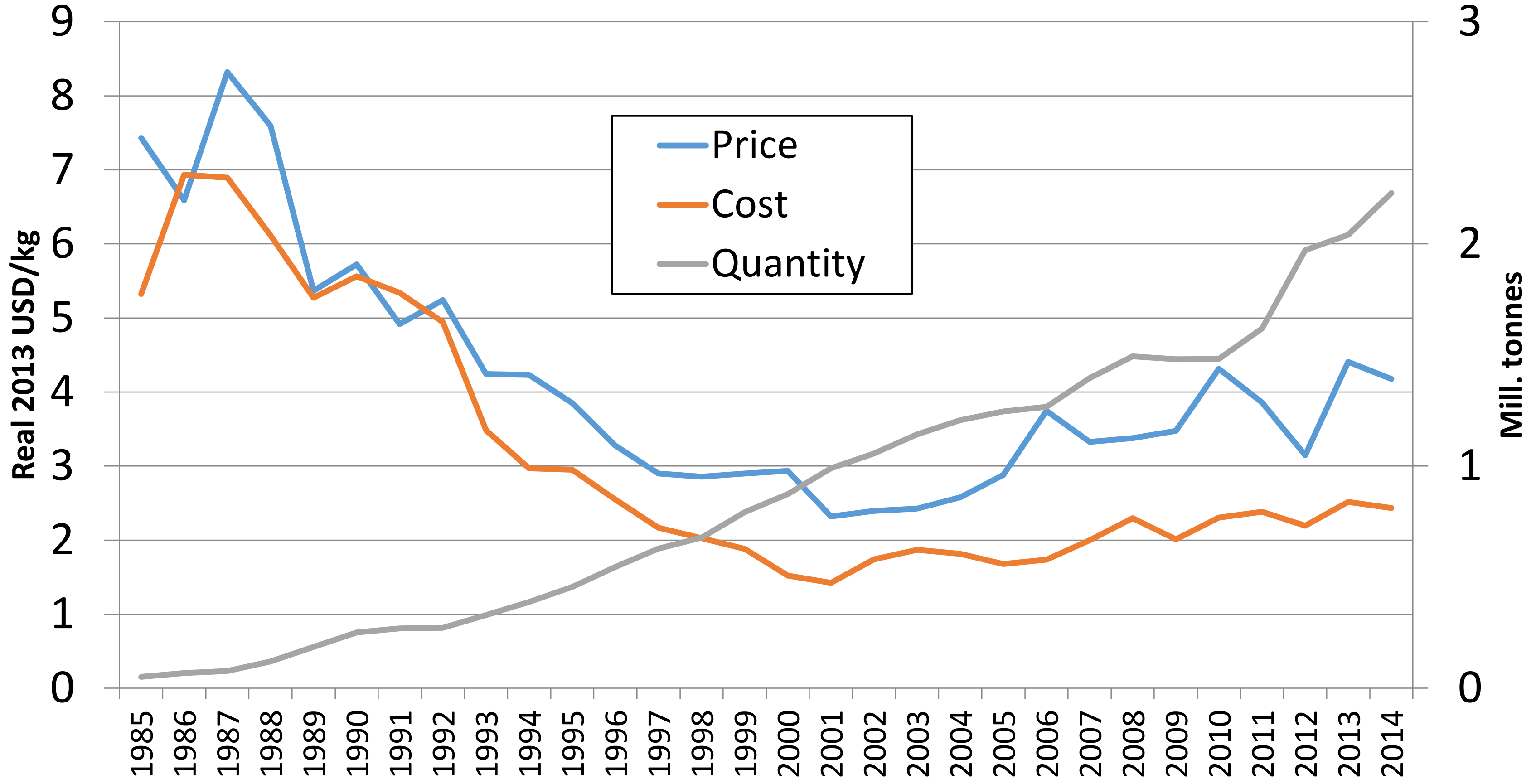
Atlantic BFT Harvest & Indexes US Ex-Vessel Prices (Nominal USD and YEN)
Index (2016)
Harvest (Metric Tons)
0
0.5
1
1.5
2
2.5
0
10000
20000
30000
40000
50000
60000
1980
1985
1990
1995
2000
2005
2010
2015
ABT Harvest (MT)
US Nominal Indexed
Yen Nominal Indexed



Atlantic BFT Harvest & Indexes US Ex-Vessel Prices (Real, USD an YEN)
Index (2016)
Harvest (Metric Tons)
0
0.5
1
1.5
2
2.5
3
3.5
0
10000
20000
30000
40000
50000
60000
1980
1985
1990
1995
2000
2005
2010
2015
ABT Harvest (MT)
US Real Indexed
Yen Real Indexed

Innovation in Farmed Salmon

Dramatic Reductions in Production Costs



Source: Norwegian Directorate of Fisheries, FAO, Kontali

Salmon Feed Utilization Changes (Norwegian farmed Atlantic)

	FIFO Fishmeal	FIFO Fish oil	FFDR Fishemal	FFDR Fish Oil
1990	4.4	7.2	4.4	7.2
2013	1.0	1.7	0.7	1.5
Percent Decrease	**77.3%**	**76.4%**	**84.1%**	**79.2%**
Annual Percent Decrease	**6.2%**	**6.1%**	**7.7%**	**6.6%**

Source: Ytrestøyl, Aas, Åsgård (2015)

Note: FIFO is Fish In / Fish Out Ratio, FFDR is Forage Fish Dependency Ratio

New Product Forms

Branded salmon

Pre-prepared meals

Better Cuts

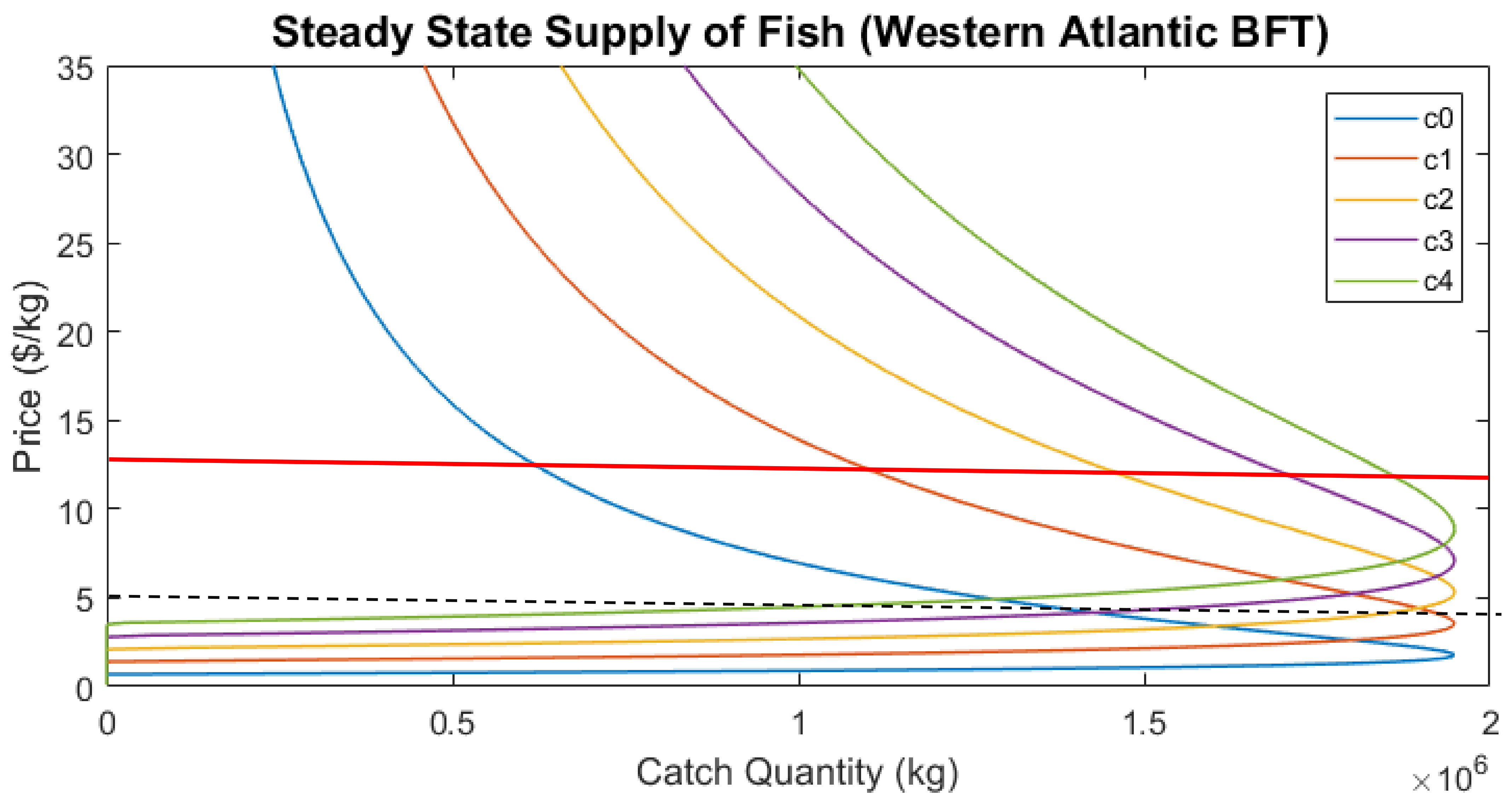
Salmon relevance for bluefin

Relevant/Potentially Similar

- Farmed prices transmitted to wild-caught
- High degree of market integration and substitutability across species
- Market development increases demand
- High dependence on forage for feed (lessening for salmon)
- High environmental dependence in recruitment (?)

Different

- No backward-bending supply in salmon due to management (more on this later)
- Direct environmental impact of farming on wild
- Stressors other than overfishing more important for salmon (e.g. habitat loss, dams, environmental impacts of farmed)
- High environmental dependence in recruitment (?)

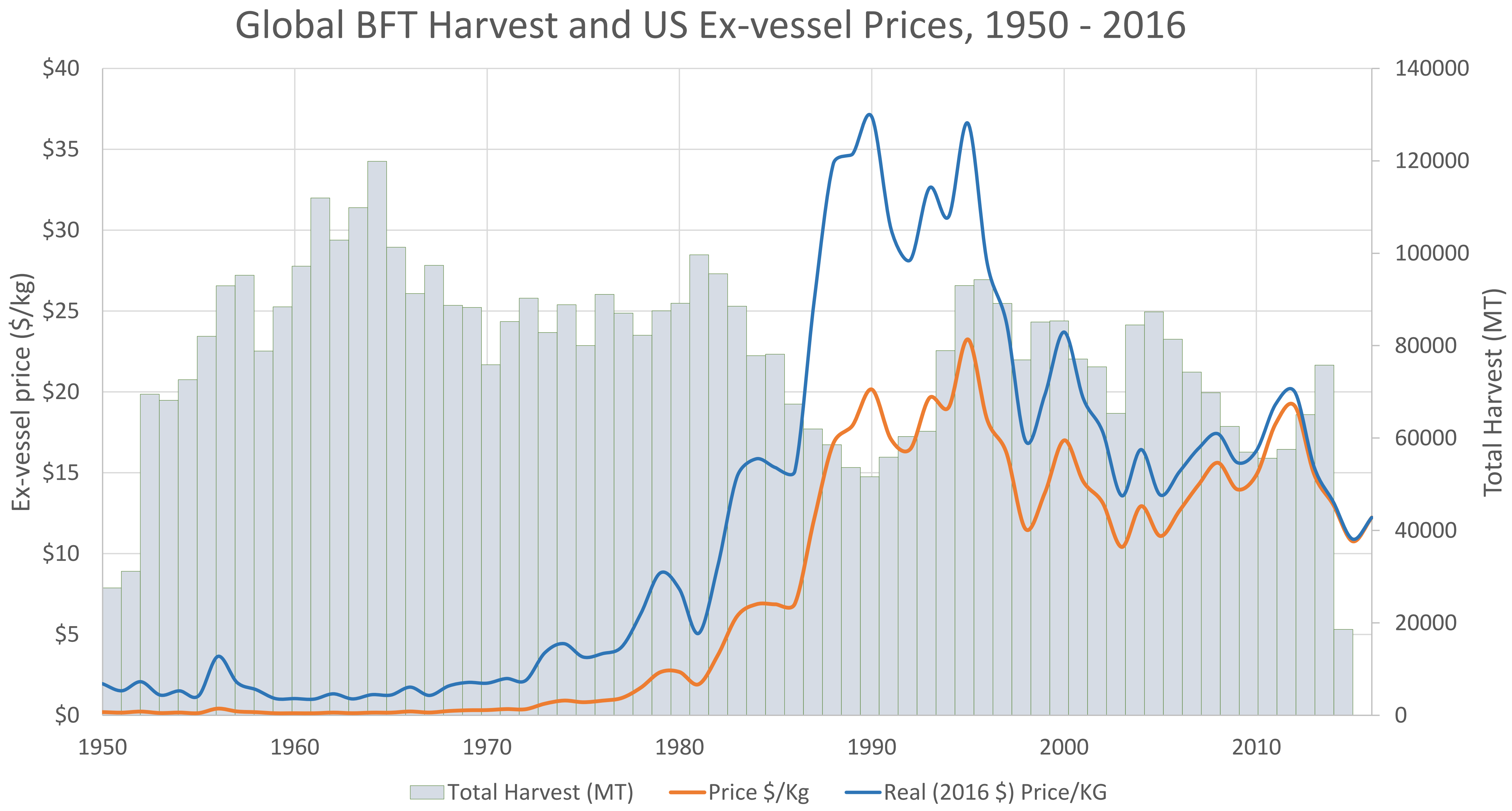

Steady State Supply of Fish (Western Atlantic BFT)
Price ($/kg)
Catch Quantity (kg)
×10^6
c0
c1
c2
c3
c4
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2

Region	Stock	Main Fishing Countries	ISSCAAP IUU Avg. Estimate (classification tunas, bonitos, billfishes)	Avg. Estimate by Region (Agnew 2009)
Indian Ocean	Southern Bluefin Tuna	Taiwan, Japan, Indonesia, Australia	6%	25%
Pacific Ocean	Pacific Bluefin Tuna	US, Taiwan, Mexico, Japan	6%	18%
Pacific Ocean	Southern Bluefin Tuna	Taiwan, New Zealand, Japan, Australia	6%	18%
Atlantic Ocean	Atlantic Bluefin Tuna	Spain, Morocco, Italy, France	6%	17%
Atlantic Ocean	Southern Bluefin Tuna	Taiwain, South Africa, South Korea, Japan	6%	17%

Estimates of IUU Fishing for Bluefin in different regions (WWF 2015 Report)

Take-aways

- While there is governance through regional and national policy for BFT, there is still overfishing
- To rely less on wild-capture fish for ranching, we need to ramp up innovation in areas that will only improve the closed-cycle process
- Current ex-vessel price of BFT (~$13/kg) is an incentive to keep fishing


Global BFT Harvest and US Ex-vessel Prices, 1950 - 2016
Ex-vessel price ($/kg)
Total Harvest (MT)
$40
$35
$30
$25
$20
$15
$10
$5
$0
140000
120000
100000
80000
60000
40000
20000
0
1950
1960
1970
1980
1990
2000
2010
Total Harvest (MT)
Price $/Kg
Real (2016 $) Price/KG