SGSSI MPA Review Science Symposium

13-14 June 2023
Aurora Conference Centre
Cambridge, UK

Hosted by the Government of South Georgia & the South Sandwich Islands

Paul Carroll, Unsplash

Krill

- **Modelling Antarctic krill distribution at South Georgia: from physics to fisheries management.** *Emma Young (BAS)*
- **Resolving ecosystem effects of the South Georgia winter krill fishery.** *Cecilia Liszka (BAS)*
- **Krill and Climate Change.** *Simeon Hill (BAS)*
- **Using the best available science to set revised fishery catch limits for Antarctic krill within the South Georgia and South Sandwich Islands Marine Protected Area.** *Philip Trathan (University of Southampton)*
- **Setting Focus on the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Article II.** *Inigo Everson (University of East Anglia)*

Emma Young

British Antarctic Survey


ESA


Sue G


Pete Lens

Modelling Antarctic krill distribution at South Georgia: from physics to fisheries management

Emma Young, Sally Thorpe, Eugene Murphy

Funded by GSGSSI

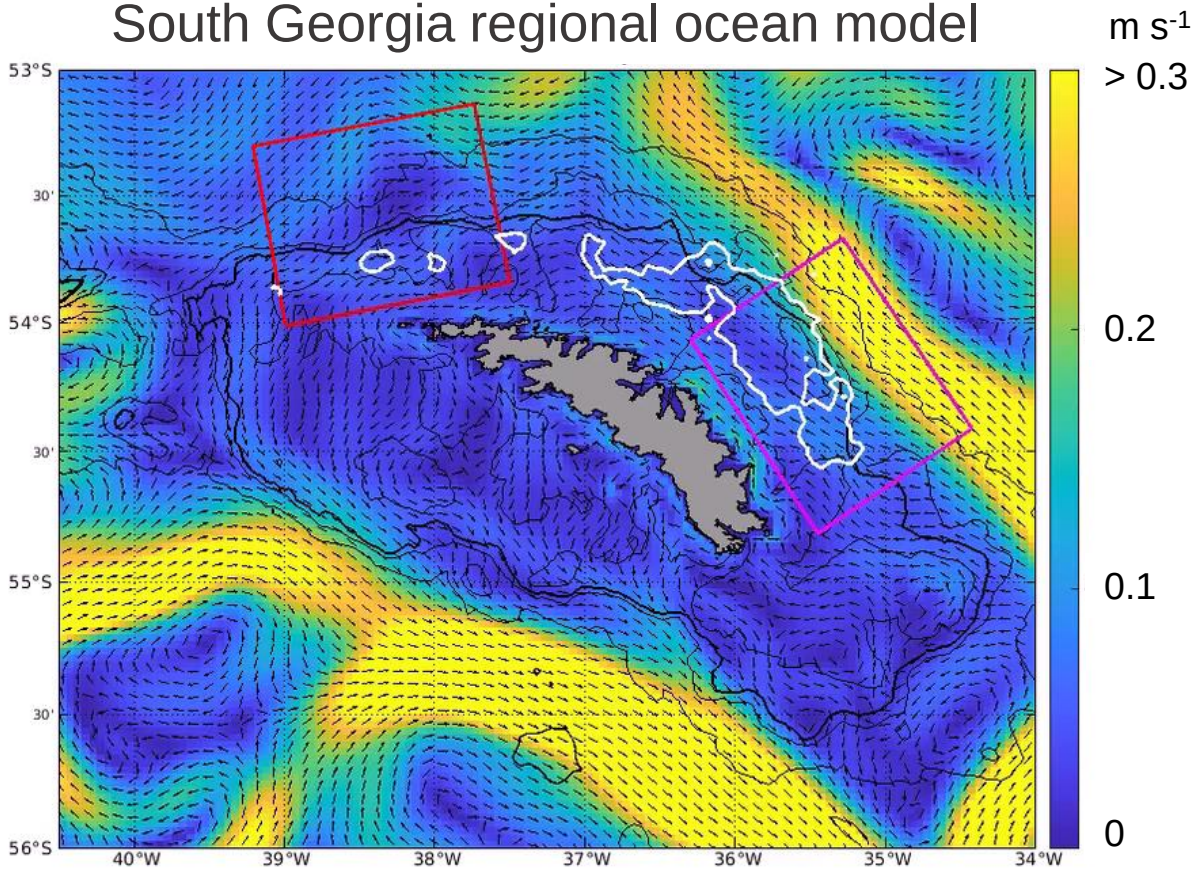
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

POLAR SCIENCE FOR PLANET EARTH

Project aims

- Identify source regions for krill recruitment onto the northern shelf of South Georgia, and quantify transfer between key areas of fishing and predator foraging demand
- Determine key transport pathways and timescales of dispersal from the winter krill fishing grounds, and connectivity to areas of high predator demand in the following summer
- Investigate temporal variability in transport on and around the South Georgia shelf

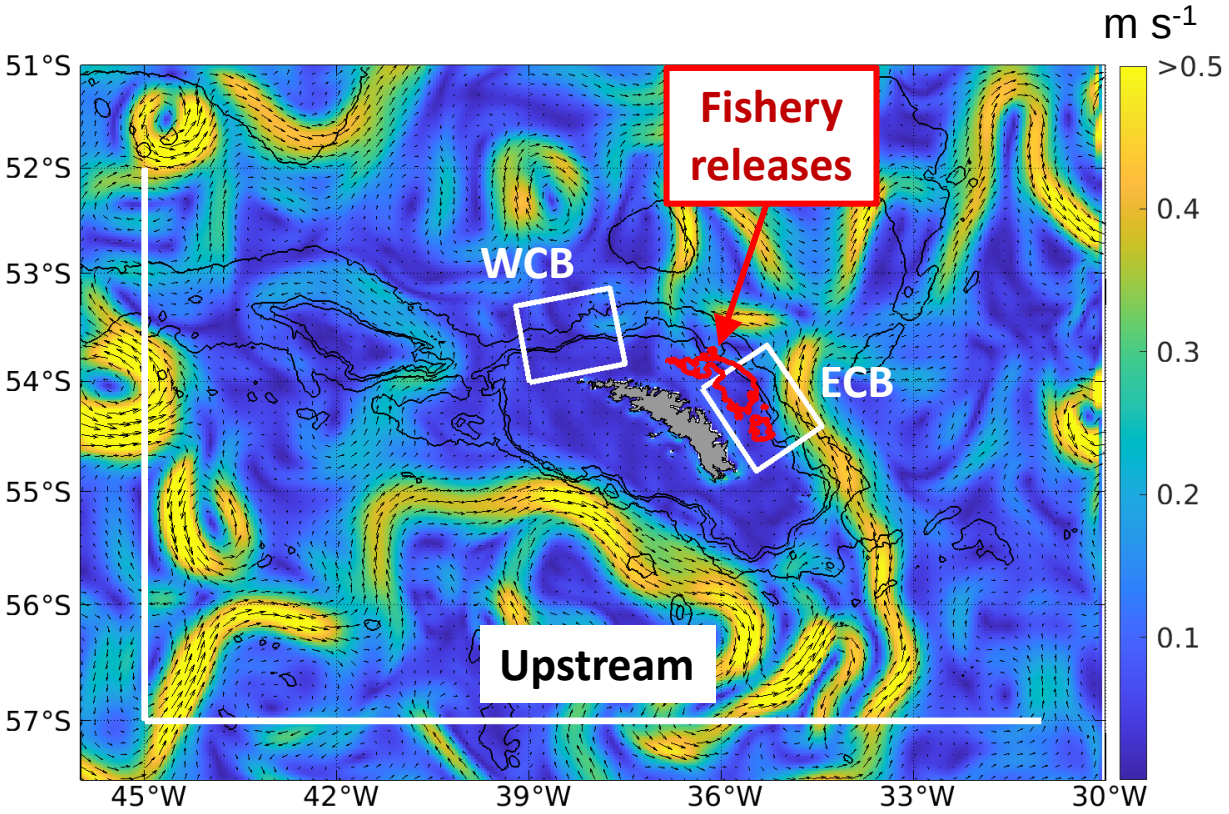
South Georgia regional ocean model



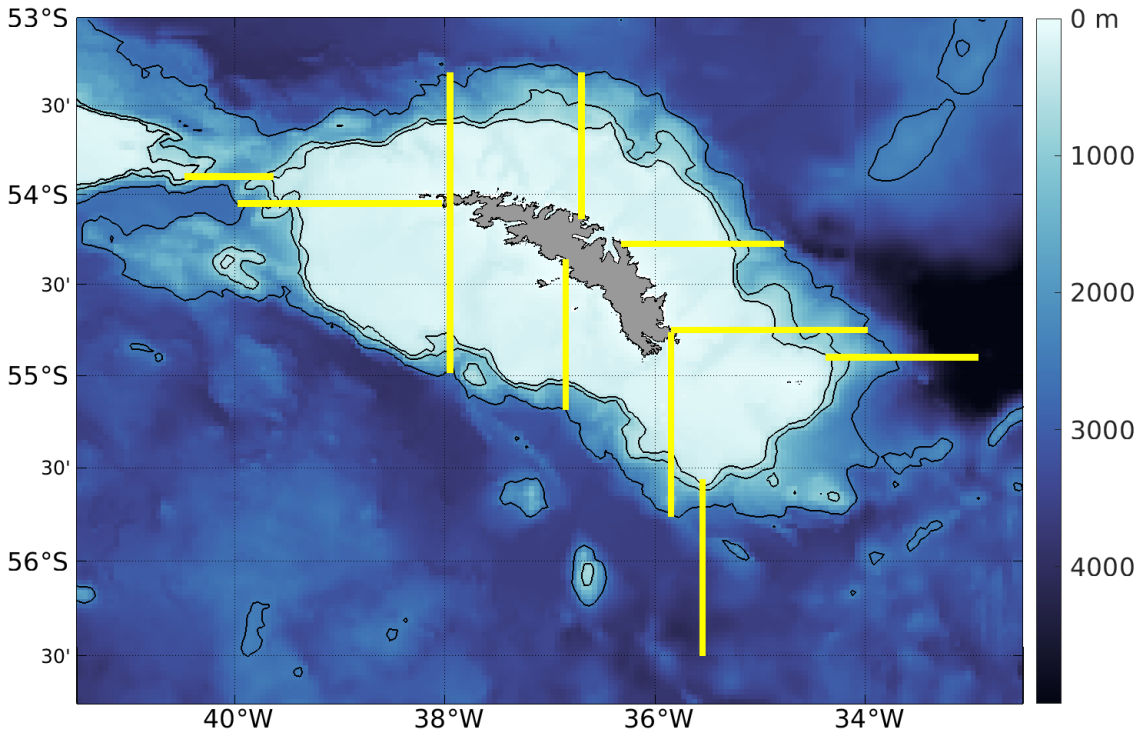
Simulated currents at 10 m depth on South Georgia shelf. Model output is available for 1992-2012.

Methods

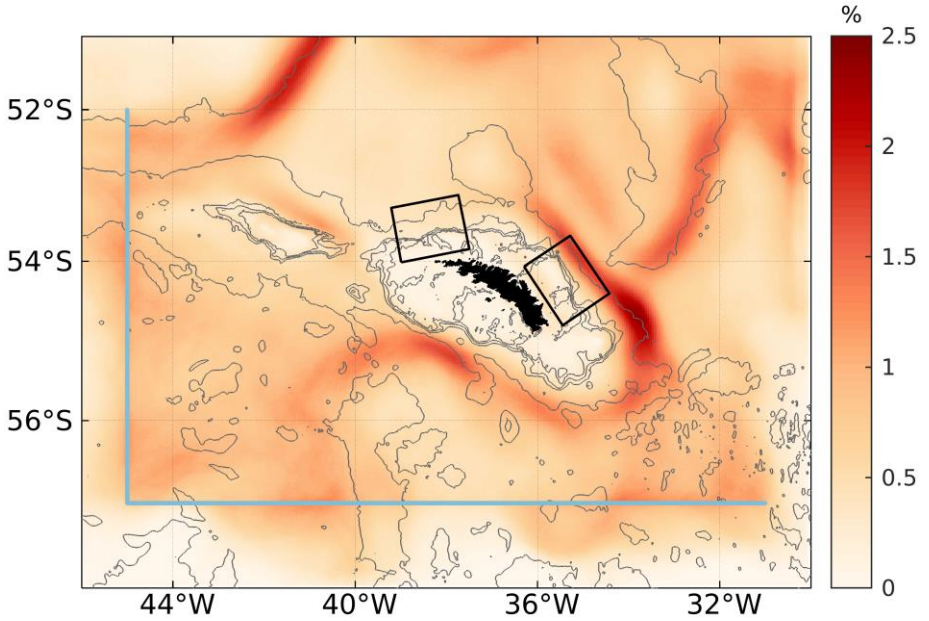
Particle tracking experiments



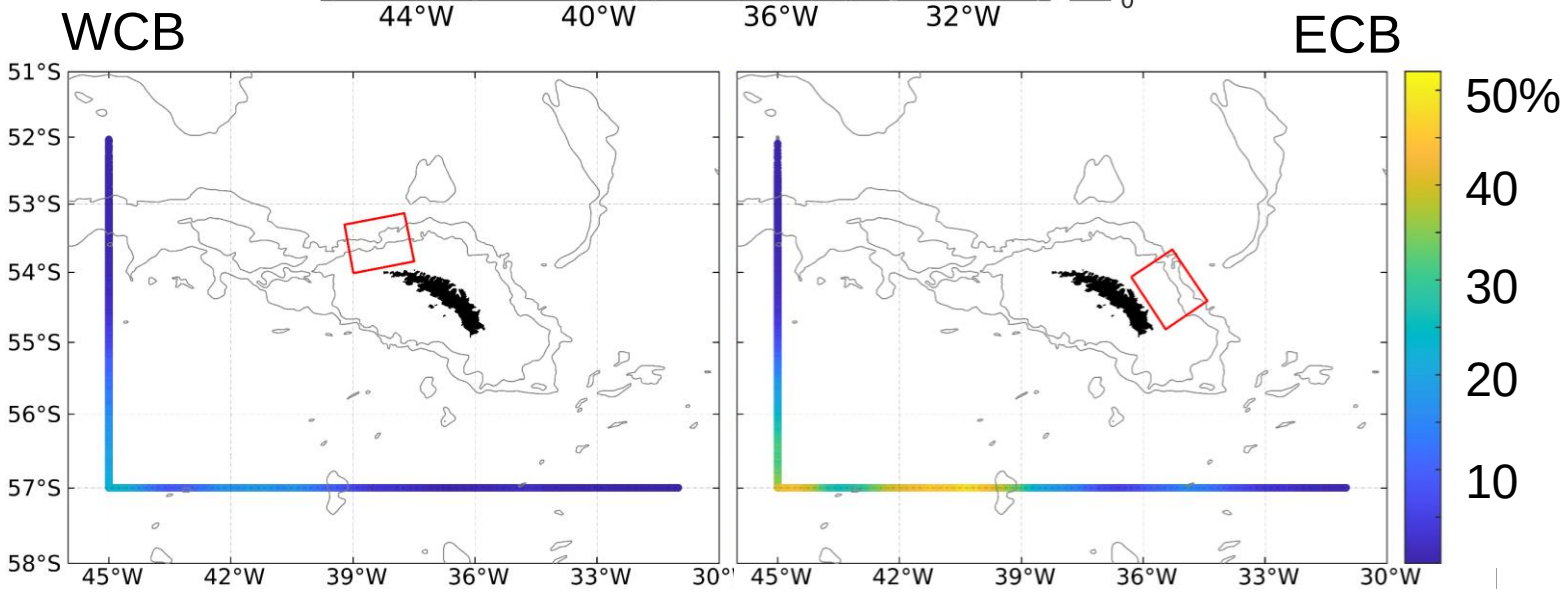
Oceanographic analyses



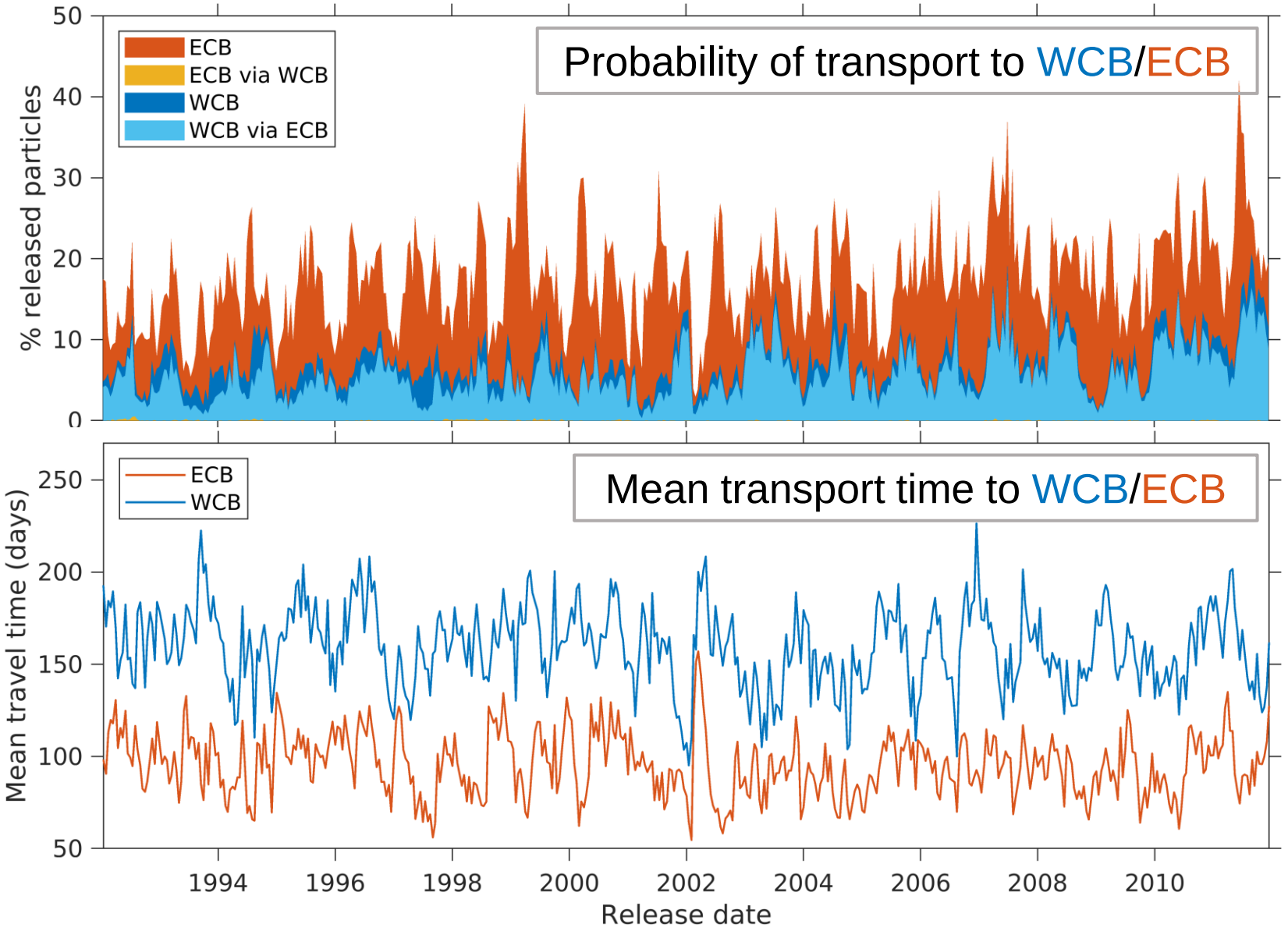
Transport pathways from upstream releases



Probability of transport to WCB/ECB



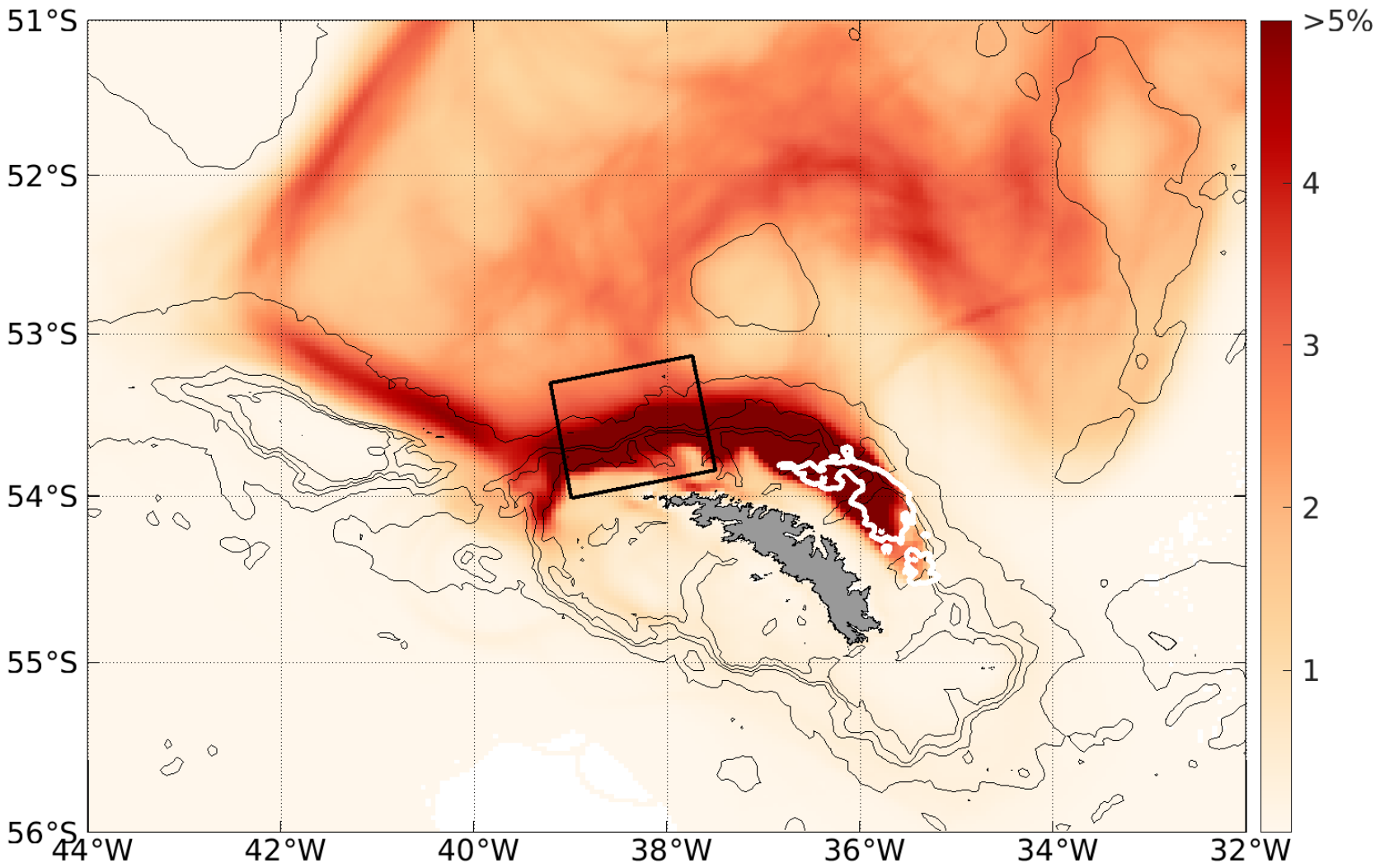
Temporal variability in transport to South Georgia



Mean = 159 days

Mean = 96 days

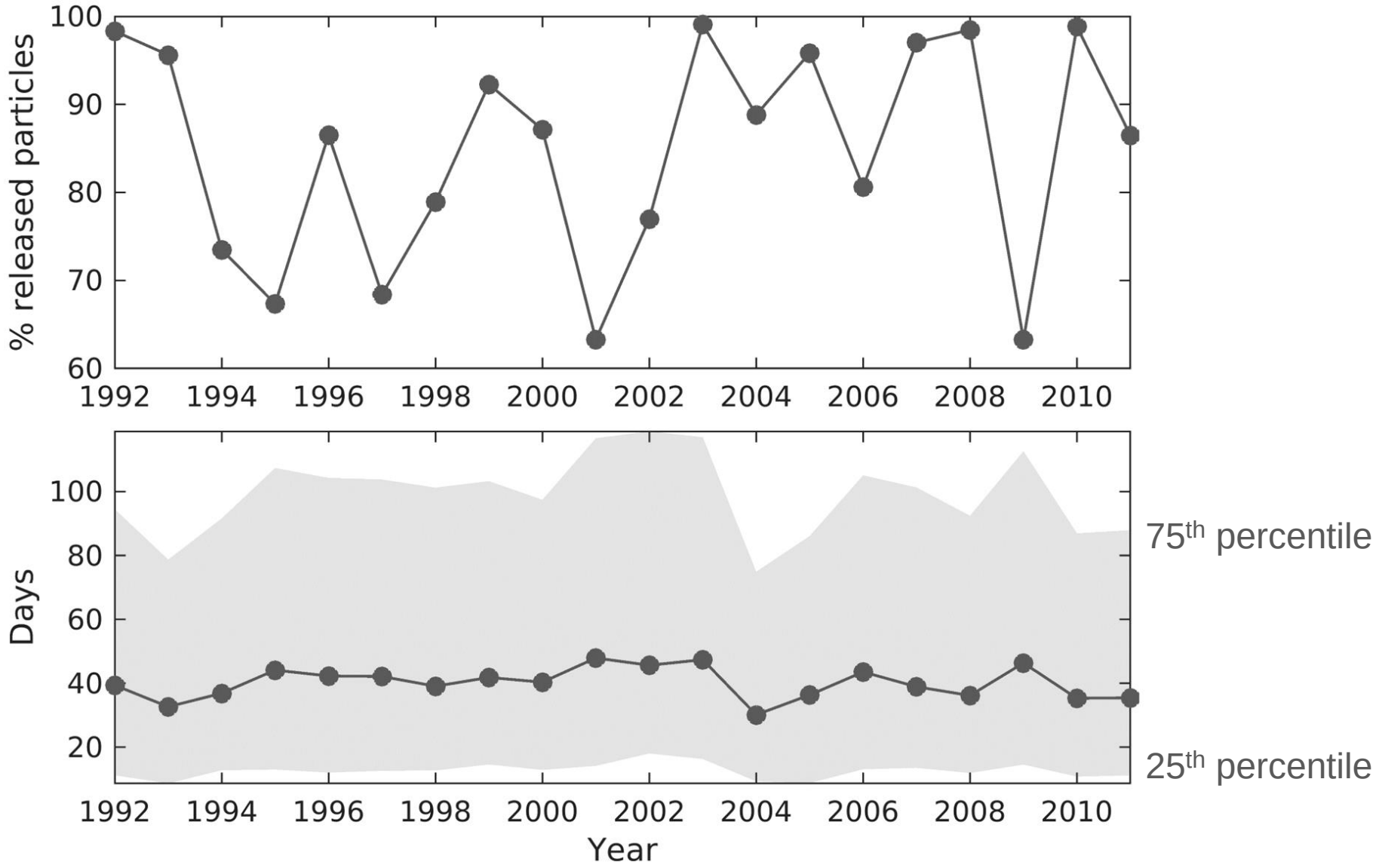
Transport pathways from winter krill fishing grounds



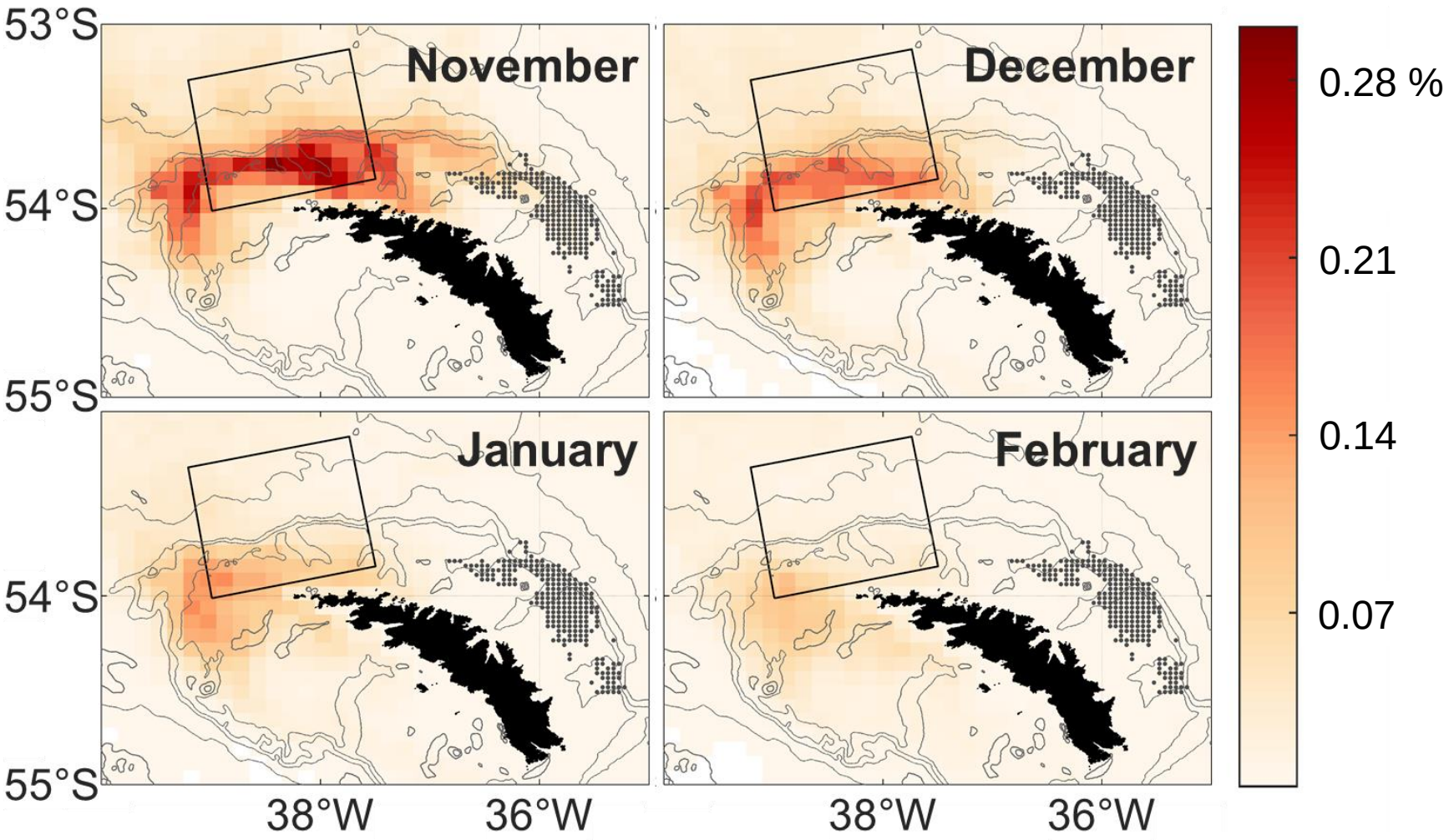
Annual variability in transport to the WCB

Transport to WCB

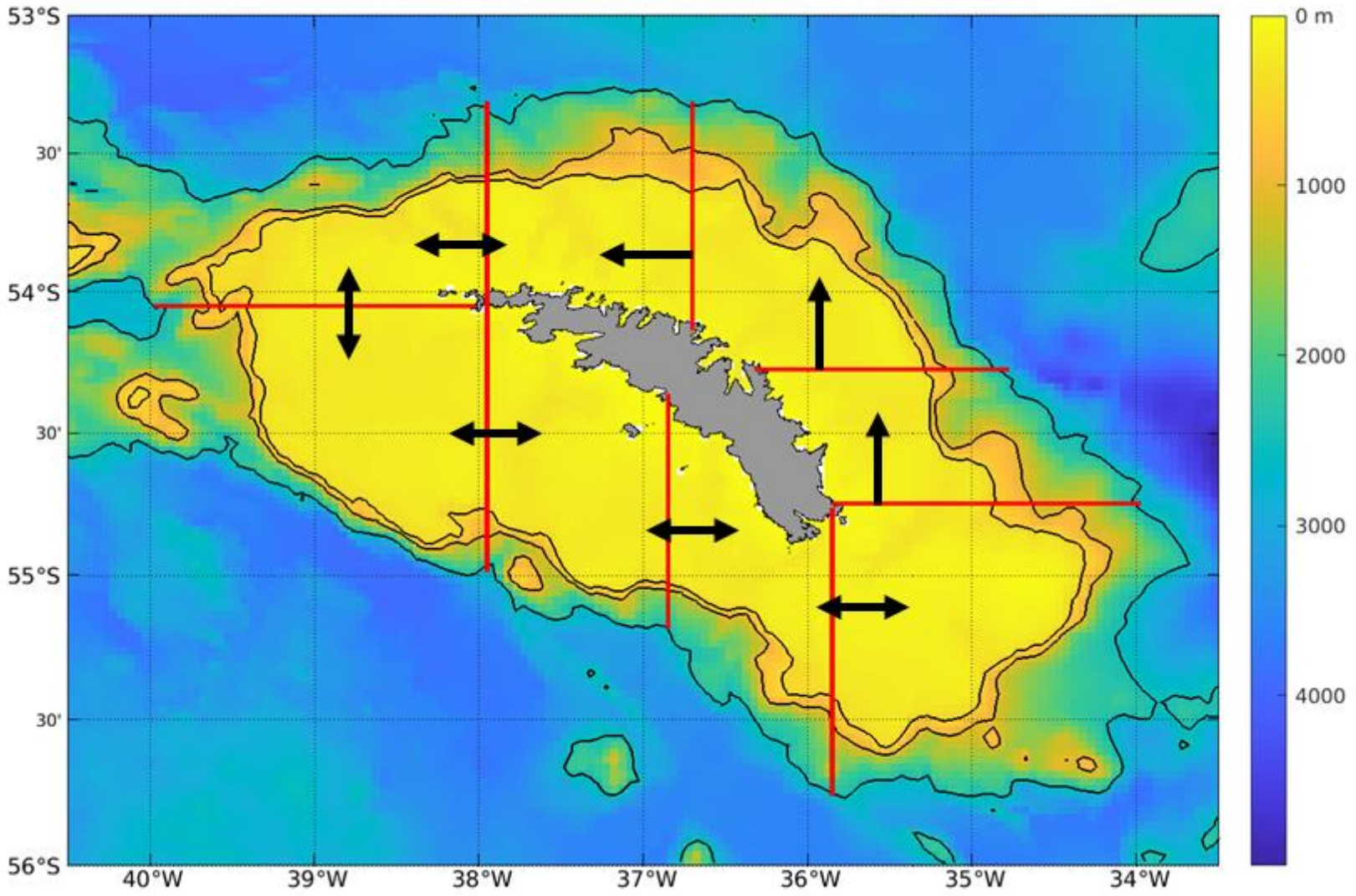
Median transport time to WCB



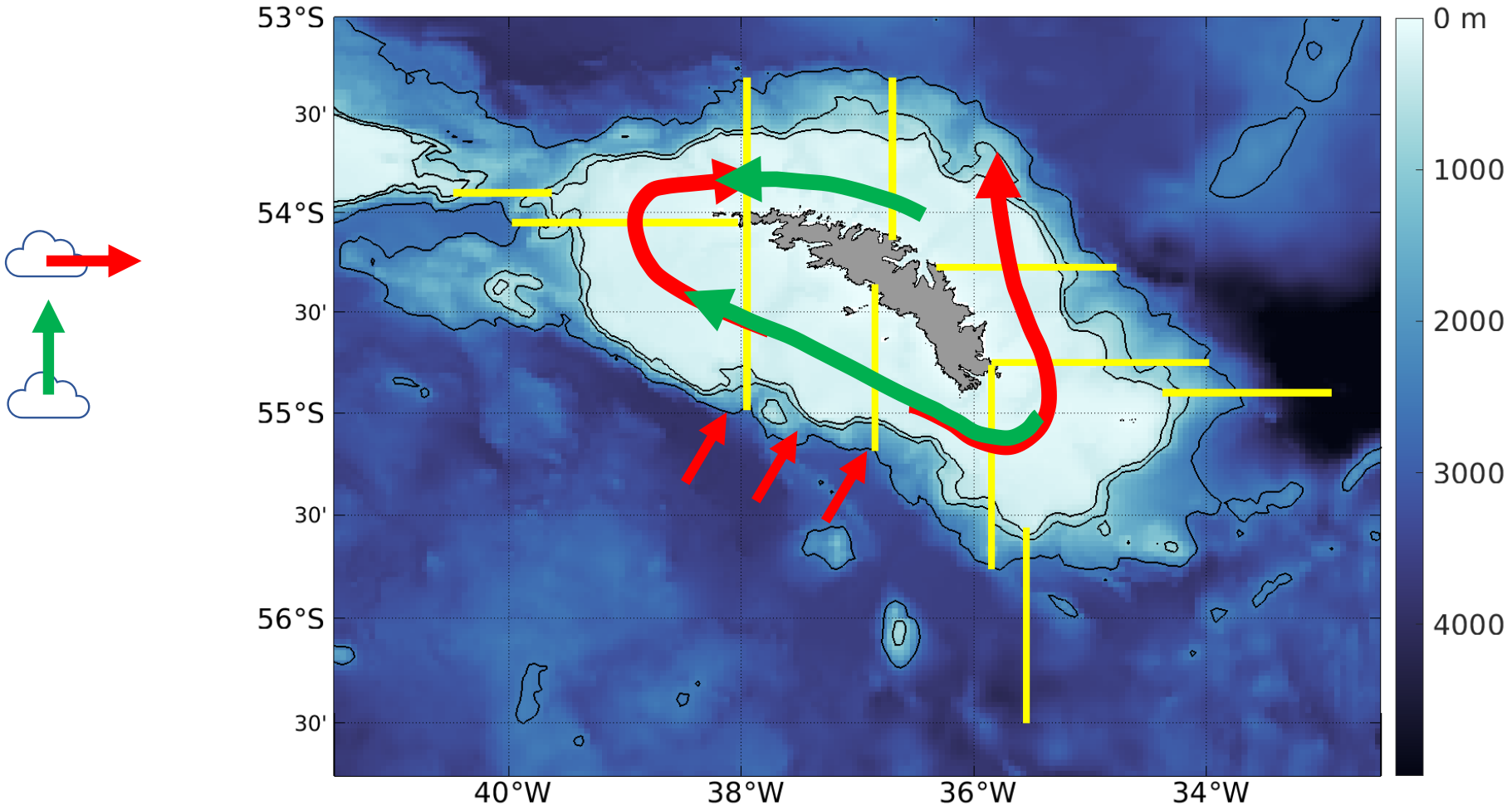
Mean summer distribution of particles from the winter krill fishery



Links to oceanographic flows: mean circulation

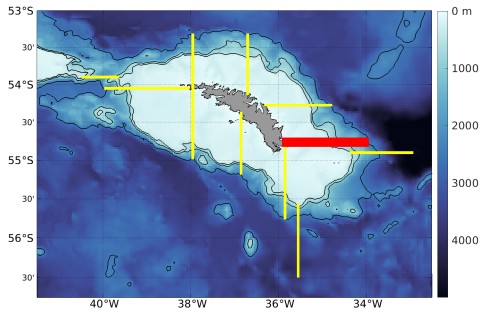


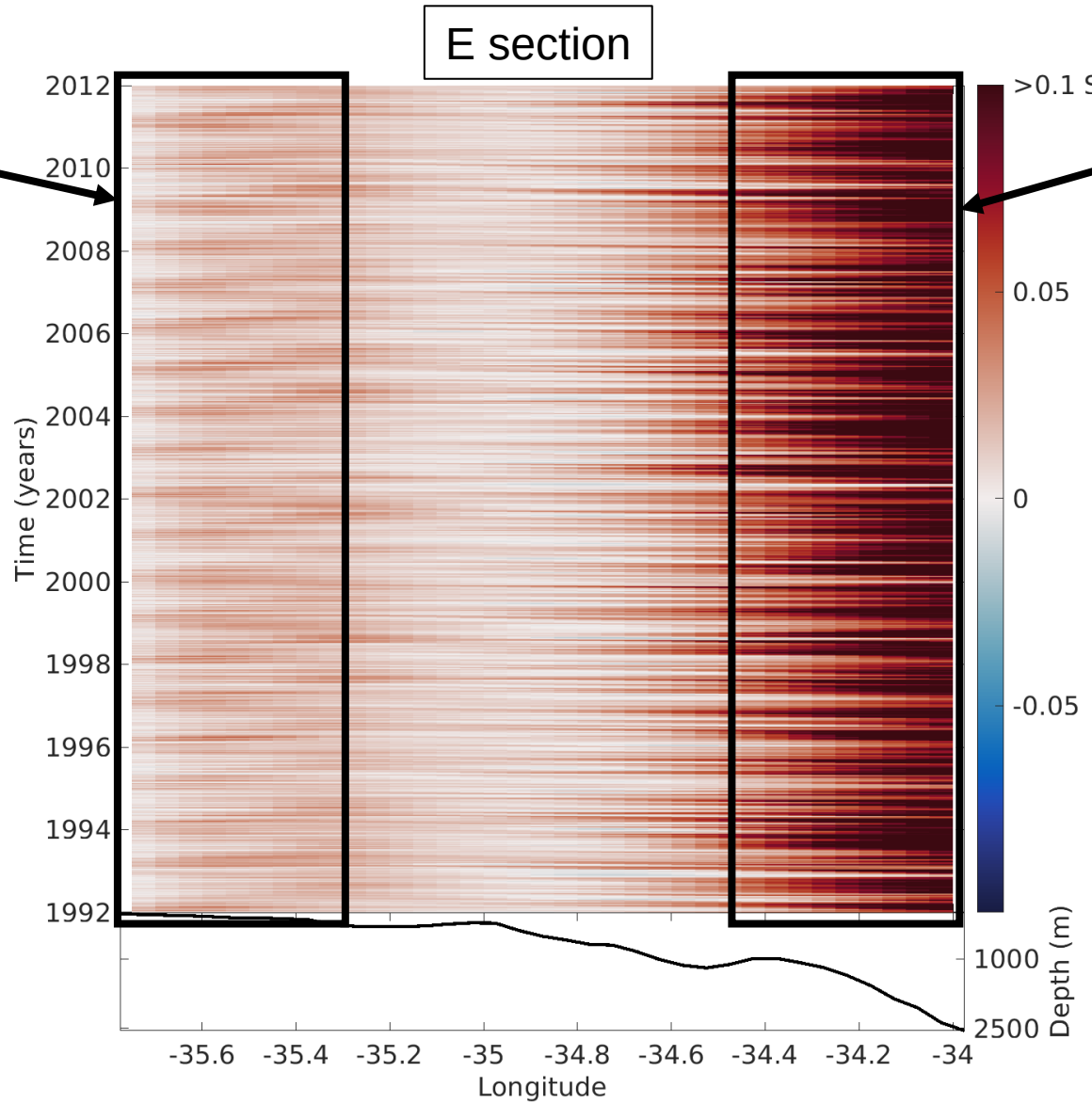
Oceanographic variability: impact of winds



Seasonal oceanographic variability

Seasonal baroclinic flows





Variability in strength of SACCF and proximity to shelf edge

Hovmöller plot

Variability in fluxes through a section (x) with time (y)

5-day mean fluxes integrated over upper 100 m

Summary

- **Strong connectivity along the northern shelf of South Georgia.**
  Variability in the ocean circulation, linked in part to the regional winds, drives temporal variability in transport from upstream.

- **Strong connectivity from the winter krill fishing grounds to the WCB.**
  Krill found in the fishing grounds in winter may be present in the WCB the following spring and summer.

- **Volume transport on and around the South Georgia shelf is linked to regional winds, and as a result to large-scale climate indices.**
  Understanding these mechanisms will be important for long-term ecosystem management at South Georgia.

Cecilia Liszka

British Antarctic Survey

Resolving ecosystem effects of the South Georgia winter krill fishery



Cecilia Liszka, Sophie Fielding, Norman Ratcliffe, Jen Jackson, Geraint Tarling, Tracey Dornan, Russell Leaper, Susannah Calderan, Paula Olson, Ryan Irvine, Klemens Pütz, Mark Belchier, Susan Gregory, Vicki Foster, Martin Collins

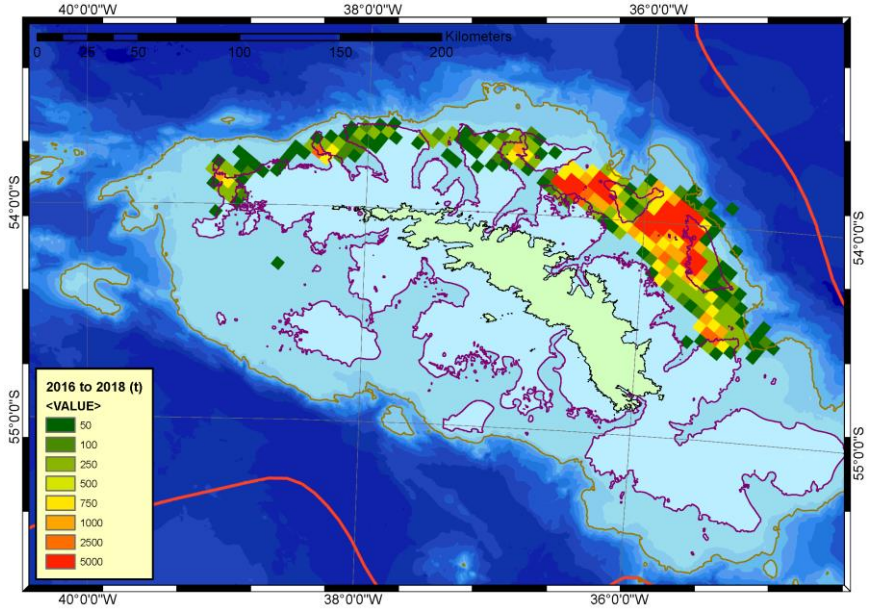
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

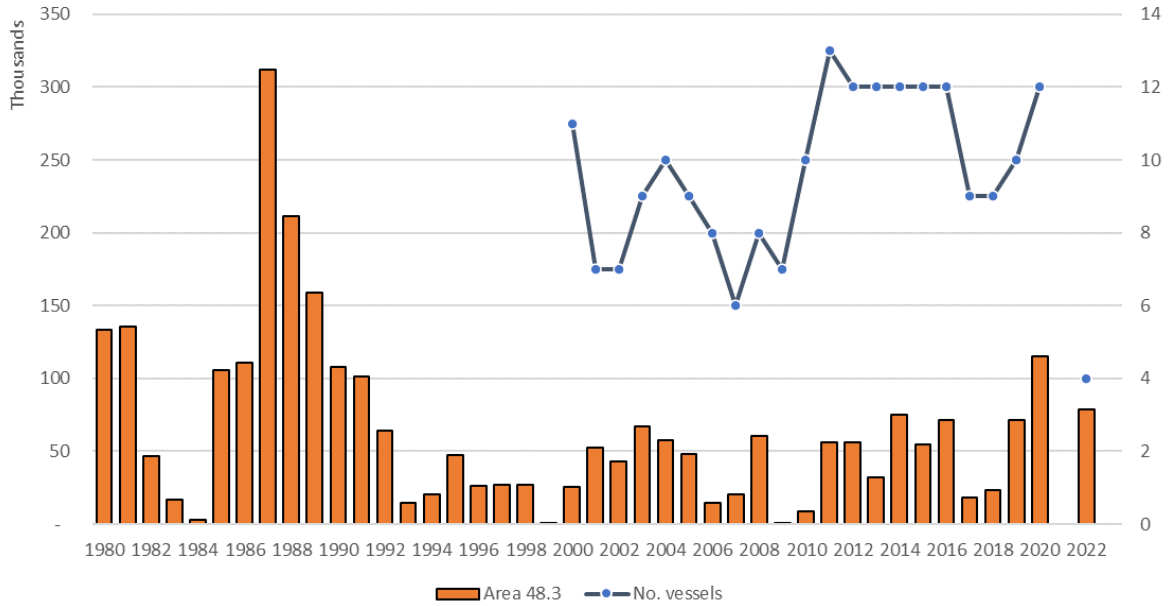
Government of South Georgia & the South Sandwich Islands

Krill, CCAMLR & the fishery

- Enhanced restrictions in SG MPA
  - Restricted to winter (May-Sept)
  - No fishing within 30 km NTZ
- Fishery concentrated on SG shelf
- Catches on increasing trend?
- CCAMLR require improved data for management

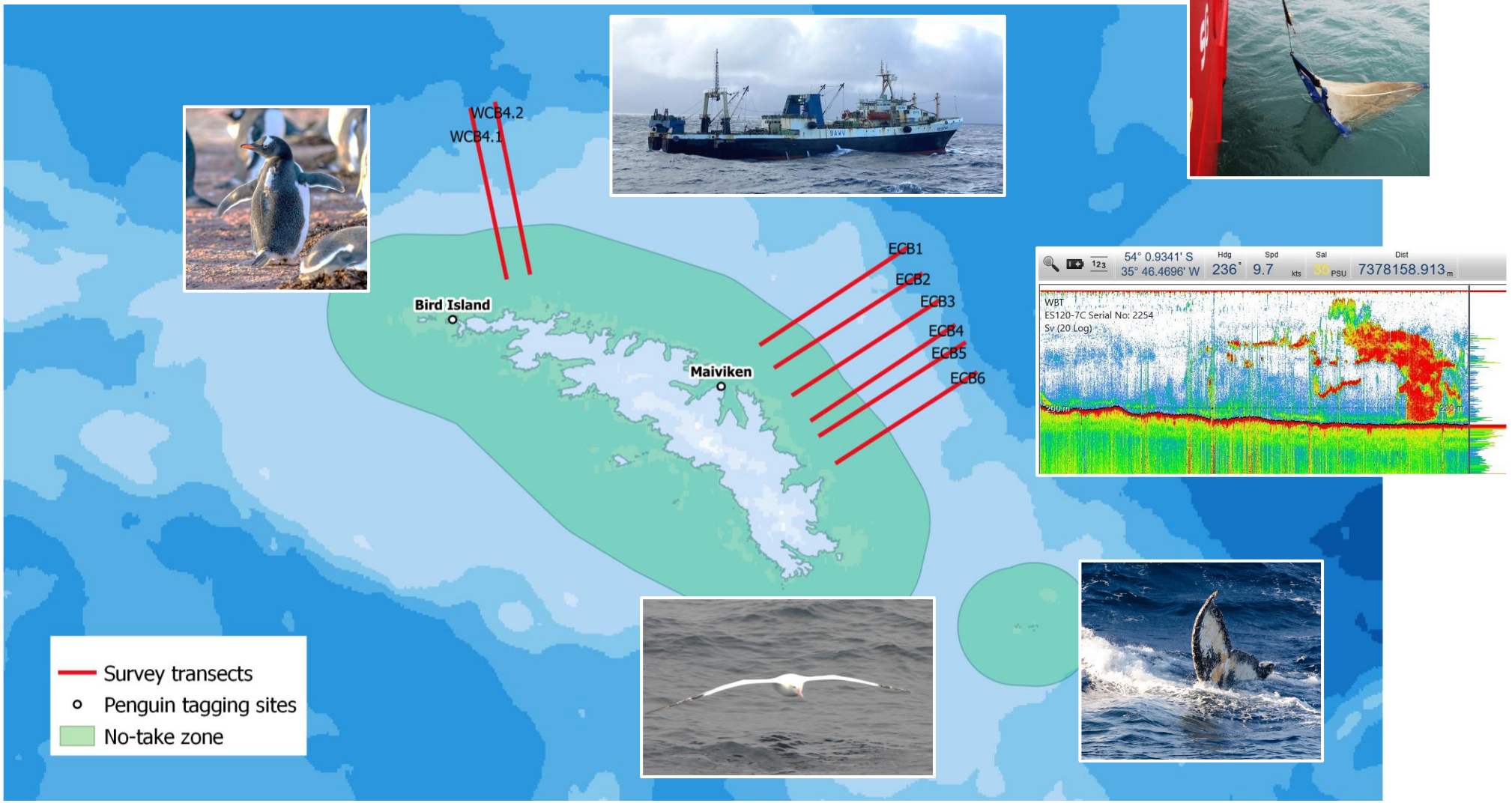
BUT…lack of winter data…





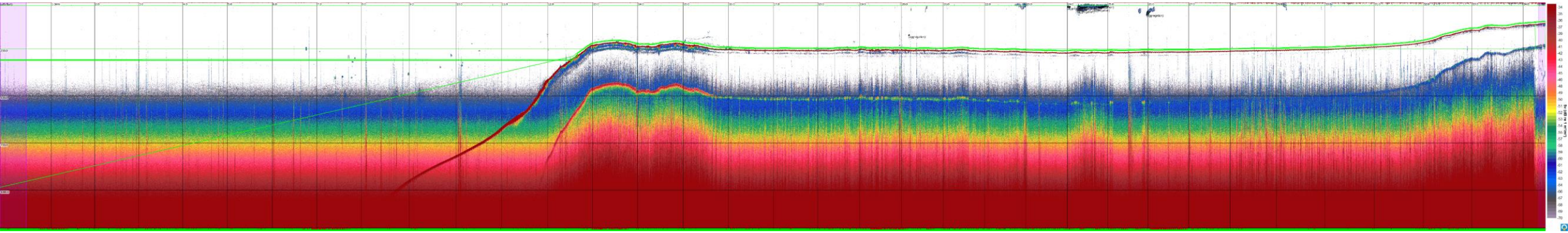
“Winter Krill Project” activities

- 2 years initially
- 3 winter surveys per year
- Krill acoustics – ECB 1-6 + WCB 4.1-4.2
- Plankton tows
- Seabird & marine mammal observations
- Penguin tracking
- Fishery operation

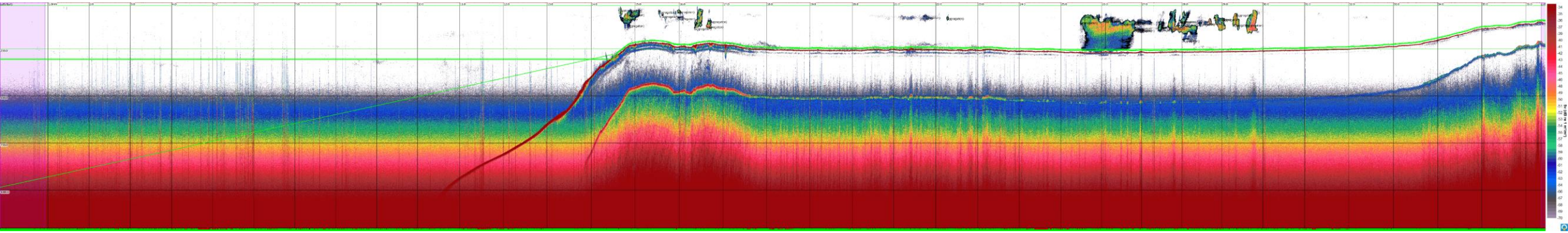


Example echograms: July – ECB6

DAY



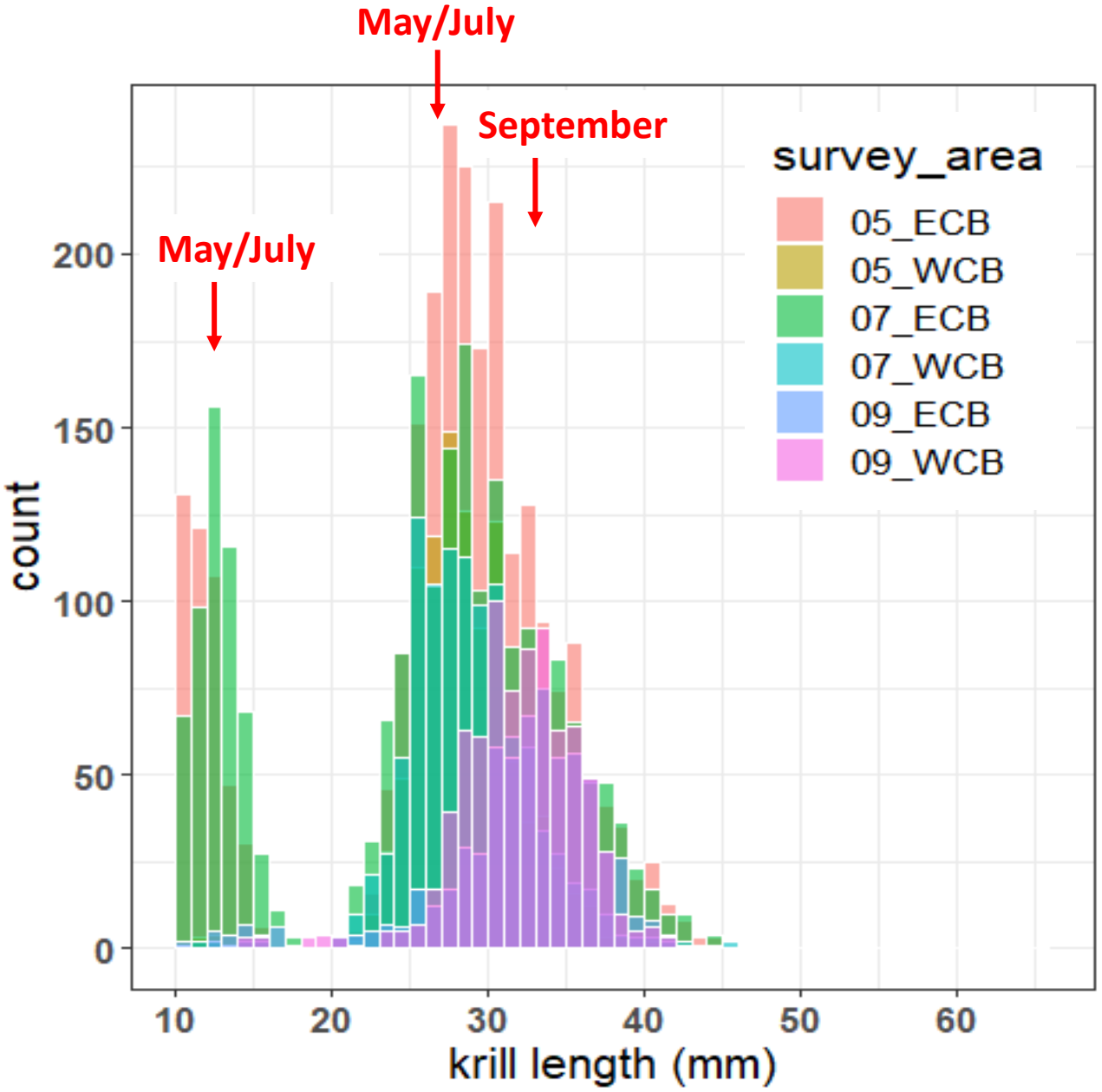
NIGHT



Krill length frequency

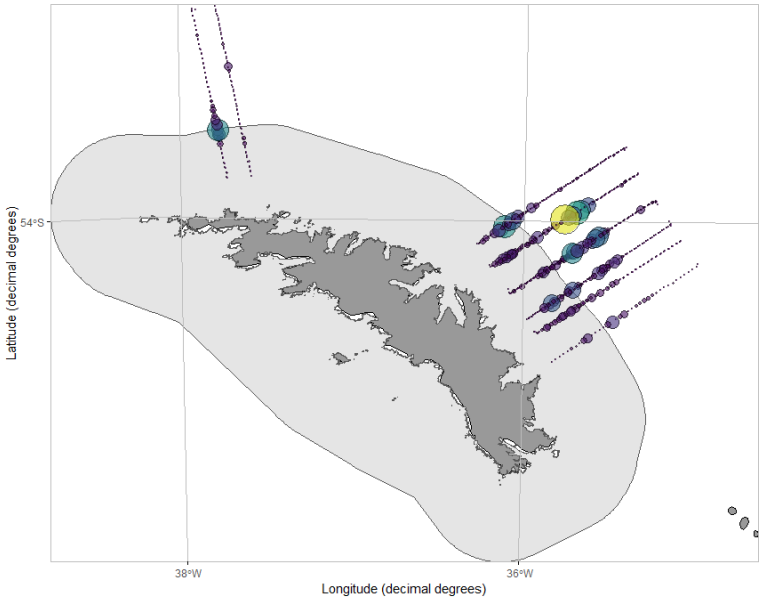
- Lots of krill caught in ECB in May (n=2485) and July (n=2173)
- Small – modal size 27-29 mm (ECB & WCB)
- 10-16 mm cohort in May/July

- Much less in ECB in September (n=649)
- Bigger – modal size 33 mm
- Smallest cohort gone

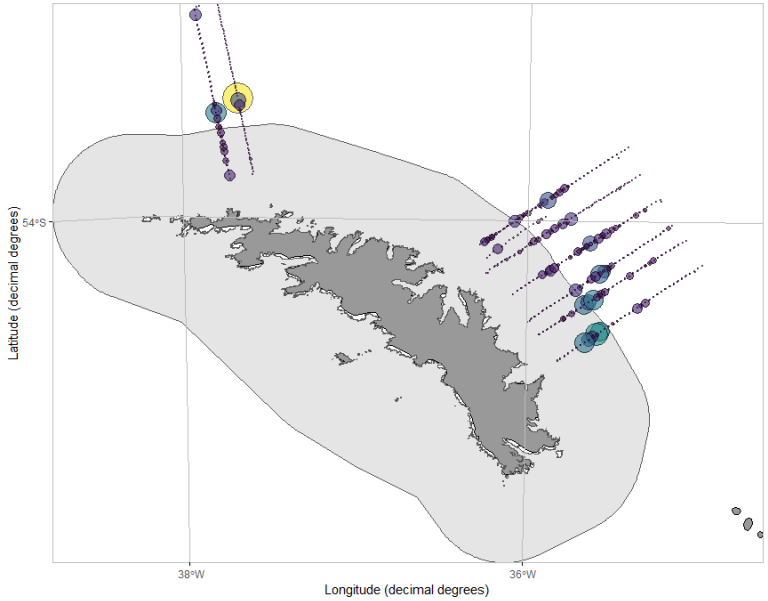


Krill density & biomass distribution – all transects

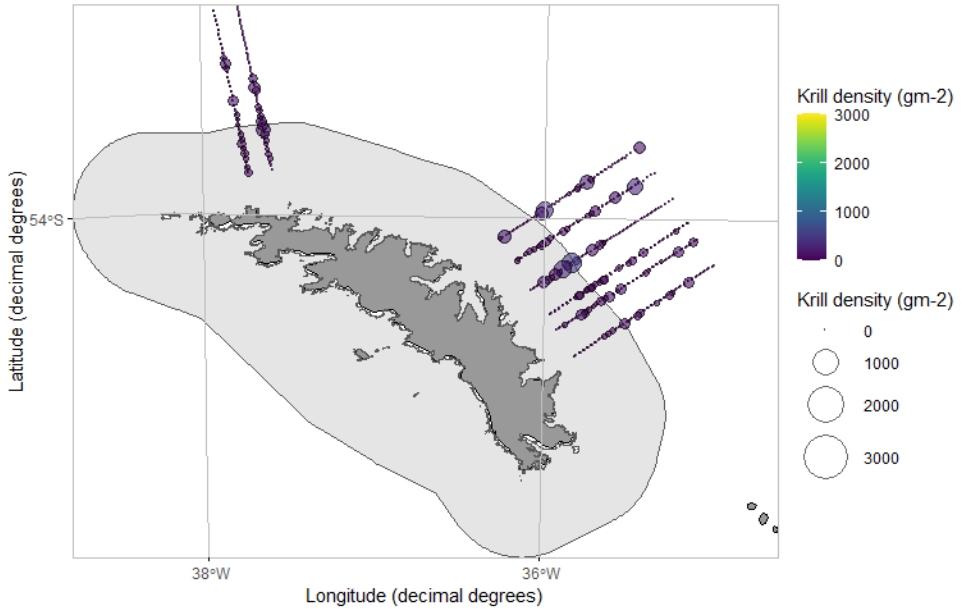
May



July

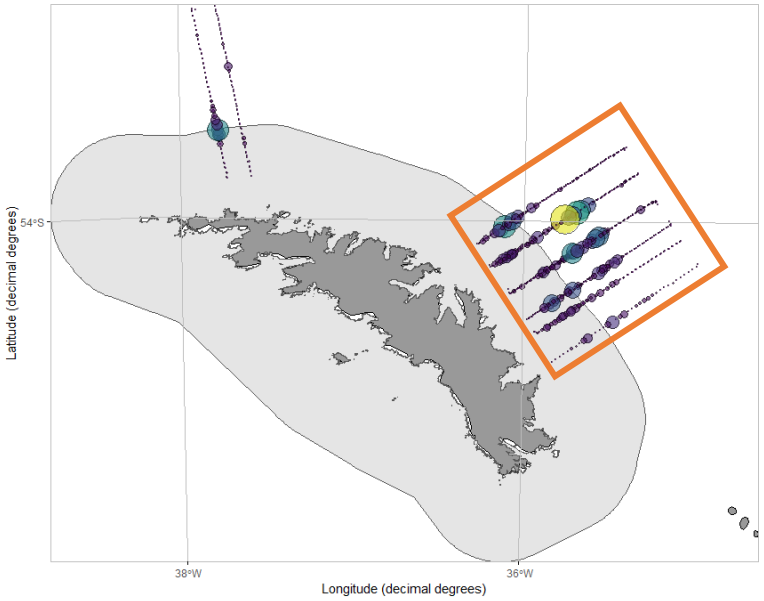


September



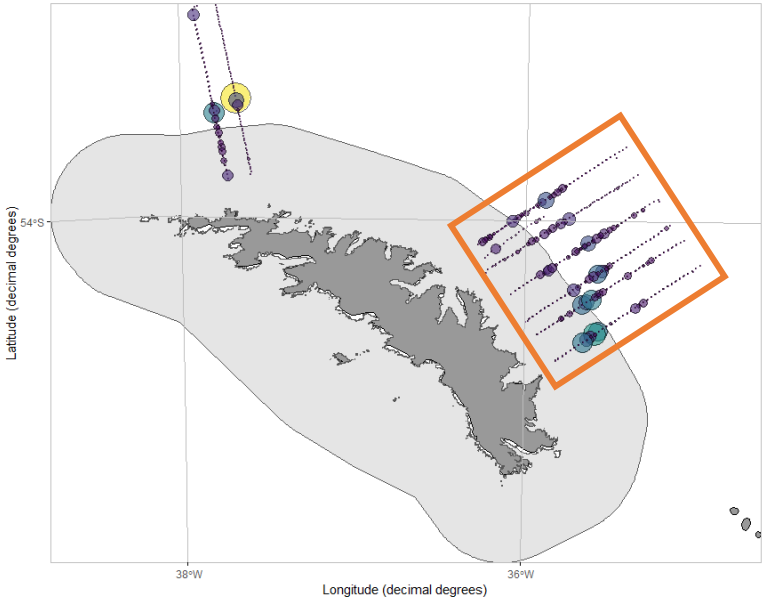
Krill density & biomass distribution – all transects

May



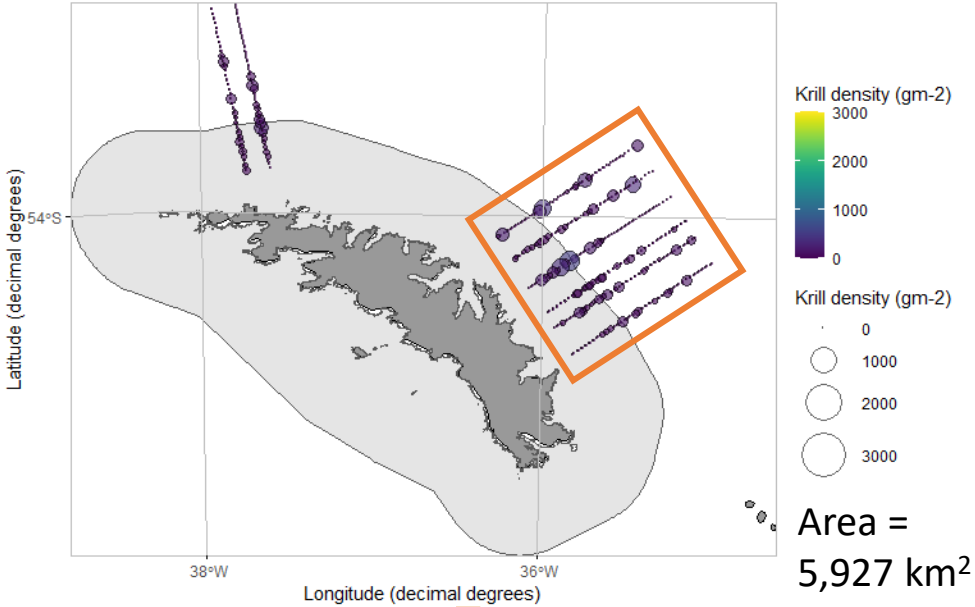
ECB mean krill density	45.3 g m^{-2}
ECB estimated biomass (tonnes)	268,500 tonnes

July



ECB mean krill density	42.1 g m^{-2}
ECB estimated biomass (tonnes)	249,800 tonnes

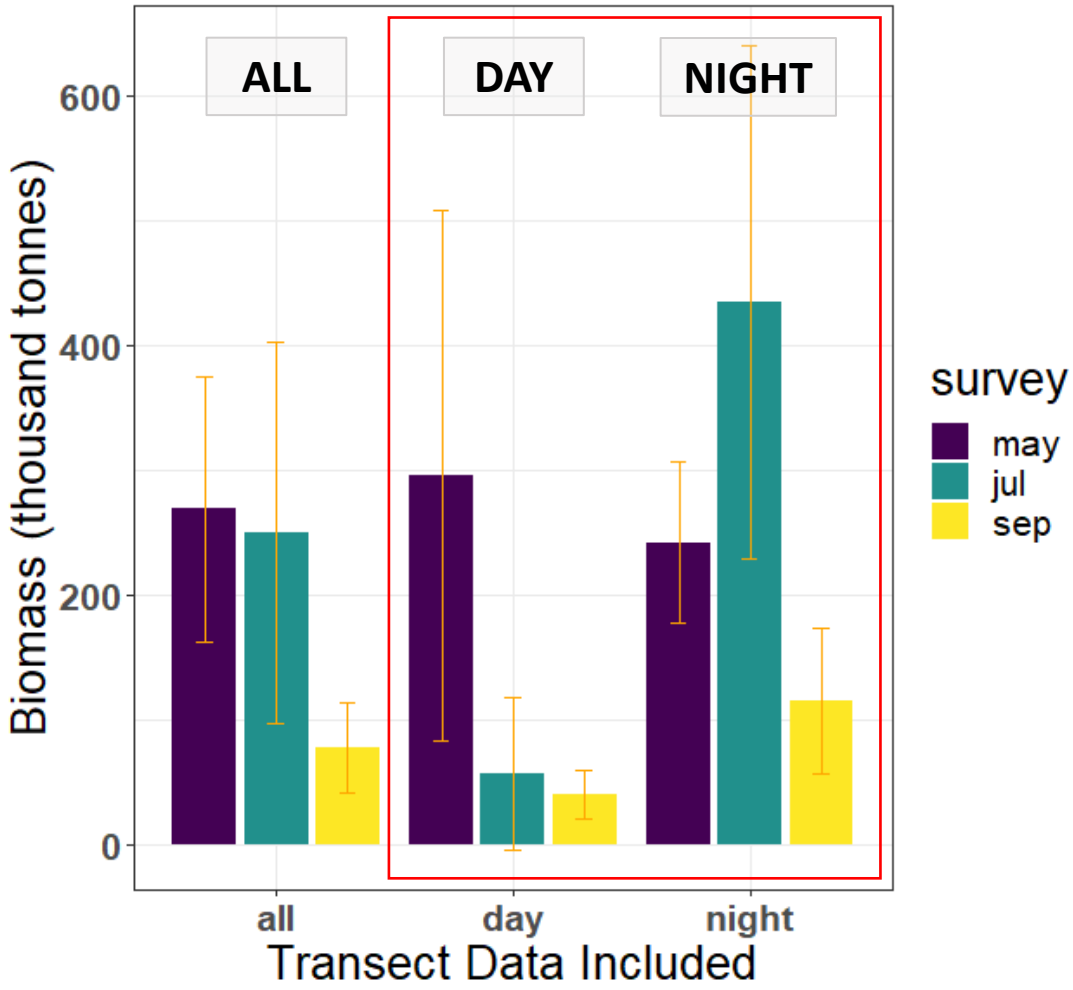
September



Area = 5,927 km^2

ECB mean krill density	13.0 g m^{-2}
ECB estimated biomass (tonnes)	76,800 tonnes

Winter krill biomass & density in ECB

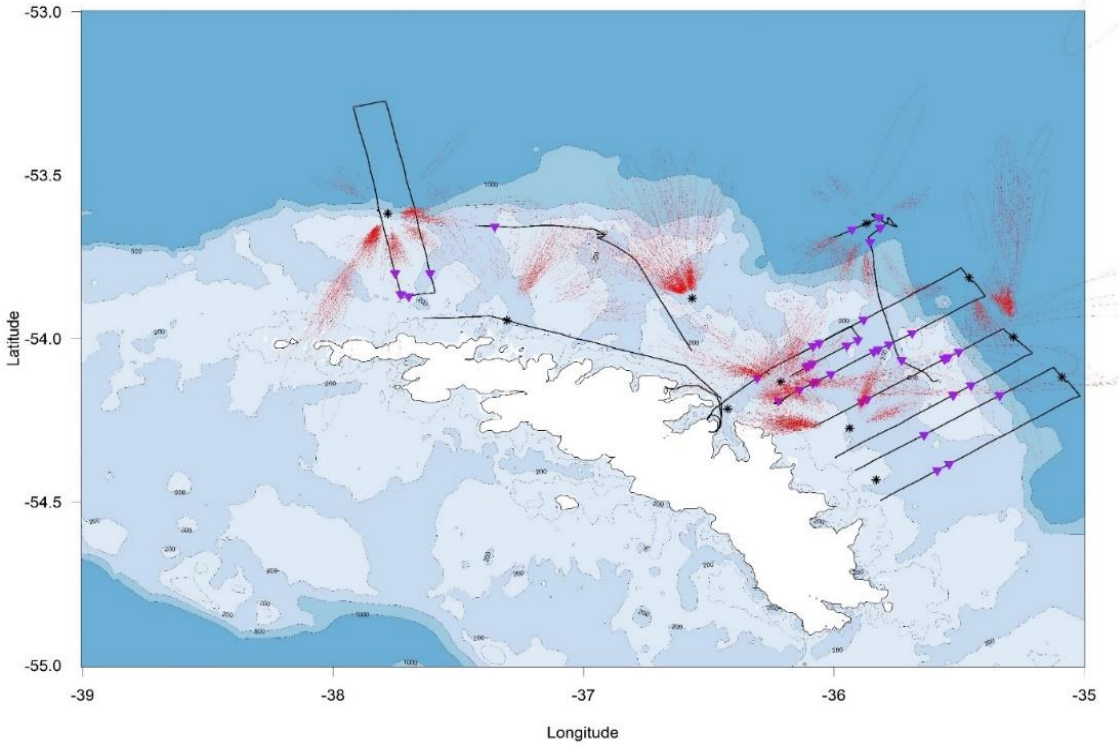


	NIGHT TRANSECTS			DAY TRANSECTS		
	MAY	JULY	SEPT	MAY	JULY	SEPT
Density (g m^{-2})	**40.8**	**73.3**	**19.4**	**49.9**	**9.6**	**6.8**
CV	14%	24%	26%	37%	55%	24%
Biomass (1000 tonnes)	**242**	**434**	**115**	**296**	**57**	**40**
Lower bound	117.18	228.37	56.50	83.10	-4.16	21.17
Upper bound	306.00	640.00	173.04	508.01	117.40	59.50

For context:
Krill density ranged from ~3 – 130 g m^{-2} in WCB over 1997-2013 (Fielding et al, 2014)

At-sea observations of seabirds & marine mammals

Humpback sightings & sonobuoy detections in July



Humpback fluke images submitted to Happywhale (www.happywhale.com) for photo-ID

At-sea observations of seabirds & marine mammals

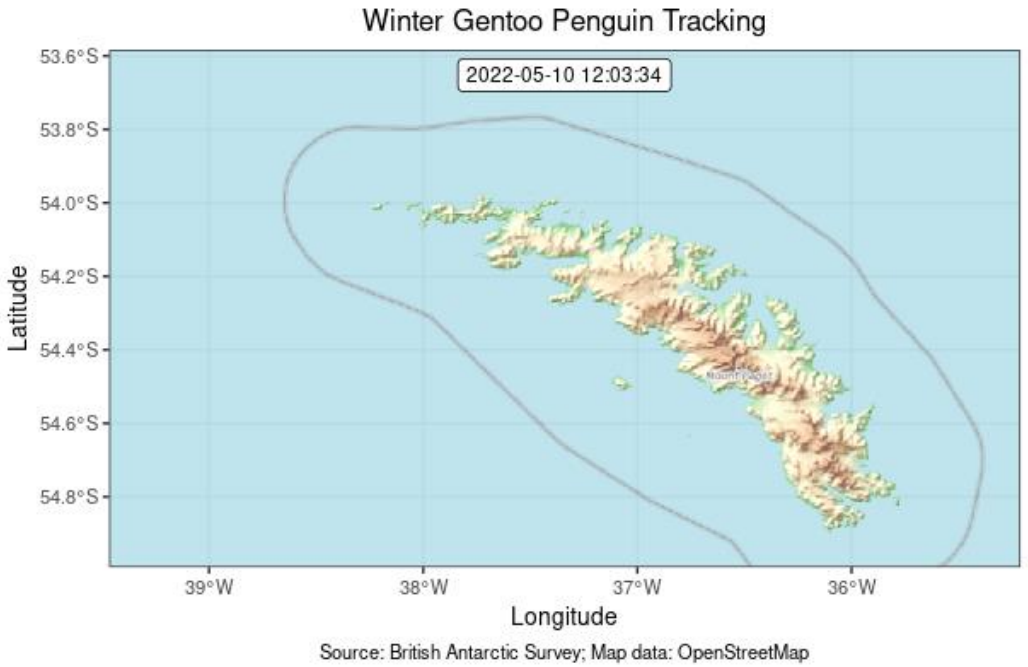
NOTE

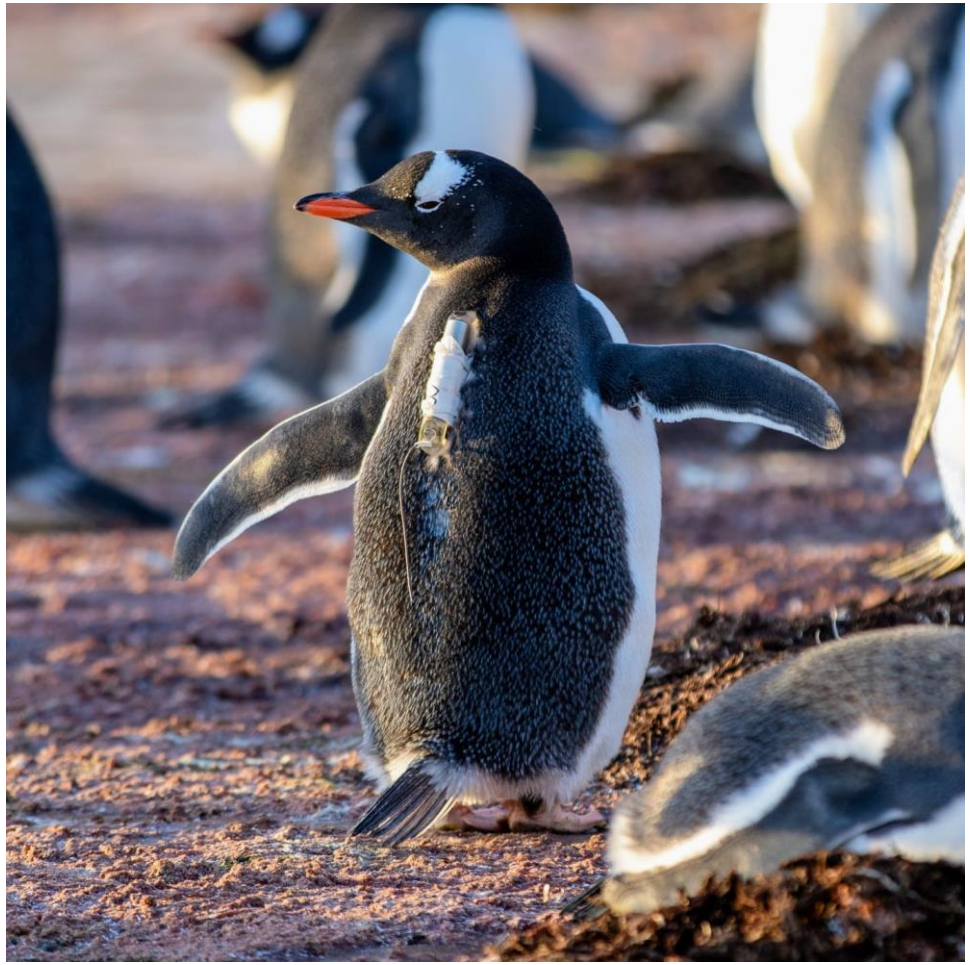
Marine Mammal Science

Observations of southern right whales (*Eubalaena australis*) surface feeding on krill in austral winter at South Georgia

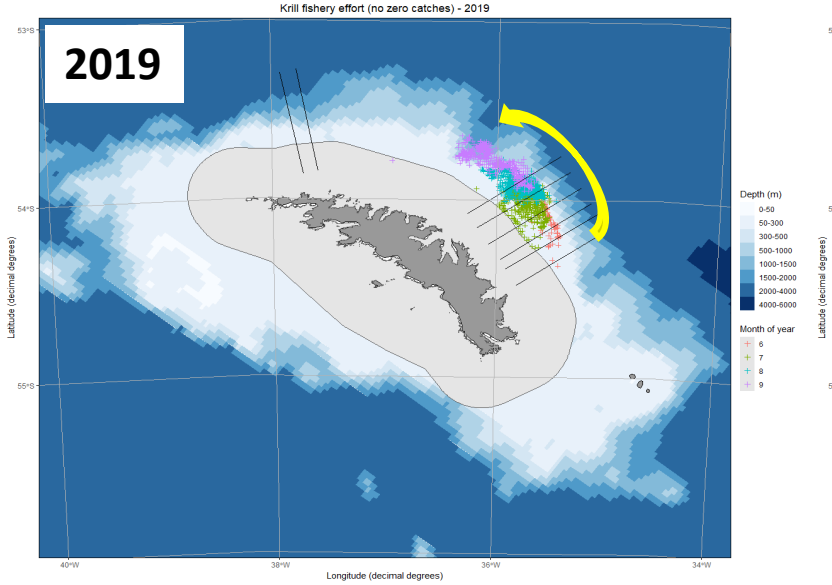
Susannah V. Calderan[1] | Tracey Dornan[2] | Sophie Fielding[2] | Ryan Irvine[3] | Jennifer A. Jackson[2] | Russell Leaper[4] | Cecilia M. Liszka[2] | Paula A. Olson[5] | Martin A. Collins[2]

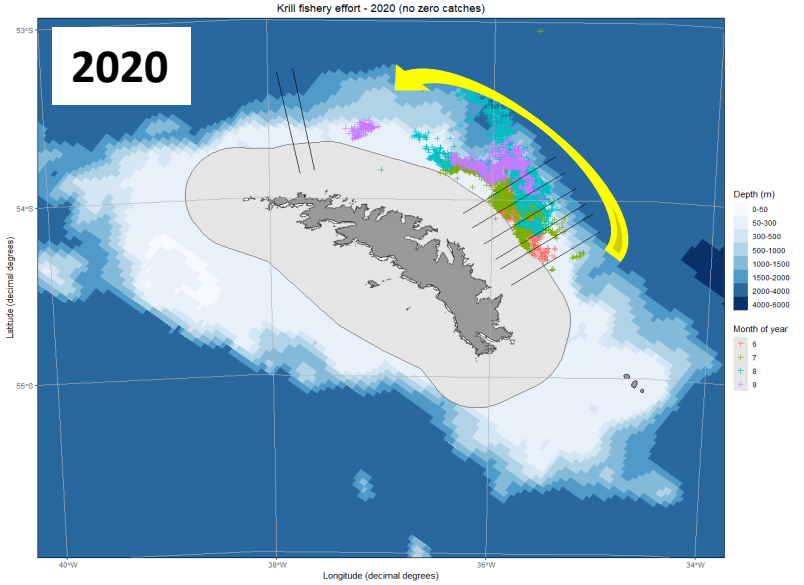
Gentoo penguin satellite tracking

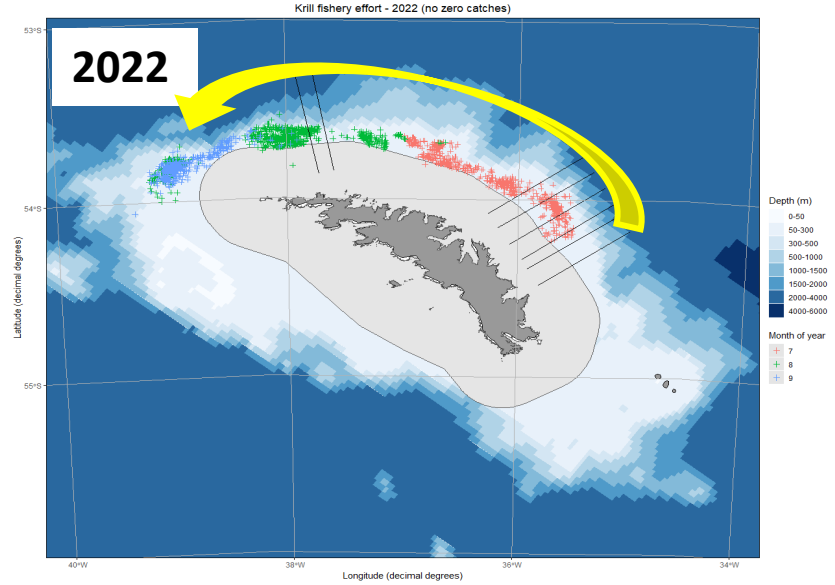


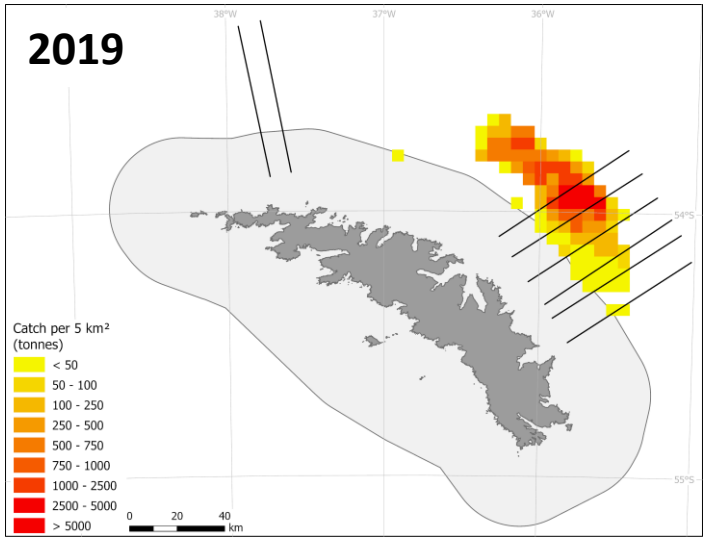


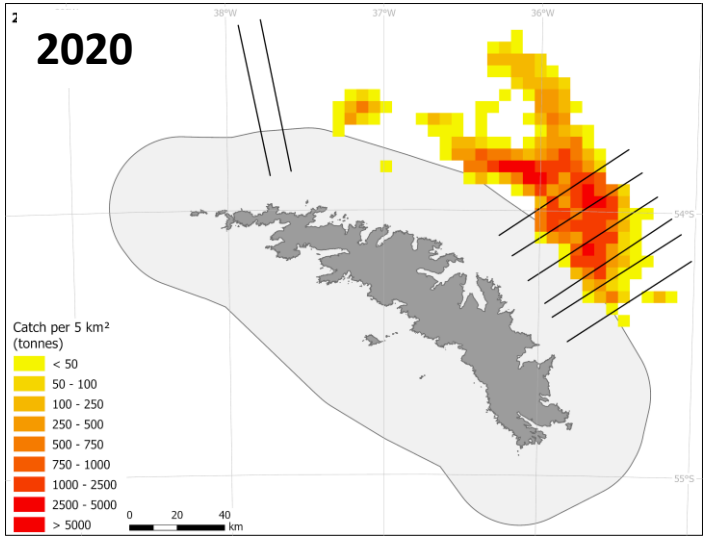
Distribution of fishery effort

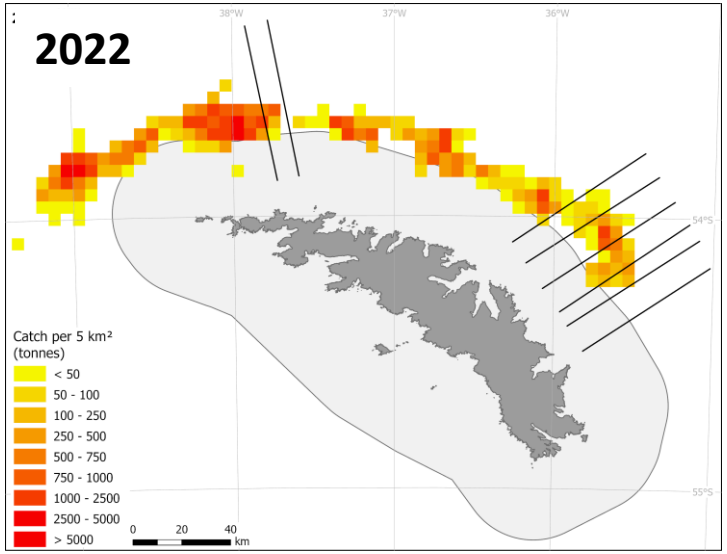












Thanks to our partners, funders, and KEP and Pharos teams ☺

Questions or comments: ceclis56@bas.ac.uk

https://www.bas.ac.uk/project/winter-krill-at-south-georgia/

Simeon Hill

British Antarctic Survey


ESA


Sue G


BFSAI

Krill & Climate Change

Simeon Hill

GSGSSI Marine Protected Area 5-Year Review Science Symposium

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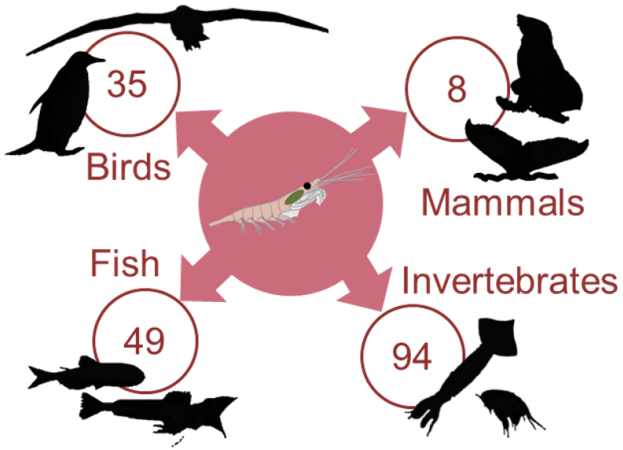
Antarctic krill is a key species in the Southern Ocean… including SG & the SSI

Hill & Thorpe in press

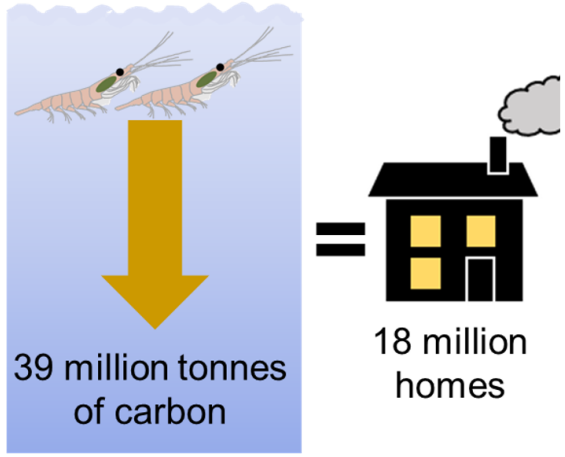
Antarctic krill is a key species in the Southern Ocean… including SG & the SSI

Number of krill

Number of species that eat krill

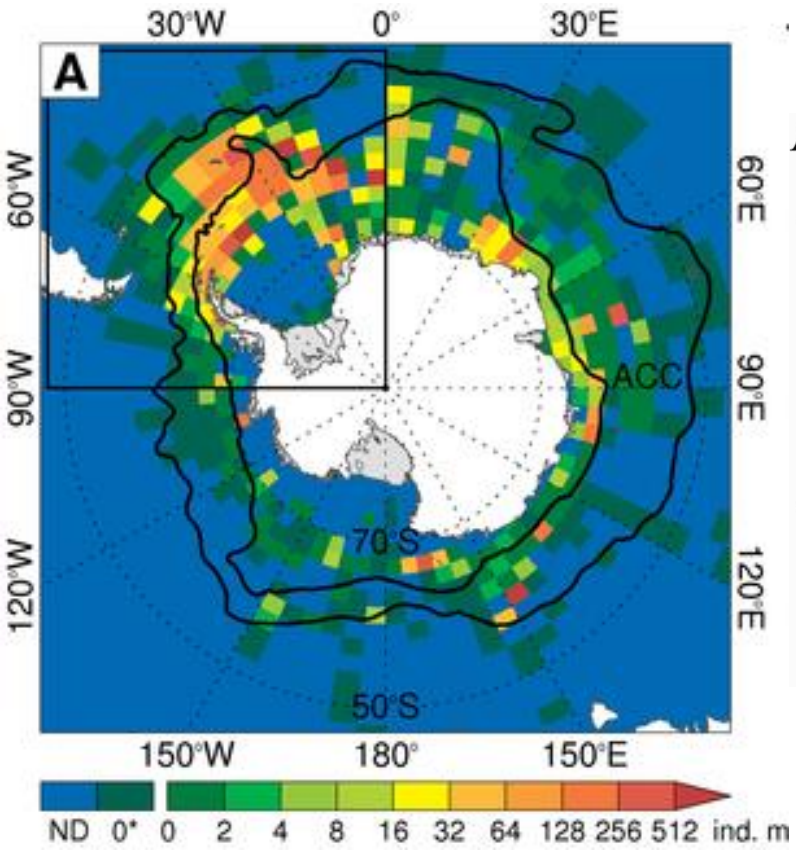


How krill help to slow down climate change

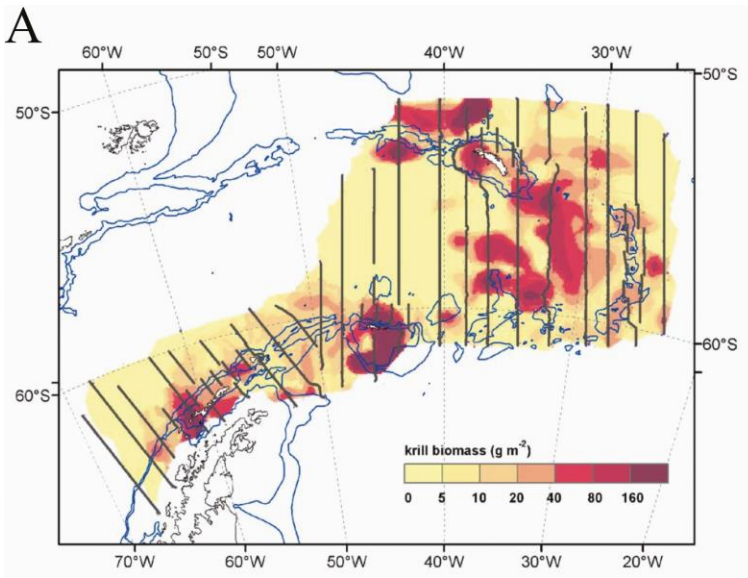


Hill & Thorpe in press

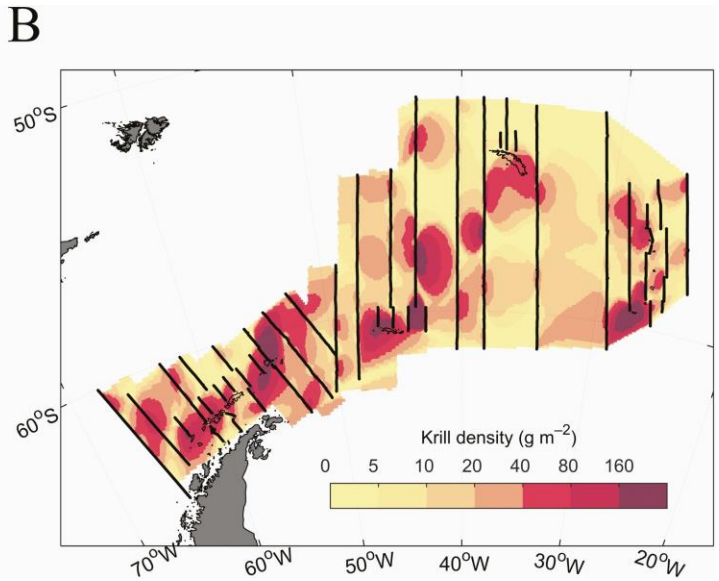
Antarctic krill is a key species in the Southern Ocean… including SG & the SSI



2000

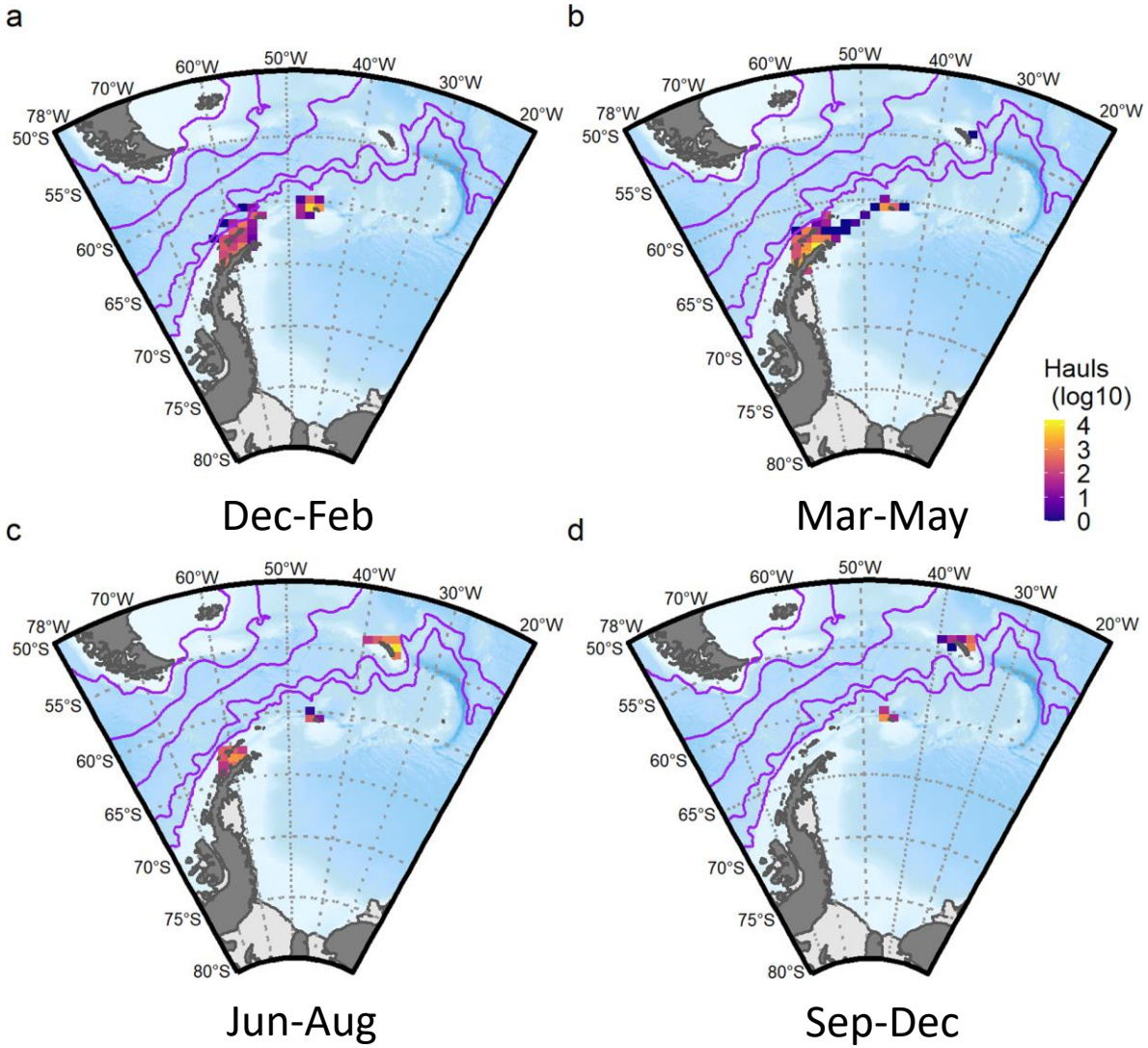


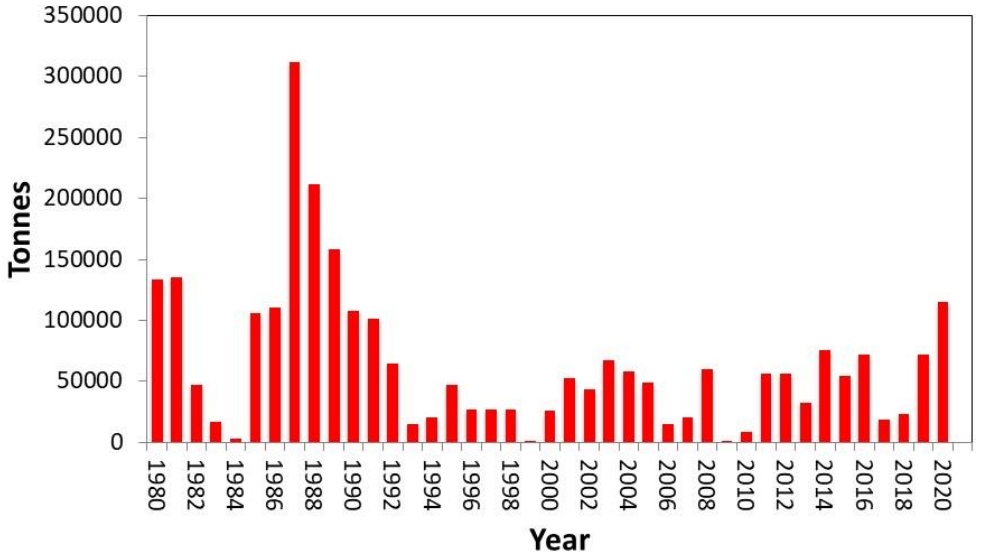
2019



Hill et al 2013 https://doi.org/10.1371/journal.pone.0072246
Krafft et al 2021 https://doi.org/10.1093/jcbiol/ruab046

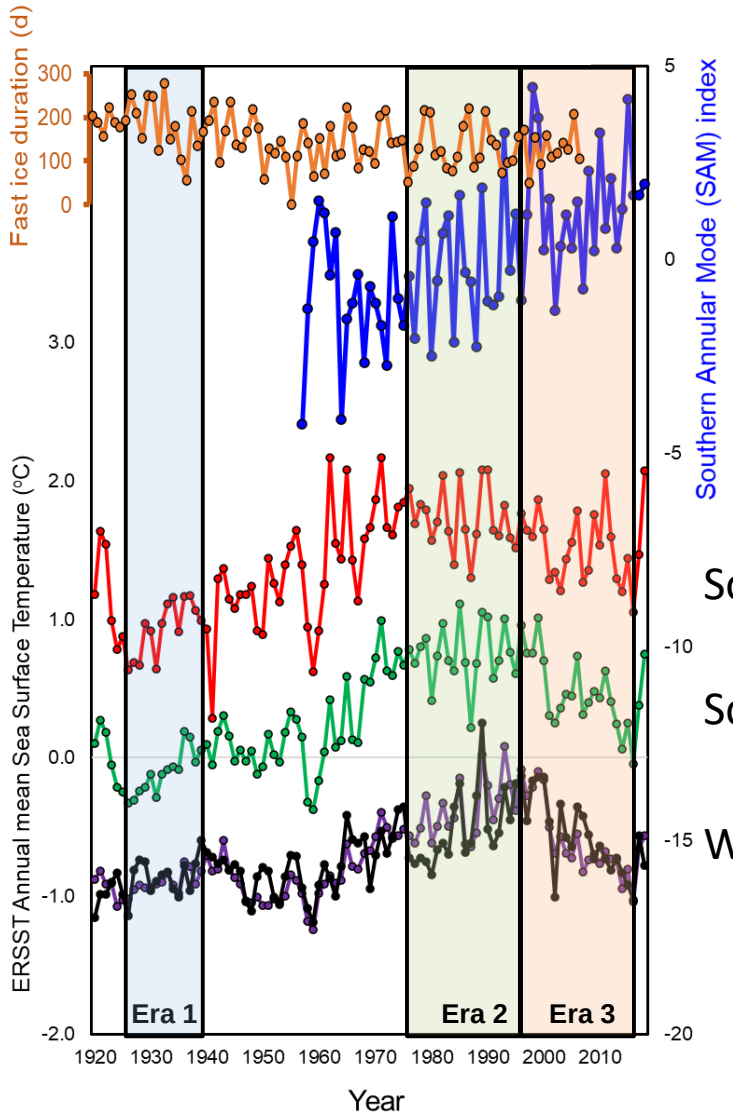
Antarctic krill is a key species in the Southern Ocean… including SG & the SSI





Meyer et al 2021 https://doi.org/10.1038/s43247-020-00026-1
CCAMLR data

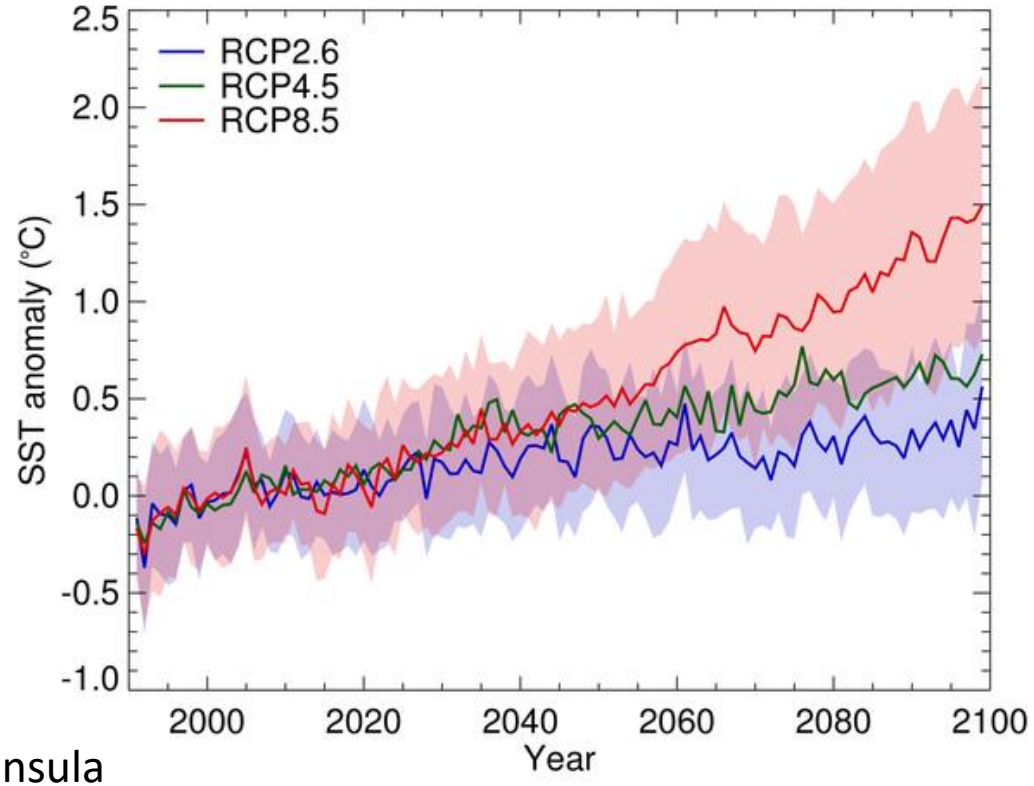
The climate has changed rapidly and will continue to do so



South Georgia

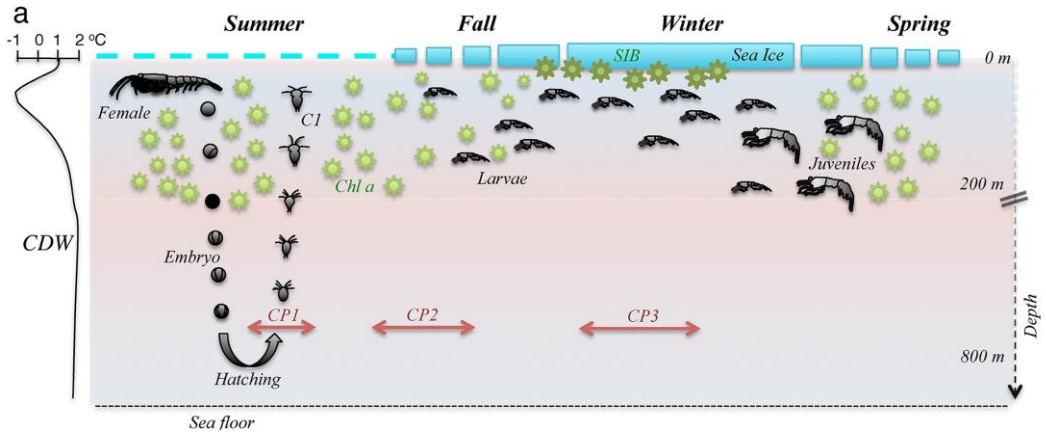
Scotia Sea

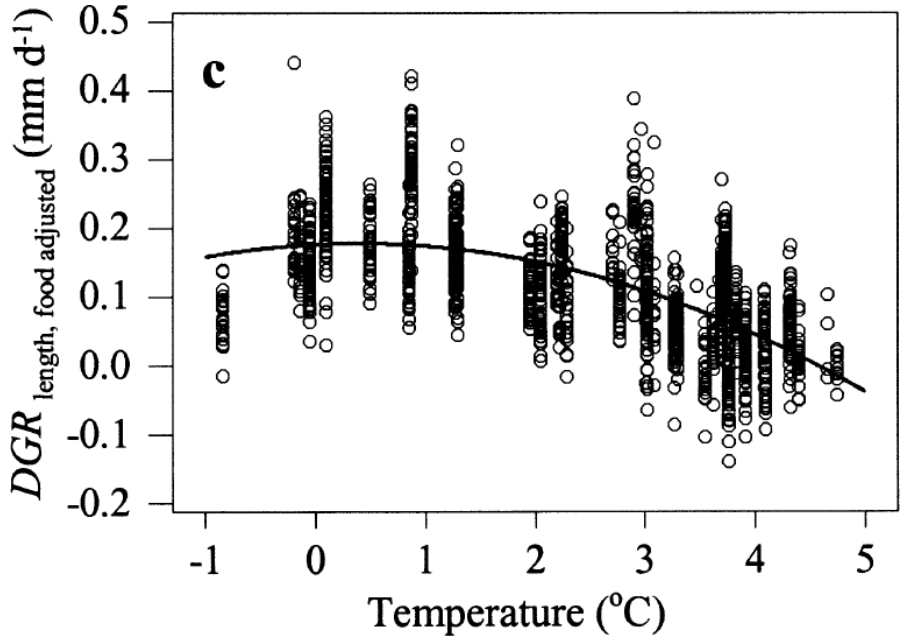
West Antarctic Peninsula



Atkinson et al 2021 https://doi.org/10.1111/gcb.16009
Hill et al 2013 https://doi.org/10.1371/journal.pone.0072246

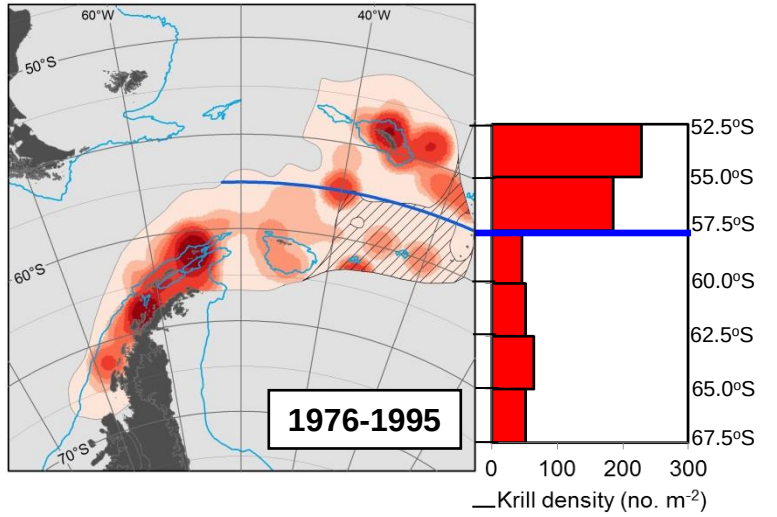
Why does this matter?

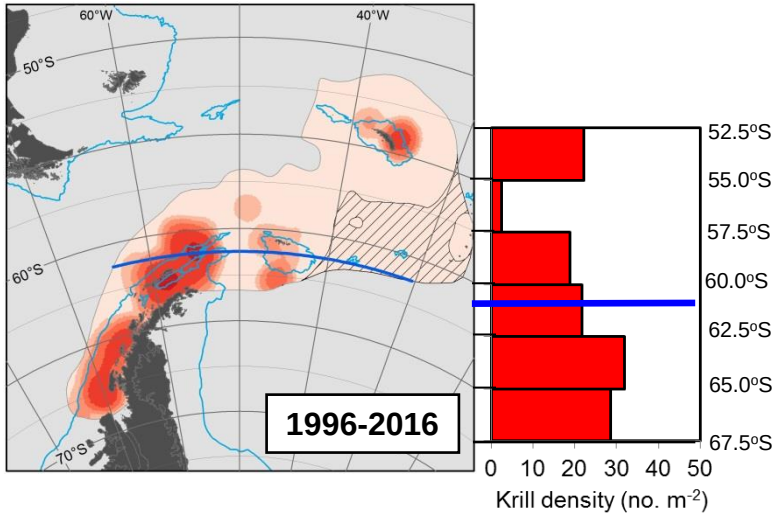


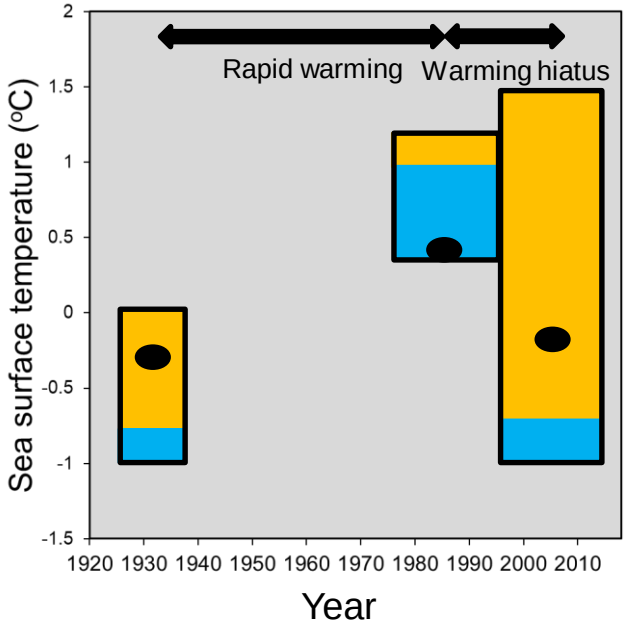


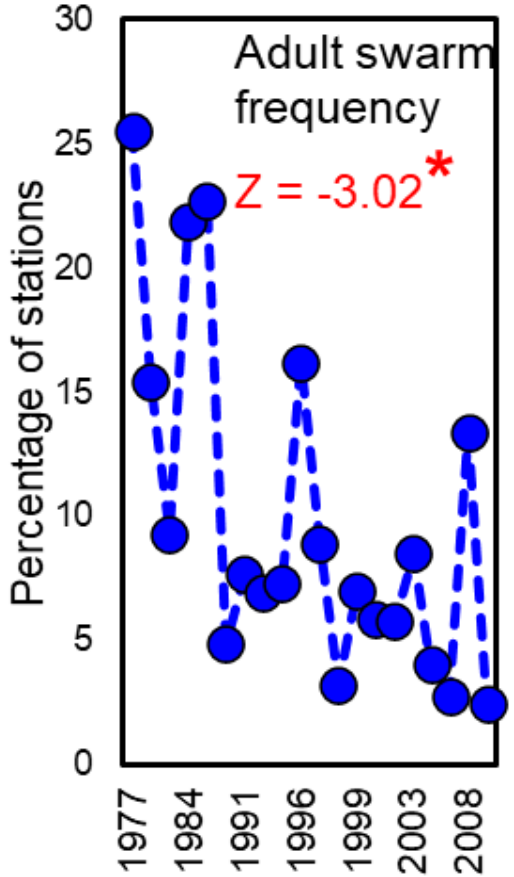
Piñones & Fedorov 2016 https://doi.org/10.1002/2016GL069656
Atkinson et al 2006 https://doi.org/10.4319/lo.2006.51.2.0973

Has the krill population changed?



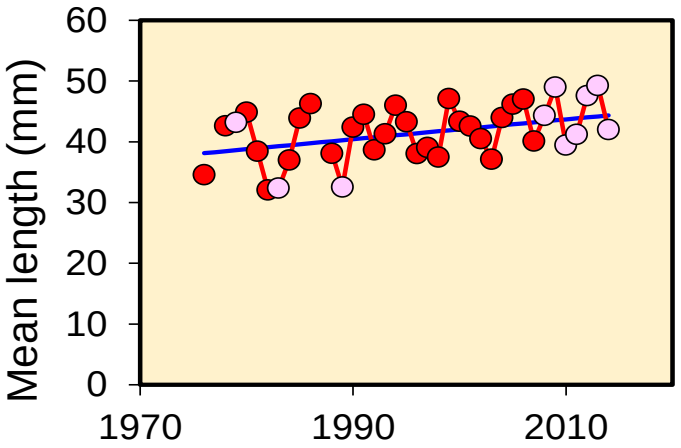


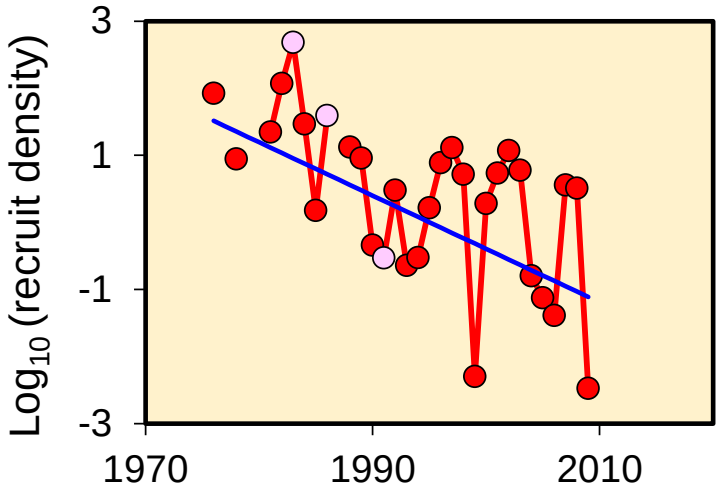




Atkinson et al 2019 https://doi.org/10.1038/s41558-018-0370-z
Atkinson et al 2021 https://doi.org/10.1111/gcb.16009

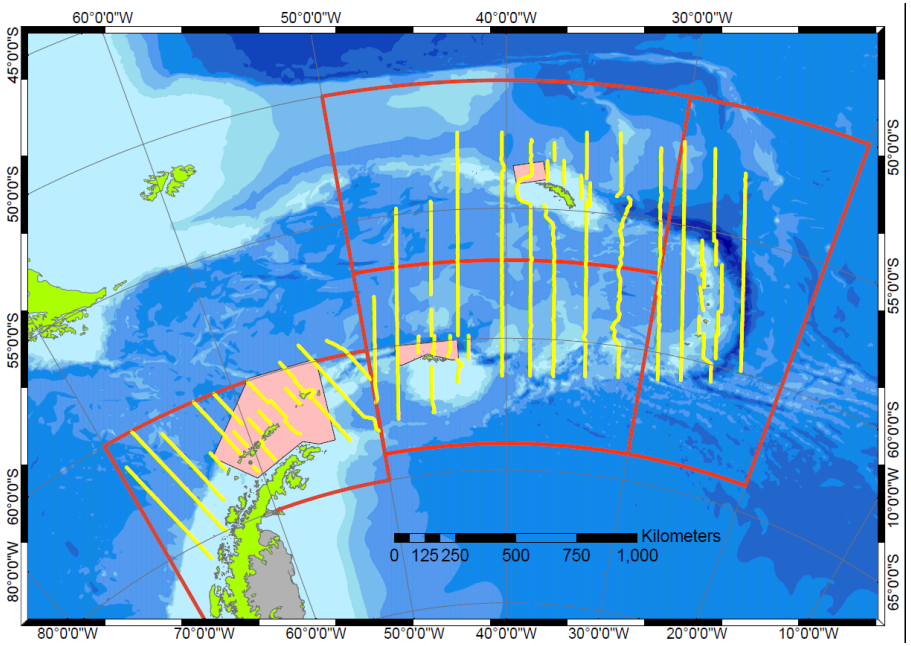
Has the krill population changed?

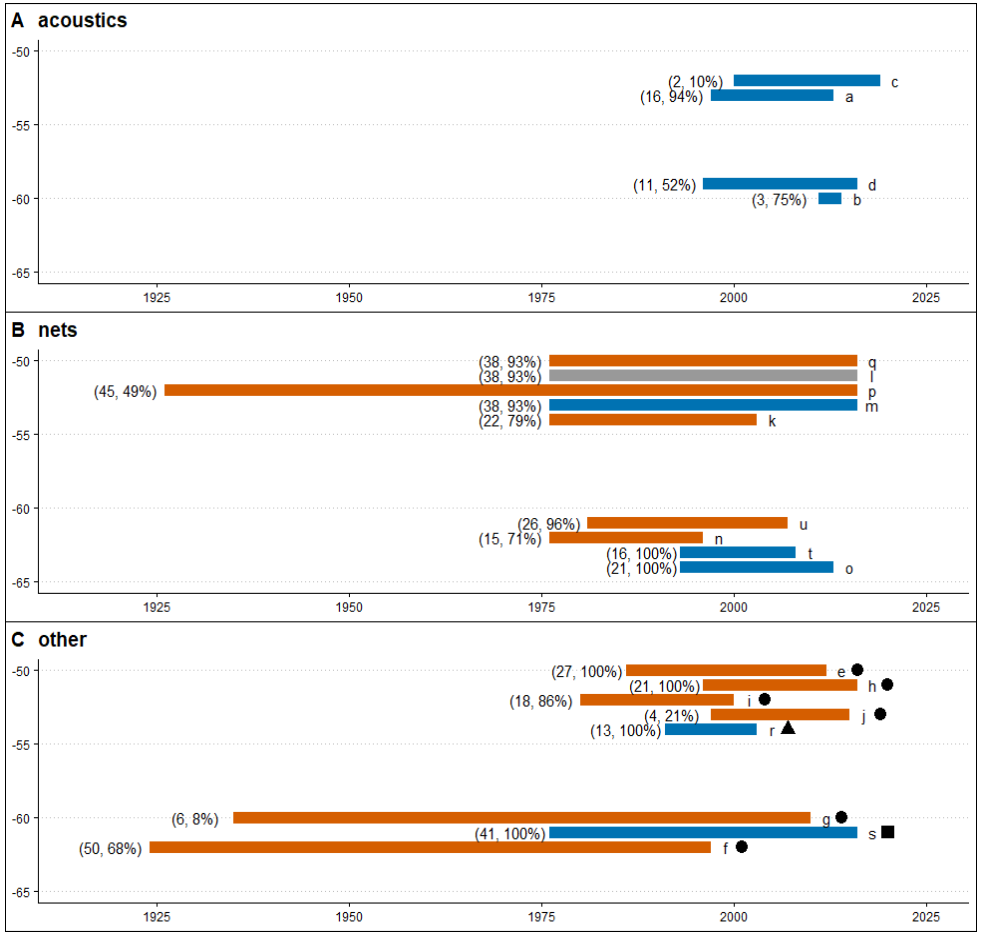




Atkinson et al 2019 https://doi.org/10.1038/s41558-018-0370-z

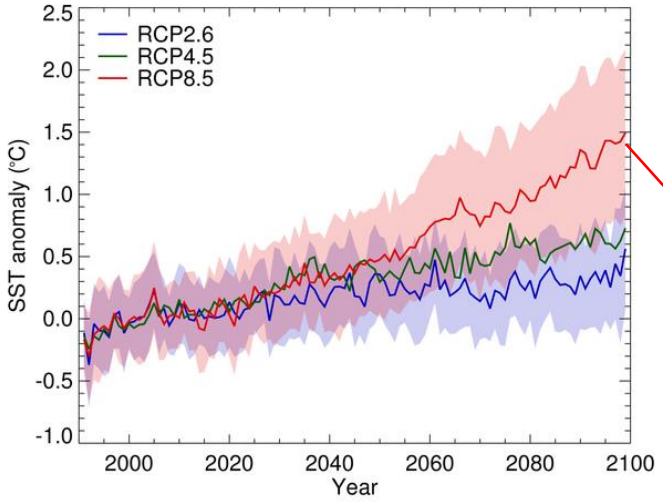
Are you sure?





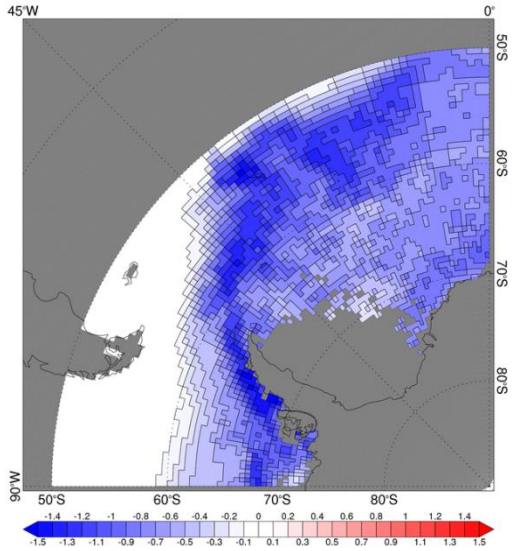
Hill et al 2016 *CCAMLR Science Vol 23*
Hill et al in rev

The future

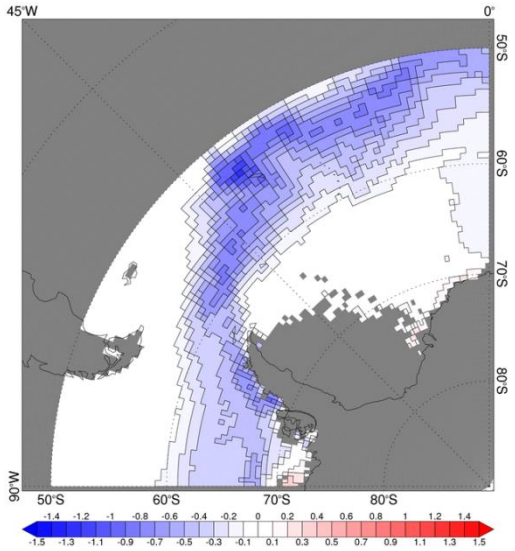


RCP 8.5

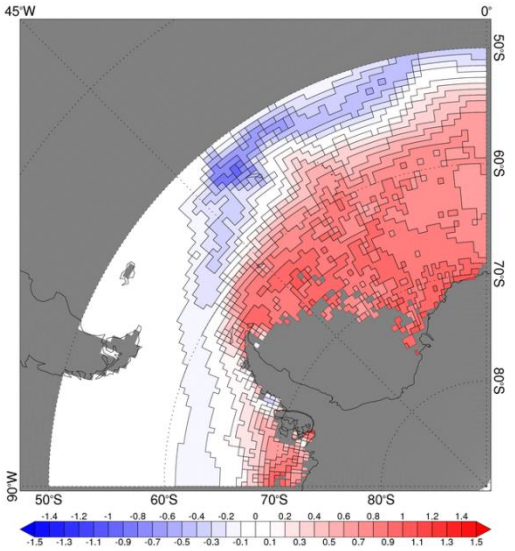
Chl-a * 0.5



Climatological Chl-a

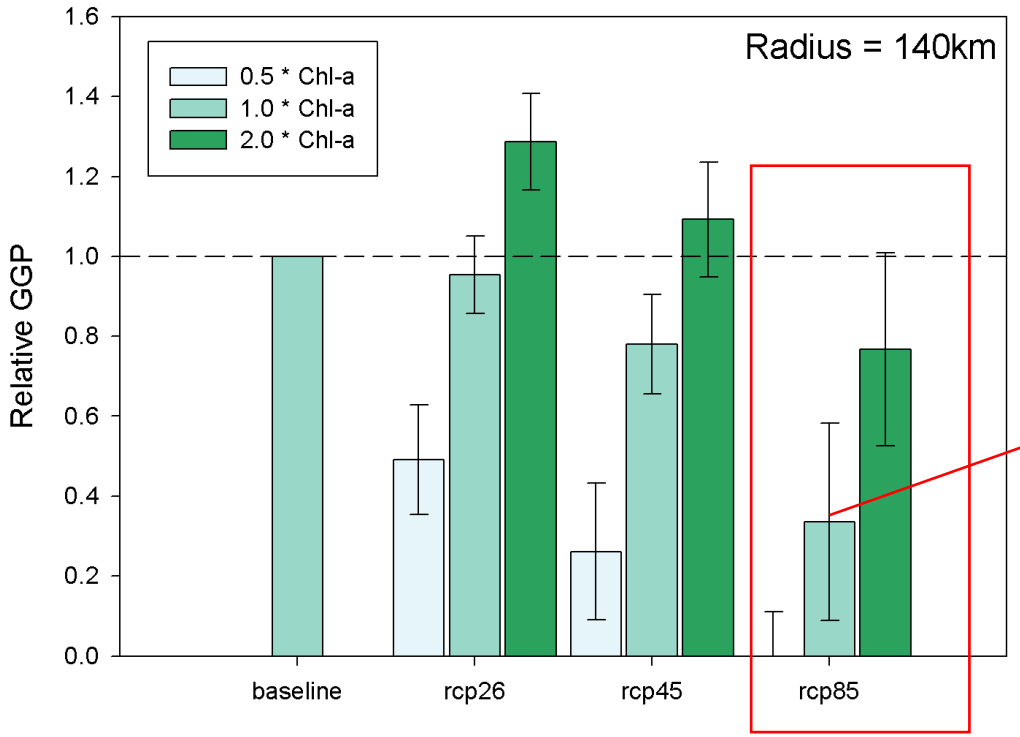


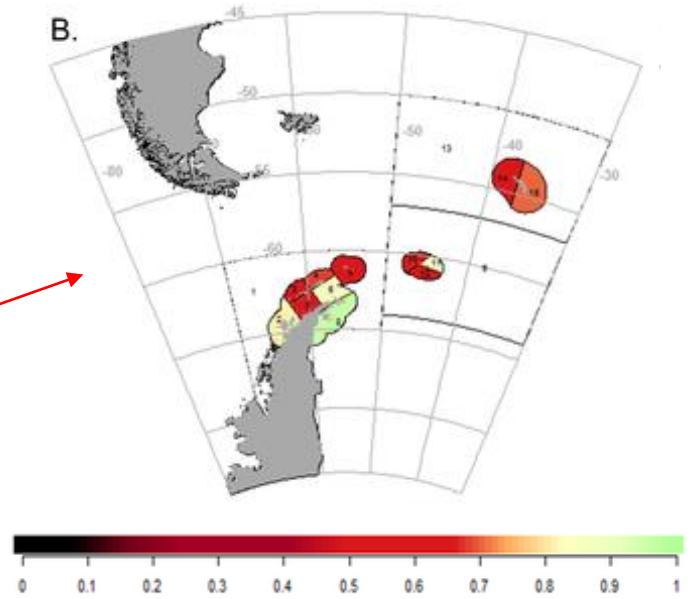
Chl-a * 2.0



Hill et al 2013 https://doi.org/10.1371/journal.pone.0072246

Krill predators

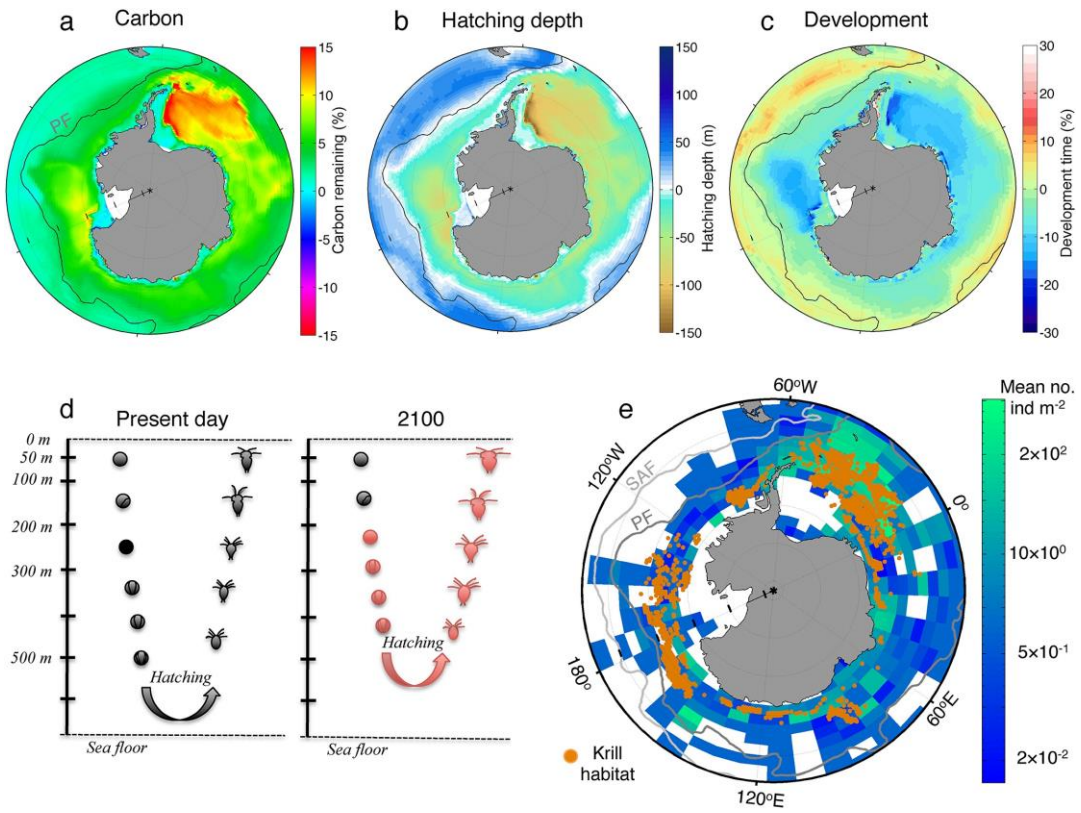


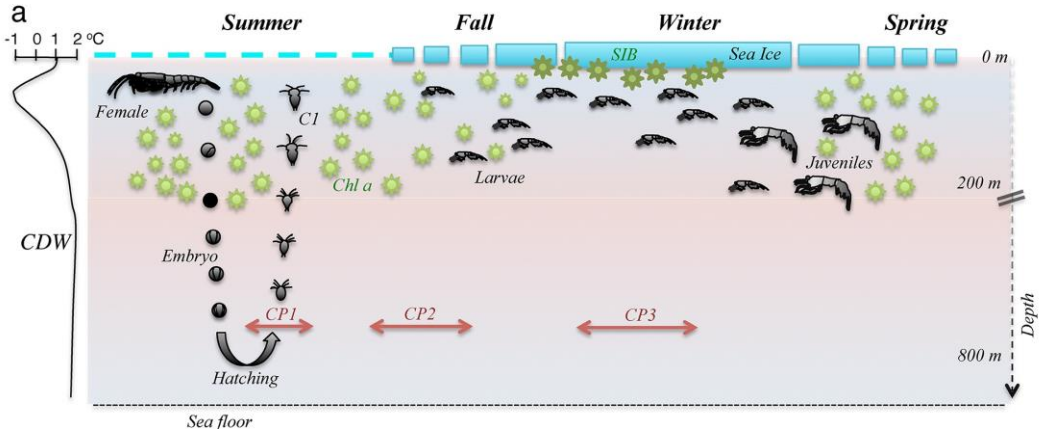


Proportion of abundance compared to no climate change

Hill et al 2013 https://doi.org/10.1371/journal.pone.0072246
Klein et al 2018 https://doi.org/10.1371/journal.pone.0191011

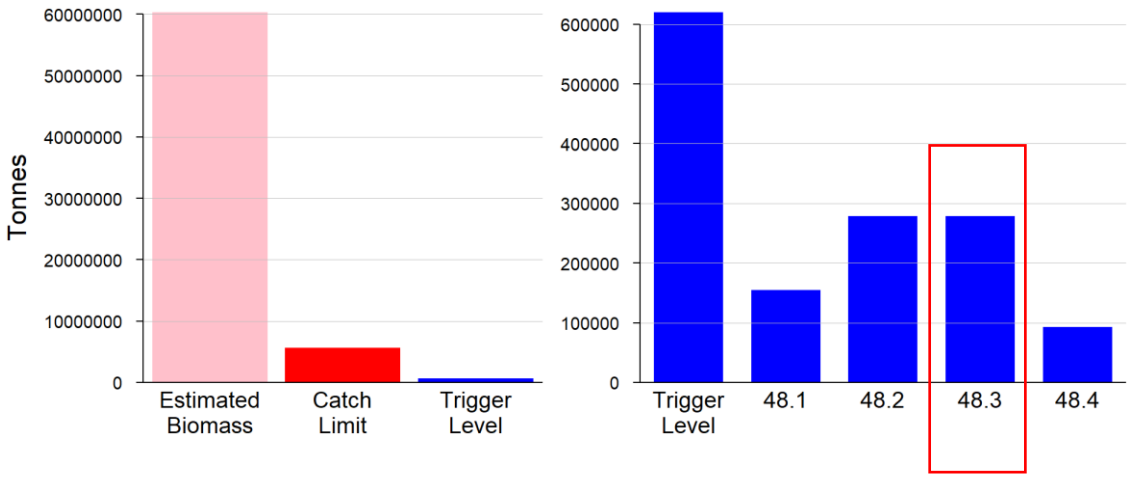
The future

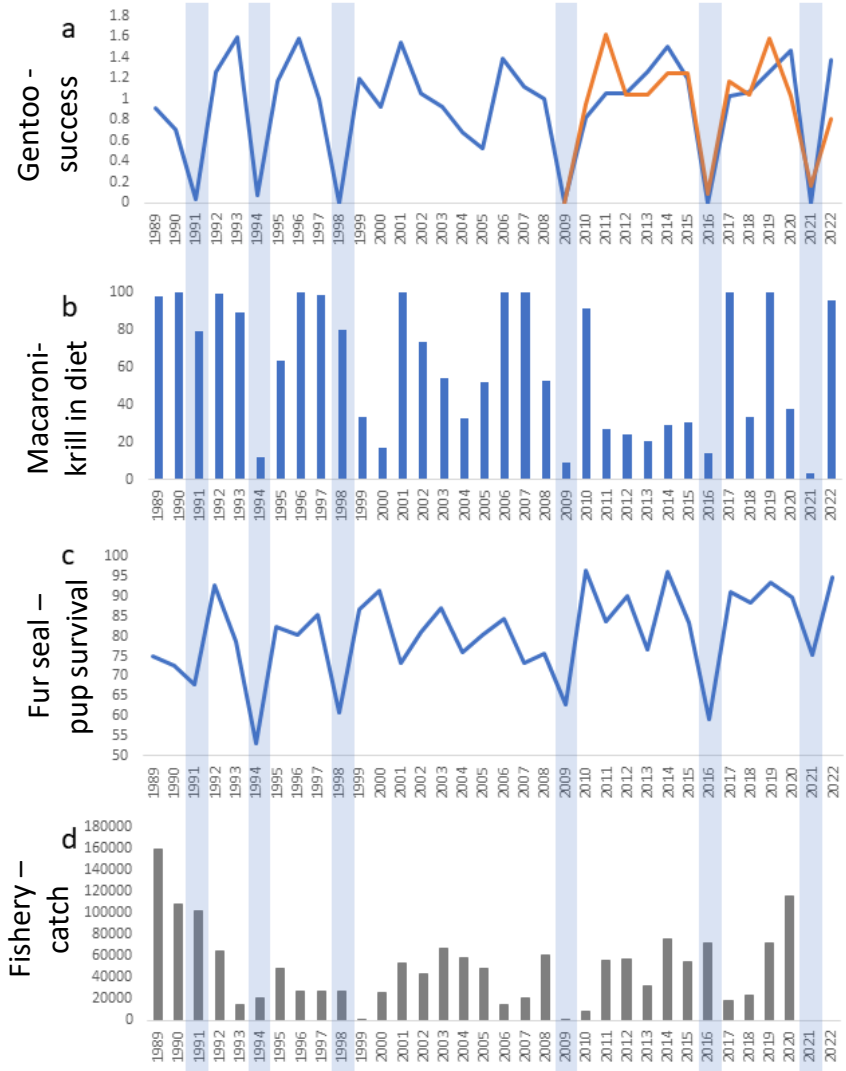




Piñones & Fedorov 2016 https://doi.org/10.1002/2016GL069656

Managing the fishery





Delegation of the UK 2022 SC-CAMLR-41/BG/35

Managing the fishery

Monitoring

Detecting change
Forecasting

Hill et al in rev

Managing the fishery

Wilson Center

LATIN AMERICAN PROGRAM

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LIVE WEBCAST | UPCOMING EVENT

Protecting Antarctica: Argentine-Chilean Environmental Diplomacy in the Southern Ocean

Wednesday
Jun. 14, 2023
10:00am – 11:00am ET
Online Only

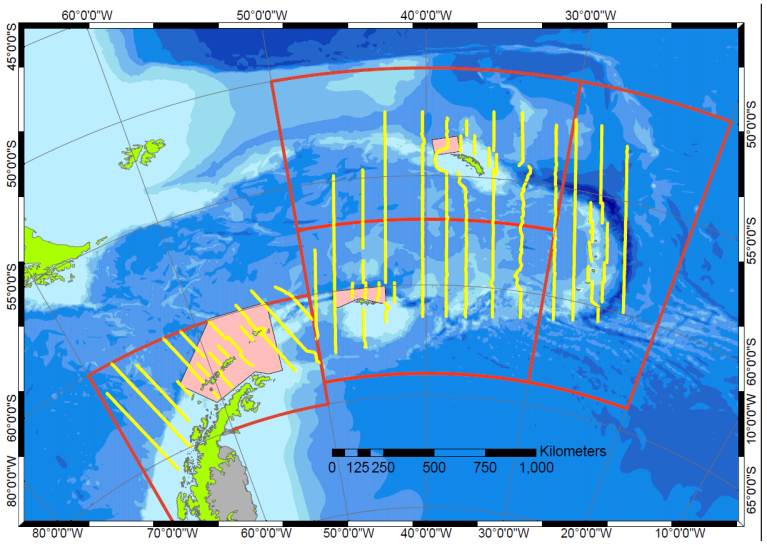
RSVP FOR WEBCAST

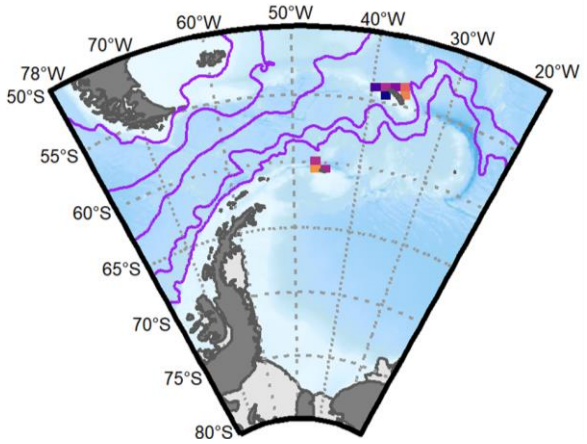
"scientists warn that El Niño will intensify these warming trends, accelerate ice loss in Antarctica and increase global sea-level rise. To confront these threats, Argentine and Chilean diplomatic efforts are in overdrive to protect the Western Antarctic Peninsula; at an international conference in Santiago next month, member states will vote on the MPA proposal from Argentina and Chile"

Objectives

Preserve wildlife?
Preserve revenue?

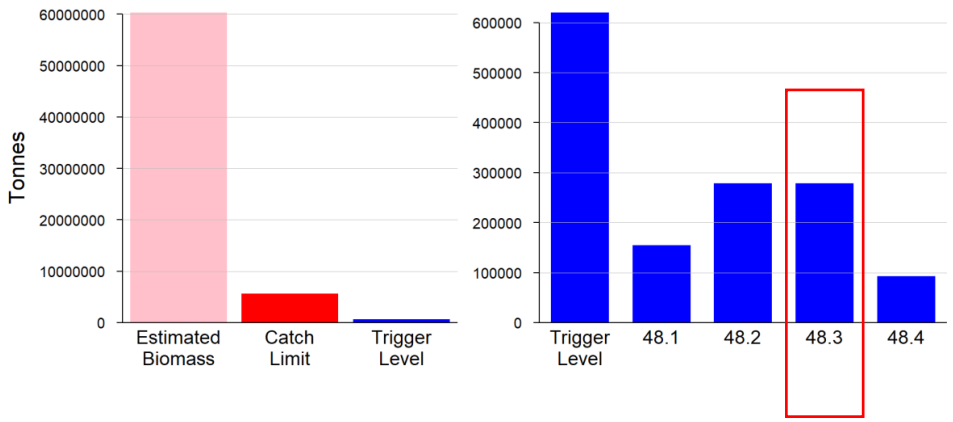
Managing the fishery





Scale

Monitoring
Objectives
Catch limits



Thank you

Philip Trathan

University of Southampton


ESA

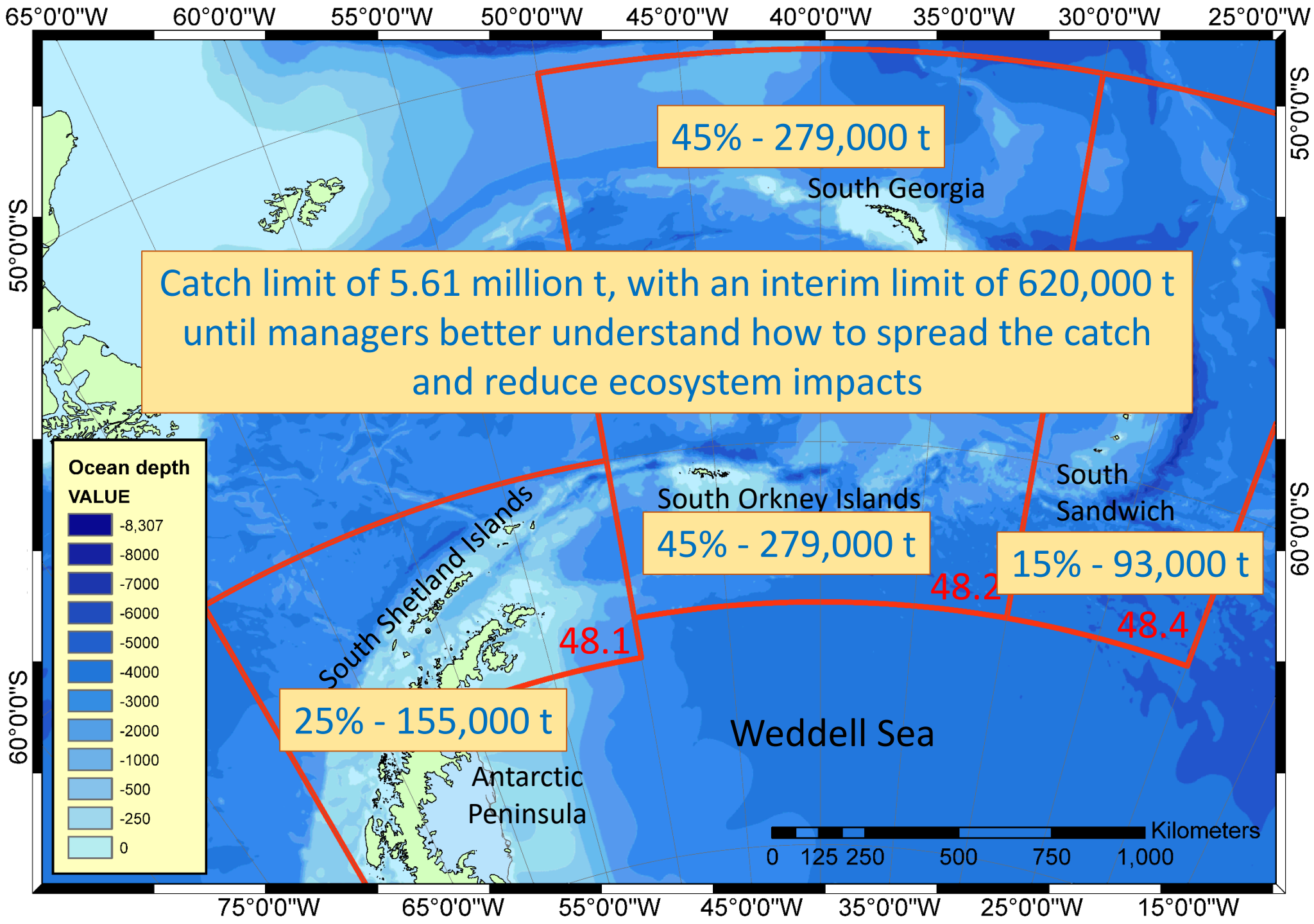

Sue G


Judith Brown

Using the best available science to set revised fishery catch limits for Antarctic krill within the South Georgia and South Sandwich Islands Marine Protected Area

Philip N. Trathan

Antarctic krill (*Euphausia superba*)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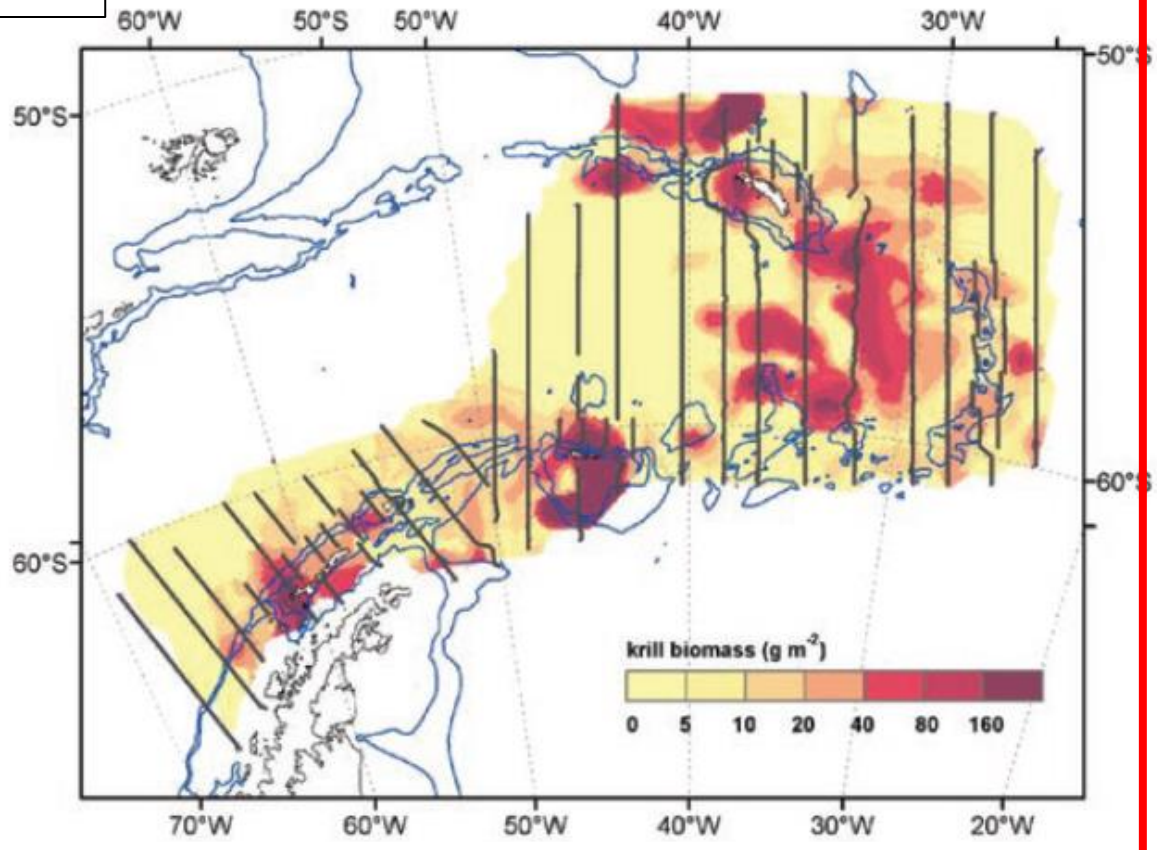
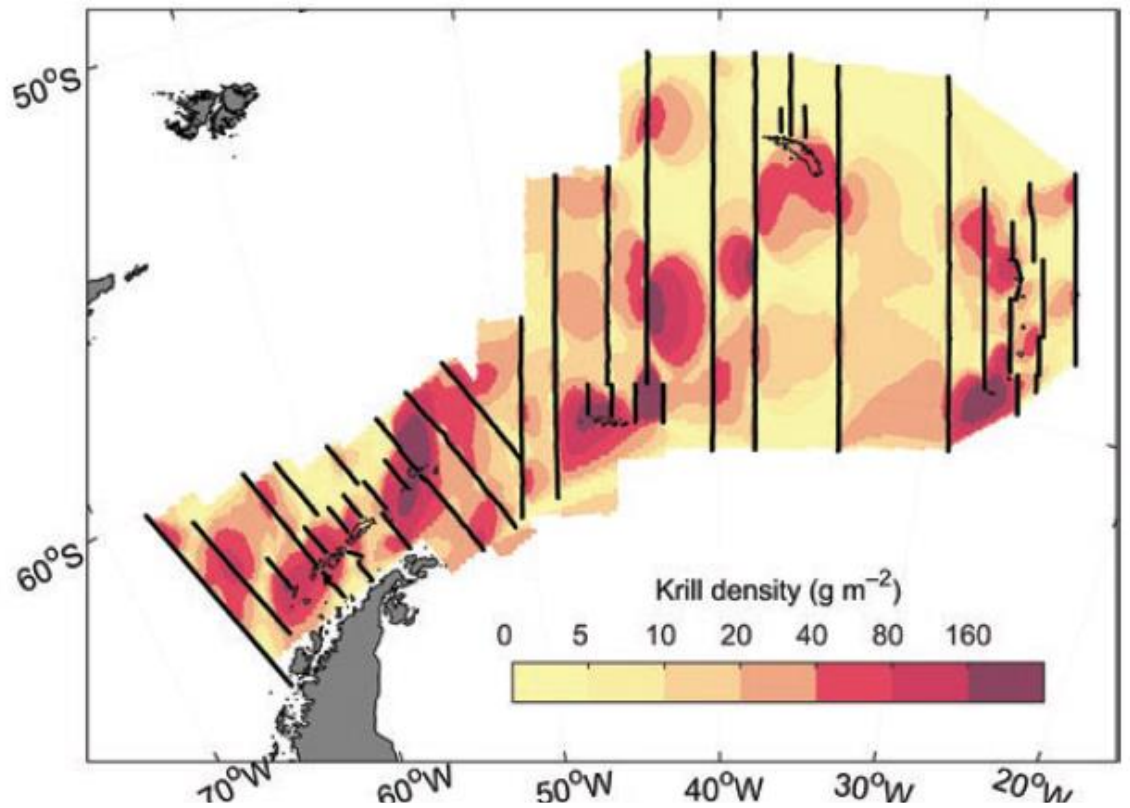
50°0'0"S
60°0'0"S
75°0'0"W
65°0'0"W
55°0'0"W
45°0'0"W
35°0'0"W
25°0'0"W
15°0'0"W
45% - 279,000 t
South Georgia
Catch limit of 5.61 million t, with an interim limit of 620,000 t until managers better understand how to spread the catch and reduce ecosystem impacts
Ocean depth
VALUE
-8,307
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
-500
-250
0
South Shetland Islands
South Orkney Islands
45% - 279,000 t
South Sandwich
15% - 93,000 t
48.2
48.4
48.1
25% - 155,000 t
Weddell Sea
Antarctic Peninsula
Kilometers
0 125 250 500 750 1,000

2000



2019

Krafft et al. 2021



Stratum	2000 survey Mean krill density (g m^{-2})	Krill biomass (t)	2018–19 survey Mean krill density (g m^{-2})	Krill biomass (t)
Antarctic Peninsula		9,278,000		19,235,000
Scotia Sea		34,928,000		31,585,000
Eastern Scotia Sea		587,000		8,049,000
South Shetland Islands		6,615,000		3,325,000
South Orkney Islands		7,797,000		2,275,000
South Georgia		846,000		161,000
South Sandwich Islands		247,000		1,672,000

Survey year 2000

Area ~2,065,244 km^2
Density 29.2 g m^{-2} (CV 12.8%)
Standing stock 60.3 million t
Fielding et al. 2011

Survey year 2019

Area ~2,000,000 km^2
Density 30.0 g m^{-2} (CV 13.0%)
Standing stock 62.6 million t
Krafft et al. 2021

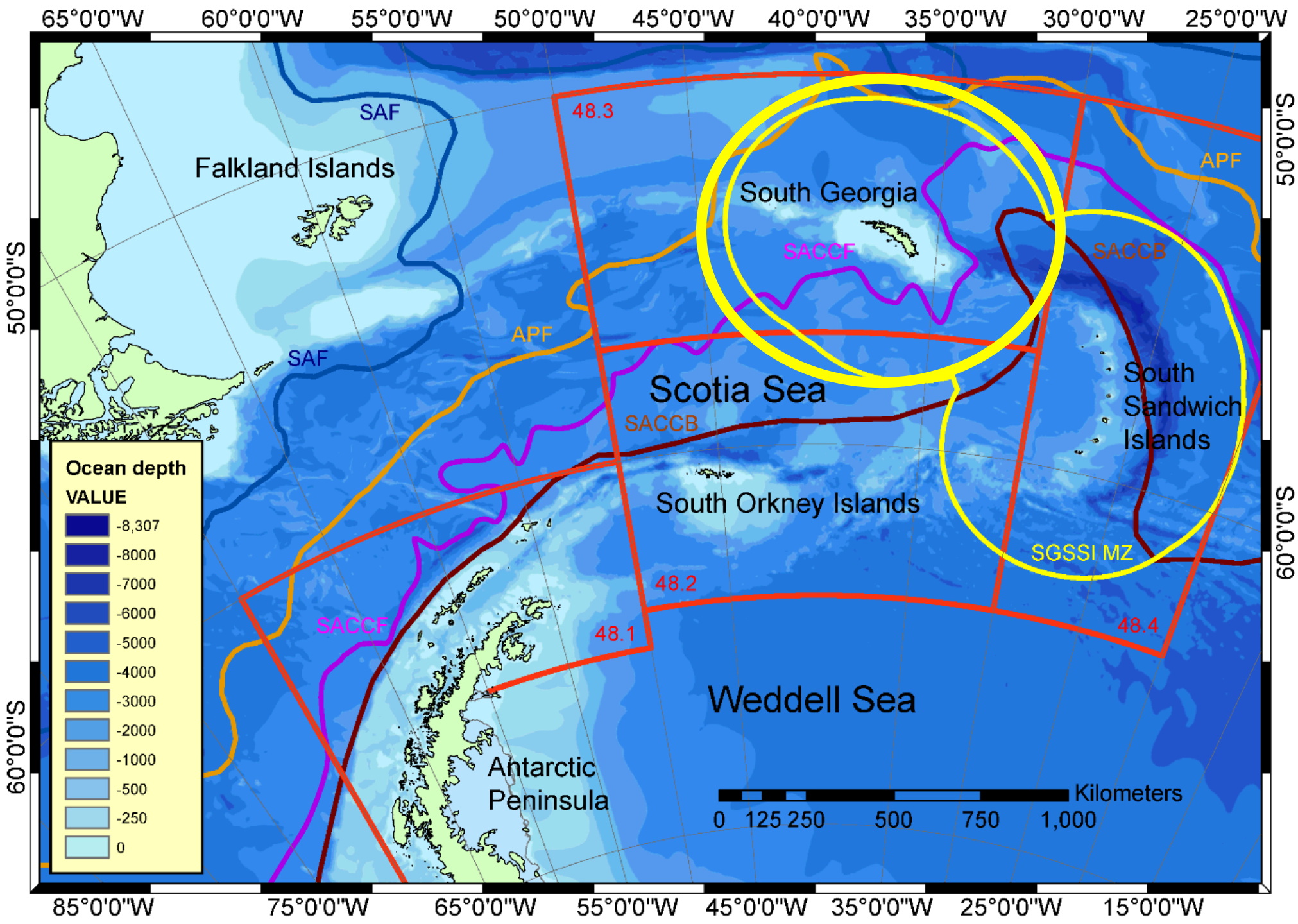
CCAMLR revised krill management framework

CCAMLR-38 paragraph 5.17: The Commission endorsed the advancement of the krill fishery management strategy agreed by the Scientific Committee (SC-CAMLR-38, paragraphs 3.18 to 3.45) that comprised three key priority elements:

(i) a yield assessment model to estimate precautionary harvest rates
(ii) regular updates of biomass estimates, initially at the Subarea scale, but potentially at multiple scales
(iii) a risk assessment framework to inform the spatial allocation of catch.

	Season	Subarea 48.1	Subarea 48.2	Subarea 48.3	Subarea 48.4
(i) Krill yield model	Summer	Yes	Yes	Yes	Extrapolation
	Winter	Yes	Some data	Some data	Extrapolation
(ii) Krill biomass estimates	Summer	Yes	Yes	Yes	Some data
	Winter	Some data	No data	Some data	No data
(iii) Risk assessment					
Fishery footprint	Summer	Yes	Yes	No data	No data
	Winter	Yes	Some data	Yes	No data
Predator layers	Summer	Yes	Yes	Yes	Some data
	Winter	Some data	No data	Some data	No data

Pilot project implementation in Subarea 48.1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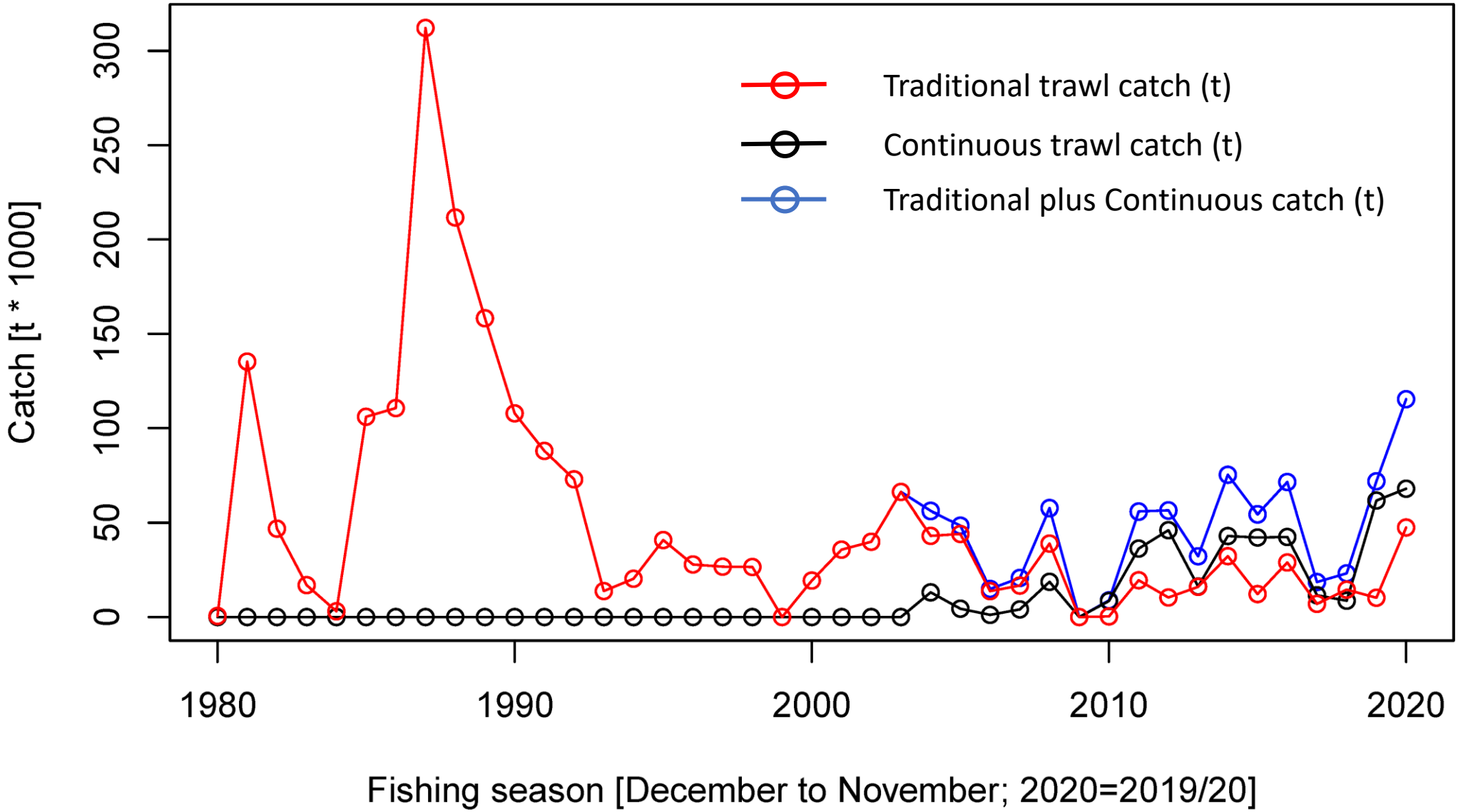
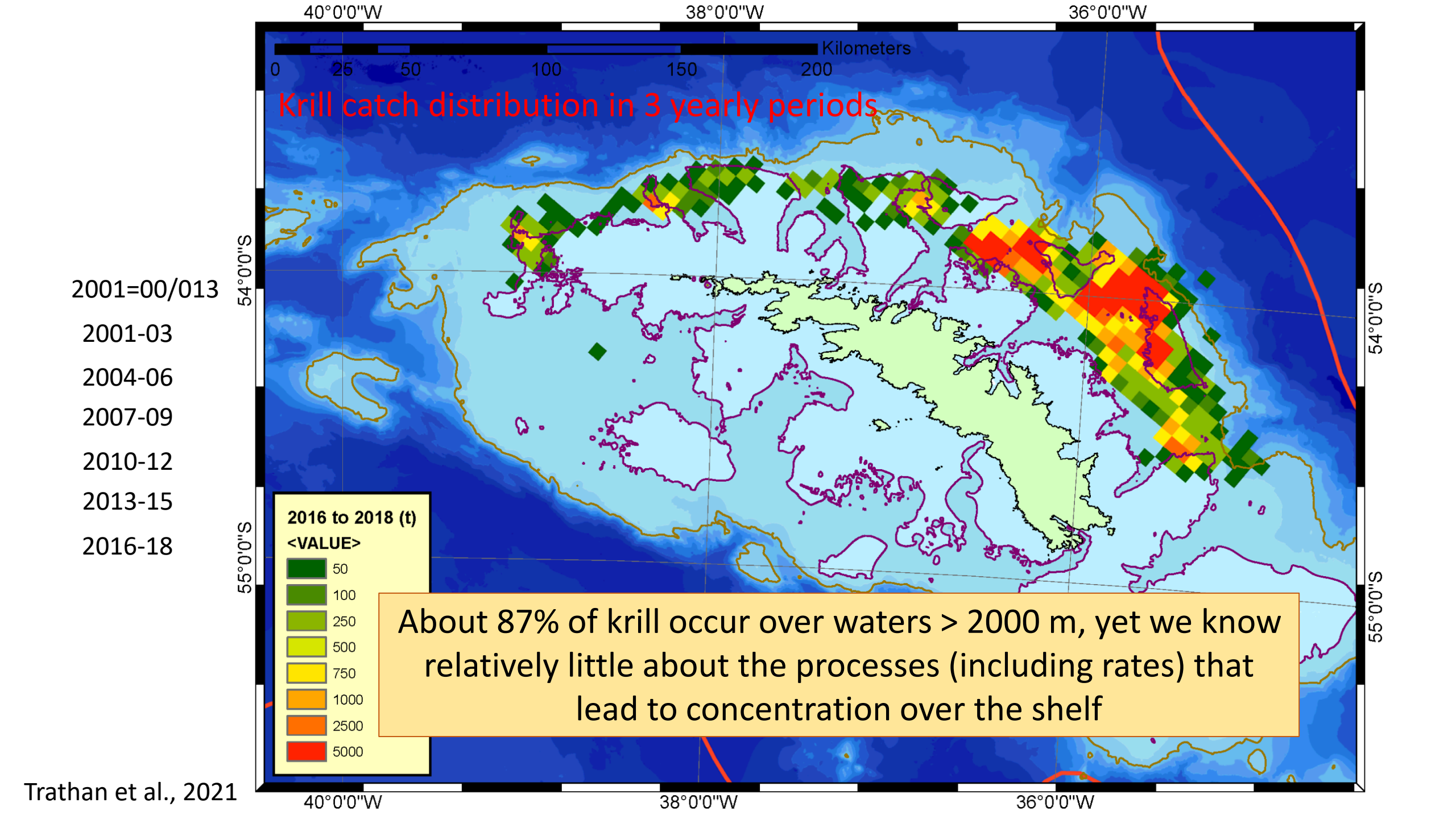
25°0'0"W
50°0'0"S
60°0'0"S
85°0'0"W
75°0'0"W
65°0'0"W
55°0'0"W
45°0'0"W
35°0'0"W
25°0'0"W
15°0'0"W
SAF
Falkland Islands
48.3
APF
South Georgia
SACCF
SACCB
SAF
APF
Scotia Sea
SACCB
South Sandwich Islands
South Orkney Islands
SGSSI MZ
48.2
SACCF
48.1
48.4
Weddell Sea
Antarctic Peninsula
Ocean depth
VALUE
-8,307
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
-500
-250
0
Kilometers
0 125 250 500 750 1,000



Trathan et al., 2021

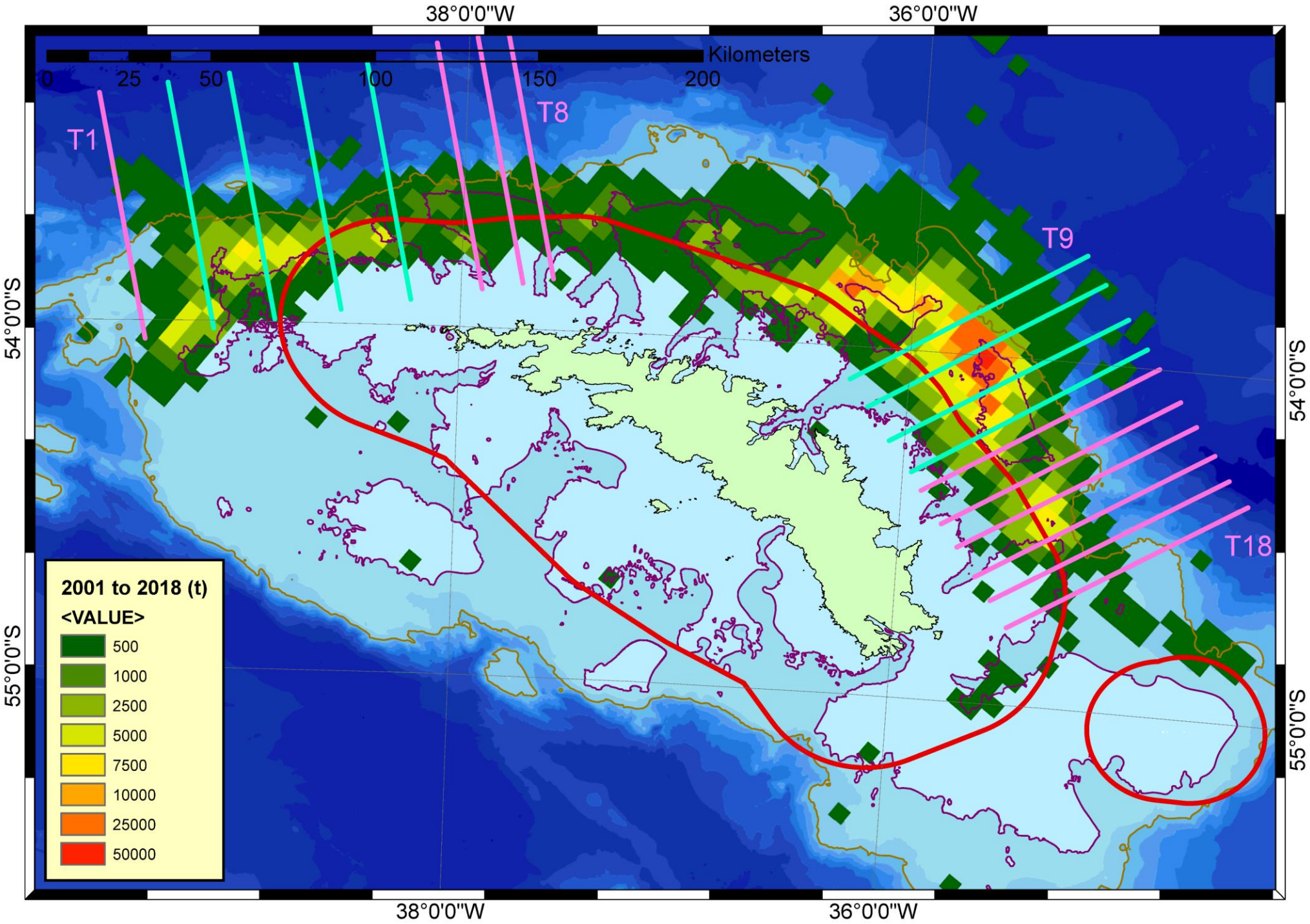


Trathan et al., 2021

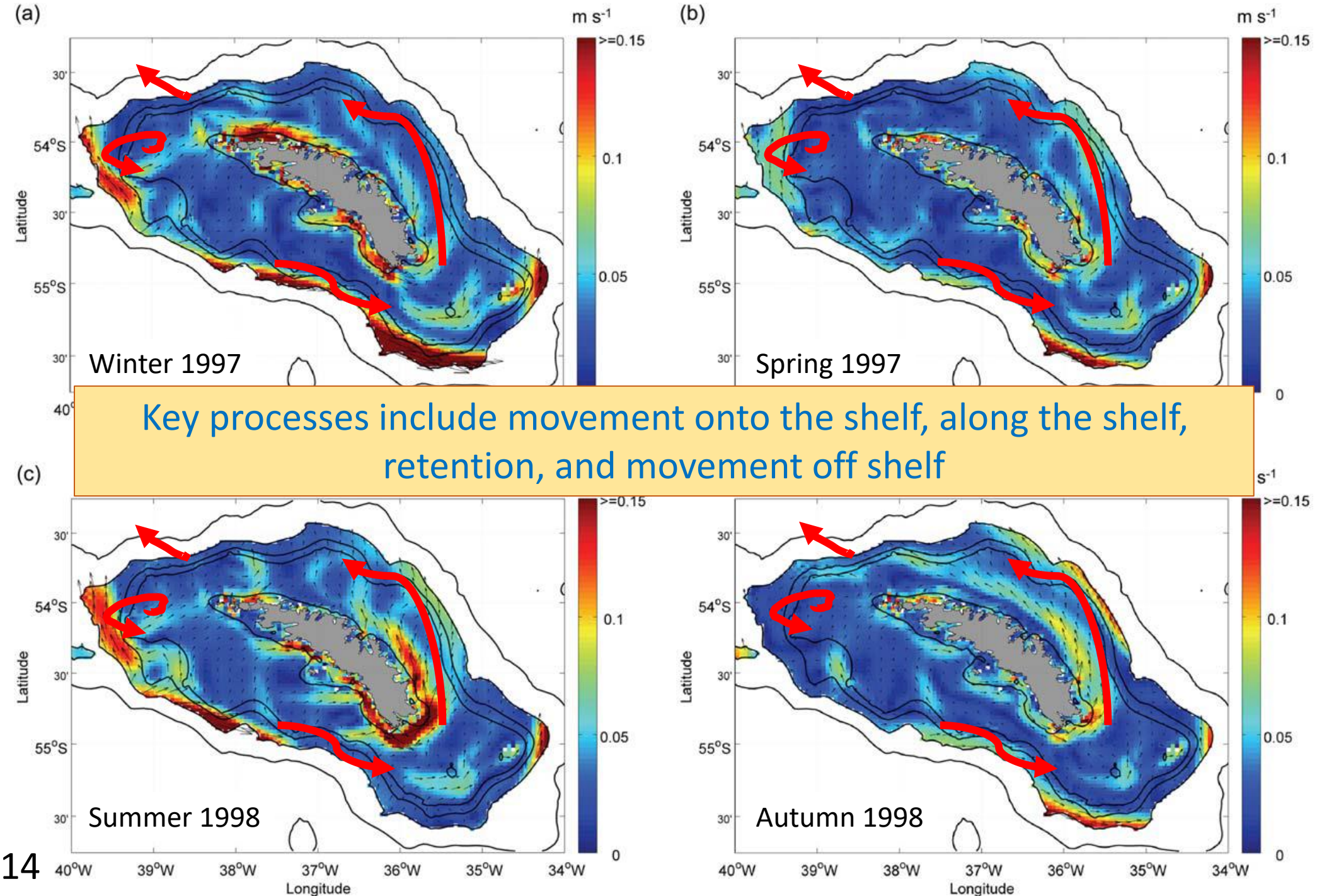
WCB [T1 – T8]
Winter 1
Summer 22+

ECB [T9 – T18]
Winter 1
Summer 3

30 km No-take



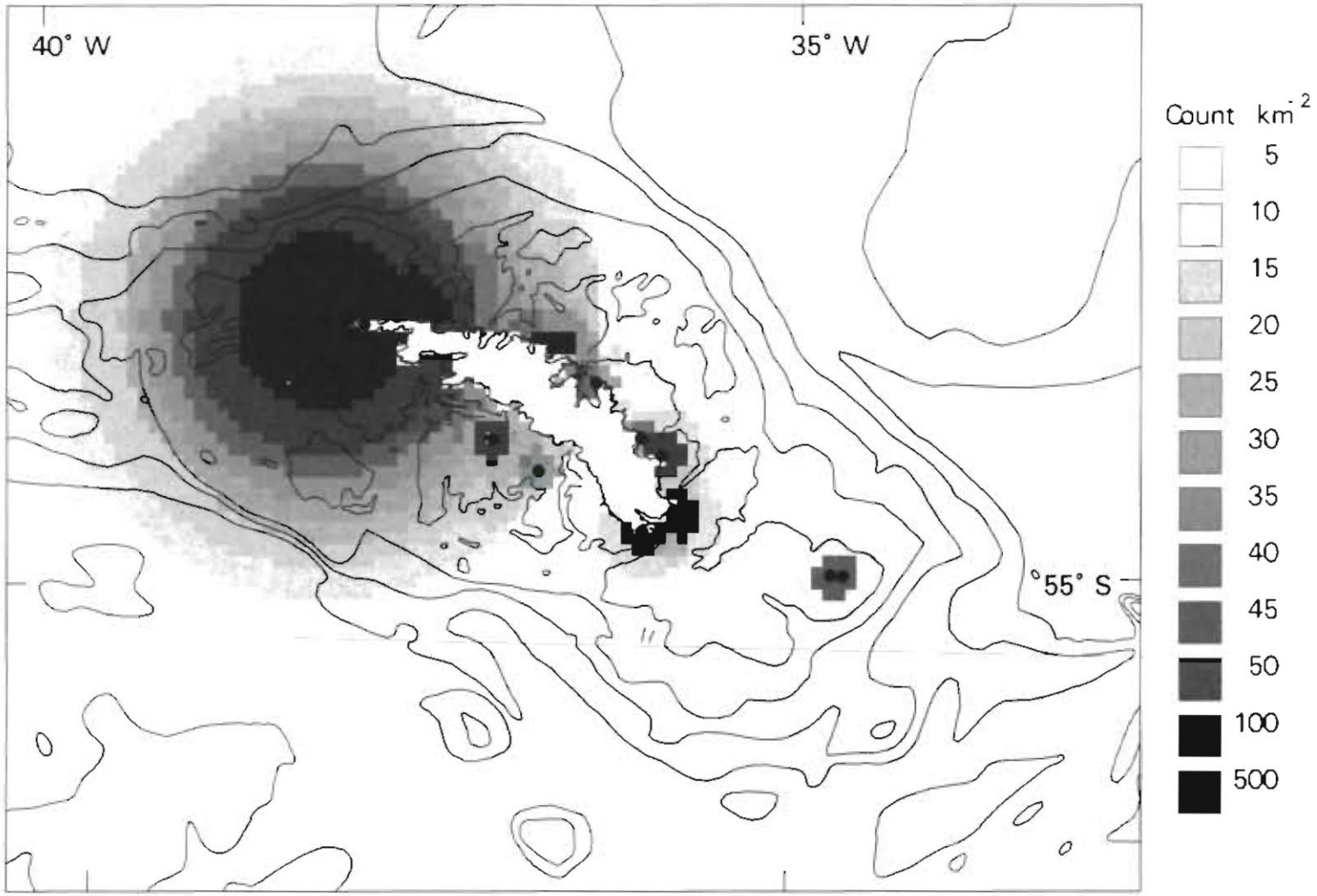
Trathan et al., 2021

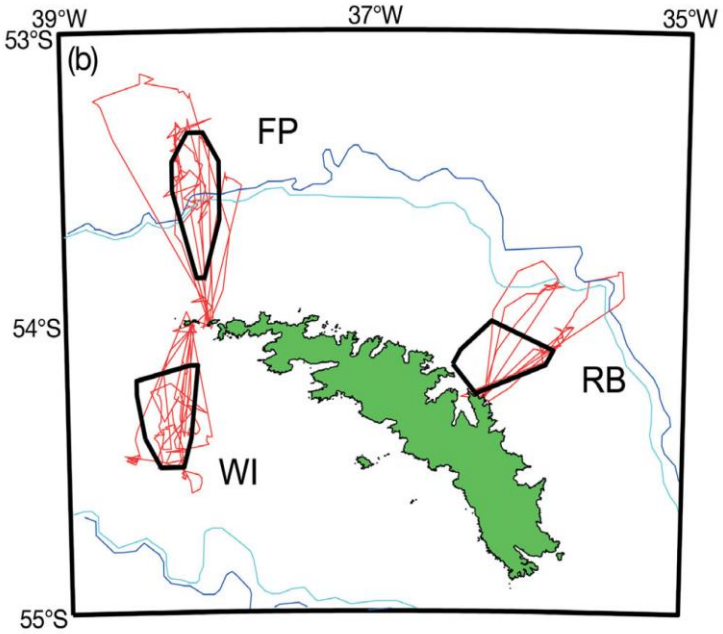


Key processes include movement onto the shelf, along the shelf, retention, and movement off shelf

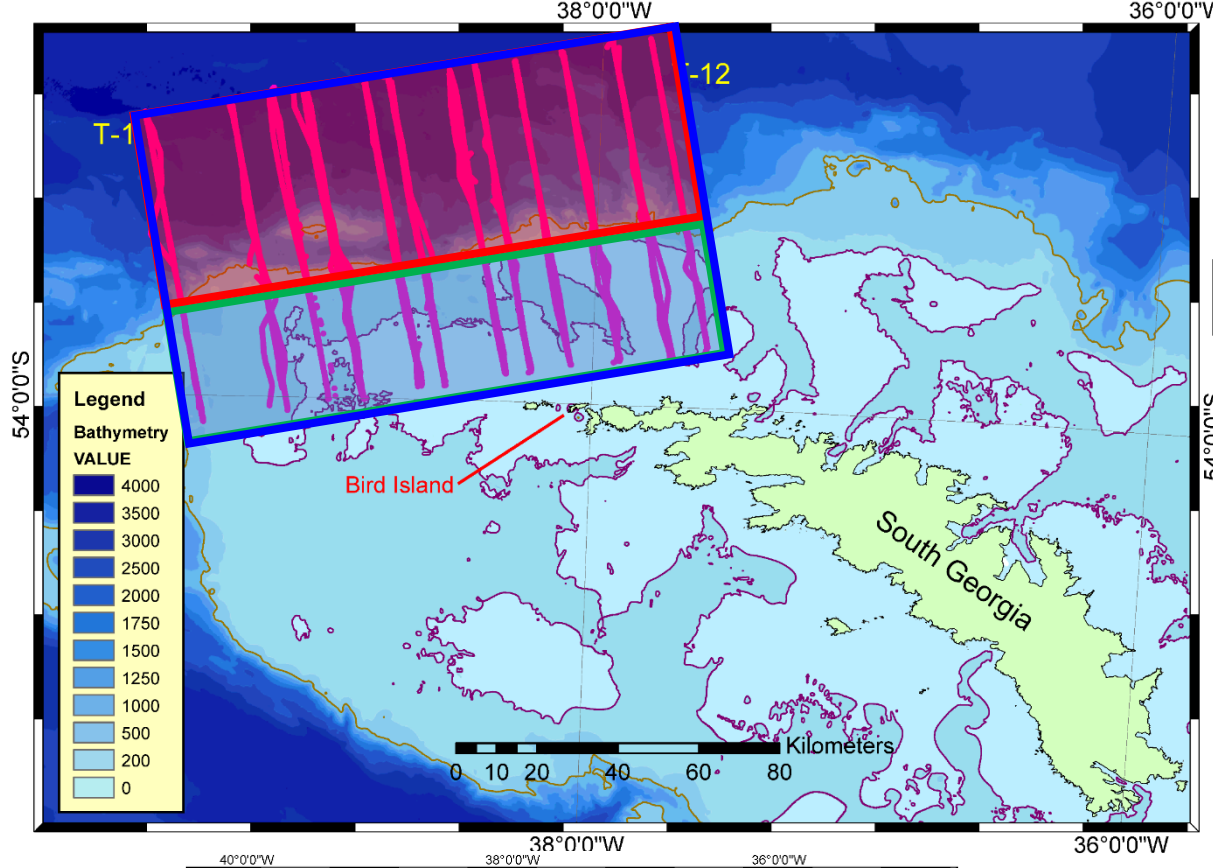
Young et al. 2014

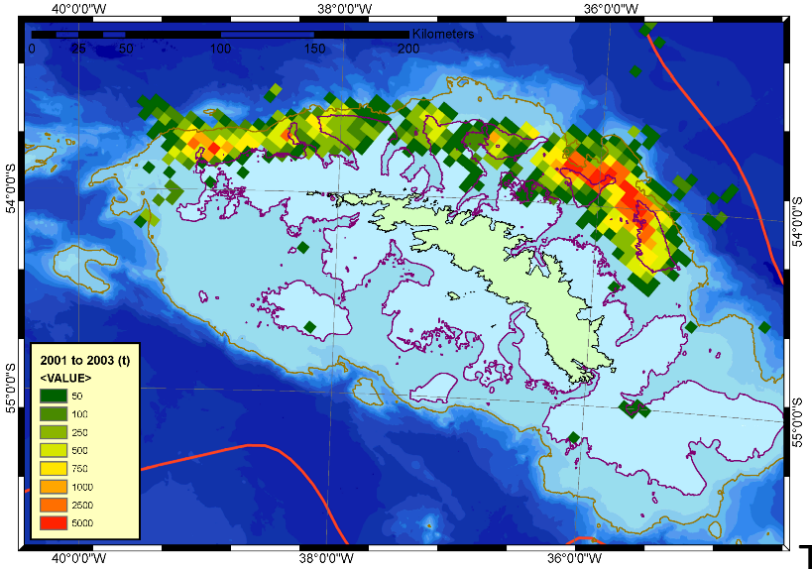
Predator demand for krill varies spatially – e.g. macaroni penguins at Bird Island





Trathan et al., 1998; 2006



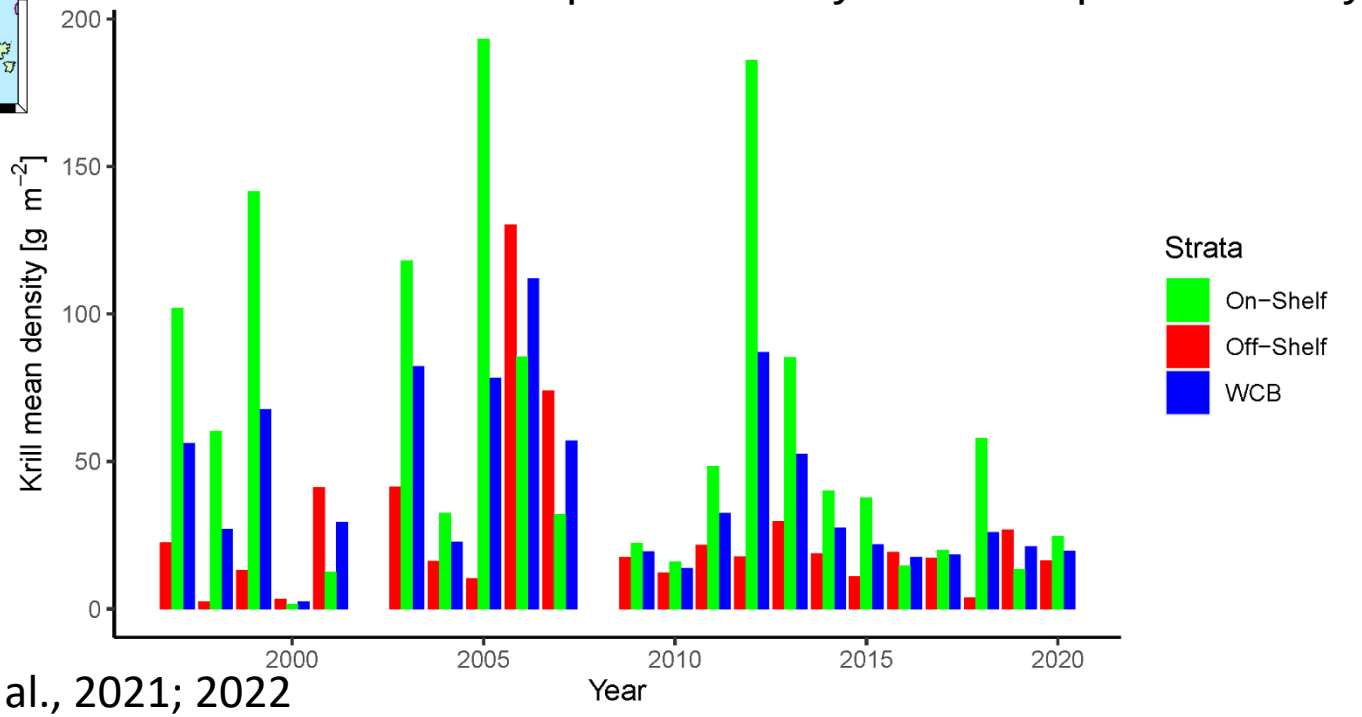


Western Core Box – occupied for 22+ years

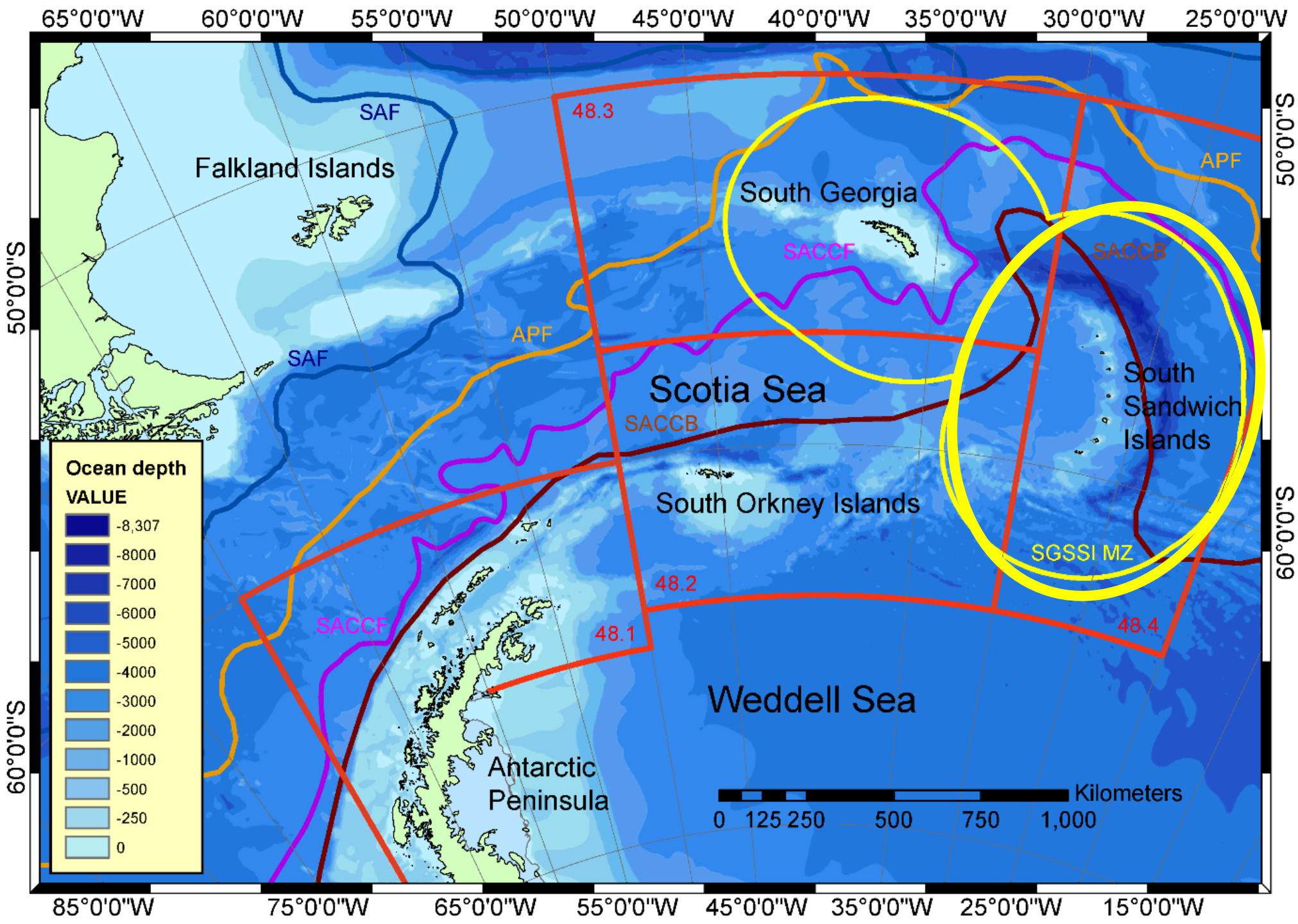
	WCB	On-Shelf	Off-Shelf
Mean density (g m^{-2})	40.56	61.14	25.80
Medium density (g m^{-2})	27.22	38.85	17.59

Area used by fishery: 25,175 km^2

Precautionary catch limit (t)	63,729	90,948	41,174
	Still precautionary		Highly precautionary



Trathan et al., 2021; 2022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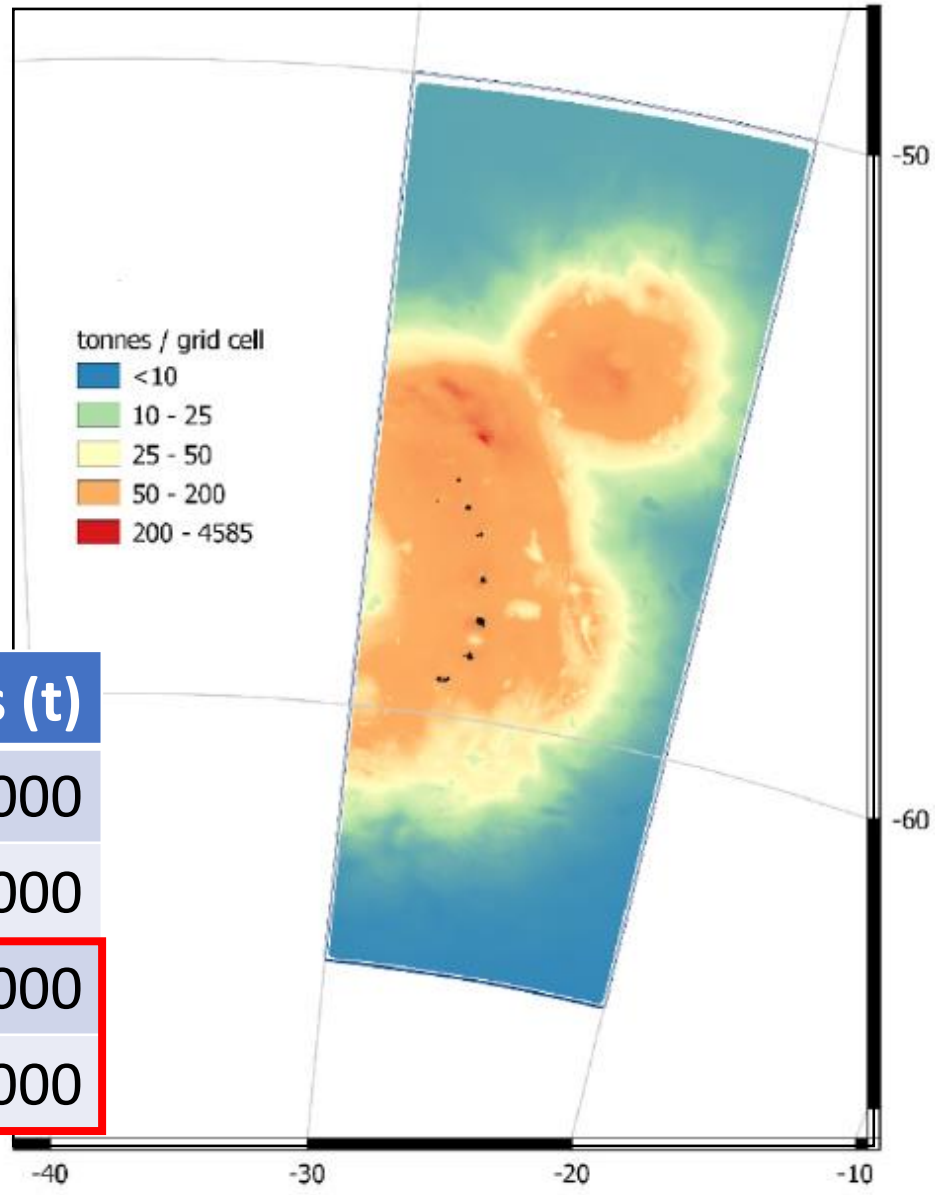
40°0'0"W
35°0'0"W
30°0'0"W
25°0'0"W
50°0'0"S
60°0'0"S
85°0'0"W
75°0'0"W
65°0'0"W
55°0'0"W
45°0'0"W
35°0'0"W
25°0'0"W
15°0'0"W
SAF
Falkland Islands
48.3
APF
South Georgia
SACCF
SACCB
SAF
APF
Scotia Sea
SACCB
South Sandwich Islands
South Orkney Islands
SGSSI MZ
48.2
SACCF
48.1
48.4
Weddell Sea
Antarctic Peninsula
Ocean depth
VALUE
-8,307
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
-500
-250
0
Kilometers
0 125 250 500 750 1,000

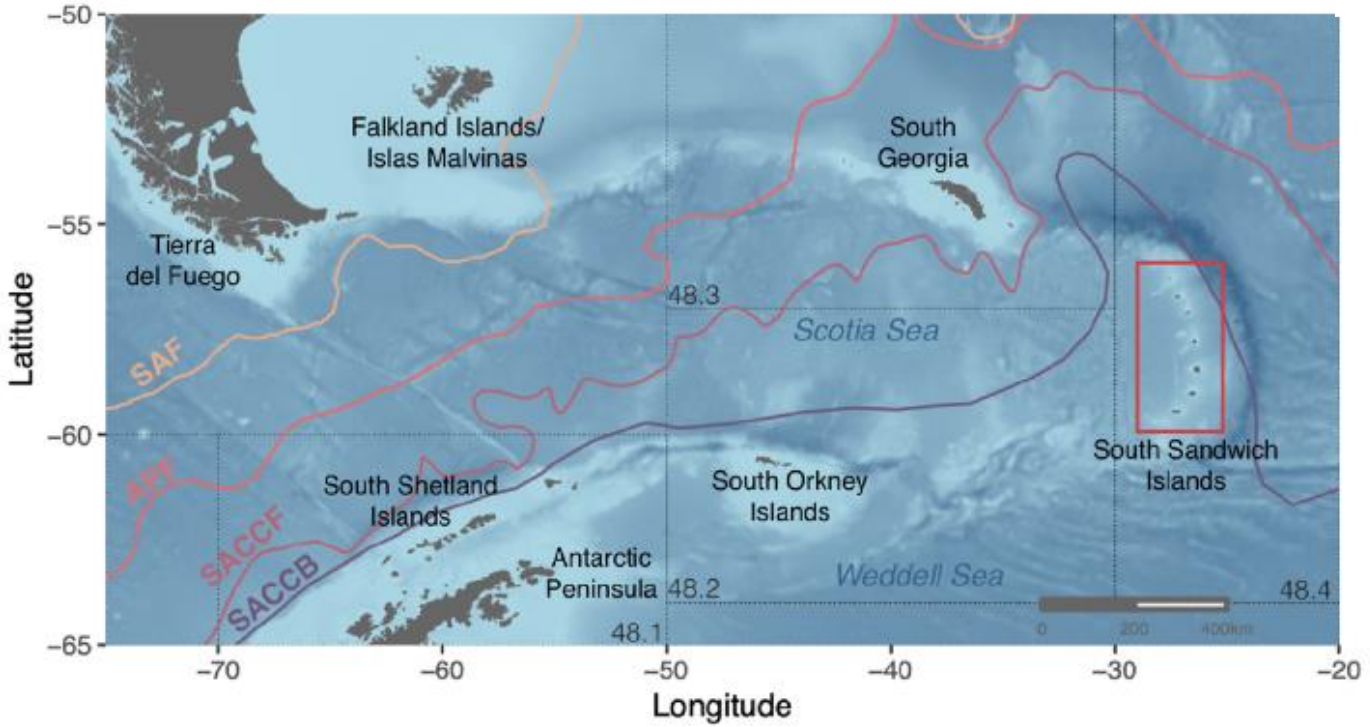
Last reported krill catch was ~50 t in the 1991/1992 fishing season

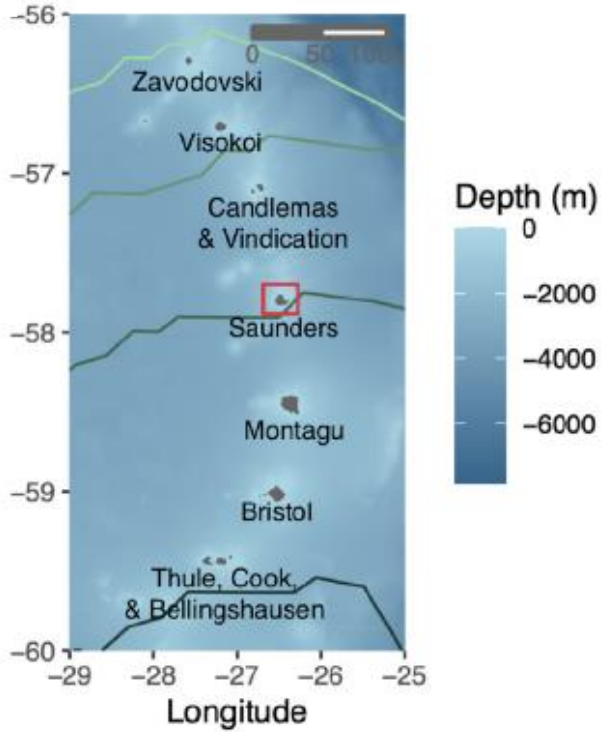
	Biomass (t)
Scotia Sea [31.5 g m^{-2}] (2000)	34,928,000
Scotia Sea [28.5 g m^{-2}] (2019)	31,585,000
South Sandwich Islands [4.0 g m^{-2}] (2000)	247,000
South Sandwich Islands [26.8 g m^{-2}] (2019)	1,672,000

Krafft et al. 2021



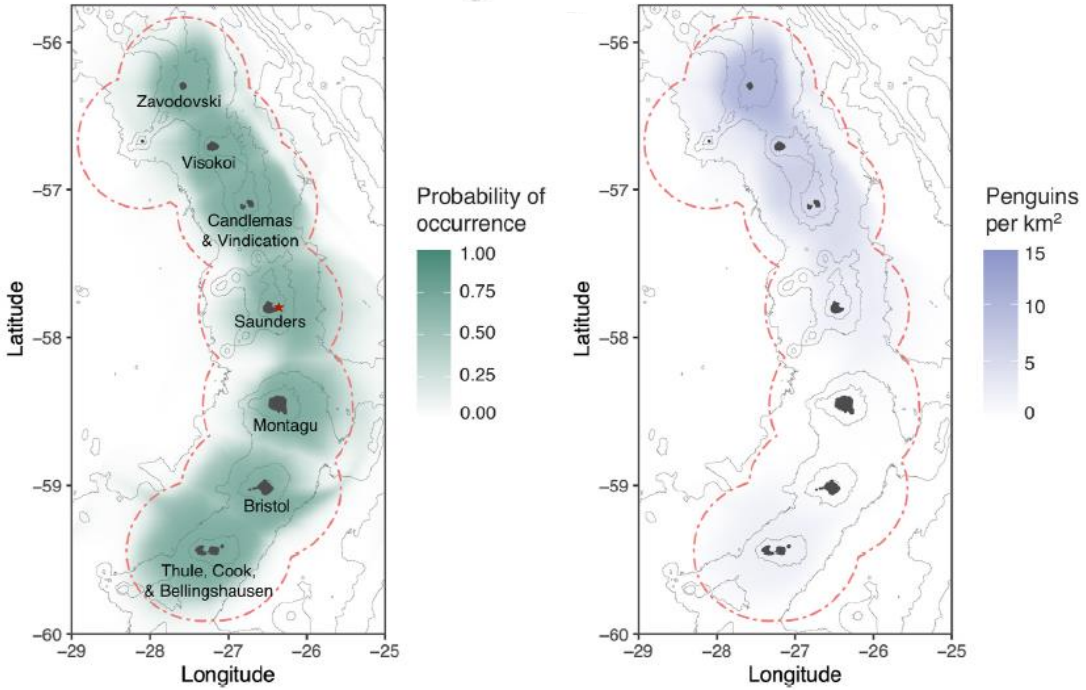
Baines et al. 2022



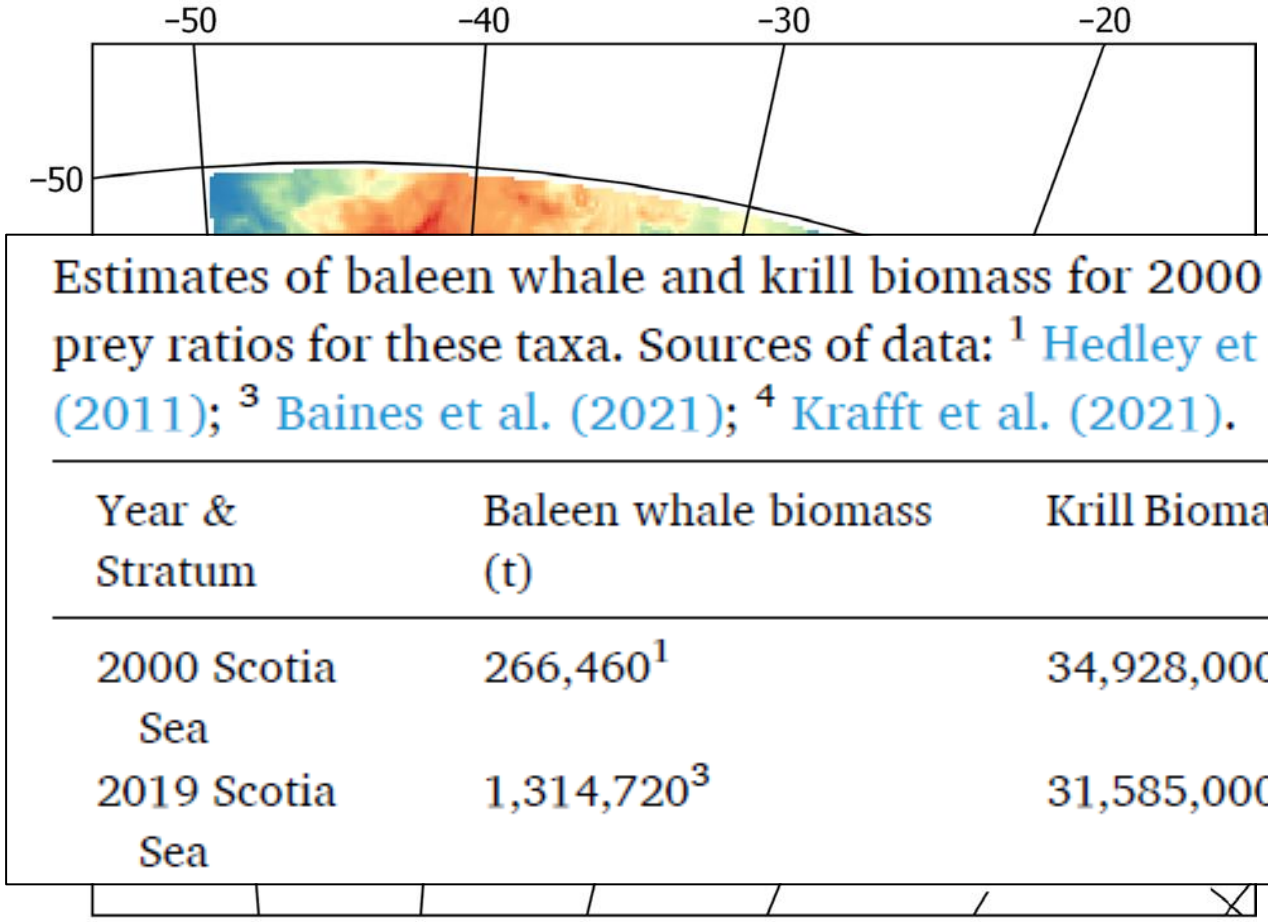


Chinstrap penguins will require 258,000 t of krill over the chick-rearing period

Clucas et al. 2022



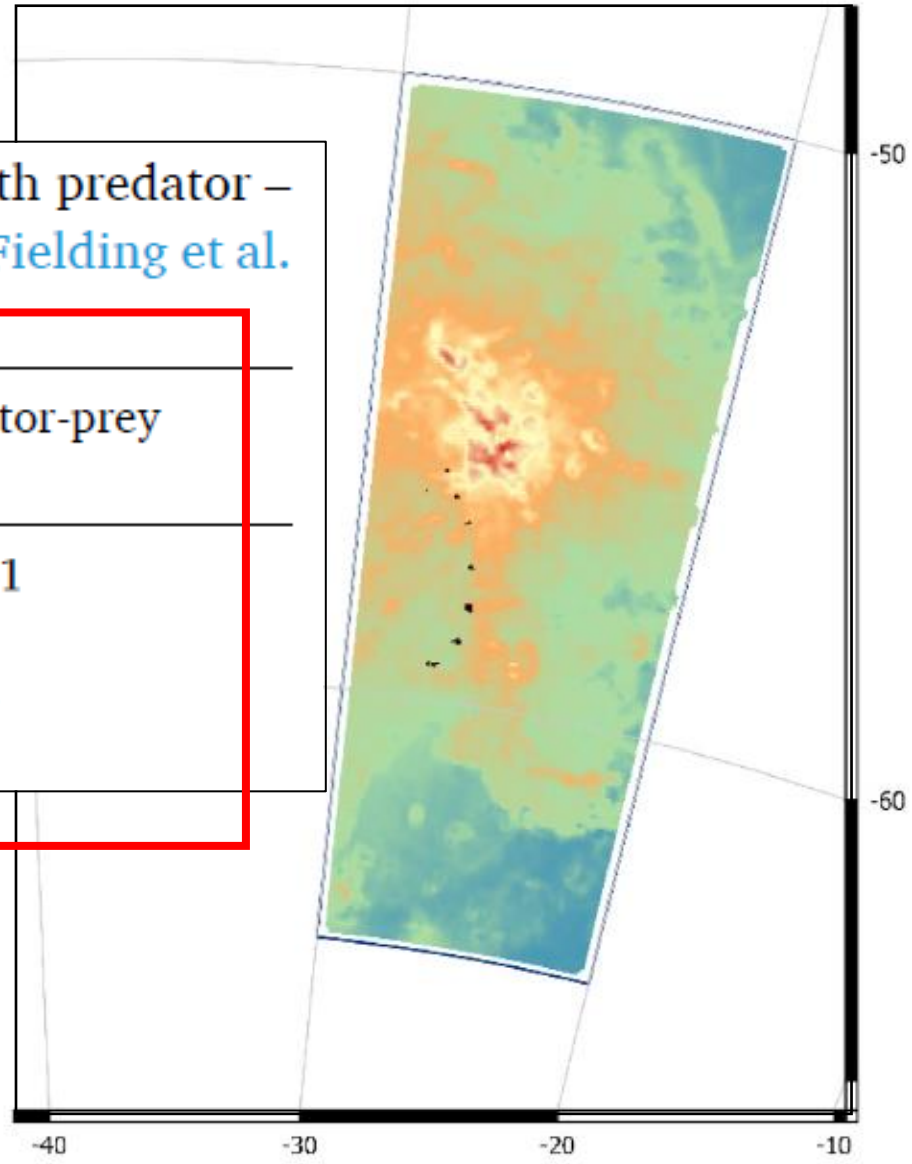
Baleen whales



Estimates of baleen whale and krill biomass for 2000 and 2019 with predator – prey ratios for these taxa. Sources of data: [1] Hedley et al. (2001); [2] Fielding et al. (2011); [3] Baines et al. (2021); [4] Krafft et al. (2021).

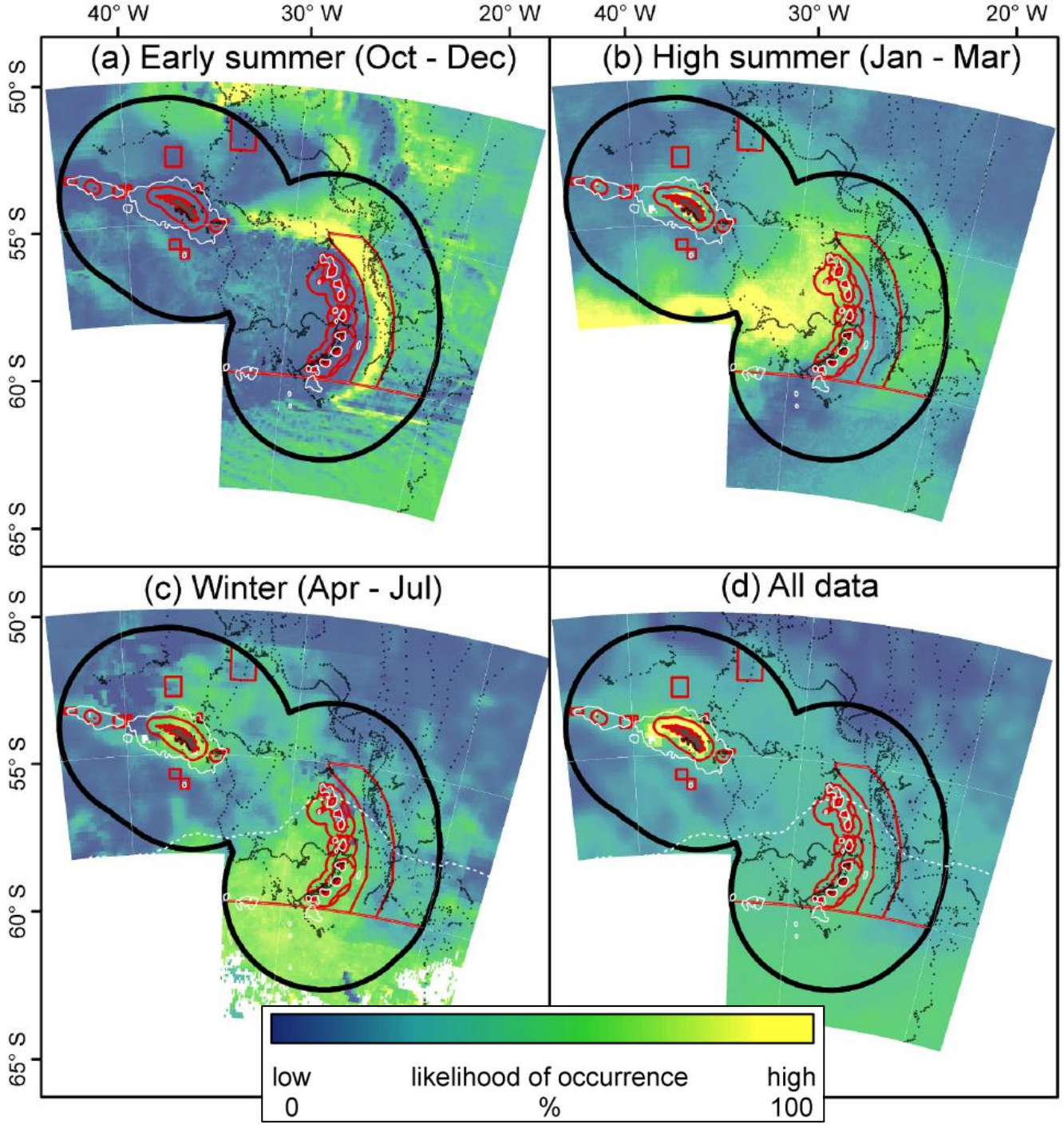
Year & Stratum	Baleen whale biomass (t)	Krill Biomass (t)	Predator-prey ratio
2000 Scotia Sea	266,460[1]	34,928,000[2]	1 : 131
2019 Scotia Sea	1,314,720[3]	31,585,000[4]	1 : 24

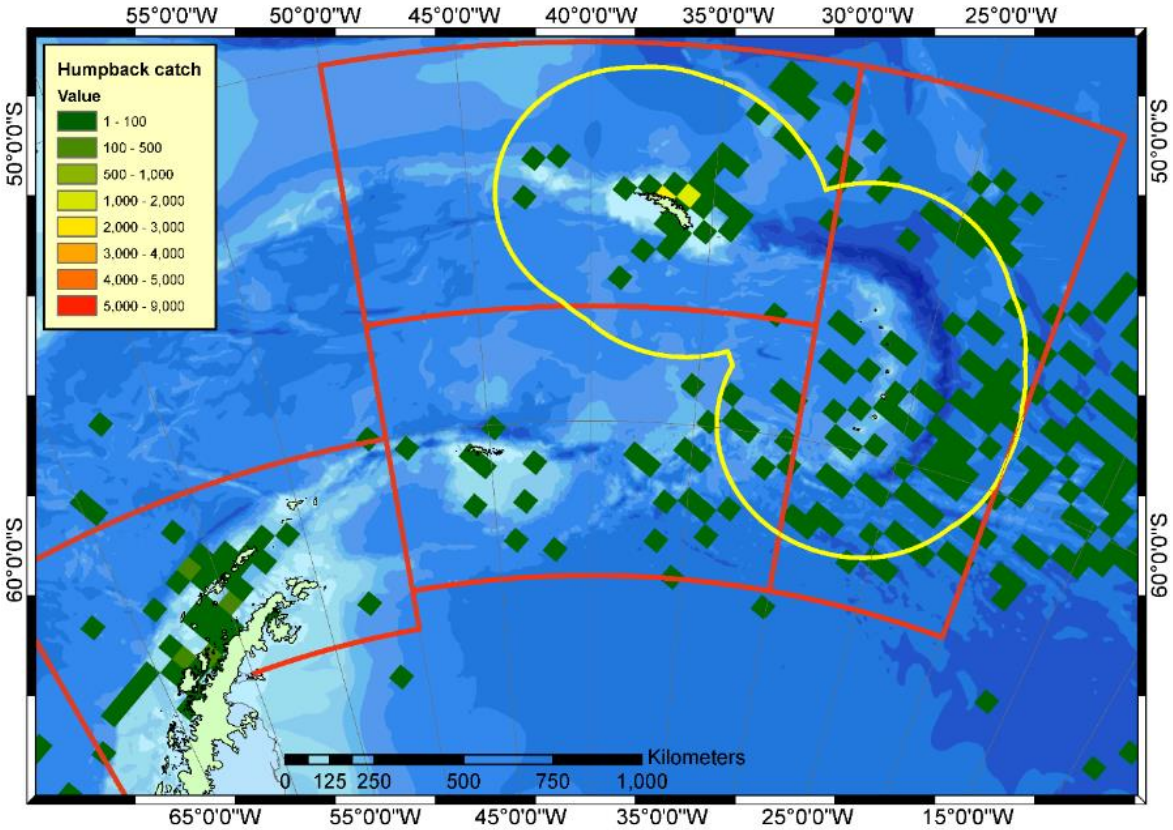
Region (CCAMLR area)	Stratum area (km^2)	Point estimate	95 % CI	CV
South Georgia (48.3)	1 033 249	30 905	22 361–42 713	0.17
South Sandwich (48.4)	944 953	12 919	7 796–21 409	0.26
Total	1 978 202	43 824	33 509–59 077	0.15



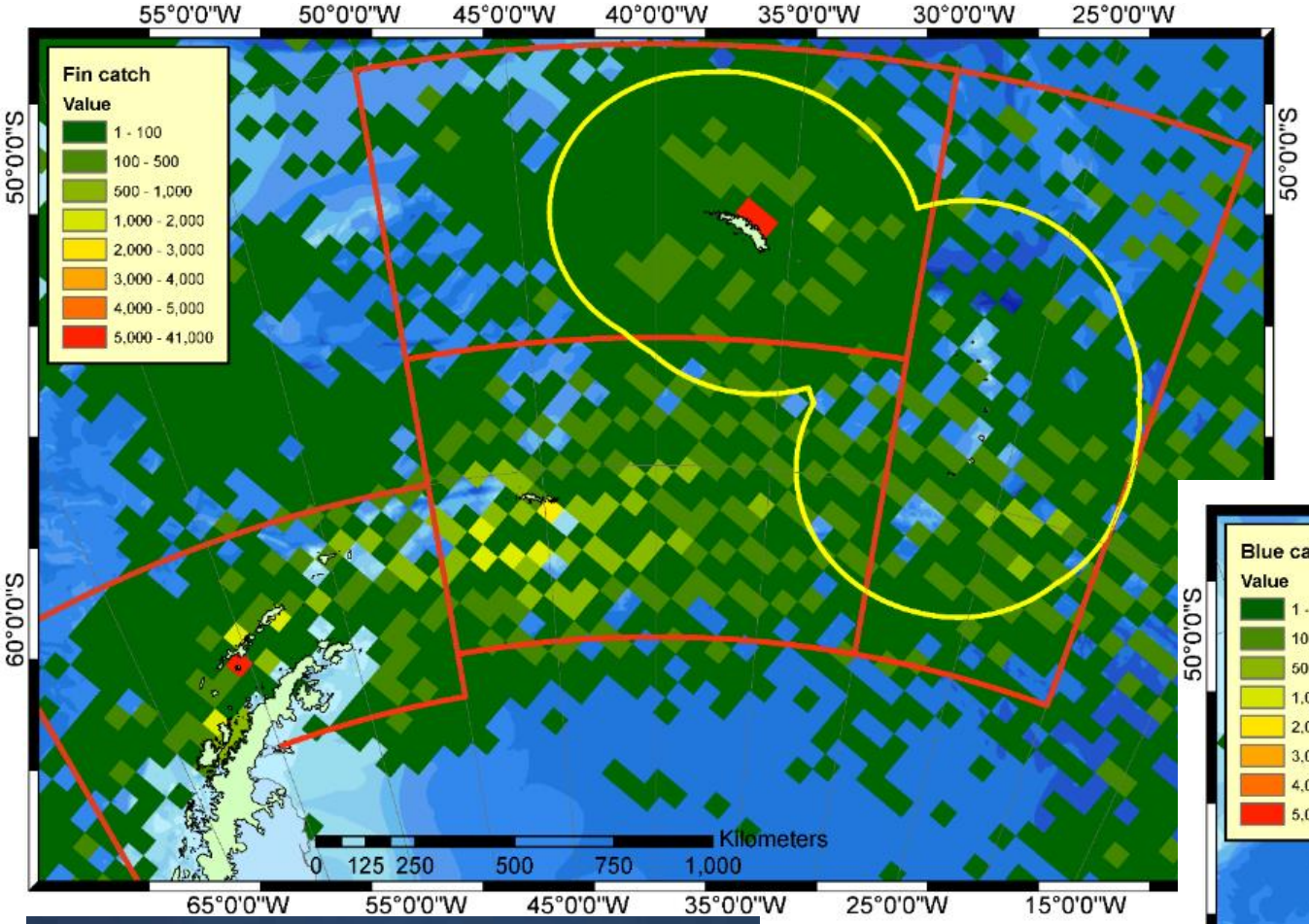
Baines et al. 2021; 2022

Bamford et al. 2022
Zerbini et al. 2019

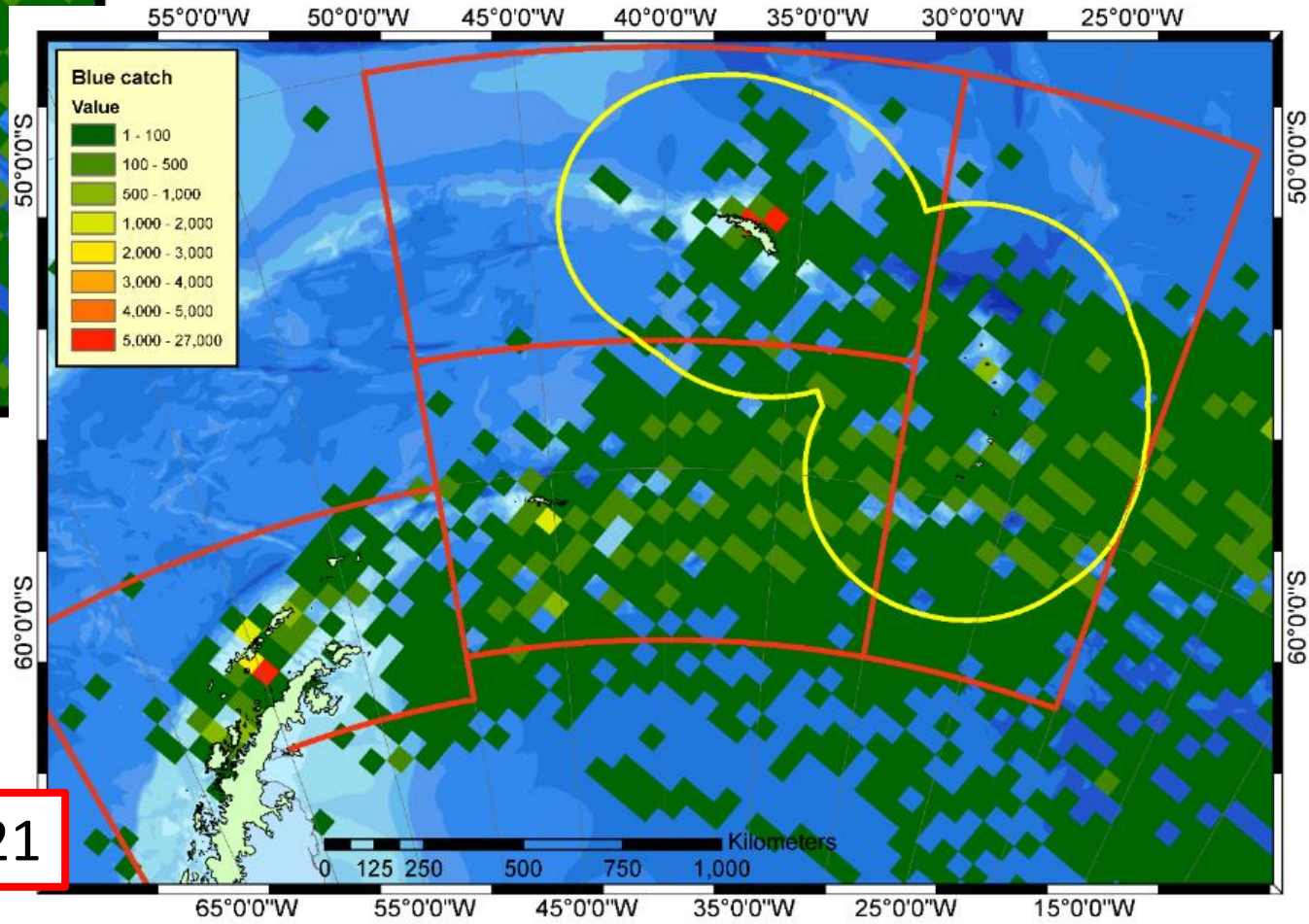




Allison, 2016



Allison, 2016



Savoca et al. 2021

Consumption of krill	Subarea 48.3		Subarea 48.4
Baleen whales			Options without data
	Winter	Need new data	
Fish			
	Winter	Analysis needed	
Macaroni penguins		Winter fishing or	
	Winter	Yes	
Antarctic fur seals		SGSSI MPA	
	Winter	Analysis needed	
Chinstrap penguins			
	Winter		
Adélie penguins			
	Winter		

Research and Monitoring

Krill Acoustic surveys

Predator population monitoring

Antarctic fur seals (2005/2006)
Macaroni penguins (2003)
Gentoo penguins (1986/1987)

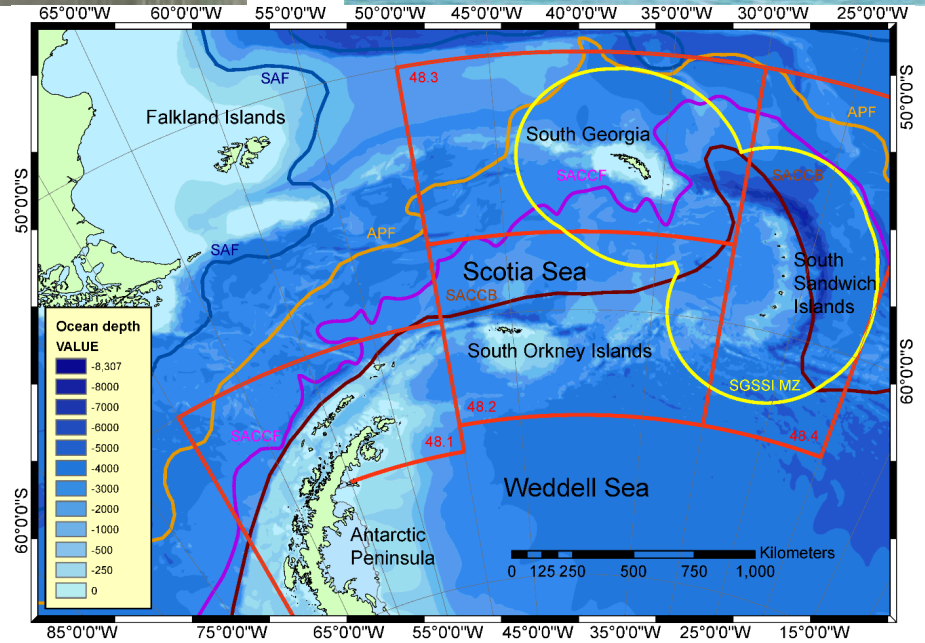
Baleen whales
Other krill-dependent taxa

Winter fishing → Summer feeding → Winter fishing → Summer feeding

Carry over effects in the ecosystem?

Fisheries Observers

Control, Monitoring and surveillance



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Inigo Everson

University of East Anglia


ESA


Sue G


Pete Lens

Setting focus on CCAMLR Article II

Inigo Everson

Environmental Sciences

University of East Anglia

SGSSI MPA Review Science Symposium: 13-14 June 2023

History

1968: SCAR Biology Symposium – Potential Krill Fishery a key focus

1976: BIOMASS launched – Key Objectives on krill in S Ocean ecosystem
FAO – Review of S Ocean Living Resources

1980: CCAMLR Convention Agreed
Article II (1) Conservation
(2) Includes Rational Use
(3) Ecosystem Approach

History

1980: CCAMLR Convention Agreed

Article II sub-paragraphs:

(1) Conservation

(2) Includes Rational Use

(3) Ecosystem Approach:

a. Single species approach
b. Maintain ecological relationships
c. Time scale for acceptable changes

History

1980: CCAMLR Convention Agreed

Article II (1) Conservation

(2) Includes Rational Use

(3) Ecosystem Approach

1982: First CCAMLR Meeting

1991: CM 32/X – Precautionary Catch Limit for Krill

Recognition: Potential overlap in krill fishing and predator foraging

Development

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Recognition: Potential overlap in krill fishing and predator foraging

What is the extent of overlap?

Is it detrimental?

Development

What is extent of overlap? Is it detrimental?

-oo0oo-

My Krill Predator Classification:

PICKERS: catch individual krill e.g. Macaroni penguin, Furseal, Crabeater seal

GULPERS: engulf krill aggregations e.g. Baleen whales

Examine with respect to krill distribution density from acoustic surveys

(Everson Submitted)

Development

What is extent of overlap? Is it detrimental?

-oo0oo-

My Krill Predator Classification:

PICKERS: catch individual krill e.g. Macaroni penguin, Furseal, Crabeater seal

GULPERS: engulf krill aggregations e.g. Baleen whales

Conclusions:

Minimal influence of Pickers on Gulpers and vice versa

Influence of Gulpers on Commercial fishing and vice versa – unknown!

(Everson Submitted)

Some Uncertainties

Top 10m layer unsampled by acoustic surveys

- Important for air breathing predators
- Does this mean standing stock is under-estimated?

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Some Uncertainties

Top 10m layer unsampled by acoustic surveys

Important for air breathing predators

Does this mean standing stock is under-estimated?

How good is acoustic identification of krill aggregations?

Plenty of theory but how much practical testing?

What further information might be gained from acoustic data?

Target identification – help understanding ‘prey switching’

Krill size classification – Large, medium and small krill

(Note: Predator preferences for ‘large krill’

See Also Discovery: Blue whale krill and Fin whale krill)

Moving Forward

Near surface krill: **Towed upward directed echosounder**

A proposal:

Using a pumped codend commercial fishing vessel as sampling platform

Attach transducer to top bar of net frame

Samples water away from ship

From Transducer depth to surface.

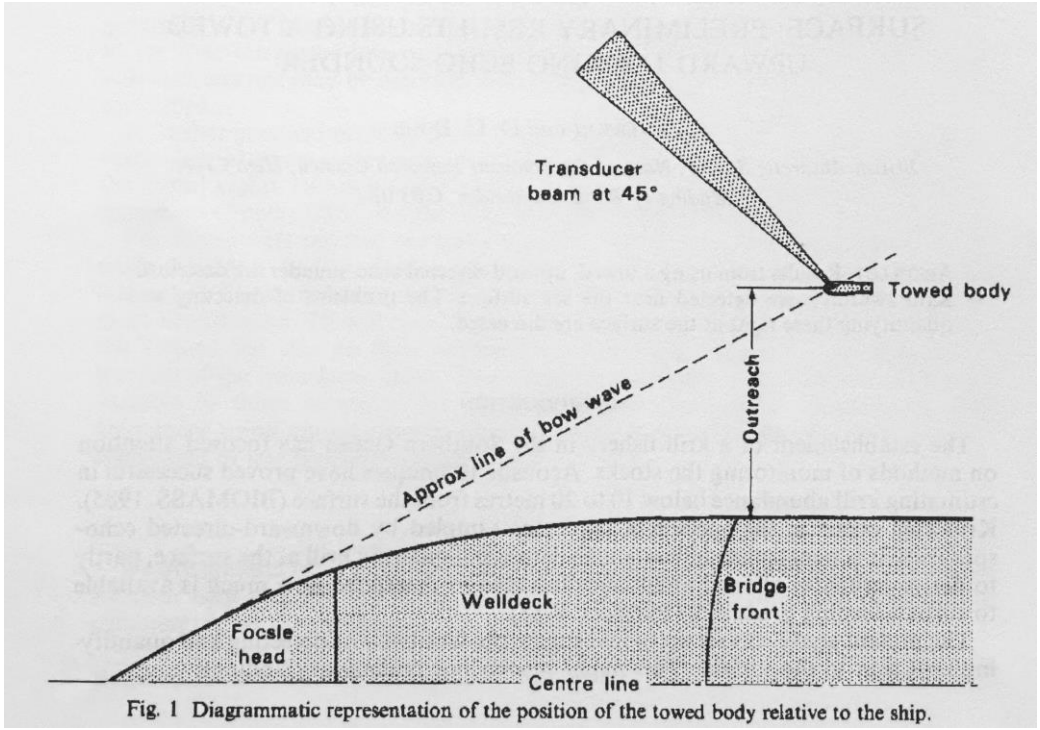

Fig. 1 Diagrammatic representation of the position of the towed body relative to the ship.

Refn: Everson and Bone 1986. BAS Bulletin No72: 61-70

Moving Forward

A further idea:

Using commercial fishing vessels as sampling platforms

***In situ* Multi-frequency acoustic rig attached to trawl warp** (based on RMT study)**.**

Aimed vertically down
Samples water in path of net
Multifrequency

Code end pump:

Provides biological samples

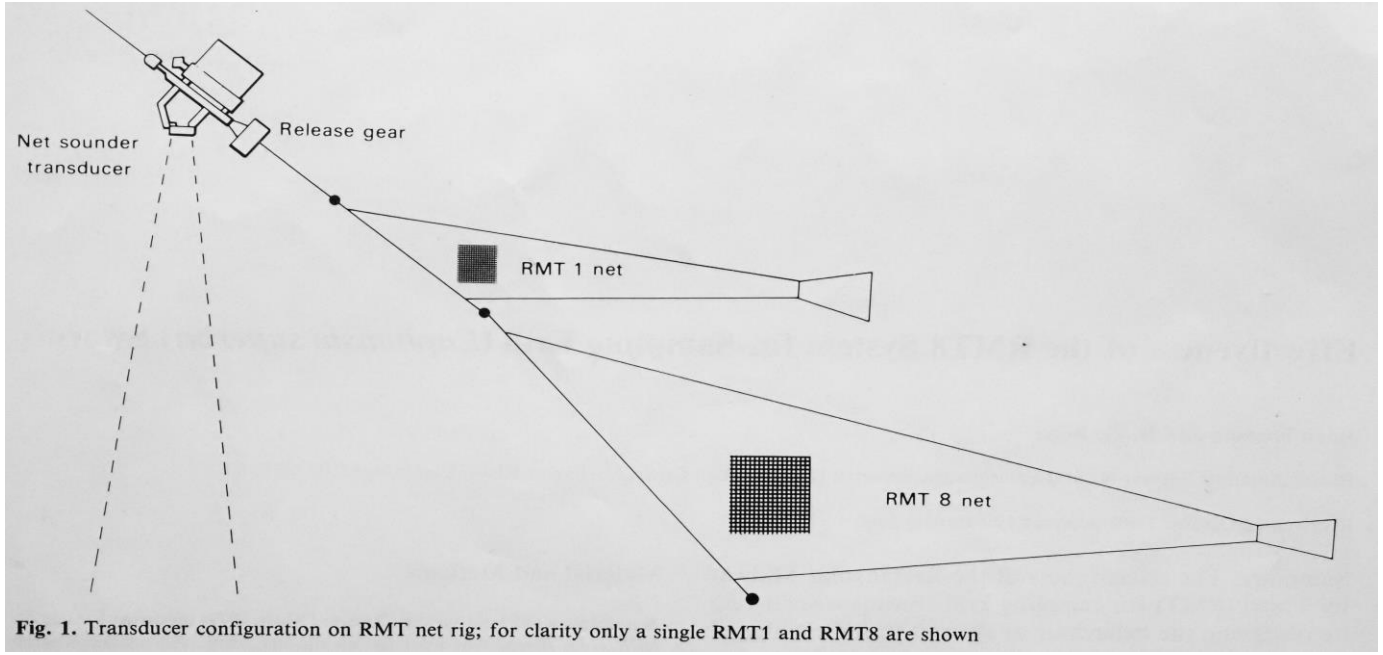

Fig. 1. Transducer configuration on RMT net rig; for clarity only a single RMT1 and RMT8 are shown

Refn: Everson and Bone 1986 Polar Biology 6:83-90

Moving Forward

Potential Results using a commercial fishing vessel as a sampling platform

Upward Transducer:

Acoustic characteristics of near surface aggregations – Predator foraging.

Netsounder:

Multifrequency acoustics analysed with respect to actual krill catches in terms of krill size packing density and other zooplankton (bycatch)

Better understanding of Krill aggregation parameters

Refine acoustic characteristics of dB difference and Sv from current formulae

Moving Forward

How can all this affect the application of Article II?

PICKERS minimally impacted by commercial operations – relax requirement

Better understanding of GULPER dynamics:

1. Refinement of acoustic krill aggregation dynamics for:
   Commercial fishing operations

   Baleen whale feeding

2. Improved understanding of distribution and abundance of krill

Moving Forward

Establishment of Research Project

Collaborate with Commercial Fishing Company

- Equipment requirements
- Logistics
- Personnel
- Funding

Obviously I am keen to see this work progress but need input and collaboration!

Thank you

Government of South Georgia & the South Sandwich Islands

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Sue G


Sue G