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THE ARCTIC UNIVERSITY OF NORWAY

BIOECONOMIC MODELLING OF COASTAL COD AND KELP FOREST INTERACTIONS:

HABITAT SERVICES, FISHERIES AND CARBON SINKS

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FISH AS FOOD

Source: www.seafoodwatch.org/

AN ECONOMIC FISHERIES MANAGEMENT PROBLEM

SIMPLE COD MODEL

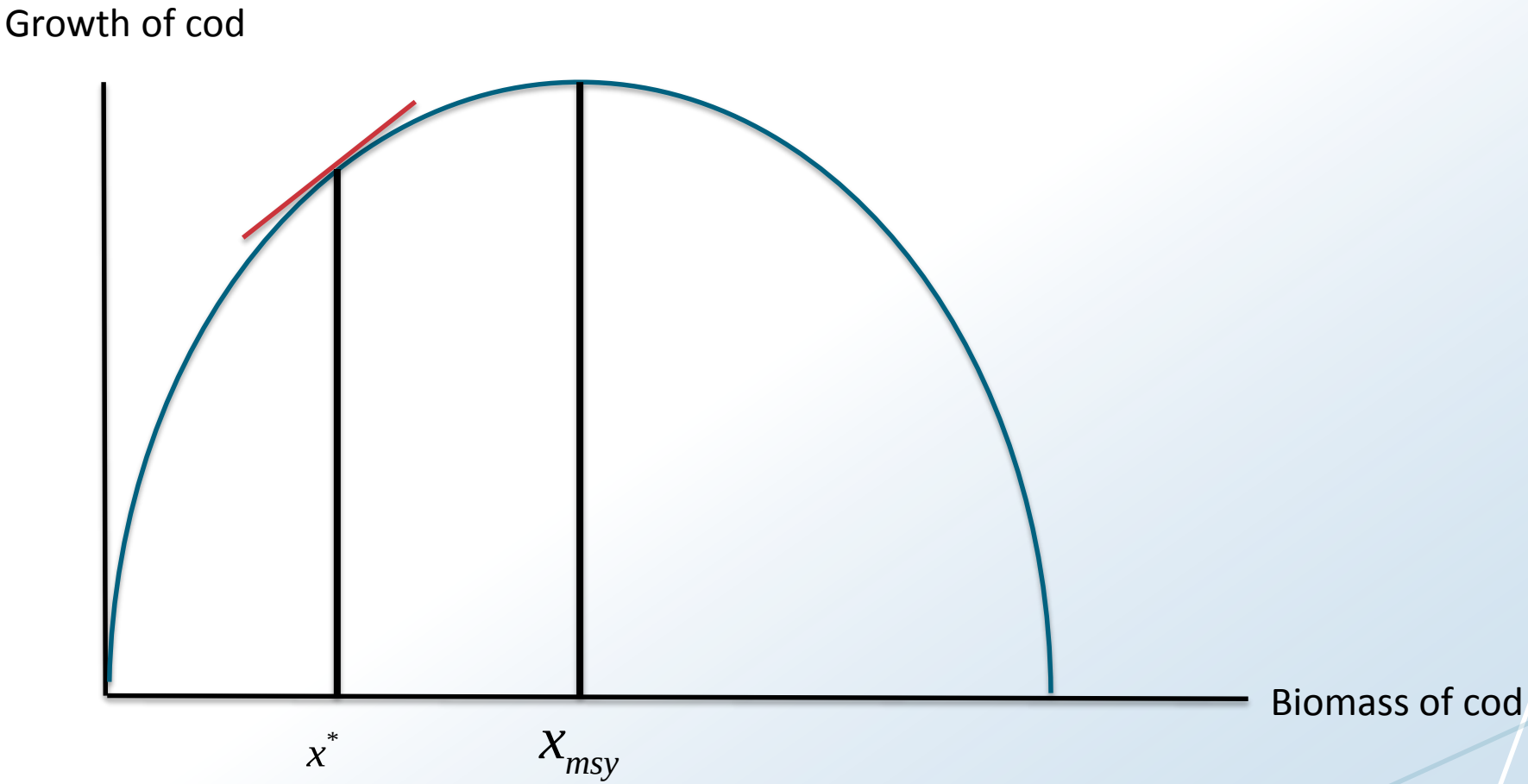
- Objective:
  - choose cod harvest to maximize discounted net benefits.

- Constraints:
  - Changes in cod biomass over time (we still use logistic growth).
  - Initial condition

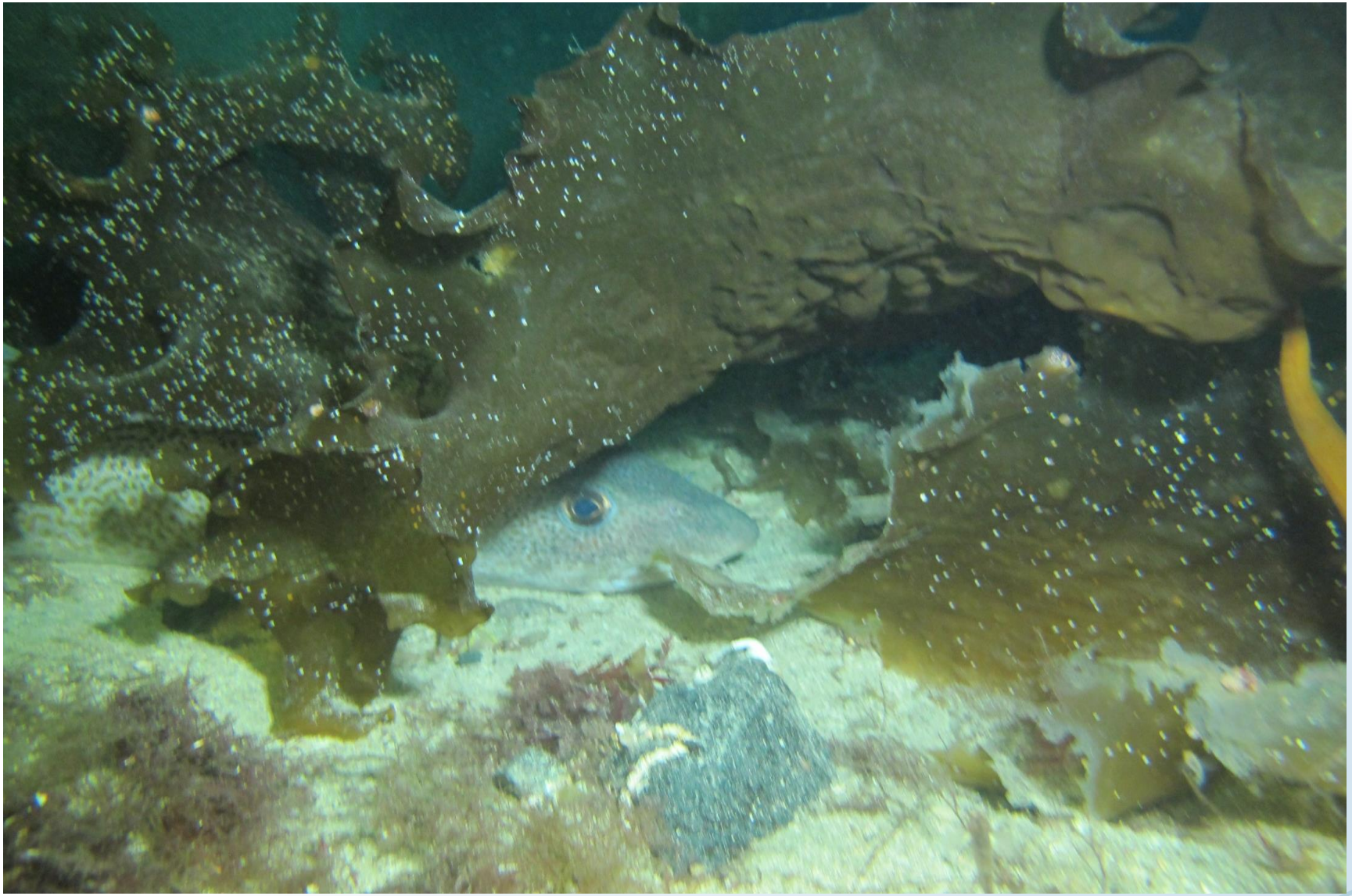
- Components of the maximisation problem:
  - Sole fisheries manager.
  - Total revenue from fisheries.
  - Cost of fishing (allow for stock externality).
  - Discounting

AN ECONOMIC FISHERIES MANAGEMENT PROBLEM

OPTIMAL STOCK OF COD

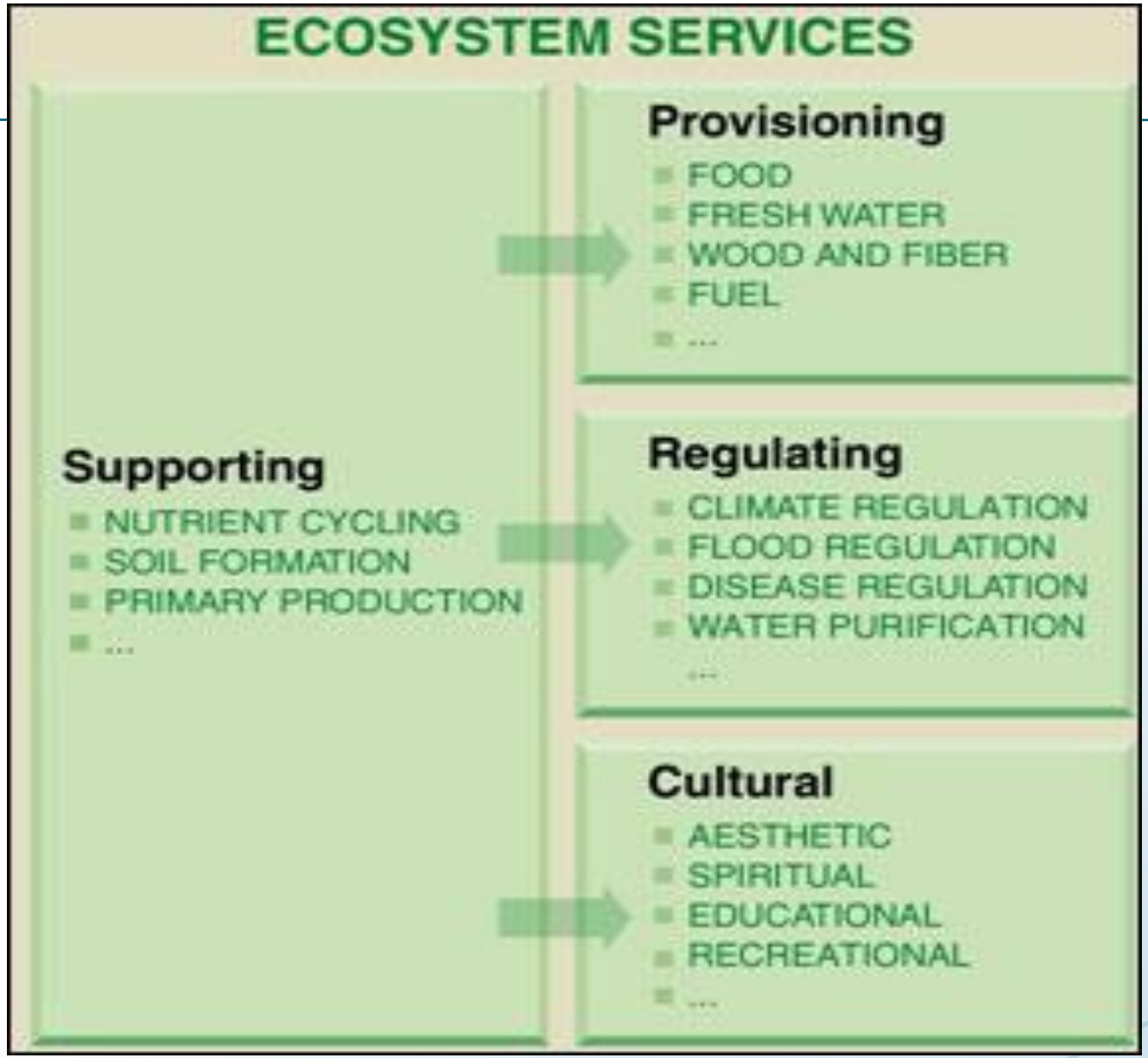


MULTIPLE MARINE ECOSYSTEM SERVICES

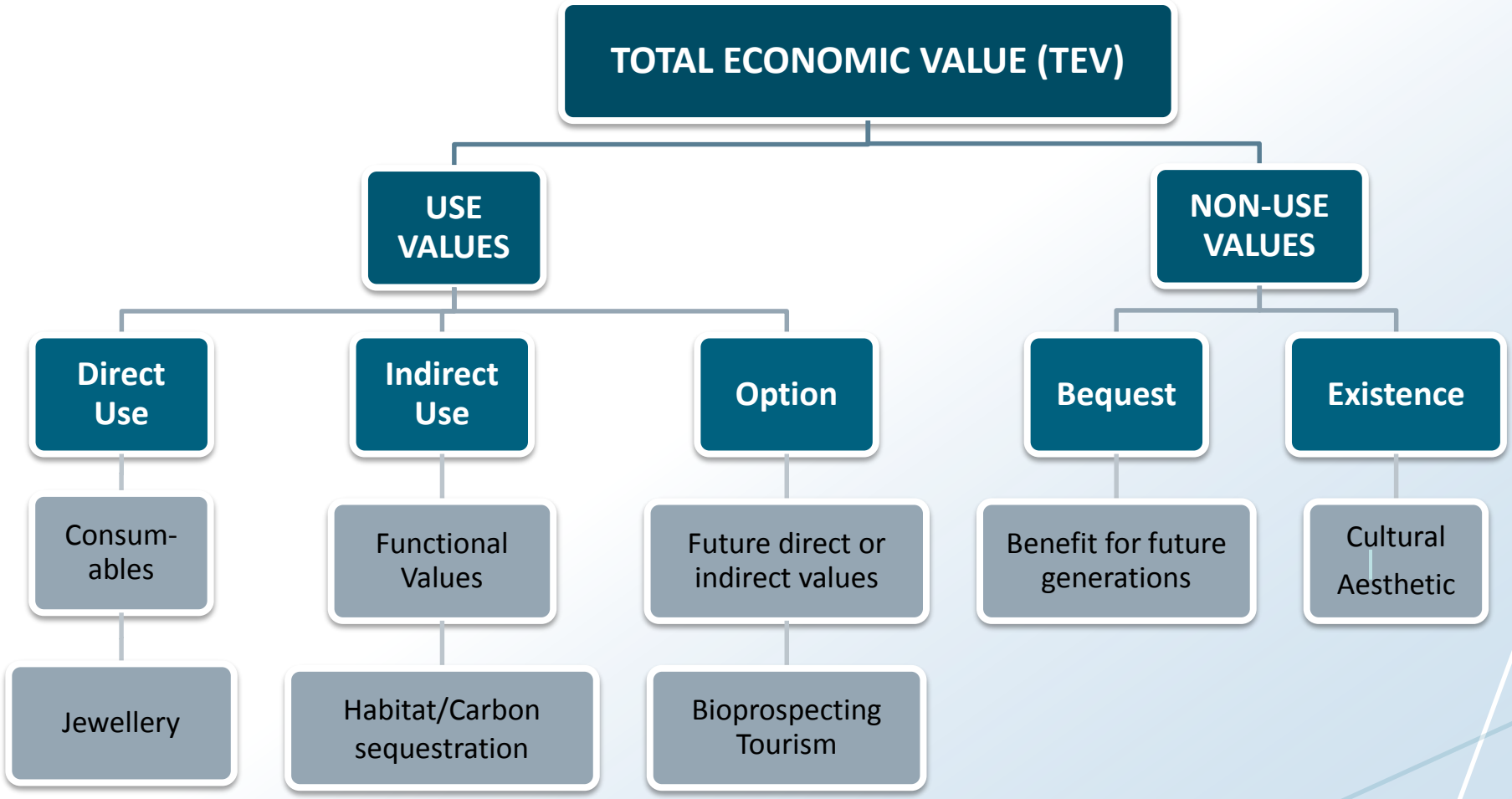


Source: Christie et al. (2016)

ECOSYSTEM SERVICES (MEA, 2005)

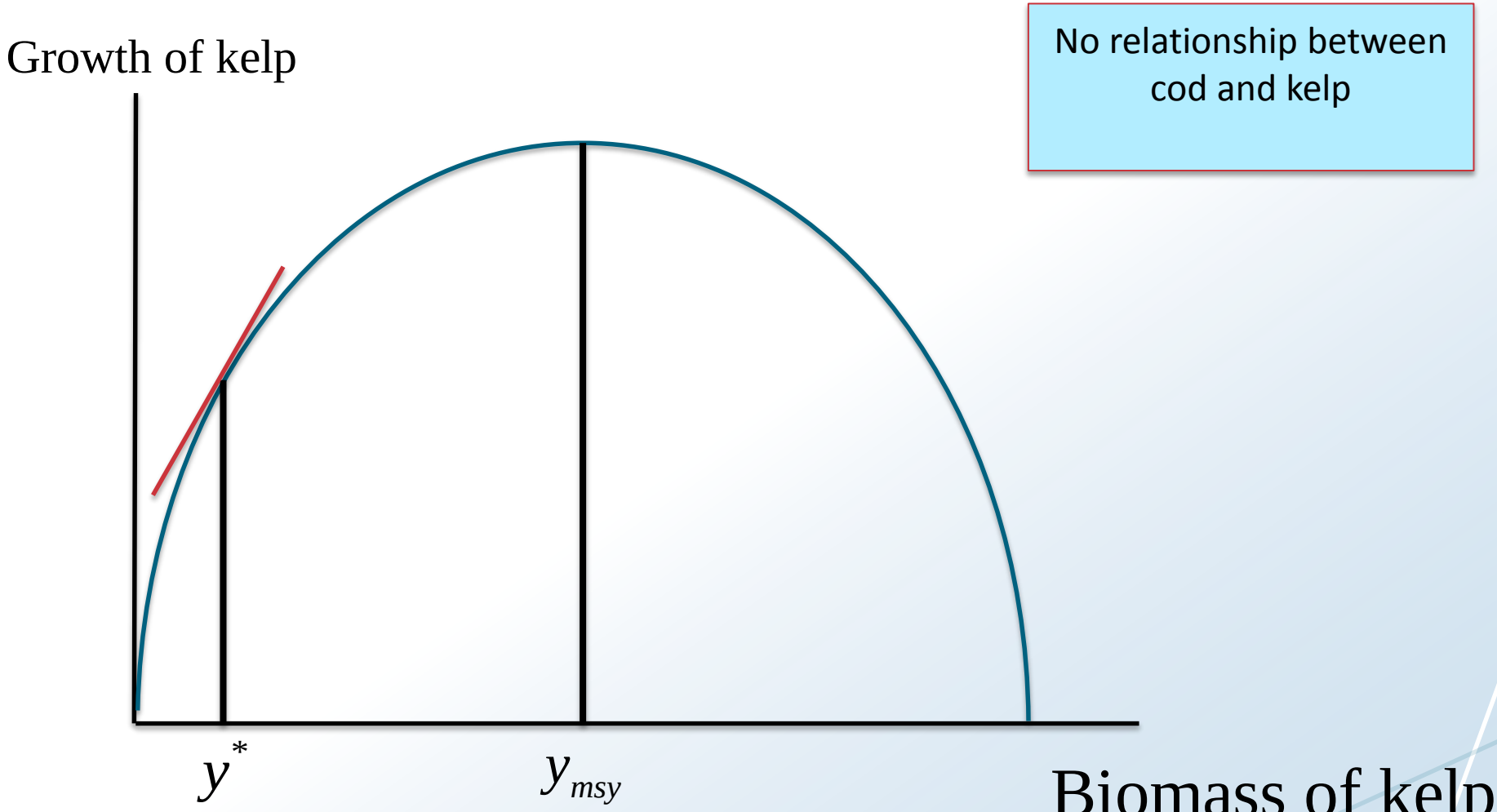


COMPONENTS OF TOTAL ECONOMIC VALUE (TEV)



MODELLING COD AND KELP INTERACTIONS

OPTIMAL STOCK OF KELP
(No relationship between cod and kelp)



MODELLING COD AND KELP INTERACTIONS

- AN EXPANDED COD - KELP MANAGEMENT MODEL

- Objective:
  - choose cod and kelp harvests to maximize discounted joint net benefits.

- Constraints:
  - Changes in cod biomass over time.
  - Changes in kelp biomass over time.
  - Interactions between cod and kelp.
  - Initial conditions (cod and kelp)

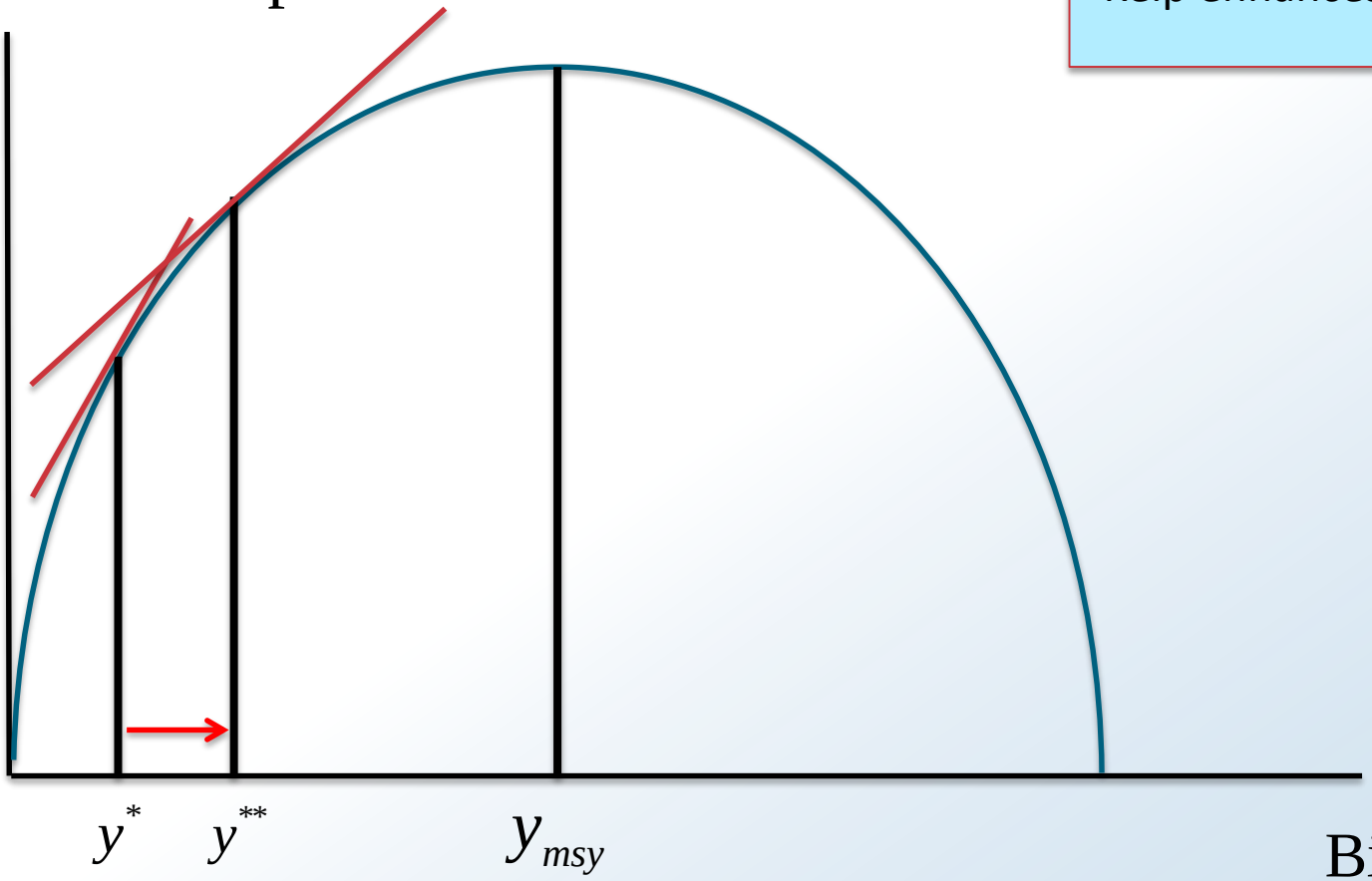
- Components of the maximisation problem:
  - Sole marine resources manager.
  - Total revenue from fisheries.
  - Total revenues from kelp harvesting.
  - Cost of fishing.
  - Cost of kelp harvesting.
  - Discounting

MODELLING COD AND KELP INTERACTIONS

OPTIMAL STOCK OF KELP
(Relationship between cod and kelp)

Growth of kelp

Kelp enhances growth of cod



Biomass of kelp

MODELLING COD AND KELP INTERACTIONS

- AN EXPANDED COD - KELP MODEL WITH CARBON STORAGE

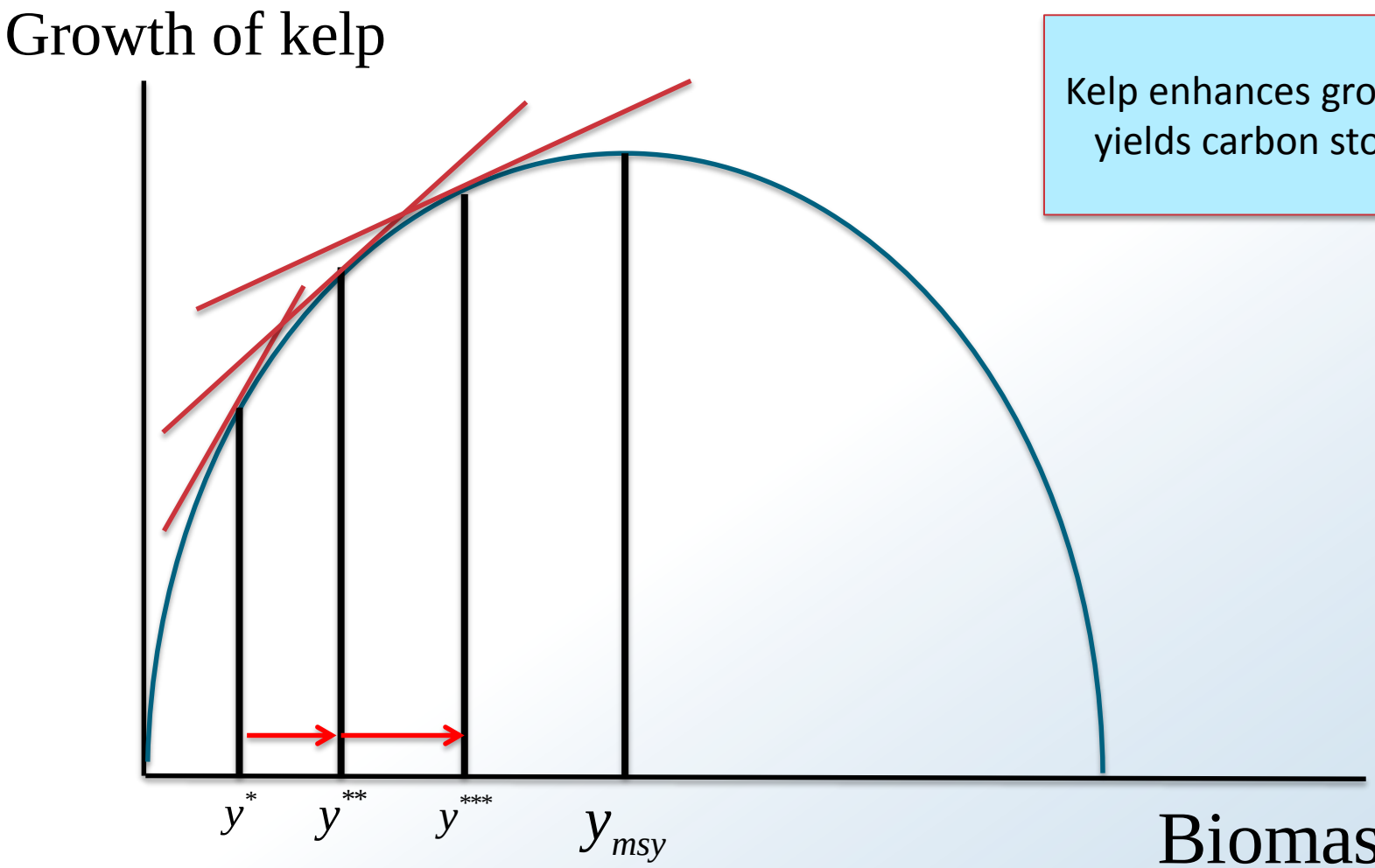
- Objective:
  - choose cod and kelp harvests to maximize discounted joint net benefits incl. carbon storage benefits.

- Constraints: (remain the same as in the previous slide).

- Components of the maximisation problem:
  - Sole marine resources manager.
  - Total revenue from fisheries.
  - Total revenues from kelp harvesting.
  - Cost of fishing.
  - Cost of kelp harvesting.
  - Discounting
  - Benefits of carbon storage (costless ecosystem services)

MODELLING COD AND KELP INTERACTIONS

OPTIMAL STOCK OF KELP
(Relationship between cod and kelp and carbon storage)



Kelp enhances growth of cod and yields carbon storage benefits

MODELLING COD AND KELP INTERACTIONS

DATA

Parameter		Unit	Measure	Source/explanation
δ	Interest rate		0.05	Eide & Heen (2002); EC (2008)
r_0	Instrinsic growth rate of coastal cod when there is no kelp forest		0.6	Armstrong (1999) for NE Atlantic cod
r_1	Intrinsic growth rate when kelp forest grow at carrying capacity		0.0001	Guesstimate
K	Carrying capacity of coastal cod when there is no kelp forest	Tons	720000	Lower estimates from ICES (2016)
g	Marginal change in carrying capacity of coastal cod with increasing kelp habitat		0.001	Guesstimate
h_x	Harvesting cost of coastal cod	NOK/tonne	170548	Kahui et al (2015)
K_y	Carrying capacity of kelp forest	ton/m2	0.01	Gundersen et al. (2011)
r_y	Intrinsic growth rate for kelp forest		0.055	Data for Laminaria Digitata
q	Catchability of coastal cod		0.0000692	Kahui et al (2015)

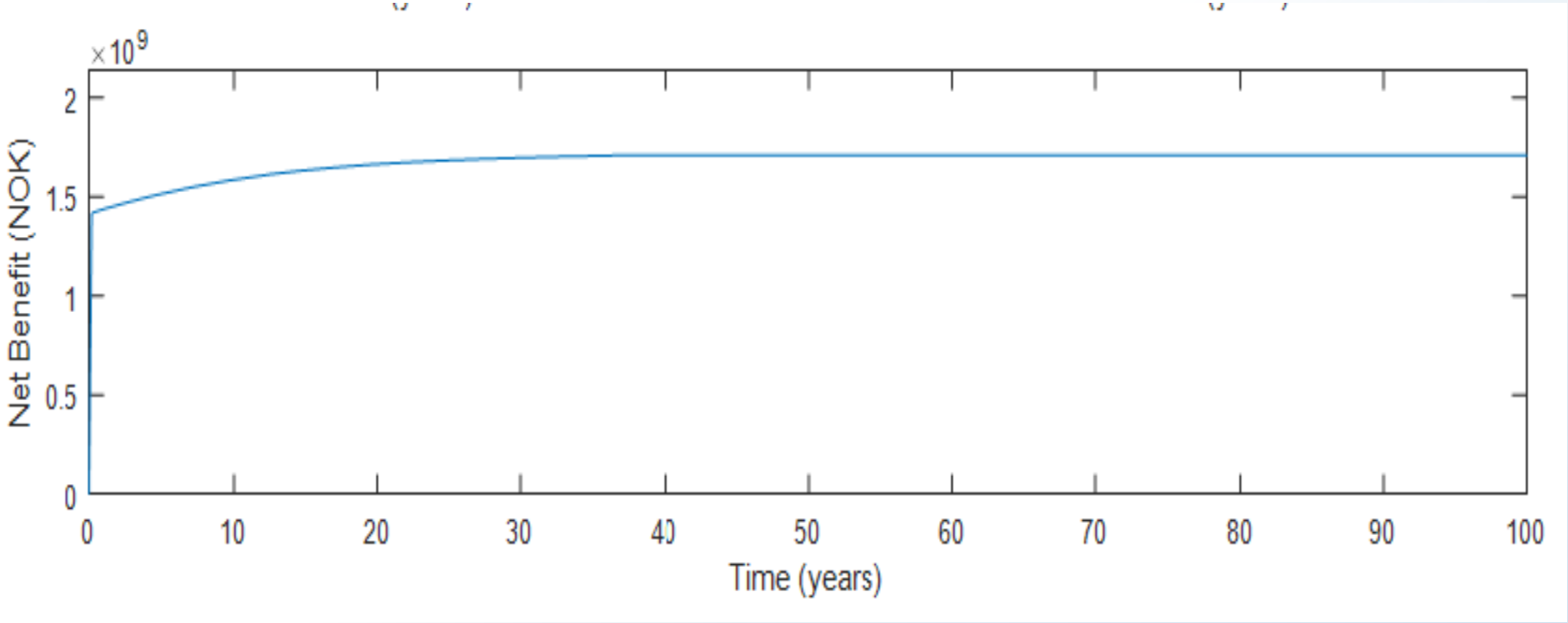
MODELLING COD AND KELP INTERACTIONS

DATA

Parameter		Unit	Measure	Source/explanation
p_v	Carbon storage	Kg C/m2	1	Gundersen et al (2011)
p_v	Carbon storage	Kg C/m2	1	Gundersen et al (2011)
c_1	Harvesting cost of kelp forest	NOK/tonn	210	
p_1	Market price for coastal cod	NOK/tonne	14000	Minimum price of live fish (Norges Råfisklag, 2016)
p_2	Market price for kelp (wet weight)	NOK/tonne	263	Minimum price (Norges Råfisklag, 2017)
p_v	Unit carbon value	NOK/tonne	193.27	Mean social cost of carbon Tol (2008)
x_0	Initial coastal cod biomass	tonne		
y_0	Initial kelp biomass	tonne		
h_x	Average annual harvest of coastal cod	Tons	54815.576	Computed from commercial and recreational catches data 1984 - 2016 (ICES, 2016)
h_y	Average annual harvest of kelp forest	Tons	150367.406	An average harvest computed from harvest data 1985 to 2016 (Institute of Marine Research)

MODELLING COD AND KELP INTERACTIONS

NET BENEFITS FROM COD-KELP OVER TIME



CONCLUDING REMARKS

- Coexistence of multiple resources in marine ecosystem.
- Need to internalize these multiple ecosystem services.
- Economics can provide useful framework for these analyses.