Investigating the influence of ‘minor’ krill-predators on the krill-predator dynamics of the Antarctic ecosystem

- Naseera Moosa (MARAM, University of Cape Town, naseera.moosa@uct.ac.za)
- Doug Butterworth (MARAM, University of Cape Town, doug.butterworth@uct.ac.za)

MARAM MArine Resource Assessment and Management Group

iMathematika neMathe eSetyenziswayo · Wiskunde en Toegepaste Wiskunde · Mathematics and Applied Mathematics

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

Contents

Session 6:
Reconciling Ecological Roles and Harvest Goals:

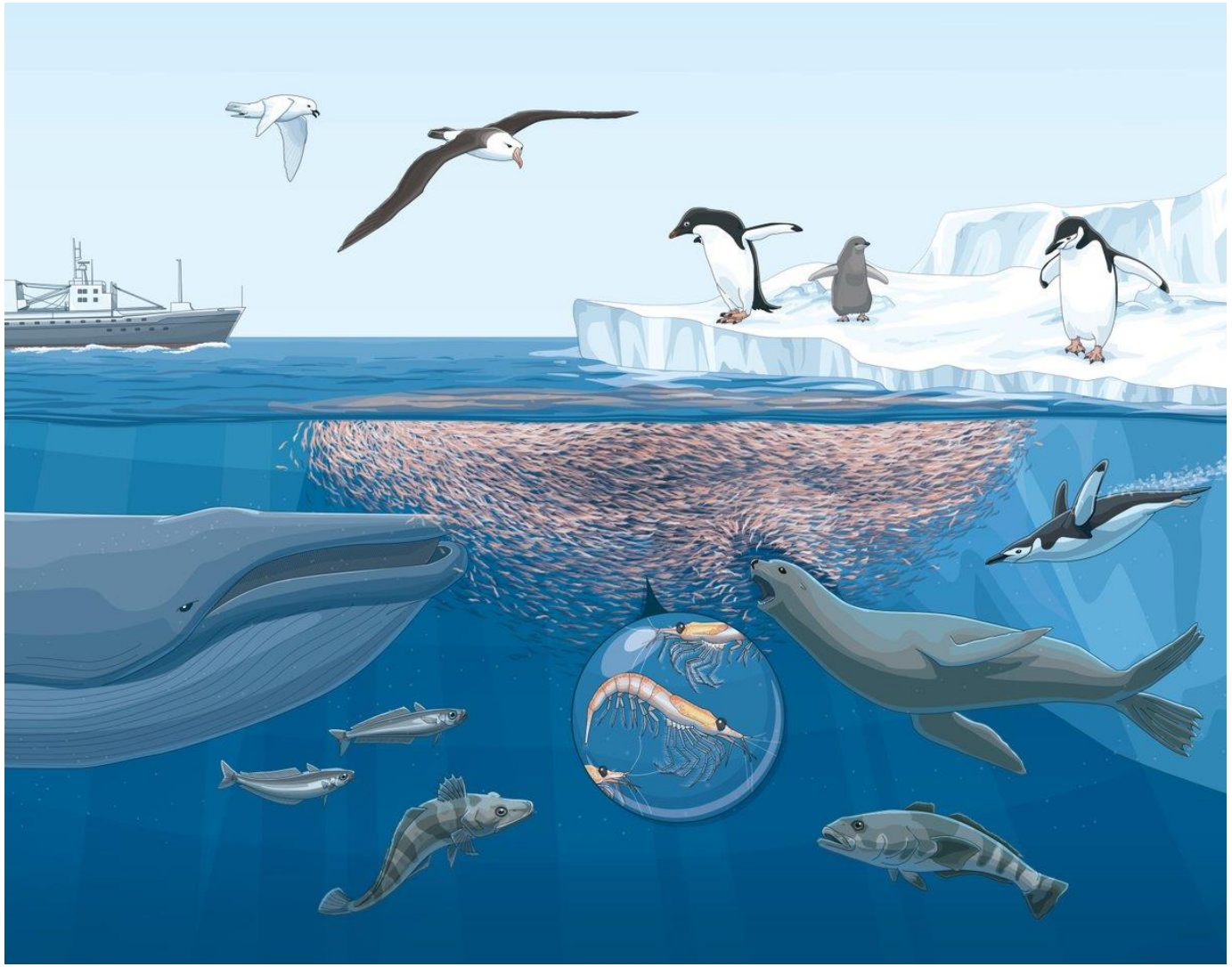
Development and Testing Management Strategies to Safeguard Marine Ecosystem Services

- Ecosystem-based fisheries management for small pelagic fish must often reconcile **the role of these species in marine food webs**, as well as **their economic and social value** as a harvested resource.

- One point this session intends to address:
  - There are **trade-offs** between assuring needs of predators in an ecosystem vs yields of small pelagic fish.

Background

Antarctic Marine Ecosystem



Species involved:

- **Krill**
- **Baleen whales**
  - Blue, Fin, Humpback, Minke
- **Seals**
  - Crabeater, Leopard, Antarctic fur
- **Penguins**
  - Adélie
- **Fish**
  - Mackerel Icefish, Marbled Rockcod

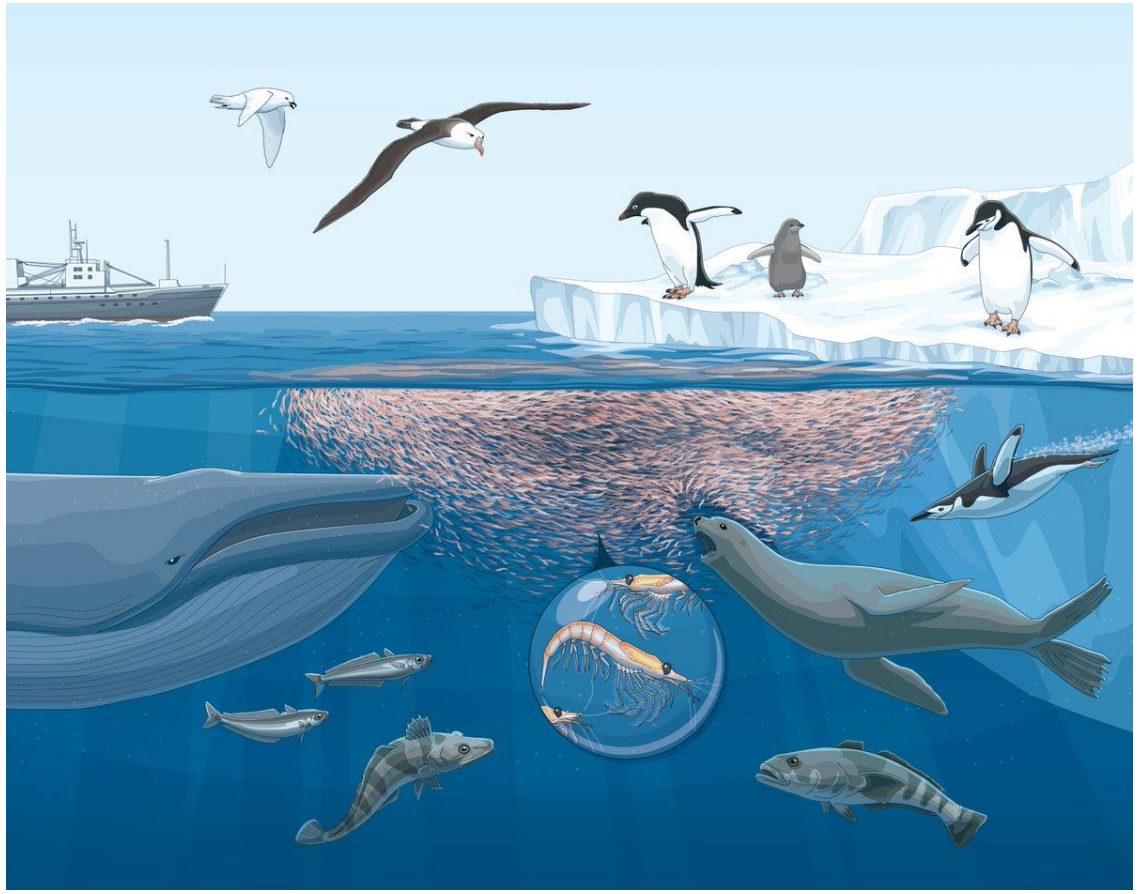
Antarctic Krill

- In the Antarctic, krill (euphausiids) are the **dominant prey**
  - *Euphausia superba* is the dominant krill species
- They are a **keystone species** within the ecosystem
- They are also a **small pelagic fish (SPF)**
- There is an **economic interest** in expanding the krill fishery
  - Krill is used as a source of oil, health supplements, and aquaculture feed.

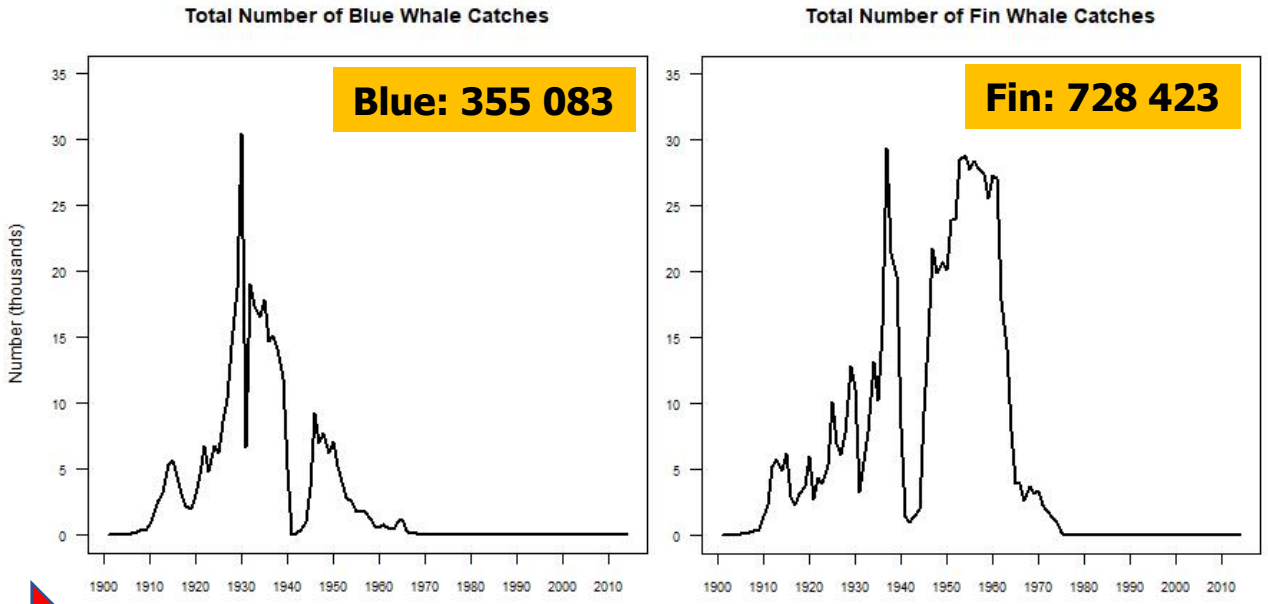
https://40years.ccamlr.org/author/dane/

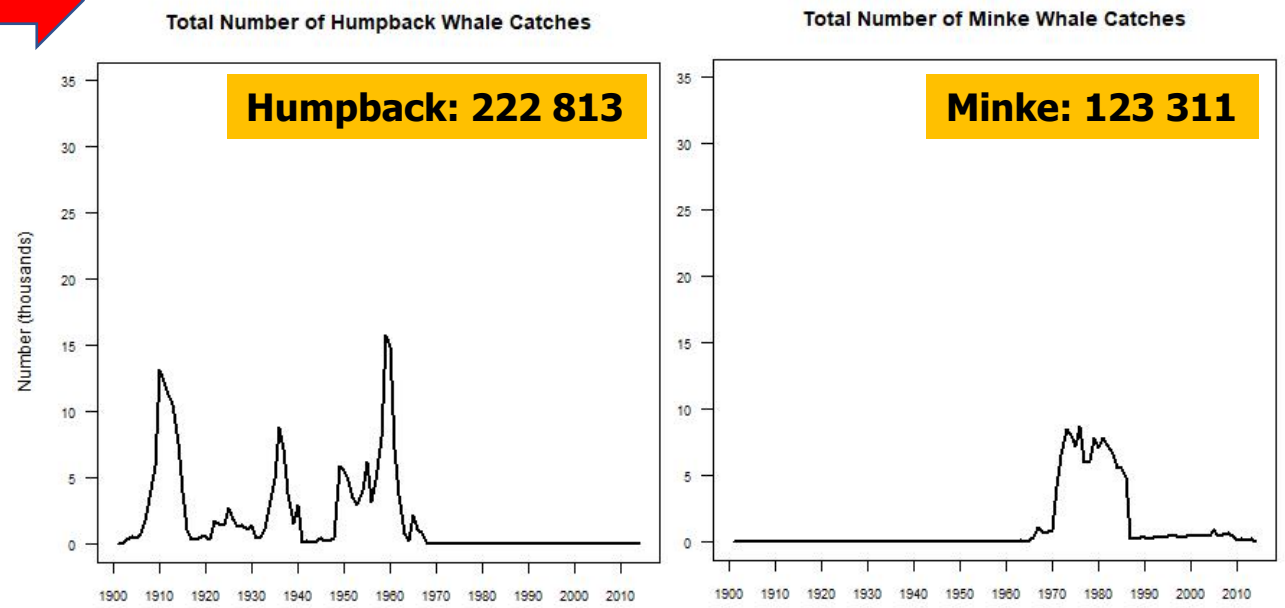
Background

Antarctic-wide whaling history



Total number caught



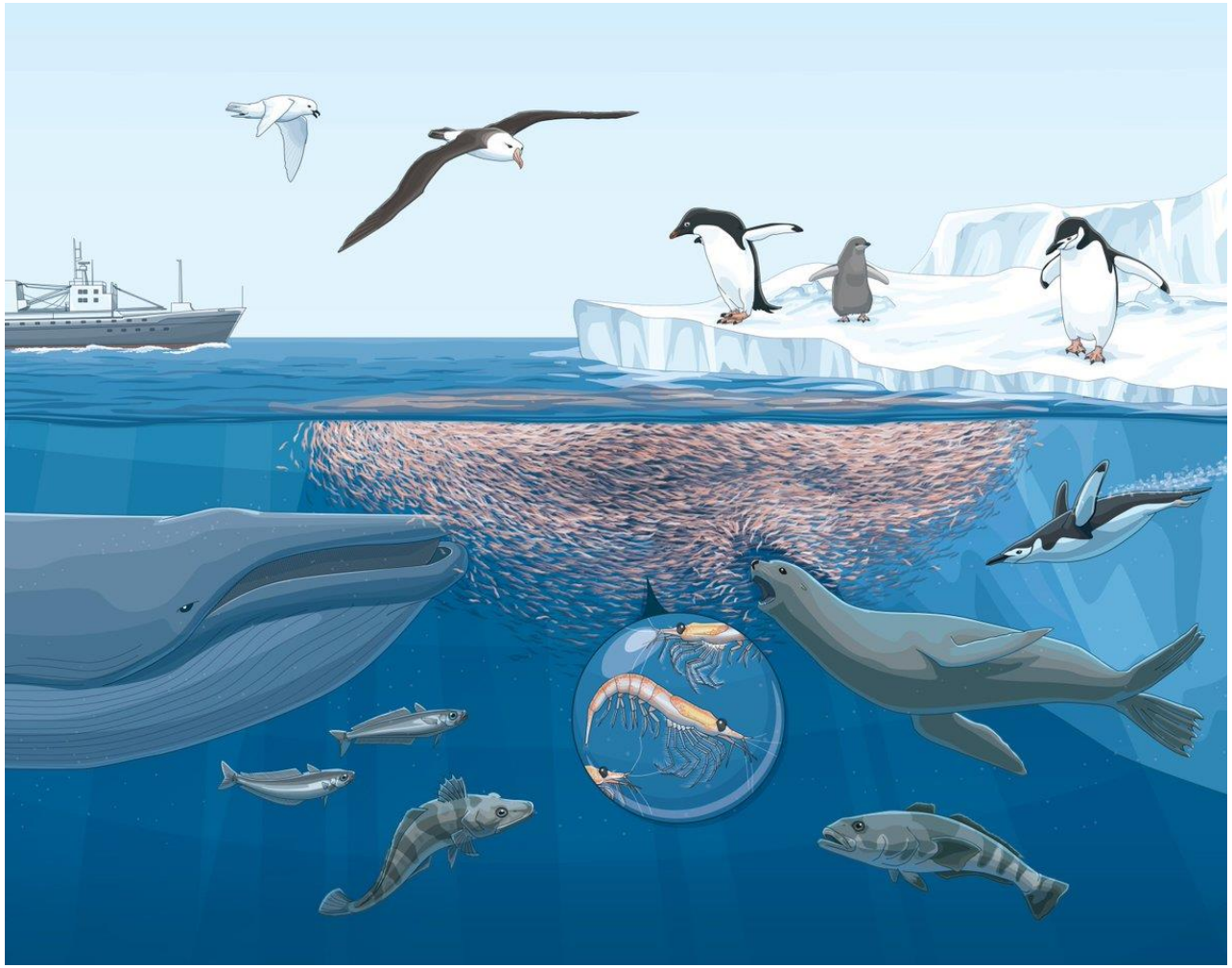


The krill-predators in the Antarctic

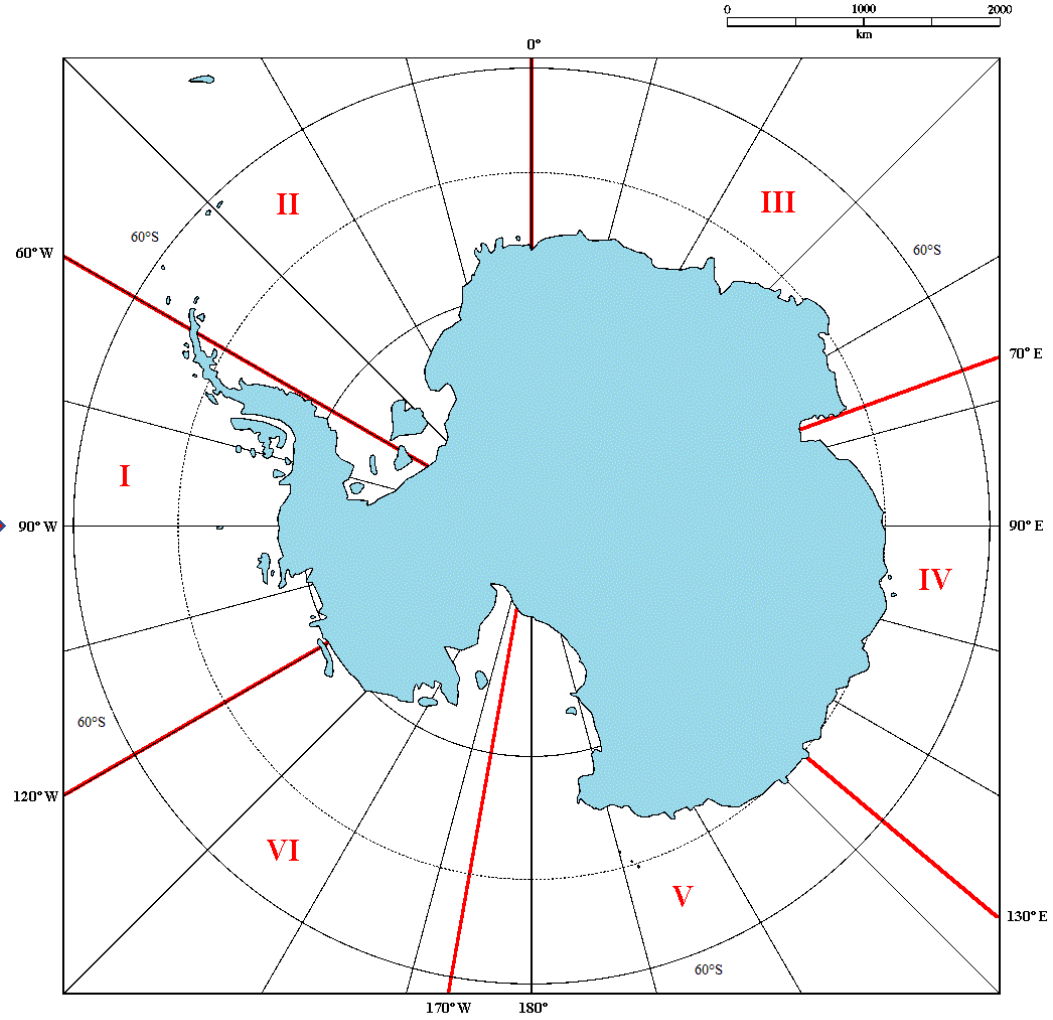
A **krill-predator** is found predominantly **south of 60°S** and ≥ **50% of its diet** consists of **krill**

	Species	Proportion of krill in diet	Annual per capita consumption of krill (mt)	Total krill consumption $\times 10^3$ (mt)
MAJOR	Blue whale	0.985	490.8	1 083
	Fin whale	0.995	310.4	11 853
	Humpback whale	1.00	200.7	19 506
	Minke whale	1.00	63.2	29 696
	Crabeater seal	0.94	4.45	34 353
	Antarctic fur seal	0.93	1.77	2 744
MINOR	Leopard seal	0.69	4.02	143
	Adélie penguin	0.562	0.06	216
	Mackerel icefish	0.85	0.00000807	259
	Marbled rockcod	0.70	0.03	44

Background



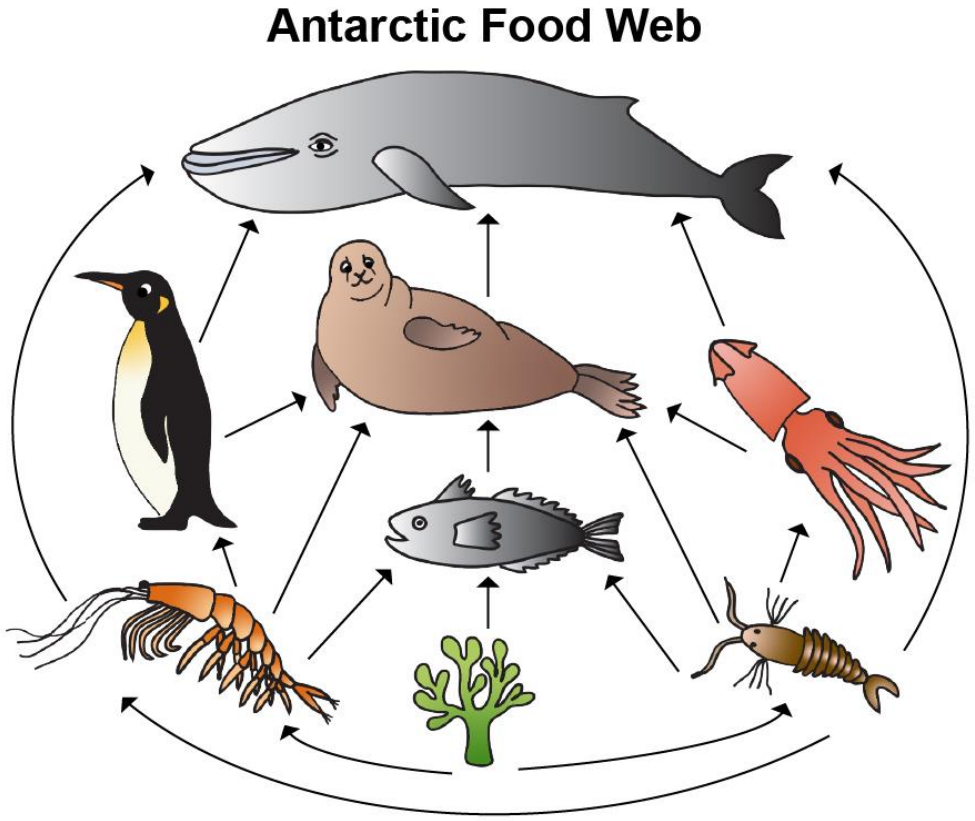
The Six IWC Management Areas



The Mori-Butterworth (2006) model

- Is an **age-aggregated production (MICE) model** that includes species interactions and an intra-specific density-dependence for each predator considered.

- It considered the **four main baleen whale** species and **two main seal** species at a **circumpolar level**

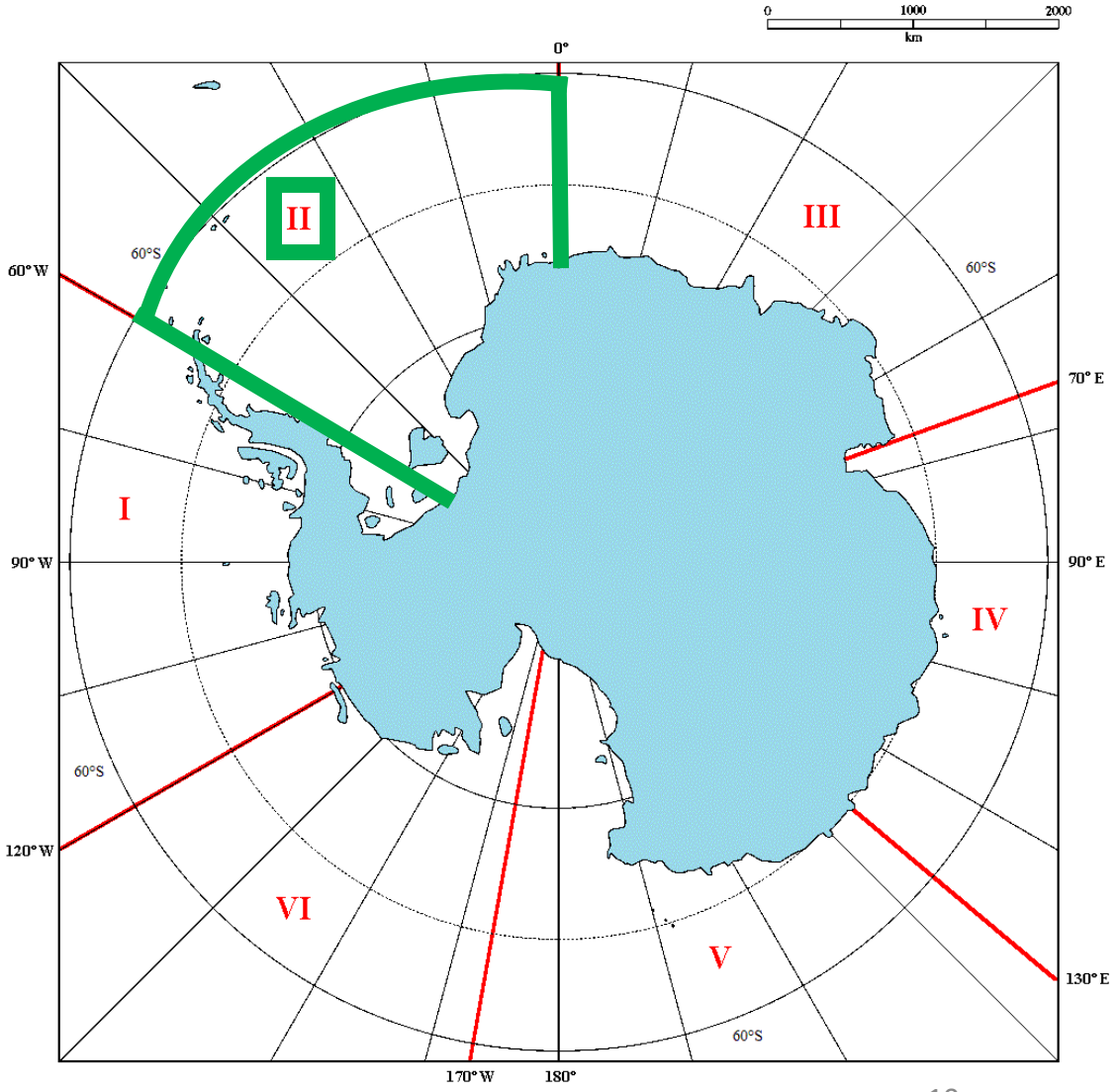


https://rebeccajohnstudio.com/rock-classification/antarctic-food-web/

Region of Interest – IWC Area II

- The area between 0° and 60°W

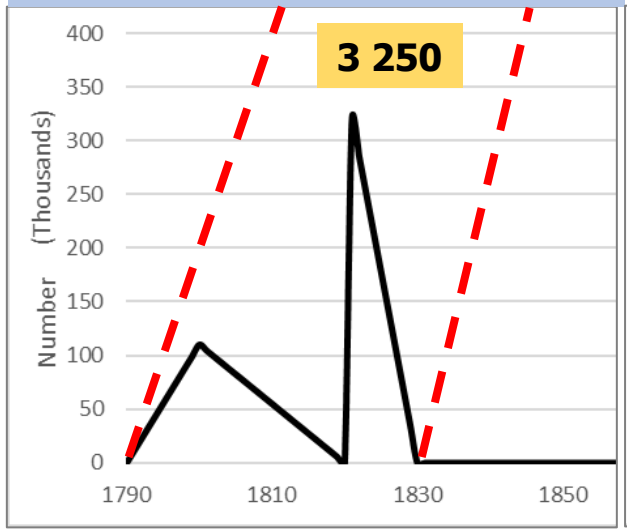
- Includes CCAMLR Statistical Areas:
  - Area 48.1 (part) - South Shetland islands
  - Area 48.2 - South Orkney islands
  - Area 48.3 - **South Georgia** & Shag Rocks
  - Area 48.4 - South Sandwich islands
  - Area 48.5 - Weddell Sea



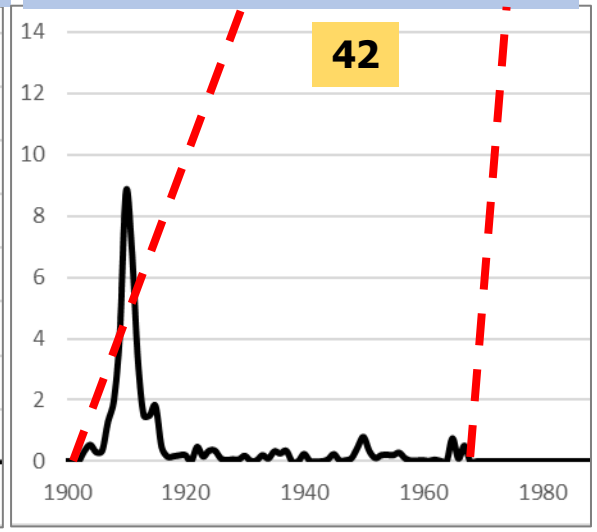
Catches in IWC Area II

Total number/tonnage caught ($\times 10^3$)

Afur seal (1790 – 1830)

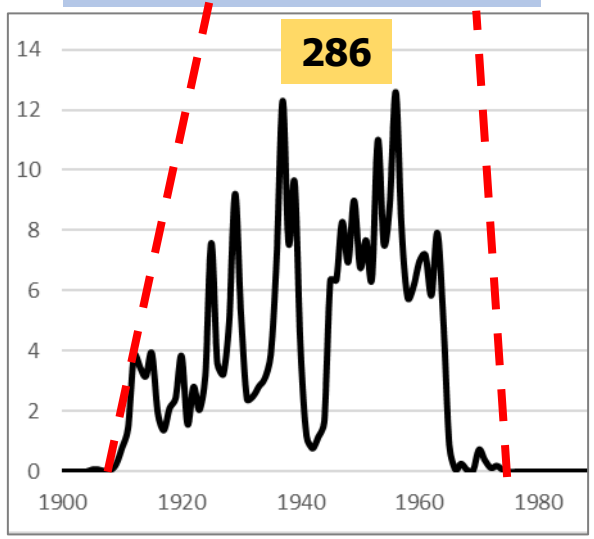


Hback (1900 – 1970)

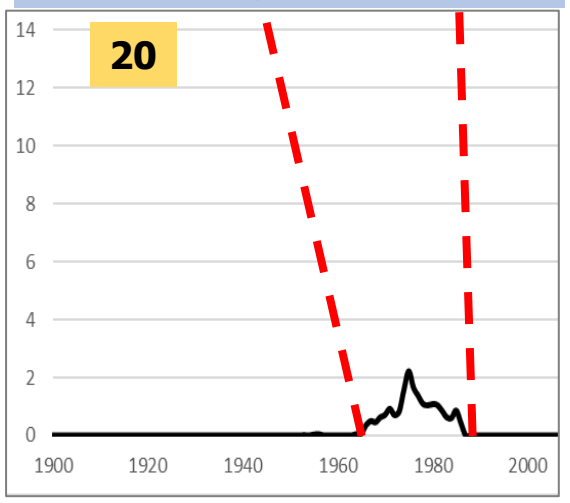


Blue (1910 – 1960)

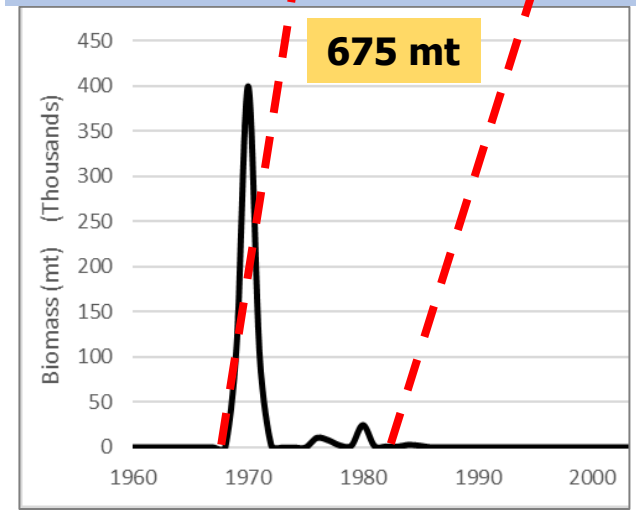
Fin (1910 – 1970)



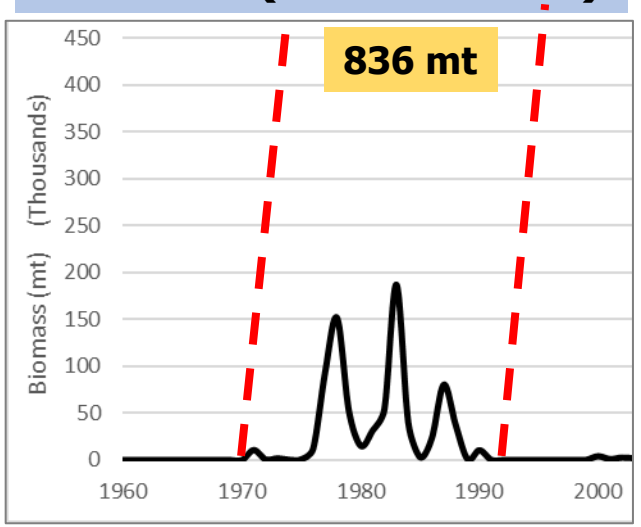
Minke (1965 – 1990)



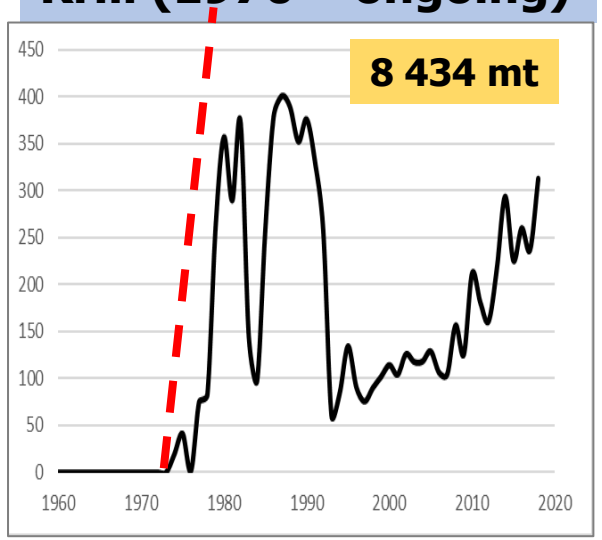
Marb Rcd (1969 – 1980)



Mack Icf (1970 – 1990)



Krill (1970 – ongoing)



The two fish species

https://www.msc.org/en-au/what-you-can-do/eat-sustainable-seafood/sustainable-seafood-guide/is-mackerel-sustainable

https://apecsportugal.wixsite.com/apecsportugal-en/post/the-long-road-to-recovery-decades-after-intensive-fishing-activity

Mackerel Icefish

- *Champsocephalus gunnari*
- Currently targeted by licensed fisheries due to them being of **economic interest**
- They are a **conserved species** by CCAMLR

Marbled rockcod

- *Notothenia rossii*
- Their **fishery has remained closed** by CCAMLR due to their depleted numbers
- This represents the **consequence** of over- and illegal fishing by humans

Study objectives:

1) Is there a **need to include** the 'minor' krill-predators in a **single management area ecosystem model**?
   - At a circumpolar level, the 'minor' krill-predators are relatively too few to impact model outputs
   - In relative terms, these 'minor' krill-predators are most abundant in **IWC Area II**

2) Do these 'minor' krill-predators **meaningfully influence** the **krill dynamics** at this level?

Data used and model formulation

Observed Abundance

- For **whales**, the estimates come from **sighting surveys**
- For **seals and penguins**, estimates come from **counts and aerial surveys** - direct method
- For **fish and krill**, estimates come mainly from **acoustic surveys** - indirect method

Model Formulation

- Using the **historical catch data** for the species considered, the **model is fitted to** the **observed abundances**.

Model Equations:

$\boldsymbol{B_y}$ = the biomass of krill in year y
$\boldsymbol{C_y}$ = the (biomass or number) caught in year y
$\boldsymbol{N_y}$ = the number or biomass of predator in year y

Krill dynamics (Schaefer form):

$$B_{y+1} = B_y + rB_y\left(1 - \frac{B_y}{K}\right) - \sum_j \frac{\lambda^j \left(B_y\right)^2 N_y^j}{\left(\bar{B}_j\right)^2 + \left(B_y\right)^2} - C_y$$

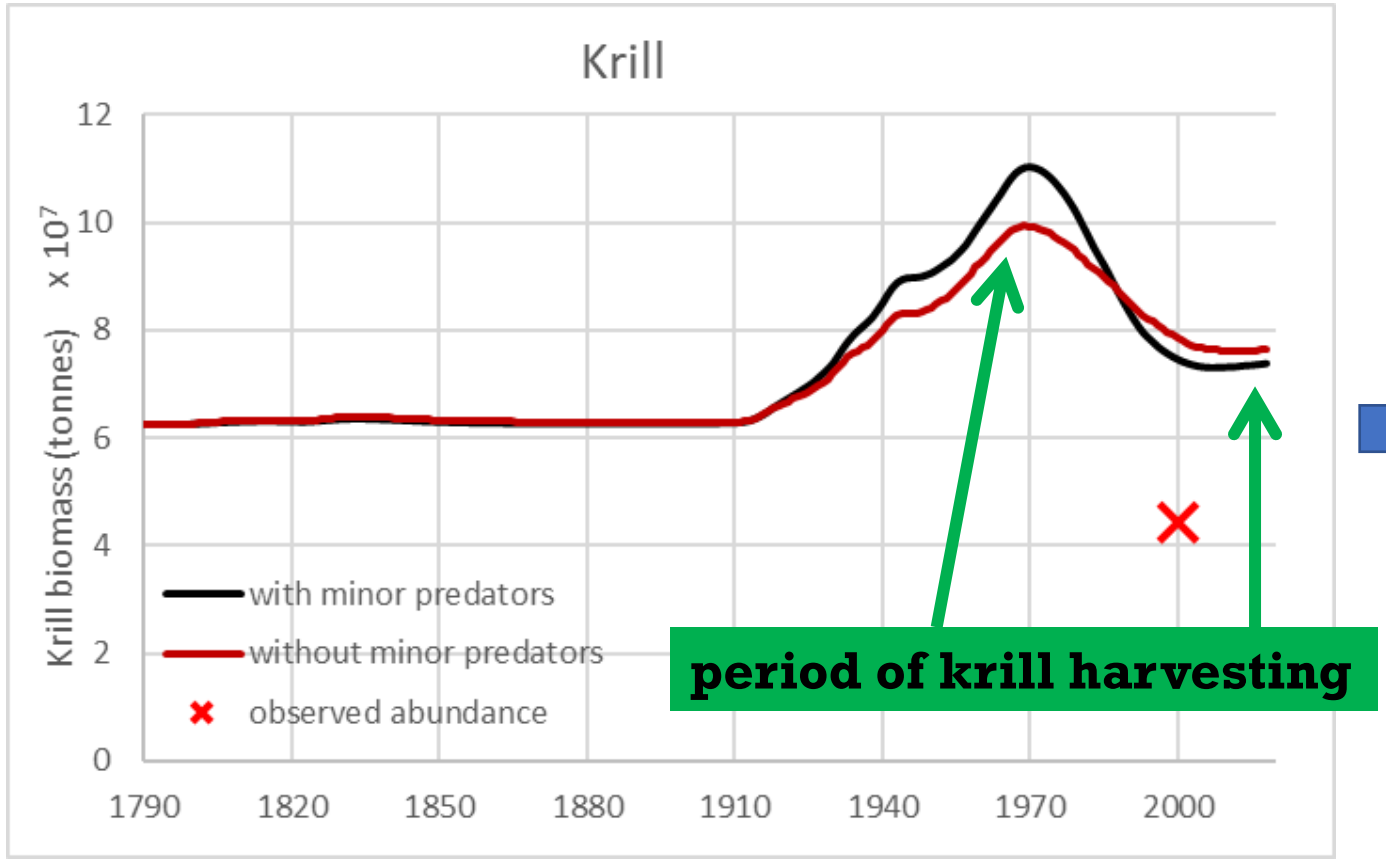
Krill-predator dynamics:

$$N_{y+1}^j = N_y^j + \frac{\mu^j \left(B_y\right)^2 N_y^j}{\left(\bar{B}_j\right)^2 + \left(B_y\right)^2} - M^j N_y^j\left(1 + \alpha^j\left(\frac{N_y^j}{N_{1780}^j}\right)\right) - C_y^j$$

Model results:

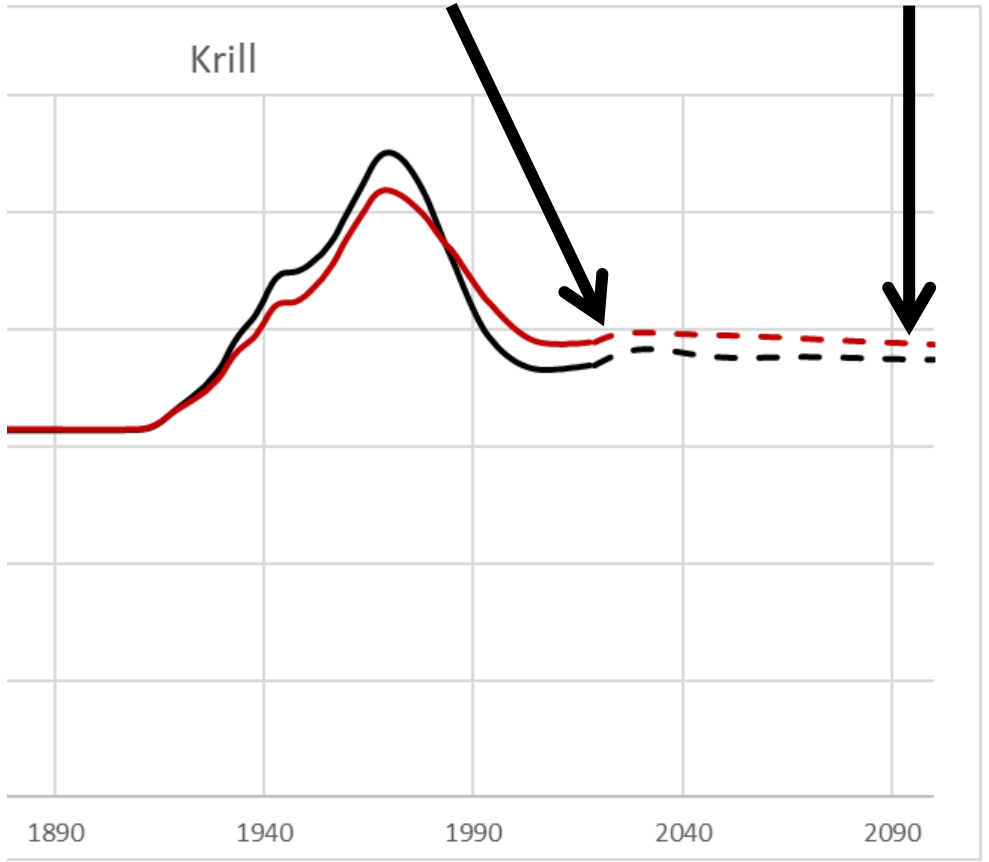
Model 1 = with minor predators
Model 2 = w/out minor predators

Krill biomass

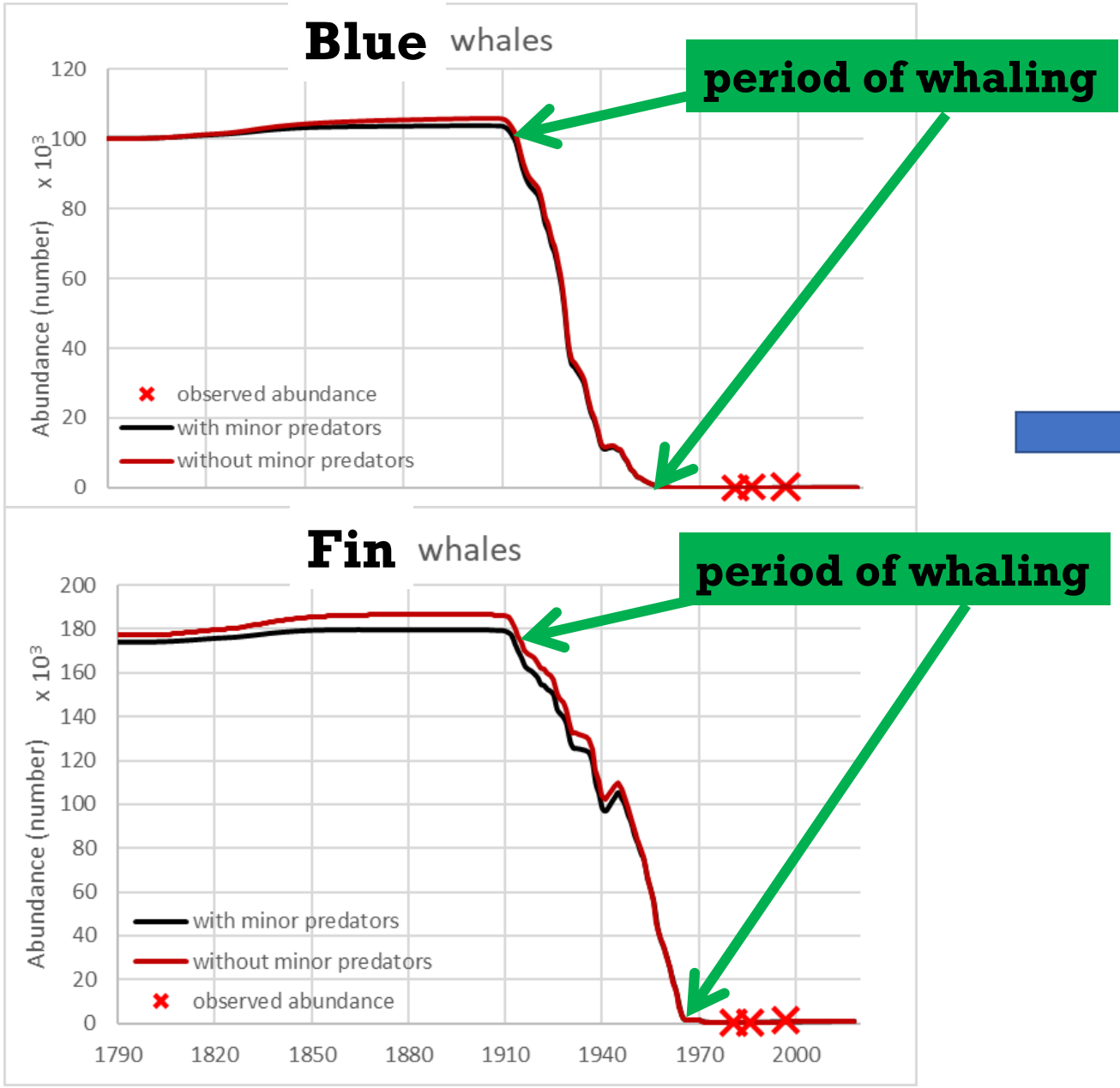


Future projections

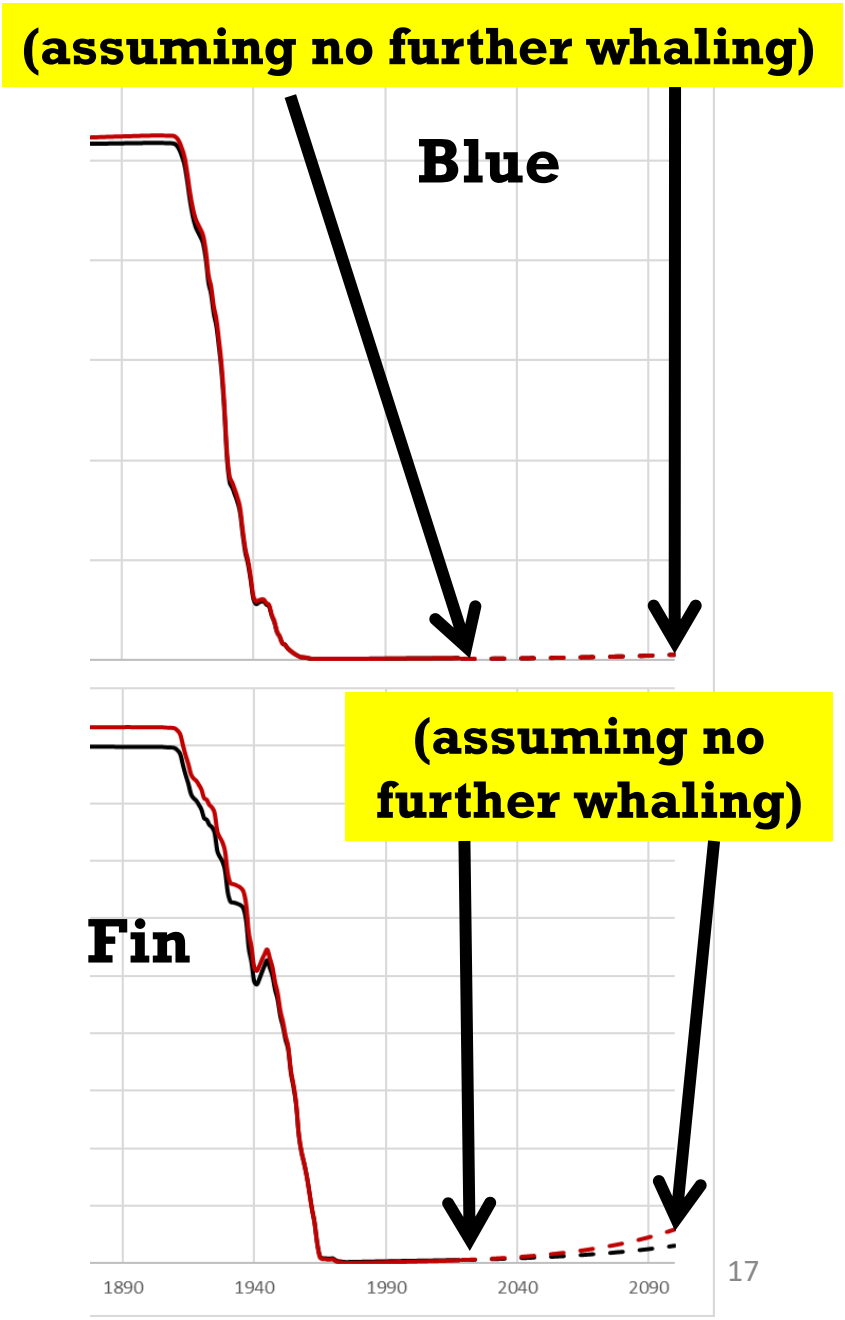
(assuming no further krill harvesting)



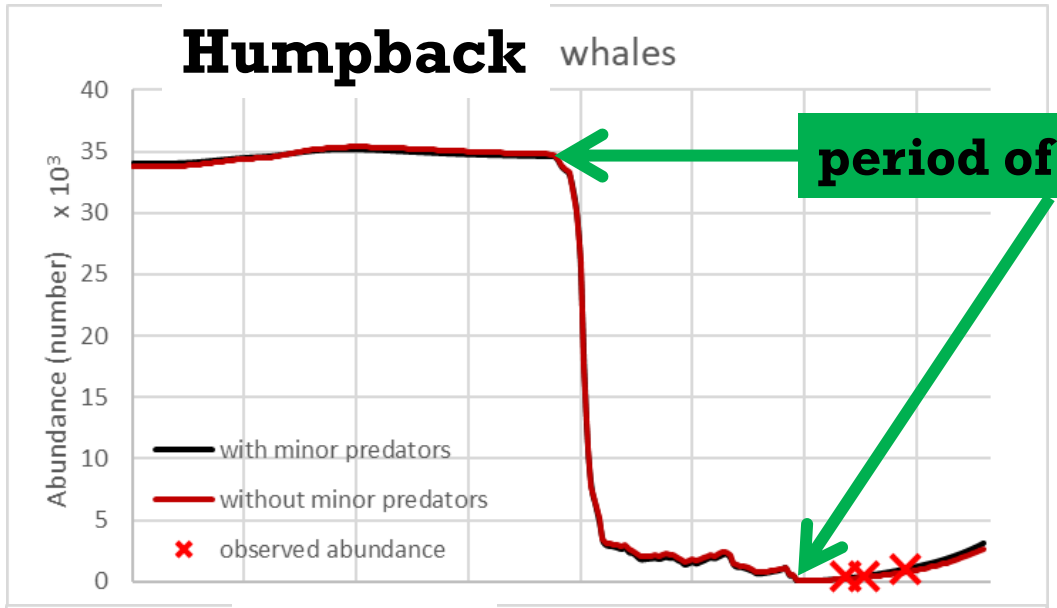
Blue and Fin whale abundances

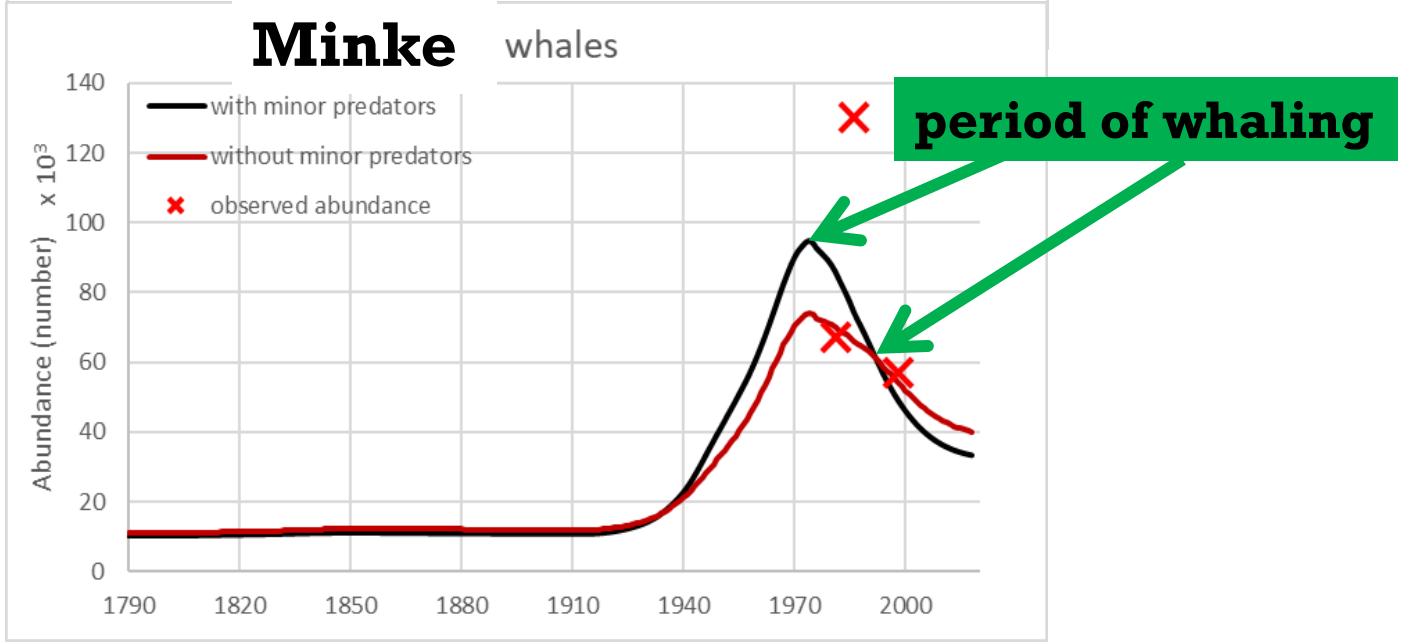


Future projections

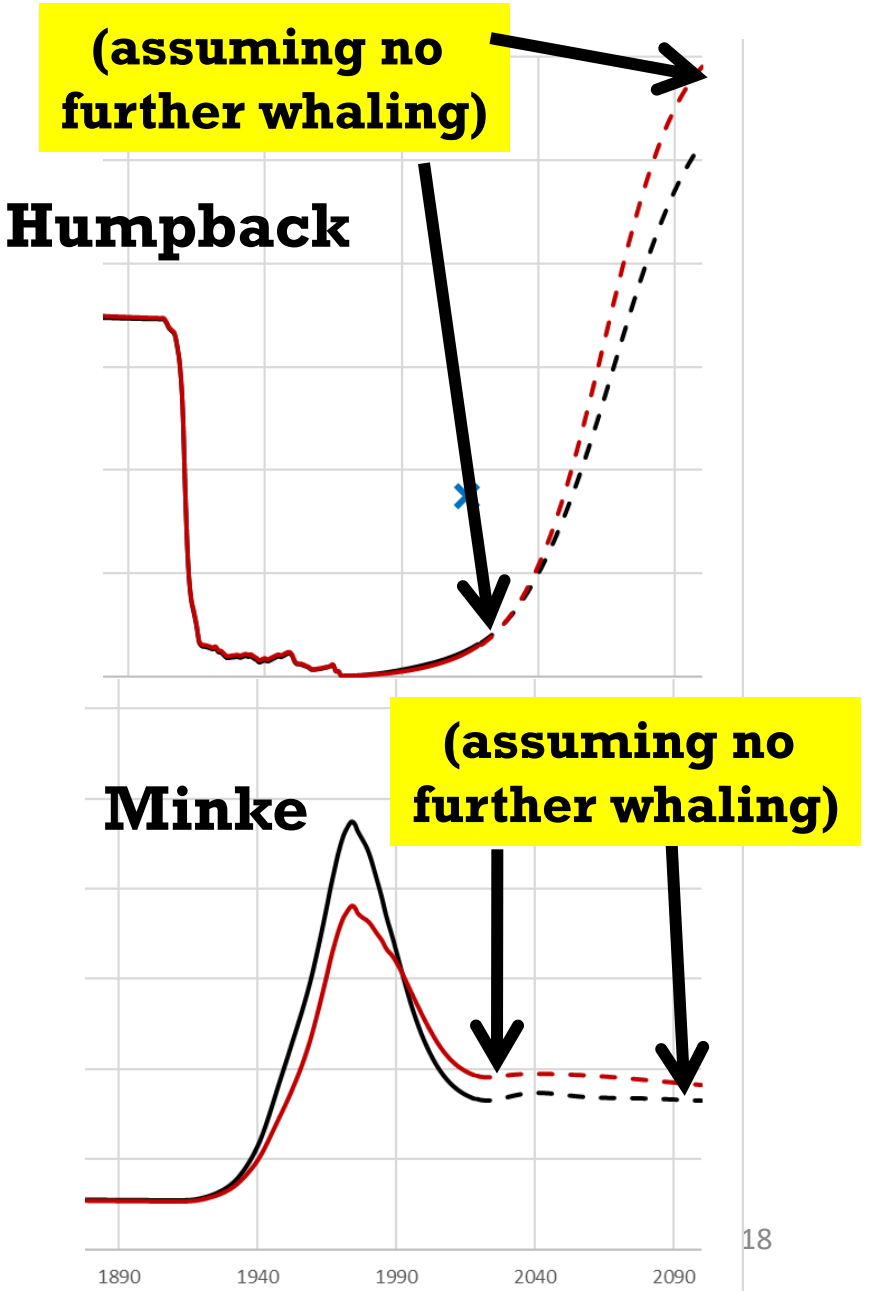


Humpback and Minke abundances

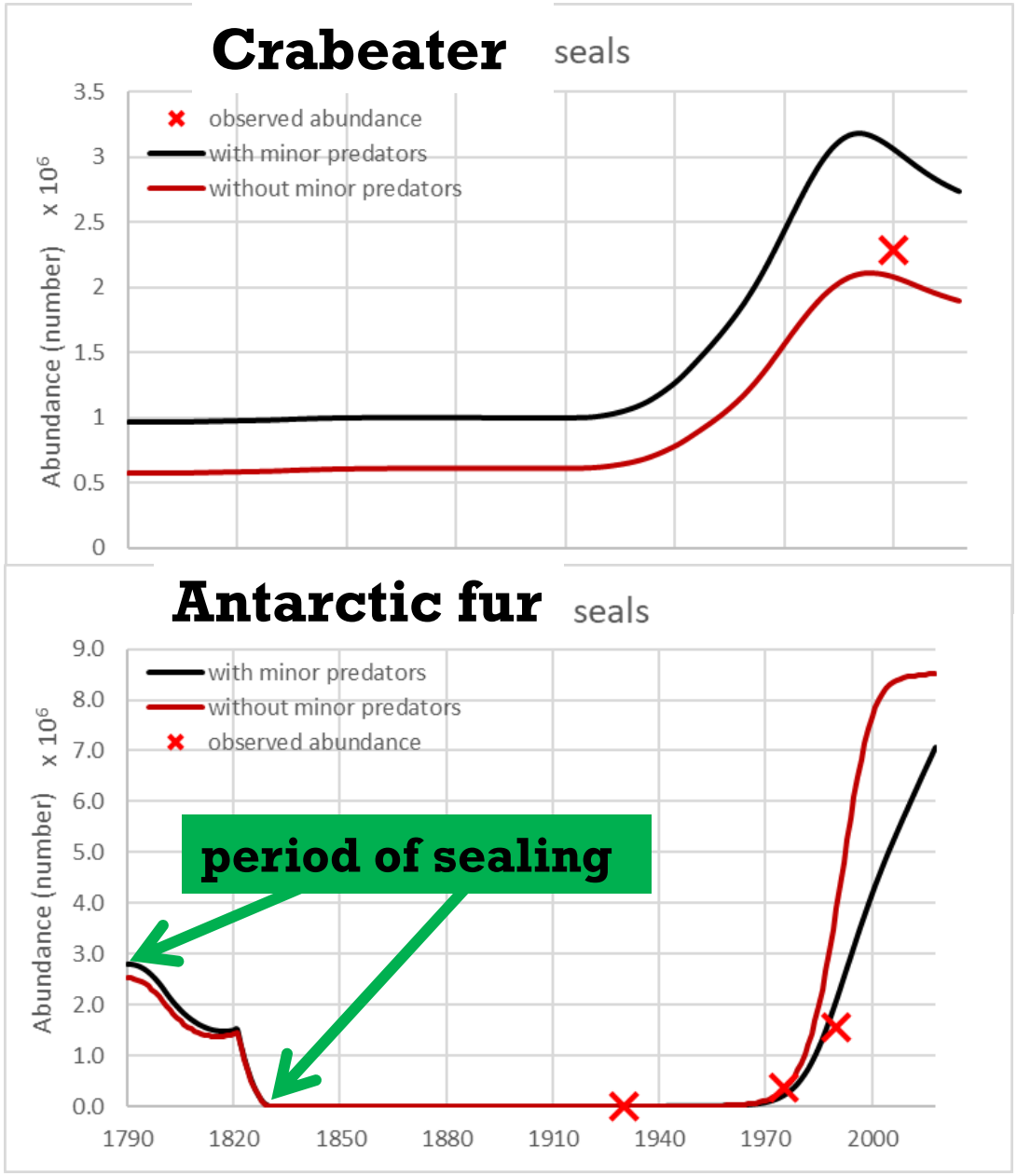




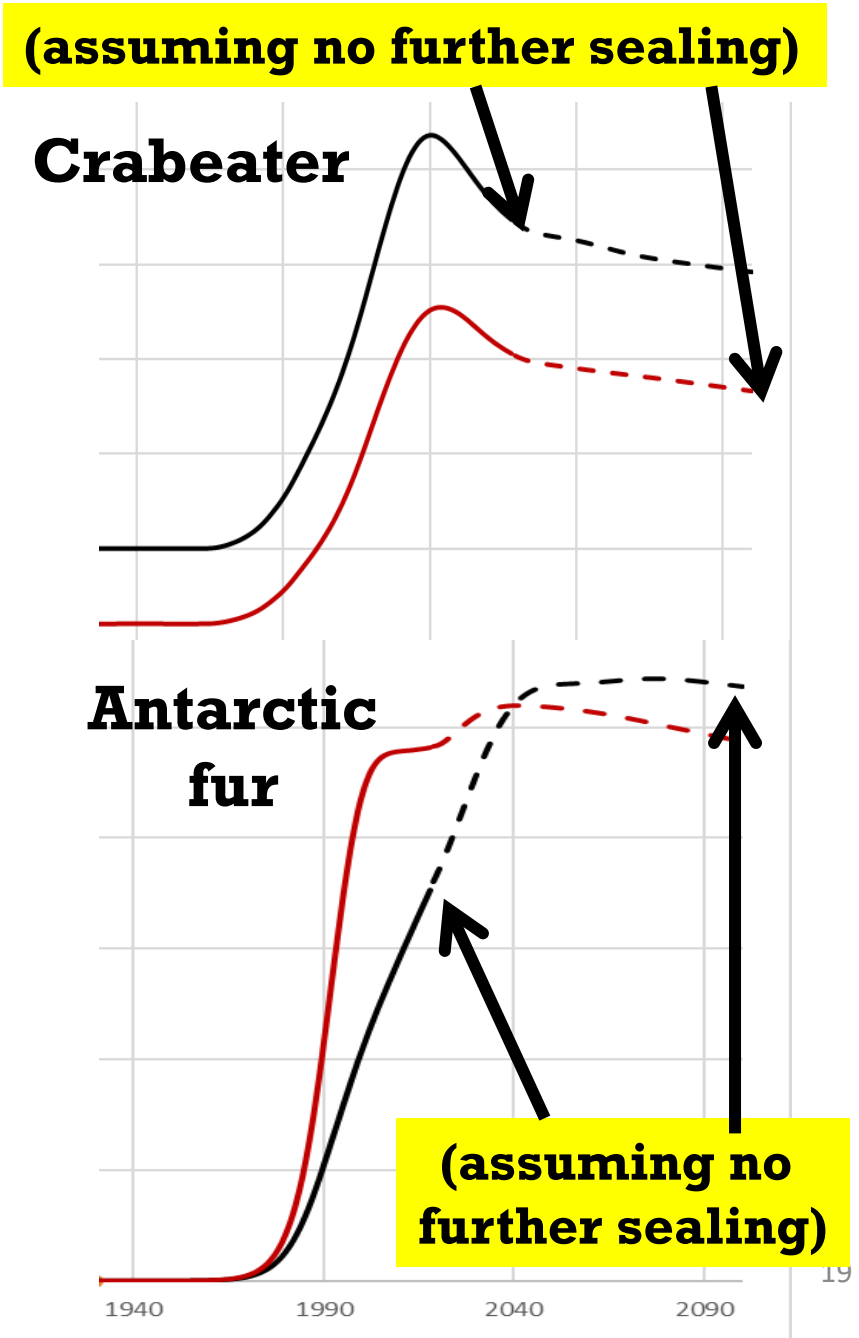
Future projections



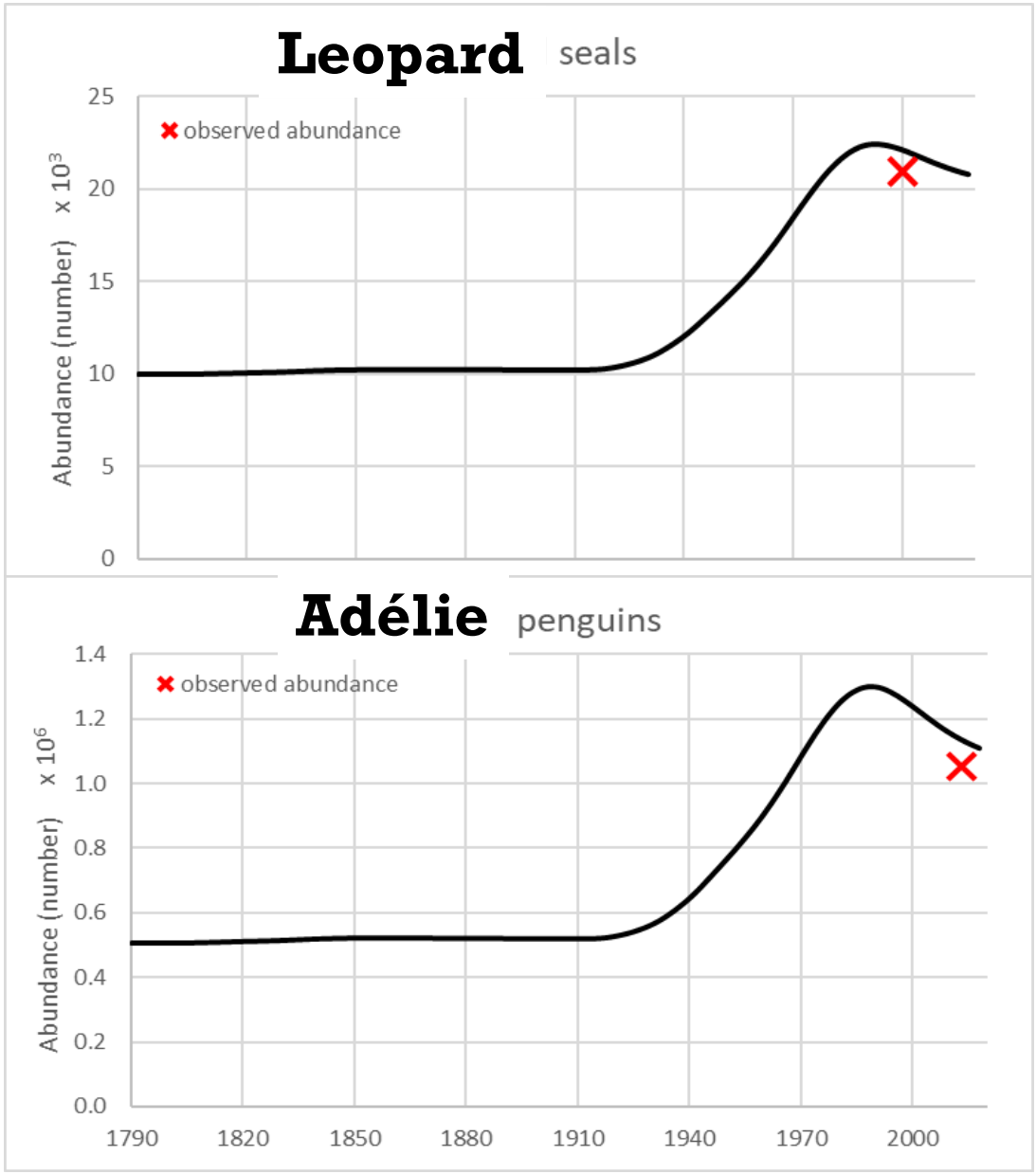
Crabeater and Antarctic fur seals



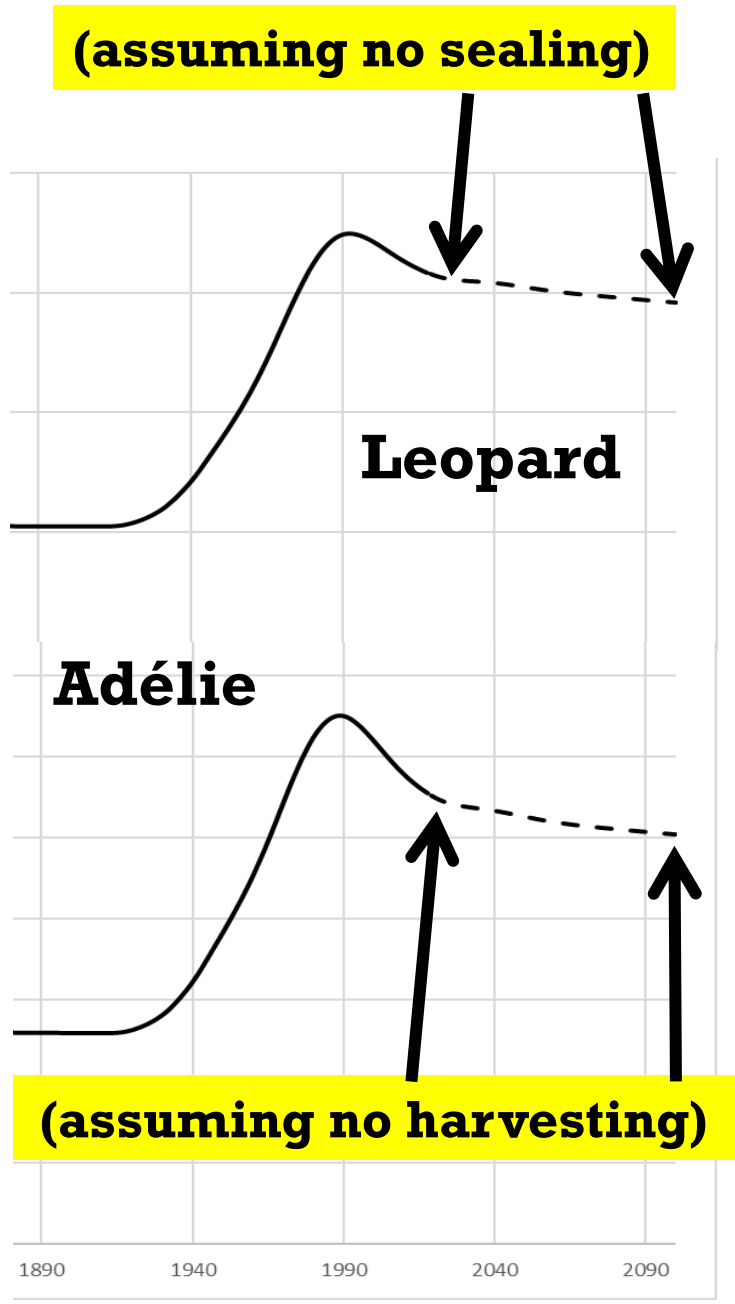
Future projections



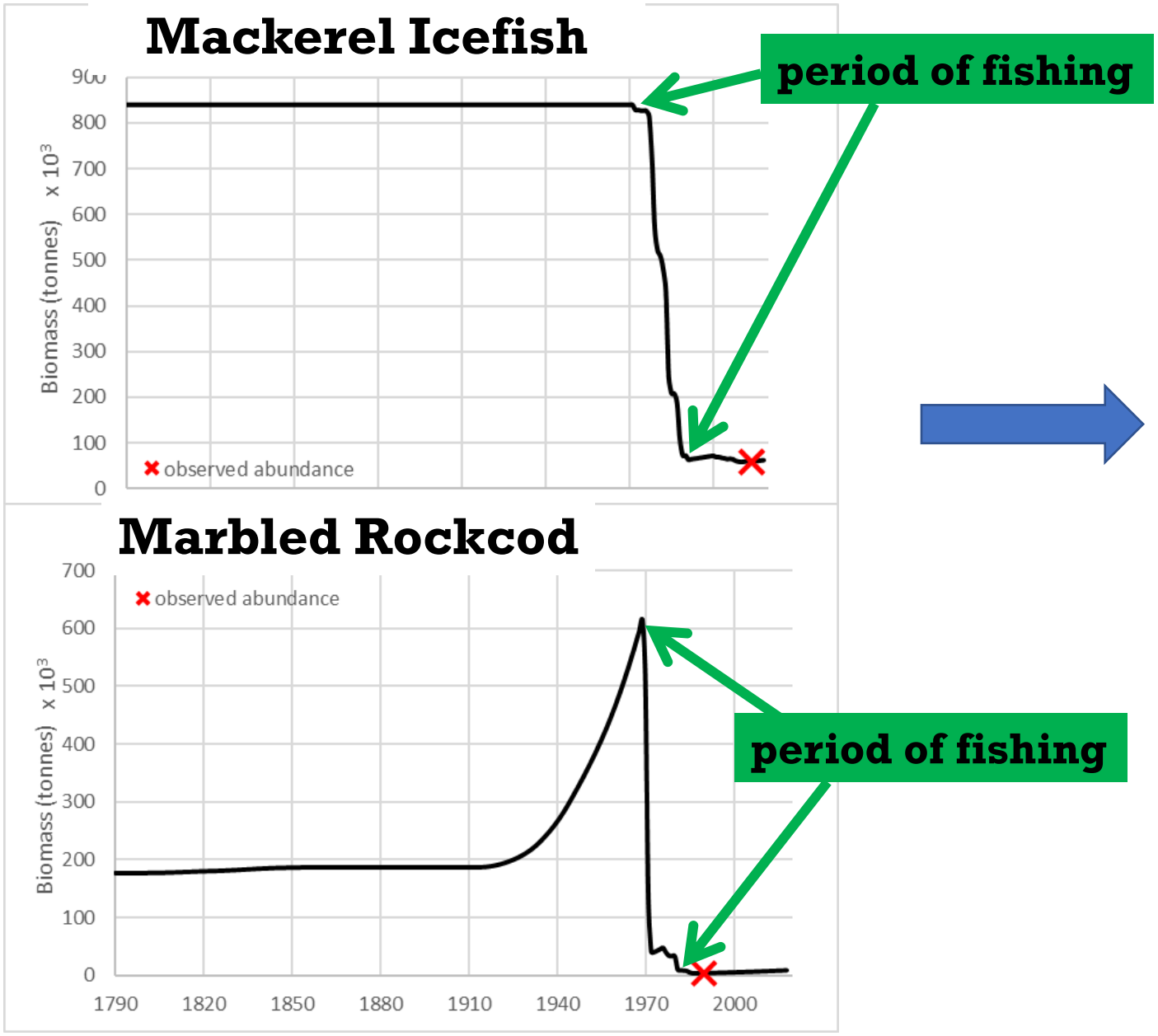
Leopard seals and Adélie penguins



Future projections

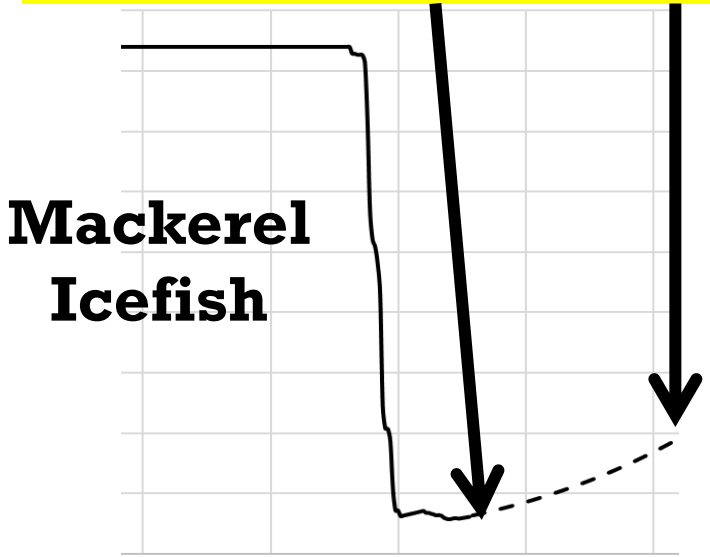


Mackerel Icefish and Marbled Rockcod

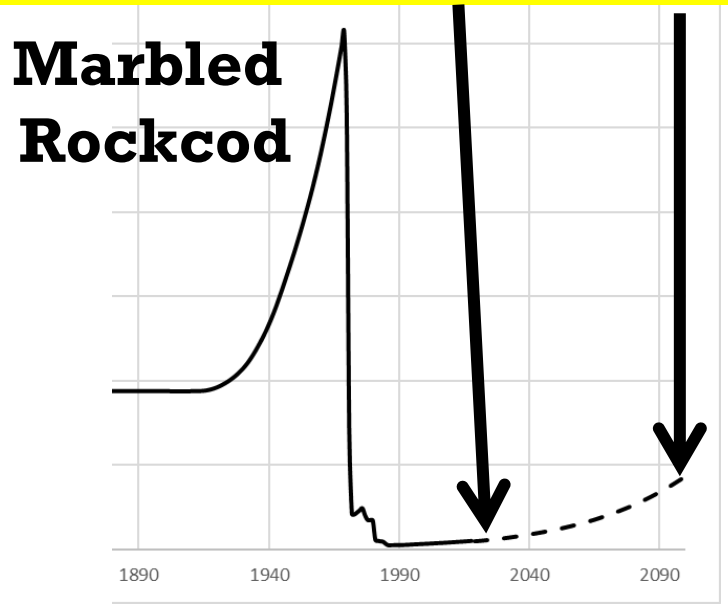


Future projections

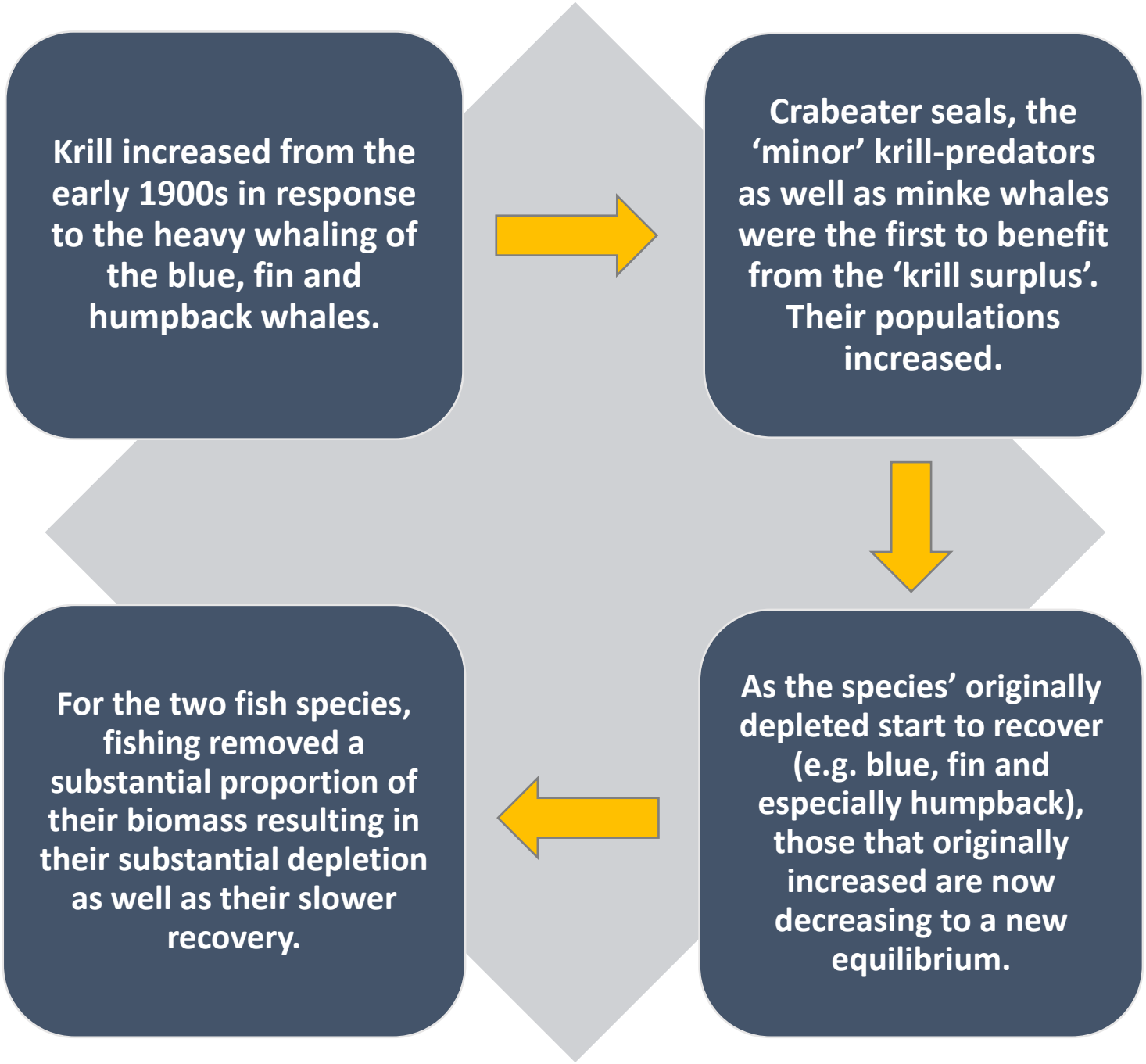
(assuming no further fishing)



(assuming no further fishing)



Discussion


Krill increased from the early 1900s in response to the heavy whaling of the blue, fin and humpback whales.
Crabeater seals, the 'minor' krill-predators as well as minke whales were the first to benefit from the 'krill surplus'. Their populations increased.
As the species' originally depleted start to recover (e.g. blue, fin and especially humpback), those that originally increased are now decreasing to a new equilibrium.
For the two fish species, fishing removed a substantial proportion of their biomass resulting in their substantial depletion as well as their slower recovery.

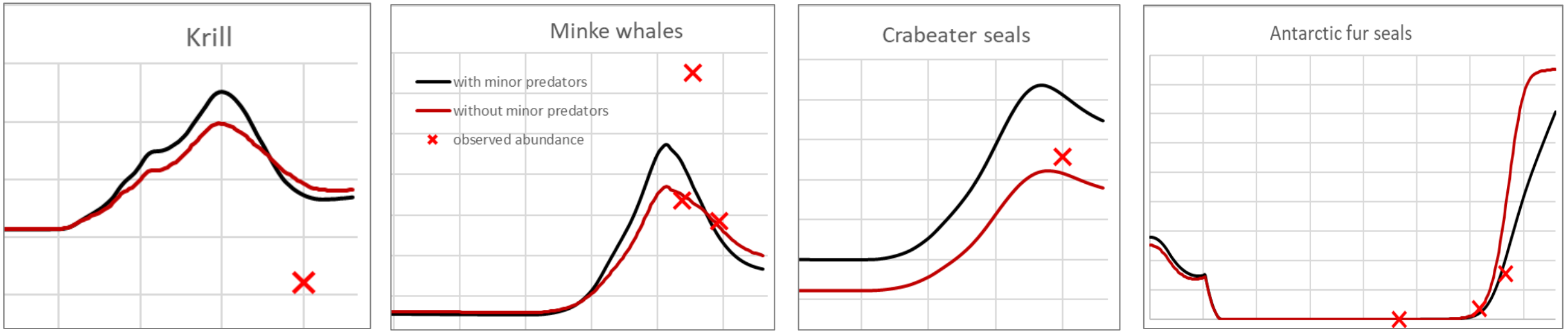
Conclusion:

1) Is there a **need to include** the 'minor' krill-predators in a **single management area ecosystem model**?

- Yes, the 'minor' krill-predators influence the dynamics of the major krill-predators in IWC Area II

2) Do these 'minor' krill-predators **meaningfully influence** the **krill dynamics** at this level?

- Yes, the krill increase is somewhat delayed with the final biomass being roughly 10% higher



Thank you for listening