NOAA Fisheries
University of Maryland Center for Environmental Science

The Wealth of Ecosystems: Valuing Natural Capital in the Context of Ecosystem Based Management

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- Wealth Accounting: sustainability indicator
  - UNU-IHDP and UNEP: Inclusive Wealth Report (2014)

    Word Bank: Changing Wealth of Nations (2011)
  - Inclusive / comprehensive / genuine wealth
  - Rigorous economic paradigm for measuring sustainability
- Valuing natural capital prices
  - Requirement to operationalize wealth accounting

    (Dasgupta, 2014; Hamilton & Hartwick, 2014; UNU-IHDP & UNEP, 2014; World Bank, 2011)
  - Difficult in practice: the "Achilles' Heel" (Smulders, 2012)
- Recent Improvement in framework and practice
  - Fenichel and Abbott (2014, JAERE), Fenichel et al. (2016, PNAS), and Fenichel et al. (2016, Nature Climate Change)

- Important stores of wealth
  - 28% of global wealth as lower bound (UNU-IHDP & UNEP, 2014)
  - Systems of Environmental-Economic Account (SEEA) Framework (Barbier, 2011 and 2013; United Nations et al., 2012)
    - Components of ecosystems can be treated as assets
    - *Changes* in the wealth of ecosystems can be valued
  - Ecosystem is not a single asset but a fund or portfolio!

- Emphasis on Ecosystem Based Management (EBM)
  - Management recognizing complexities within ecosystem (Christensen et al., 1996; Pikitch et al., 2004)
  - Needs a single "headline" indicator of wealth of EBM
  - wealth held in the ecosystem is an attractive headline index for EBM

➢ Inclusive wealth accounting theory + EBM

- Provide measures of ecosystem's contribution to larger-scale sustainability

  → headline index for EBM

- Extension of Fenichel and Abbott (2014) approach to incorporate interactions within ecosystems

  Single stock → multiple stocks

- Application to the Baltic Sea fishery

  → Easily adoptable and practical guidance for other cases

- Properly derived natural capital prices capture cross-stock effects
  - allow to recover the value of lower trophic level species

Forage fish:

- Play a significant role as conveyors of energy from plankton to larger predators
- Often a relatively low-value target in reduction or bait fisheries

- N-Multispecies system: $\boldsymbol{S}(t) = (s_1(t), s_2(t), \cdots, s_N(t))$

$$\frac{ds_i}{dt} = \dot{s}_i = G(\boldsymbol{S}) - f(\boldsymbol{S}, x(\boldsymbol{S}))$$

- Value function (Dasgupta et al., 1999)

$$V(\boldsymbol{S}(t)) = \int_t^{\infty} e^{-\delta(\tau - t)} W\left(\boldsymbol{S}(\tau), x(\boldsymbol{S}(\tau))\right) d\tau$$

- Stock price

$$p_i(\boldsymbol{S}(t)) \equiv \frac{\partial V(\boldsymbol{S}(t))}{\partial s_i}$$

- With time derivatives on value function,

$$\delta V = W(\boldsymbol{S}, x(\boldsymbol{S})) + \sum_{i=1}^{N} p_i \dot{s}_i = H(\boldsymbol{S}, \boldsymbol{p})$$

Shadow Price

- Value function: $V = \frac{1}{\delta}\left(W(\boldsymbol{s}, x(\boldsymbol{s})) + \sum_{i=1}^{N} p_i \dot{s}_i\right)$

- Differentiate V w.r.t. stock:

$$p_i = \frac{\partial V}{\partial s_i} = \frac{1}{\delta}\left(\frac{\partial W}{\partial s_i} + \sum_{j=1}^{N}\left(\frac{\partial p_j}{\partial s_i}\dot{s}_j + p_j \frac{\partial \dot{s}_j}{\partial s_i}\right)\right)$$

- Rearranging the price

$$p_i = \frac{\frac{\partial W}{\partial s_i} + \dot{p}_i + \sum_{i \neq j}^{N}\left(\frac{\partial p_j}{\partial s_i}\dot{s}_j + p_j \frac{\partial \dot{s}_j}{\partial s_i}\right)}{\delta - \frac{\partial \dot{s}_i}{\partial s_i}}$$

This term is not in the single stock case: cross-stock effects

- Inclusive Wealth (Dasgupta, 2014): $IW = \sum_{i=1}^{N} p_i s_i$

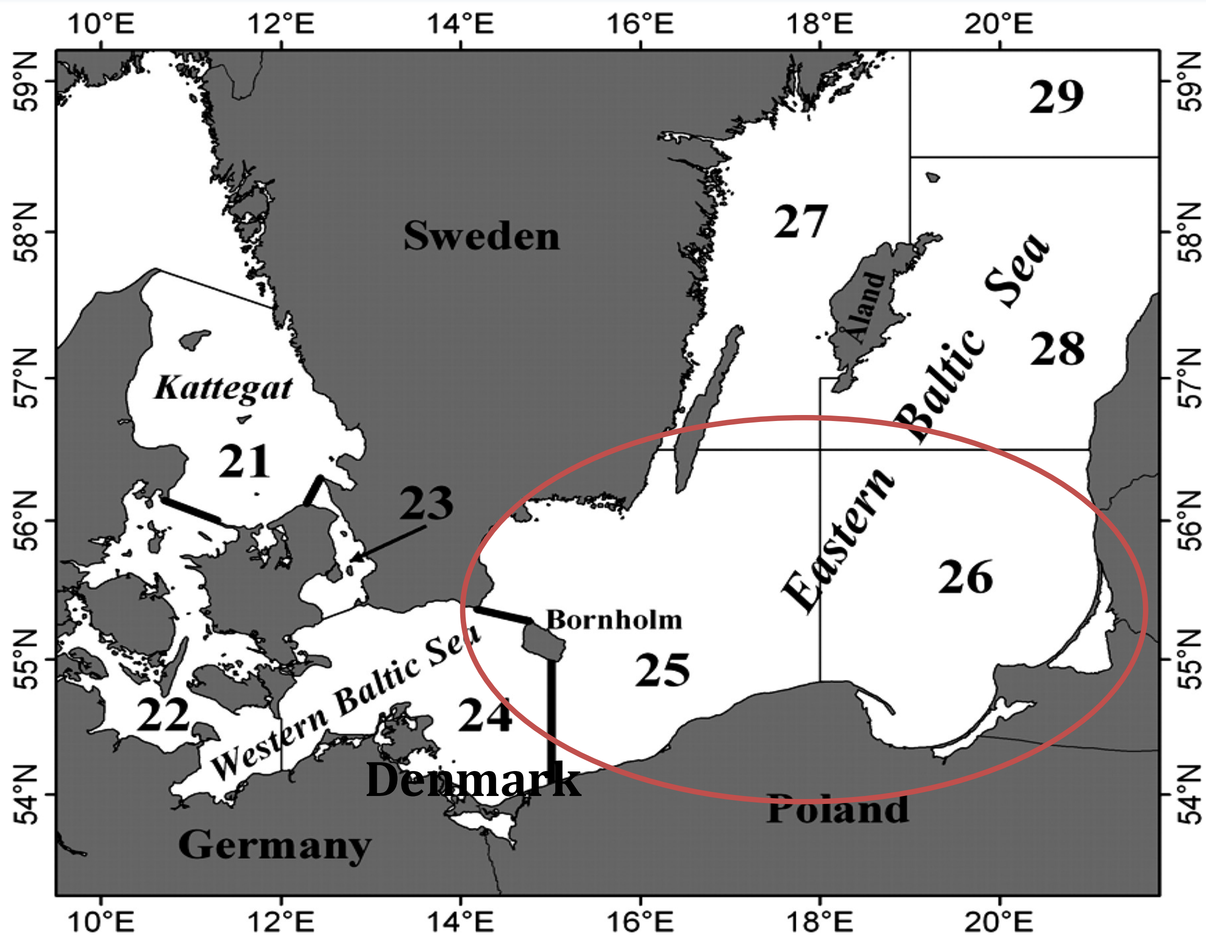
- Value function: $V = \frac{1}{\delta}\left(W(\boldsymbol{S}, x(\boldsymbol{S})) + \sum_{i=1}^{N} p_i \dot{s}_i\right)$
- Let $V(\boldsymbol{S}) = \varphi(\boldsymbol{S})\beta$ be Chebyshev polynomials, then

$$\beta = \left(\delta\varphi(\boldsymbol{S}) - \sum_{i=1}^{N} diag(\dot{s}_i)\frac{\partial\varphi(\boldsymbol{S})}{\partial s_i}\right)^{-1} W(\boldsymbol{S})$$

V-approximation

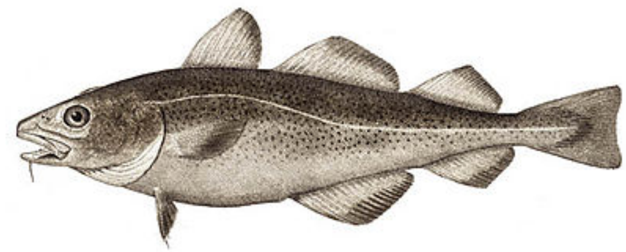
- Overdetermined: Least Squares approach

- Single stock case
  - p-approximation (Fenichel et al., 2016)
  - Pdot-approximation (Fenichel and Abbott, 2014)
- “*capN*” R-package (Yun et al., 2016)



Source: ICES 2013.

Map 1: The Baltic Sea with surrounding countries.



Cod *(Gadus morhua)*
32% revenue

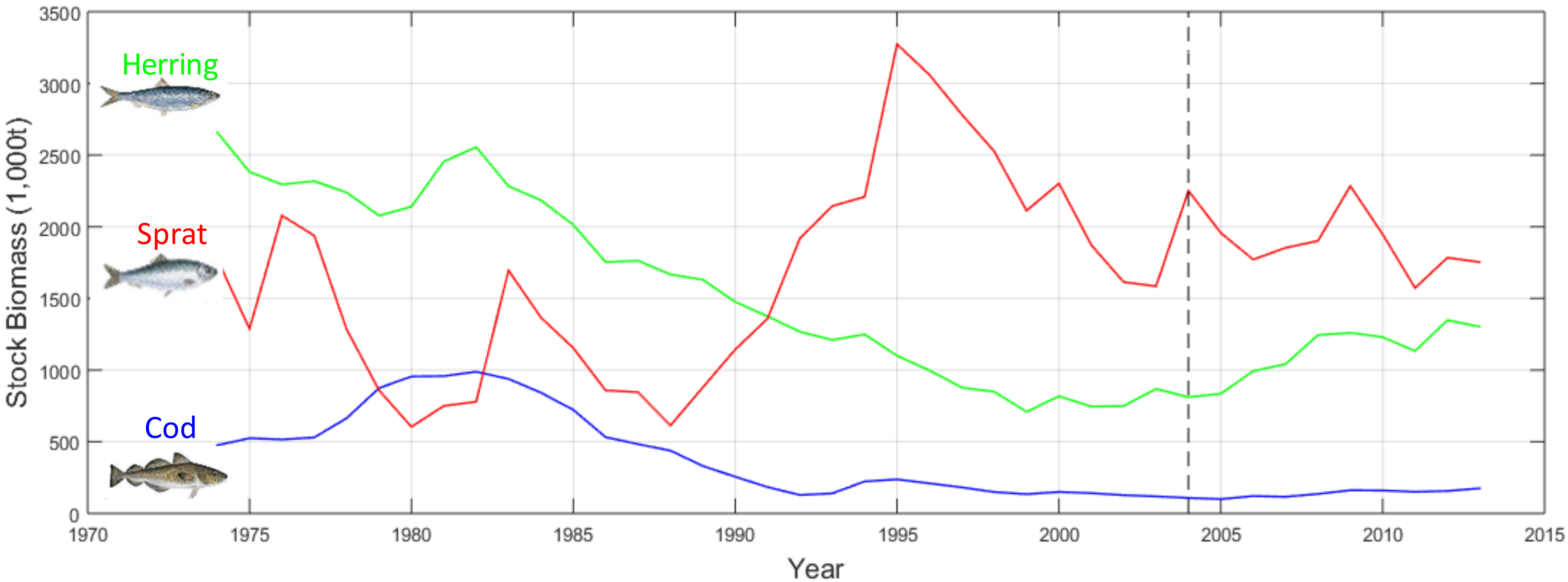
Herring (*Clupea harengus*)
26% revenue

Sprat (*Sprattus sprattus*)
19% revenue

Managed by IVQs
(Individual Vessel Quotas)

Source: STECF 2013.

Figure 1: The Baltic Sea harvest.



Source: Hutniczak (2015)

- Depletion of cod in 1980s/1990s
- Human impacts on multispecies ecosystem
- Management regime shifts: regulatory tool starts

Model structure (Hutniczak 2015)

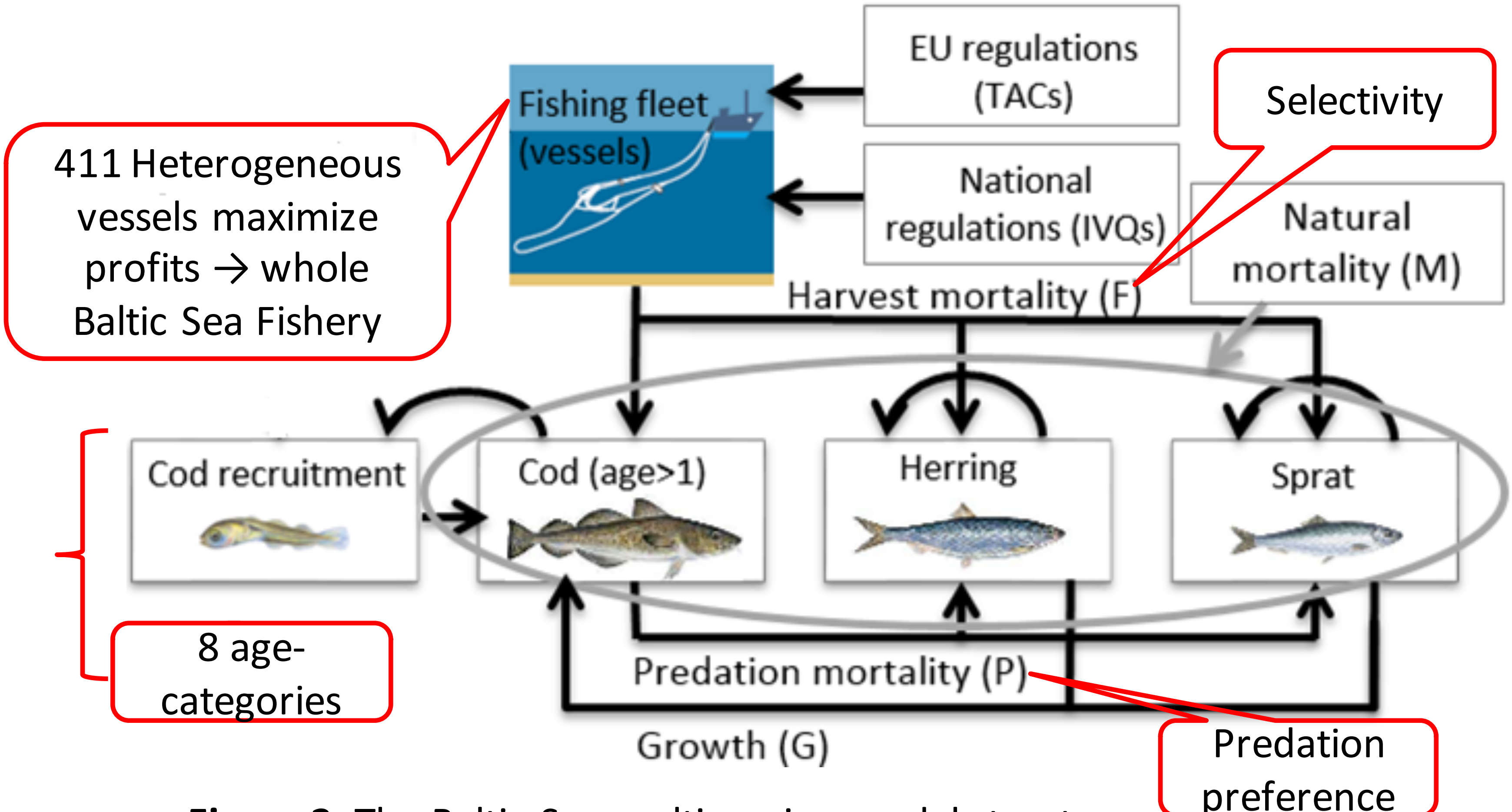
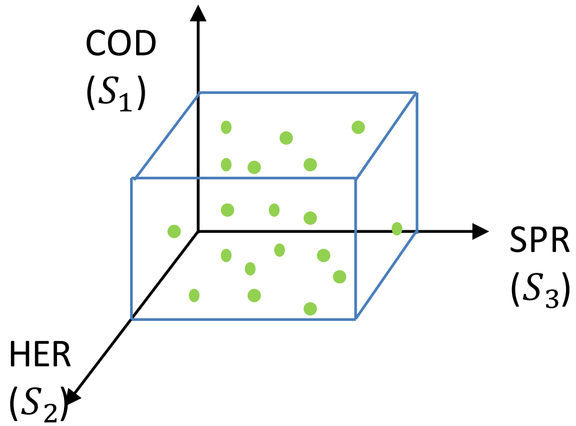


Figure 2: The Baltic Sea multispecies model structure.

Simulation Process

1. Stock Generation: Chebyshev grids of



2. Simulation of Baltic Sea Fishery

$$\max_H W_i = \sum_s p_s H_{s,i} - c_i E_i$$

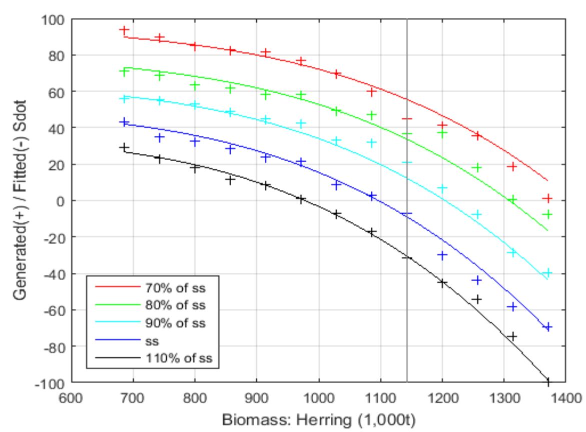
s.t.

$$H_{s,i} \leq q_{s,i}$$
$$E_i \leq \bar{E}_i$$

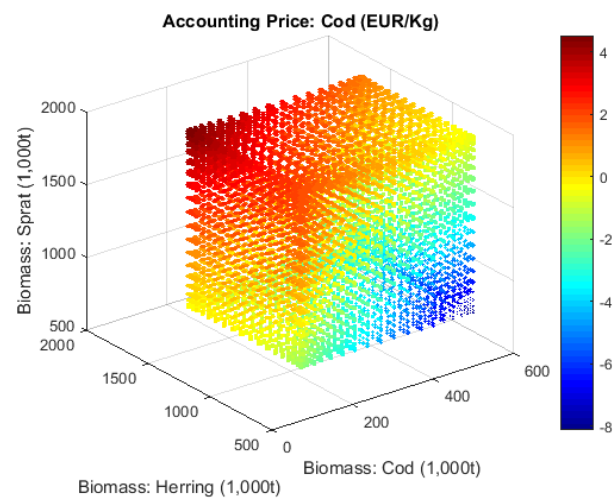
$$W = \sum_i W_i \qquad H_s = \sum_i H_{s,i}$$

$\dot{S}$ from $S_{t+1} - S_t$

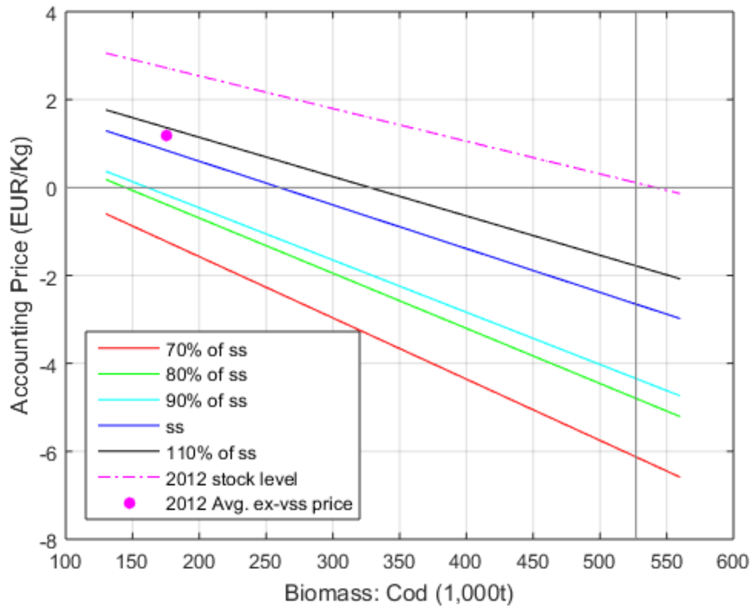
3. Polynomial fitting: and without noise (R2 > 0.97)



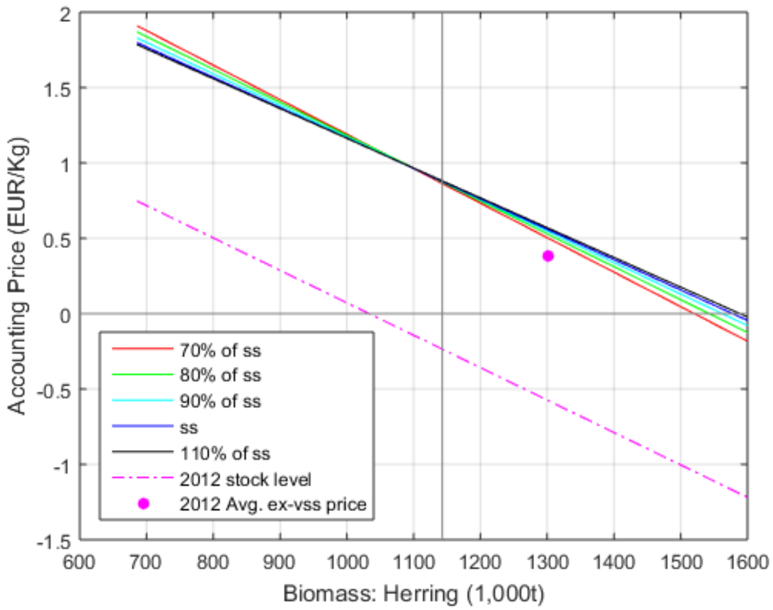
4. V-approximation: shadow price and IW

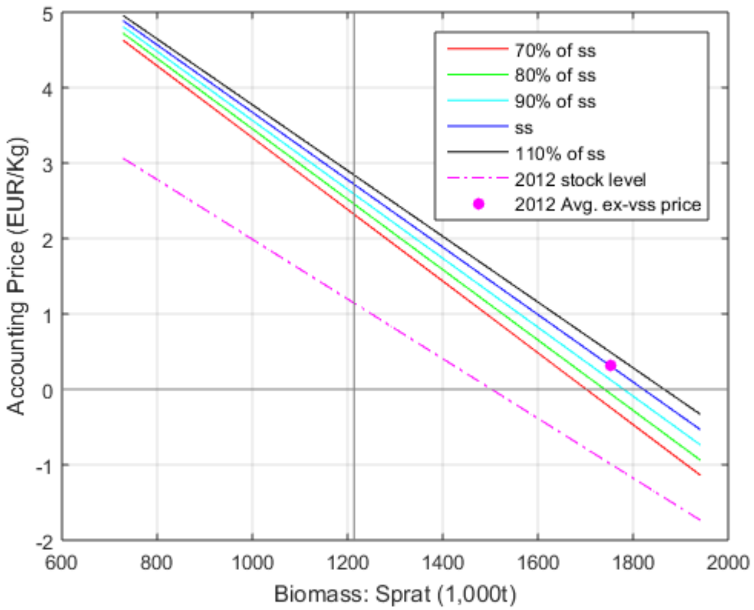


Accounting Prices

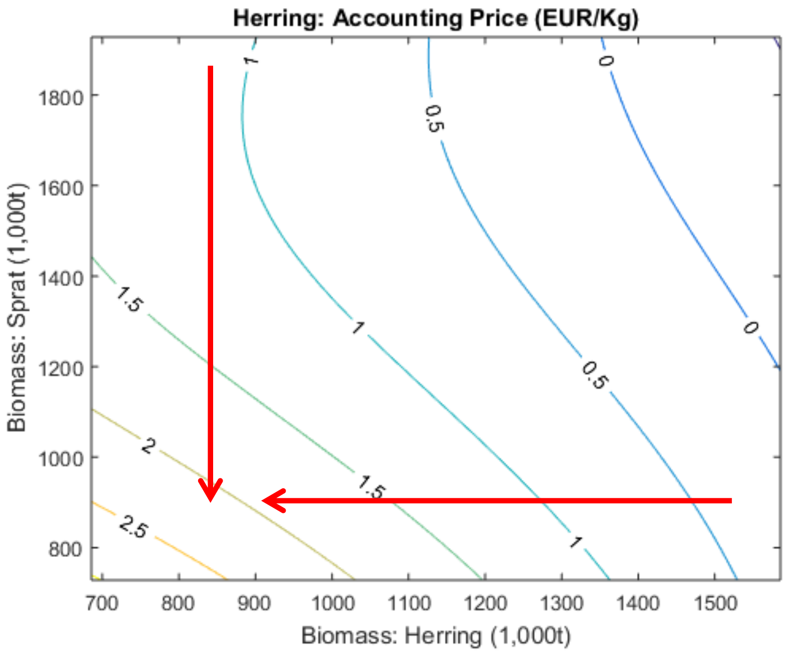


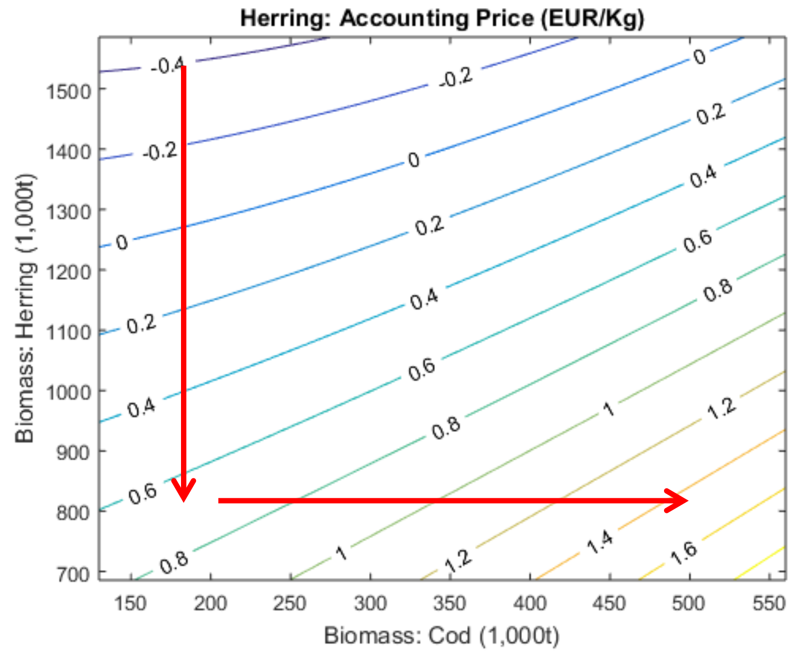
- Prices are decreasing - price as scarcity measure
- Multi-use Species (Rondeau, 2001; Horan & Bulte, 2004; Zivin et al, 2000)





Nonlinear Cross-Stock Effects





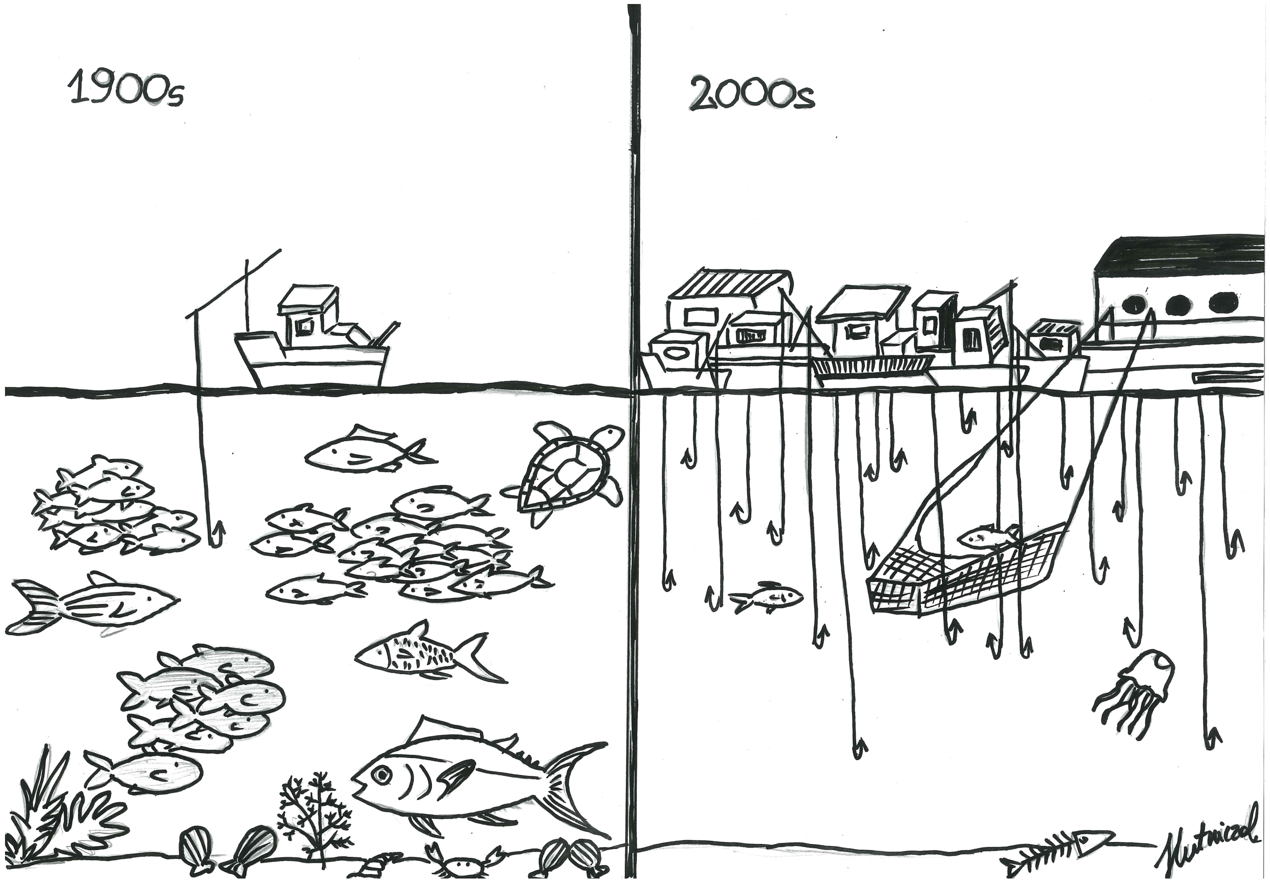
- Cod is fixed at the SS
- Acc. Price of HER ↓ as HER stock ↑ (own price-stock relation)
- Acc. Price of HER ↓ as SPR stock ↑ (substitute relation)

- Sprat is fixed at the SS
- Acc. Price of HER ↓ as HER stock ↑ (own price-stock relation)
- Acc. Price of HER ↑ as COD stock ↑ (complement relation)

➢ Nonlinear effects comes through predation relation and fishing behavior!

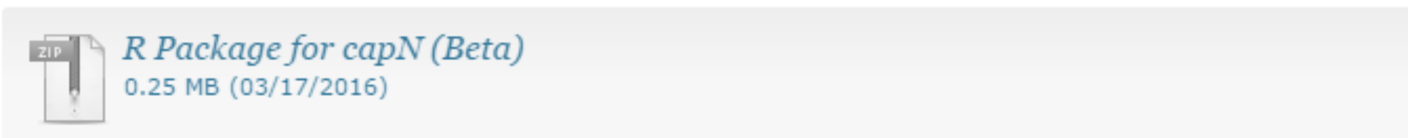
➢ $IW = \sum_{i=1}^{N} p_i s_i$: IW is not a weak linear index!

- Wealth accounting theory + EBM
  - Provision of "headline" wealth index of ecosystems in the context of EBM
  - Suggestion of capital asset pricing approaches for multiple stocks by generalizing FA approach
- Baltic Sea fishery example
  - Nonlinear price relations: cross-stock effects
  - Increasing IW after the EU regime
  - The linear index is not a weak sustainability index
- Extendable to general wealth accounting
  - Other natural capital assets or inclusive wealth


1900s
2000s

THANK YOU

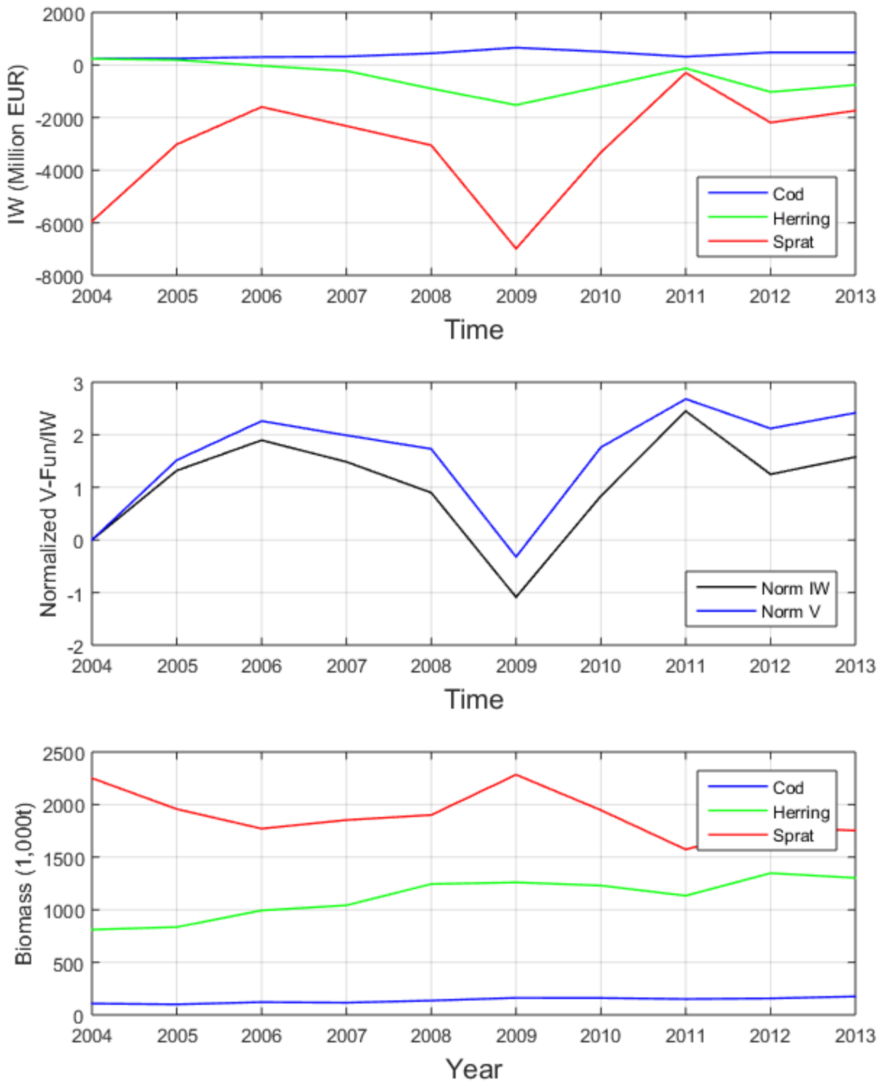
- “*capN*” R-package: beta testing v. 0.0.2



http://environment.yale.edu/profile/eli-fenichel/software

https://sites.google.com/site/yunsd2004/capn

Inclusive Wealth



- Low HER and SPR stock levels
  positive COD price
  negative HER/SPR price

- Net change of IW are more important: Normalized IW based on the year 2004
  Adj. average growth rate: 5.02%

- Peaks at 2009 and 2012
  IW are dominated by SPR stocks

Missing asset markets and lack of coordination in management within food web suggests a market failure leading to the miscalculation of the value of certain stocks. The benefit of this research is operational methodology for providing indicators of “genuine/ inclusive wealth” (World Bank 2006; Dasgupta 2007) for fisheries complexes.

Computing an inclusive wealth index for a fishery complex will provide fishery managers with an indicator as to whether management of the ecosystem is sustainable from a coupled ecological/economic perspective. Obtaining such a meaningful empirical indicator for ecosystem based management is necessary for policy evaluation and building successful management plans for the future.

The developed methodology will be used to look at development of complex natural capital value in the context of changing regulations and the underlined responses from the natural capital users who are affected by these regulations. The capital valuation technique will be used to learn how changes in management can enhance or degrade the value of natural capital.

The importance of pursing this question is to gain an understanding how the natural capital that is often integral combination of many components contributes to the national wealth.