Effect of sea ice conditions on physiological maturity of female Antarctic krill (*Euphausia superba*) west of the Antarctic Peninsula

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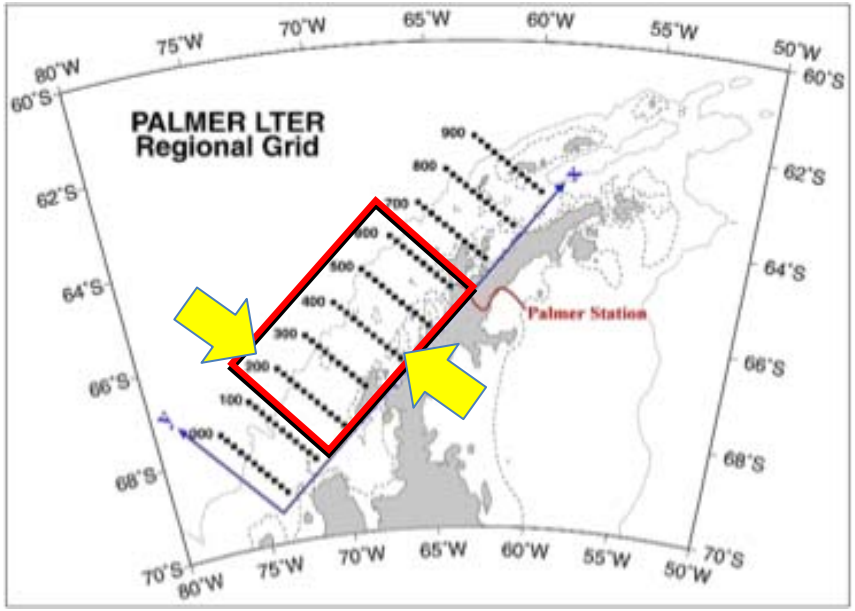
Introduction

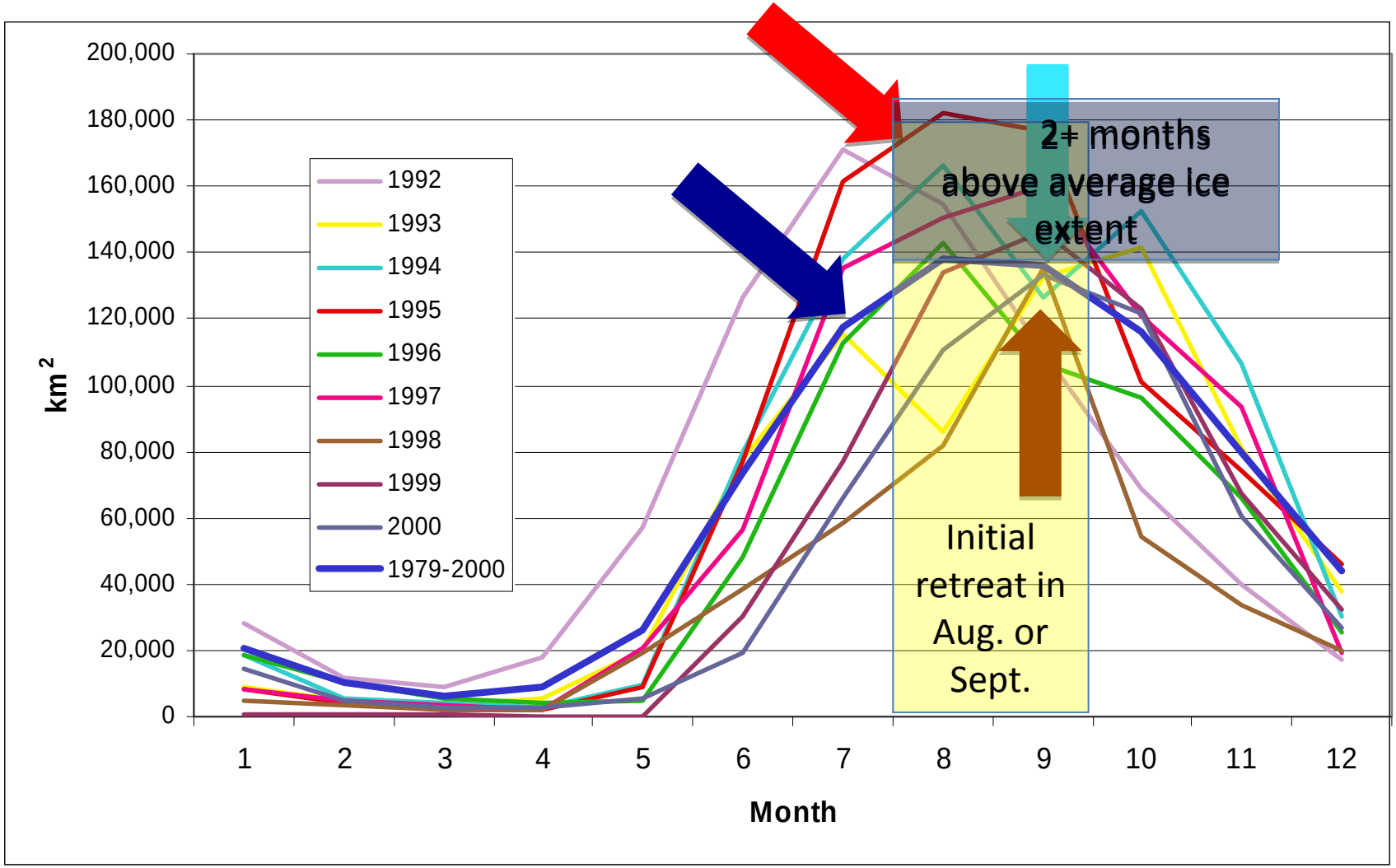
- *Euphausia superba* is a key species in the Antarctic ecosystem and may live for up to seven years
- Individuals grow and shrink, mature and regress, in relation to environmental conditions; therefore size is not a good indictor of age or maturity
- Ovarian development occurs in the spring fueled largely by energy from phytoplankton blooms
- Critical time for food availability for ovarian development in krill is spring rather than winter
- Sea ice extent and timing of ice retreat are instrumental in establishing phytoplankton blooms
- Potential to use sea ice conditions (measured by satellite using passive microwave radiation) as a proxy for food availability in spring

Study Area



- Grid lines numbered from 000-900. Lines 200-600 core sampling area - sampled each year except 1994 when line 200 was skipped since it was still ice-covered
- Consistent winter sea ice coverage from the inner end of the 400 line to the outer end of the 200 line
- Timing of ice formation, advance, and retreat varies among years
- Krill data from summer (Jan-Feb) Palmer LTER cruises 1993-2000

Sea ice conditions



Palmer LTER ice data from http://oceaninformatics.ucsd.edu/datazoo/data/pallter/datasets?action=summary&id=34

Physiological Maturity Staging Method

- Determined physiological maturity stage of individual females using key developed by Cuzin-Roudy and Amsler (1991)
- Key identifies ten reproductive stages based on external morphology of the female, ovarian morphology, and types of oocytes in the ovary
- Distinguishes details of individual reproductive behavior that cannot be identified using other keys, such as:
  - Females that have never spawned
  - Females that have spawned in a previous season but will not spawn during the present one
  - Females that have spawned this season and will spawn again
  - Females that have spawned this season and are finished for the season

Physiological Maturity Stages

Ovarian Development	Stage & color code	Significance for current spawning season
Non-Reproducing - subadult		
Oogenesis and gametogenesis - immature	2	Will not spawn
Initiation of ovarian maturation no mating activity; thelycum mature but not red		
early previtellogenesis	3	Not committed to spawn
Reproductive Cycle - all females with red thelyca oocyte development-prespawning-yolk accumulation		
Previtellogenesis (proteic yolk); mating activity begins	4	Committed to spawn
Early vitellogenesis (lipidic yolk accu	5	Preparing to spawn
Vitellogenesis (lipidic yolk accumulation)	6	Almost ready to spawn
Oocyte maturation and egg release		
Mature oocytes that are ready to be releas	7	Ready to spawn
Recently spawned & recycling the ovary (8 continuin)	8c	Will spawn again
Recently spawned (8 final)	8f	Finished for this season
Post-spawn, ovary in regression	9	Finished for this season
Non-reproducing - has spawned in a previ	10	Will not spawn

Krill variables for classification of spawning season

- Percent reproducing - females in stages 4-9 (stages that have definitely spawned during that season)
- Timing of spawning - ratio of females in later stages of ovarian development (Stages 5 and 6) to females early & late stages (Stages 4, 5 and 6)
- Percent multiple spawners – of females that have spawned during the current season, the percentage that will spawn again (8 continuing)

“Good” vs. “Poor” reproductive seasons

Spawning season	1993	1994	1995	1996	1997	1998	1999	2000
Months of above avg. spring sea ice extent	1	3	3	2	0	4	1	4
Timing of spring sea ice retreat	Aug. 1992	Nov. 1993	Aug. & Nov. 1994	Sept. 1995	Aug. 1996	Nov. 1997	Sept. 1998	Nov. 1999
% reproducing (Stages 4-9)	17	21	11	98	39	14	33	88
Timing of spawning	delayed	delayed	early	early	delayed	delayed	delayed	delayed
% multiple spawners	0	0.10	26	22	0	0.01	0	0
Total good criteria	1	1	3	5	1	1	1	2
Reproductive season	poor	poor	**good**	**good**	poor	poor	poor	**good**

- “Good” needs 2+ favorable (green) or criteria
- Krill criteria favorable or adequate only when ice criteria are

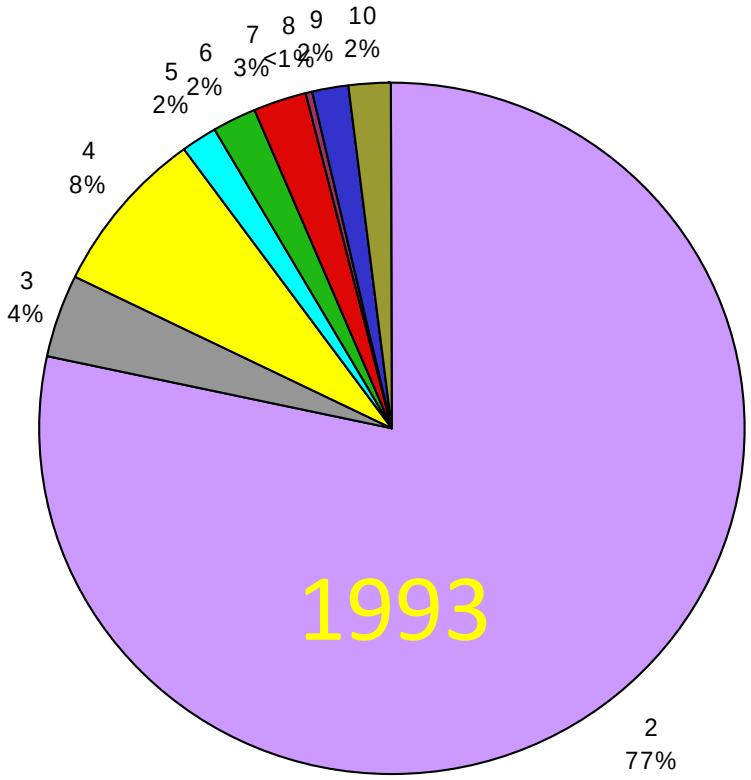
“Good” vs. “Poor” reproductive seasons

Spawning season	1993	1994	1995	1996	1997	1998	1999	2000
Months of above avg. spring sea ice extent			3	2				4
Timing of spring sea ice retreat			Aug. & Nov. 1994	Sept. 1995				Nov. 1999
% reproducing (Stages 4-9)			11	98				88
Timing of spawning			early	early				delayed
% multiple spawners			26	22				0
Total good criteria			3	5				2
Reproductive season			**good**	**good**				**good**

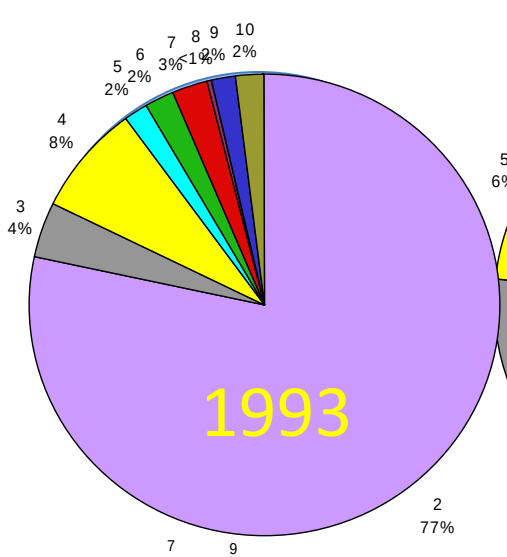
- 1995 ice extent was good but ice retreated, then advanced, then retreated for good in November.
- 1996 is the only year when both ice variables were green and it was the most active reproductive season
- 2000 high ice extent may compensate for late retreat, successful season because a high percentage of females reproducing

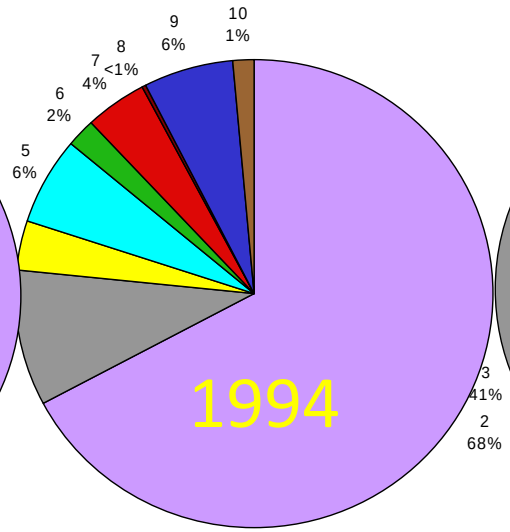
Stage composition graphs

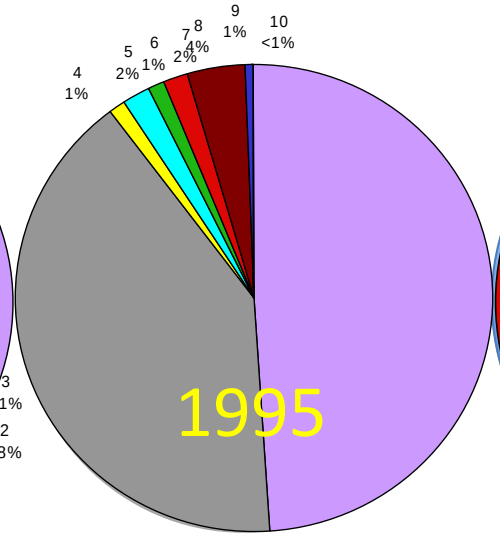
- Percent of total females staged per year
- Purple - immature, will not spawn
- Gray - might spawn, not committed
- Yellow/turquoise/green - preparing to spawn
- Red - actively spawning

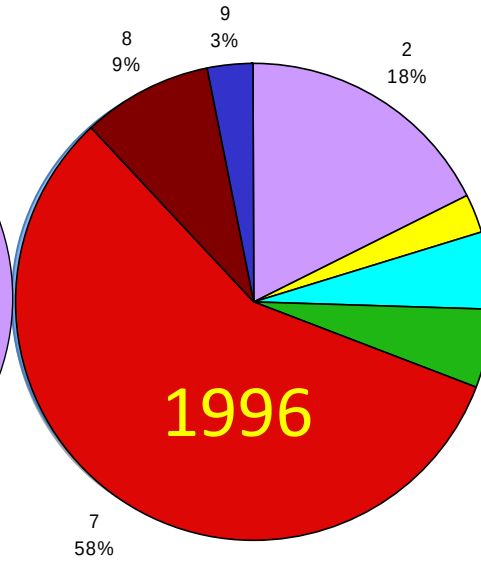


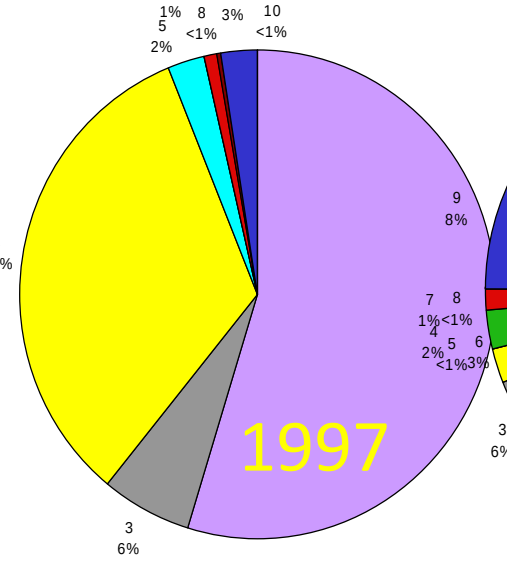
Stage Composition by Year

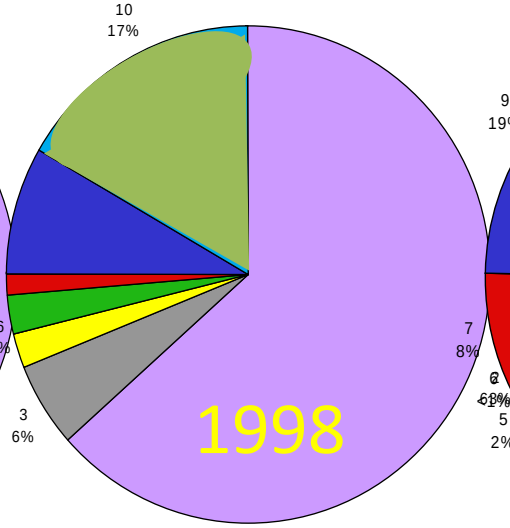


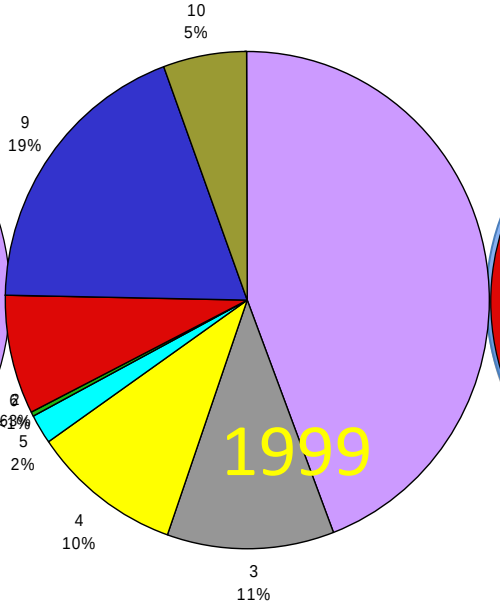


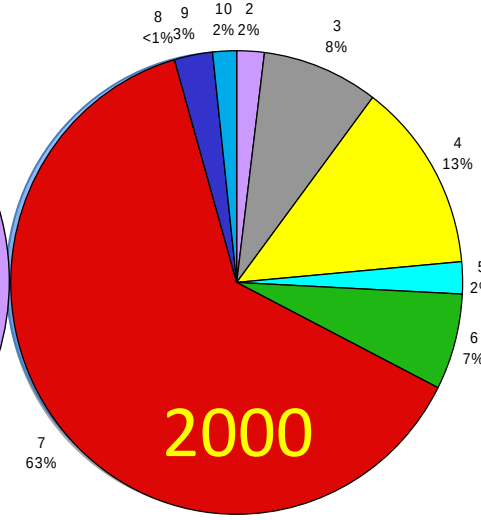






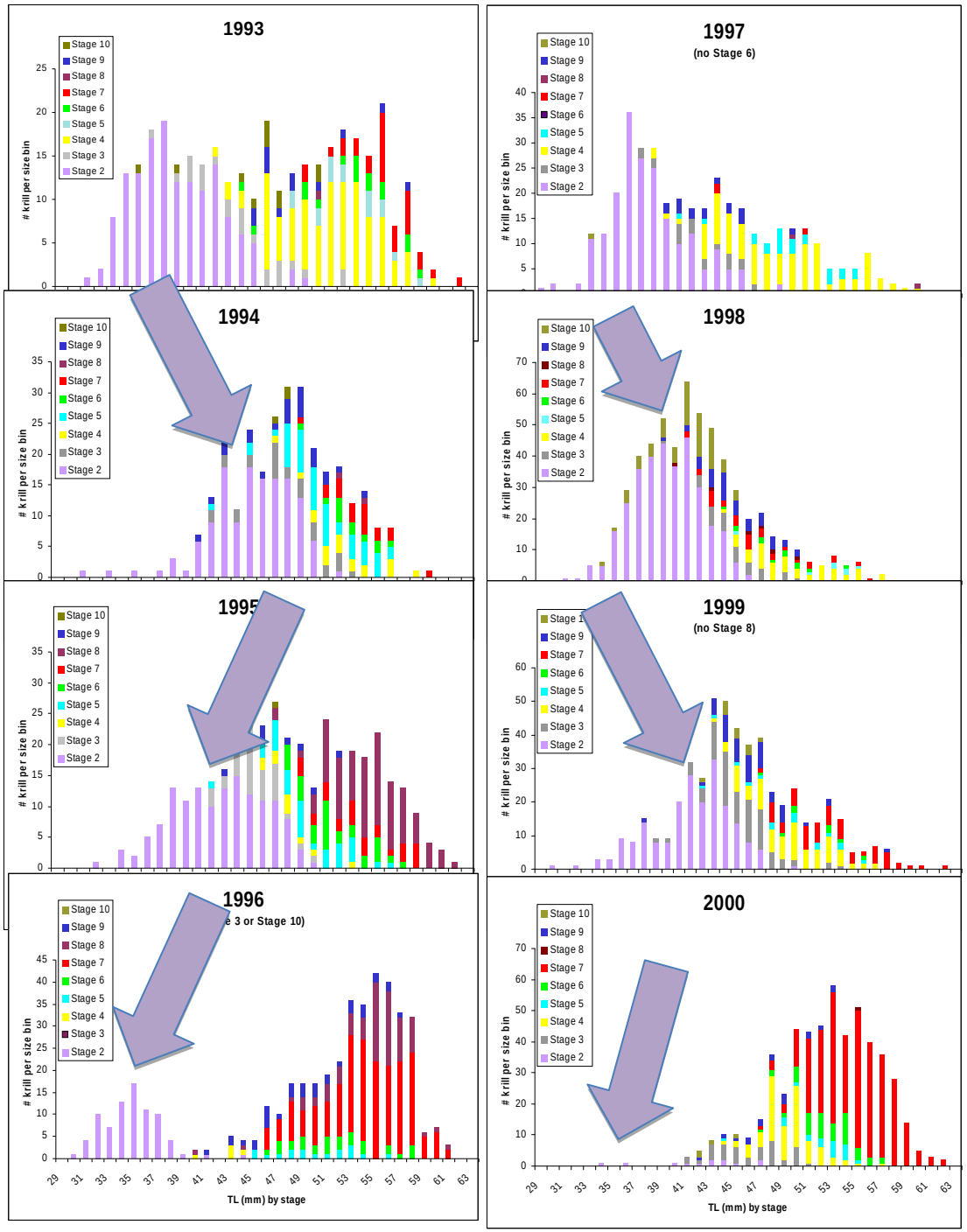






Length frequencies of maturity stages

- Lengths from 28-63mm; rarely able to sex krill <28mm
- Few spawning females <40mm; most ≥45mm
- Females may be able to delay maturity & first spawning for up to several years



Summary

- Extent and timing of retreat of sea ice in the austral spring are closely associated with the development of phytoplankton blooms and may be useful as a proxy for food availability
- Physiological maturity stages of individuals allow for a more detailed understanding of reproductive behavior and consequently of how environmental conditions may affect reproduction
- A suite of criteria encompassing both ice conditions and physiological maturity stages of *E. superba* can be used to classify reproductive seasons as good or poor
- Three reproductive seasons out of eight were classified as good, though the conditions that led to this classification were different for each year
- The high degree of overlap in the lengths of immature and mature females indicates that female krill are able to delay maturity and first spawning, possibly for several seasons, under unfavorable environmental conditions

Ice and *E. superba*

- *E. superba* reproductive activity is closely associated with phytoplankton blooms, which are closely associated with sea ice extent and timing of initial retreat
- Range of variability in this study relatively small compared to potential changes in Antarctic sea ice conditions
- Potential for relatively small changes in sea ice dynamics to dramatically affect *E. superba* reproduction, and potentially their distribution and survival
- What sort of food web would a salp-dominated Antarctic ocean support?

Acknowledgments

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