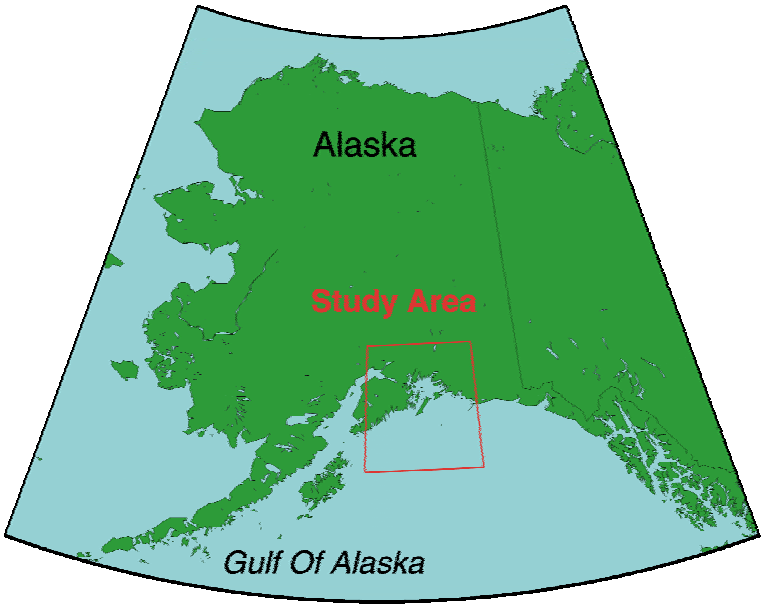
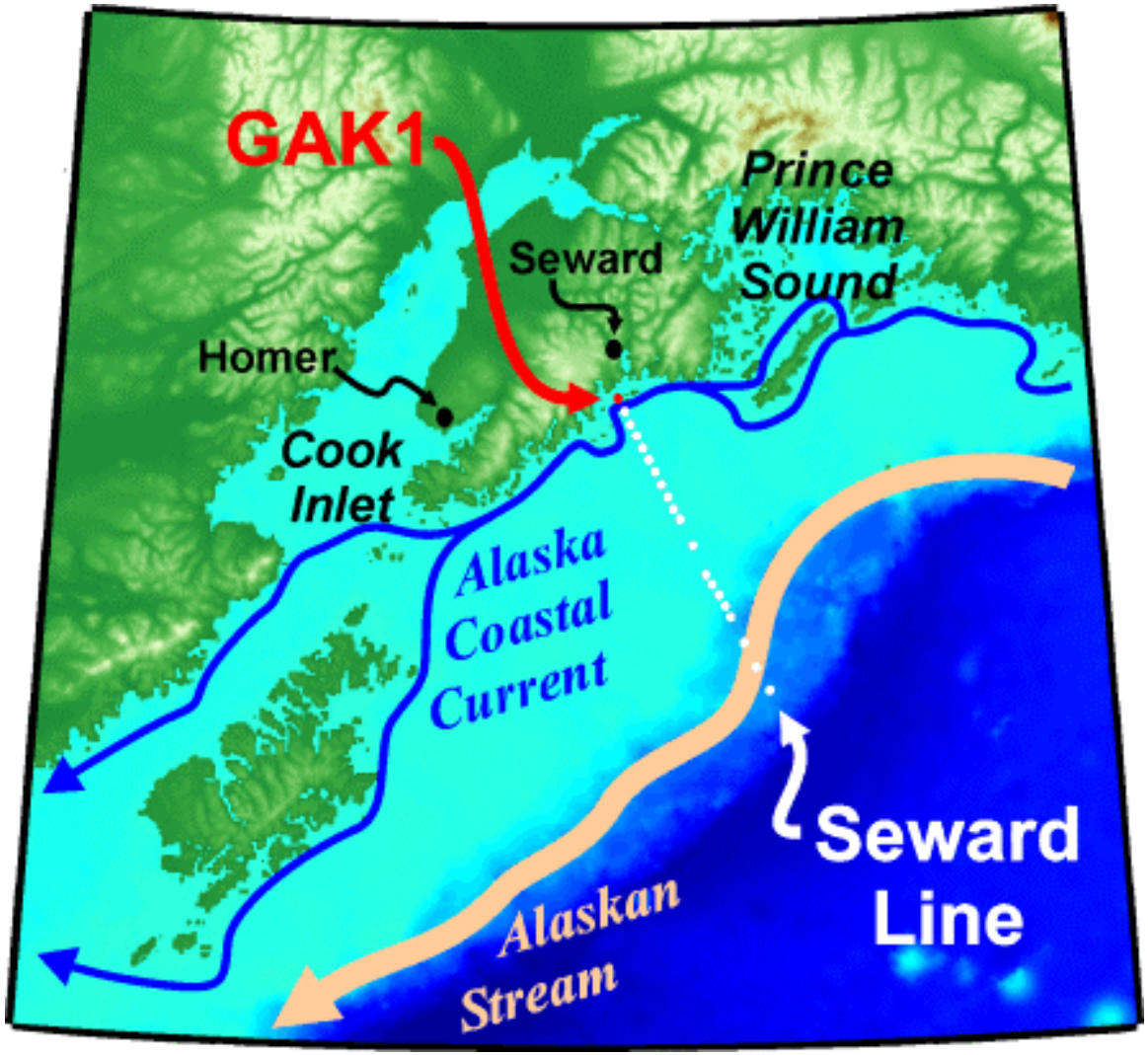
The Optimal Stability Window hypothesis and *Neocalanus* concentrations on the Gulf of Alaska shelf during May, 1998 - 2002

Kenneth O. Coyle
Institute of Marine Science, University of Alaska
Fairbanks, Alaska 99775 USA

Long Term Observation Program
Zooplankton Component
Gulf of Alaska
GLOBEC




GAK1
Prince
William
Sound
Seward
Homer
Cook
Inlet
Alaska
Coastal
Current
Seward
Line
Alaskan
Stream

Optimum Stability Window Hypothesis

Gargett (1997) Fisheries Oceanography 6: 109-117

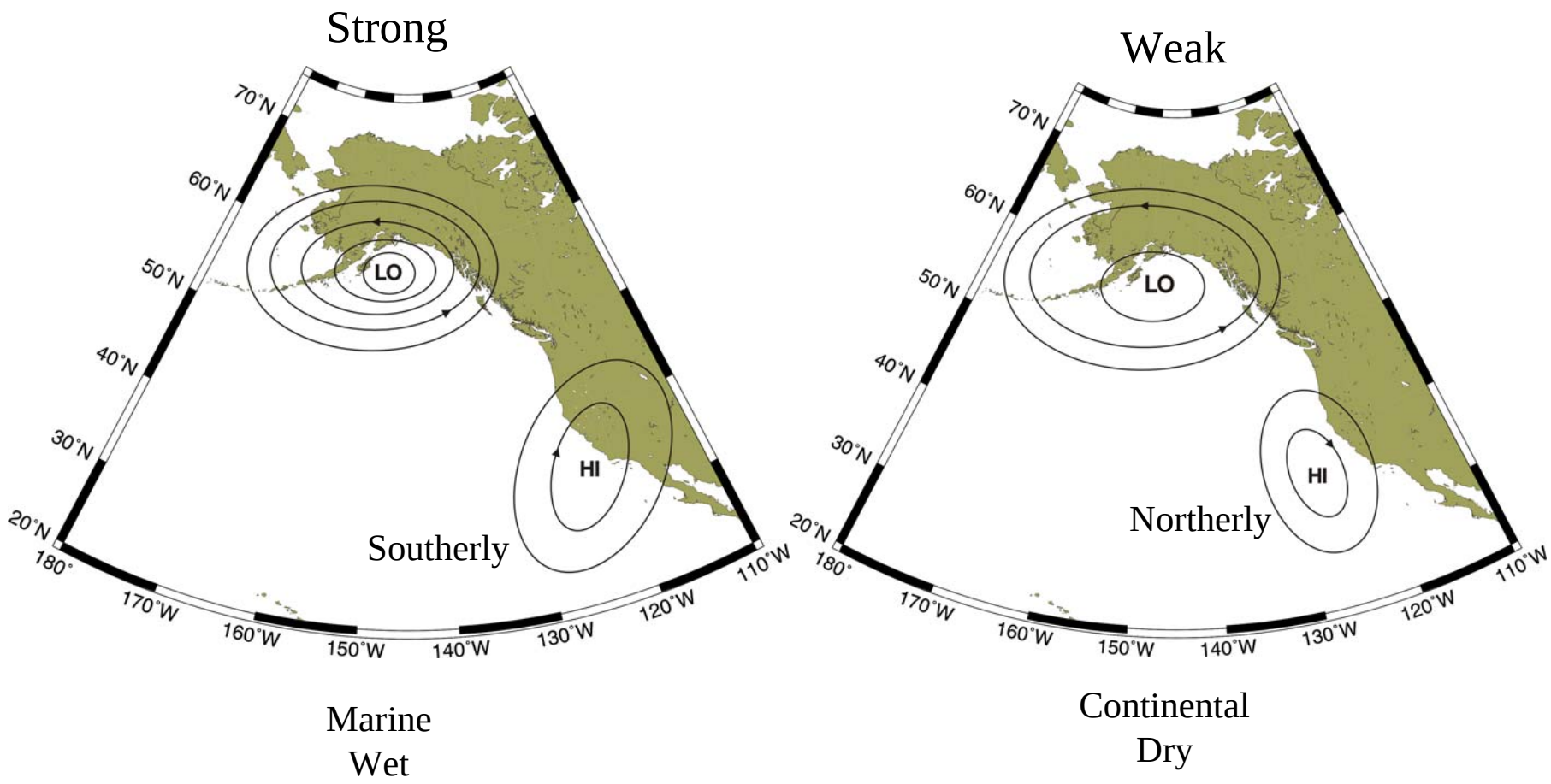
Attempts to explain the observation that salmon year class strength is out of phase between the Gulf of Alaska and the northwest coast (British Columbia, Washington, Oregon, California)

Assumptions:

1) Primary production is light limited on Gulf of Alaska (GOA) shelf but nutrient limited on the northwest coast.

2) Turbulence lowers production by mixing phytoplankton below the compensation depth on the GOA shelf but enhances production by mixing nutrients through the pycnocline on the northwest coast.

3) Water column stability is a function of salinity on the GOA shelf but a function of upwelling favorable winds on the northwest coast.



Marine
Wet

Continental
Dry

Enhanced Stability on GOA shelf
Weak upwelling on west coast

Low stability on GOA shelf
Strong upwelling on west coast

Modified from Gargett (1997)

Hypothesis and Predictions

Hypothesis: Greater precipitation and runoff during periods of a strong Aleutian Low will lead to higher overall production by reducing mixing and stabilizing the water column of the GOA shelf.

Predictions:

1) Strong Aleutian low should promote production on the GOA shelf by stabilizing the water column.
2) Zooplankton abundance and biomass should be positively correlated to the stability coefficient.
3) Zooplankton abundance and biomass should be negatively correlated to salinity above the pycnocline.

Methods

1. Large zooplankton were collected with 1-m^2 square MOCNESS with 500 μm mesh. Samples collected in 20 m depth increments from 100 m to the surface at night.
2. Small zooplankton were collected with a 25 cm diameter CalVET net with 150 μm mesh. Vertical tows from 100 m to surface during the day.
3. Water column profiles were collected with a Seabird model 911 plus CTD and fluorometer.
4. Water column stability was computed using the stratification parameter: (Simpson et al. 1977).

$$\bar{\upsilon} = \frac{1}{h}\int_{-h}^{0}(\rho - \bar{\rho})gzdz; \quad \bar{\rho} = \frac{1}{h}\int_{-h}^{0}\rho dz$$

$\bar{\upsilon}$ = work required to redistribute the mass during complete mixing.

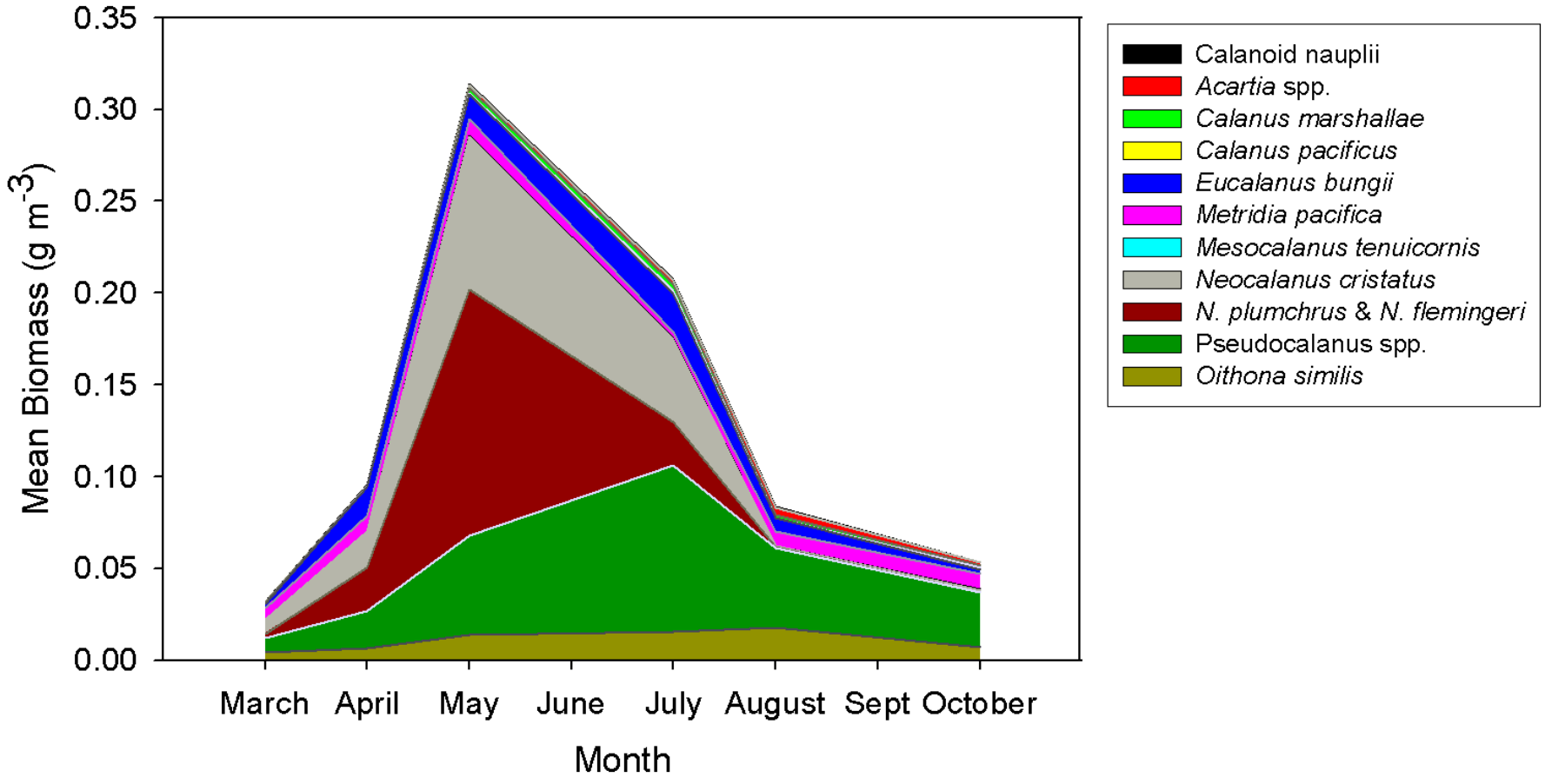
h = water column depth

z = verticle coordinate

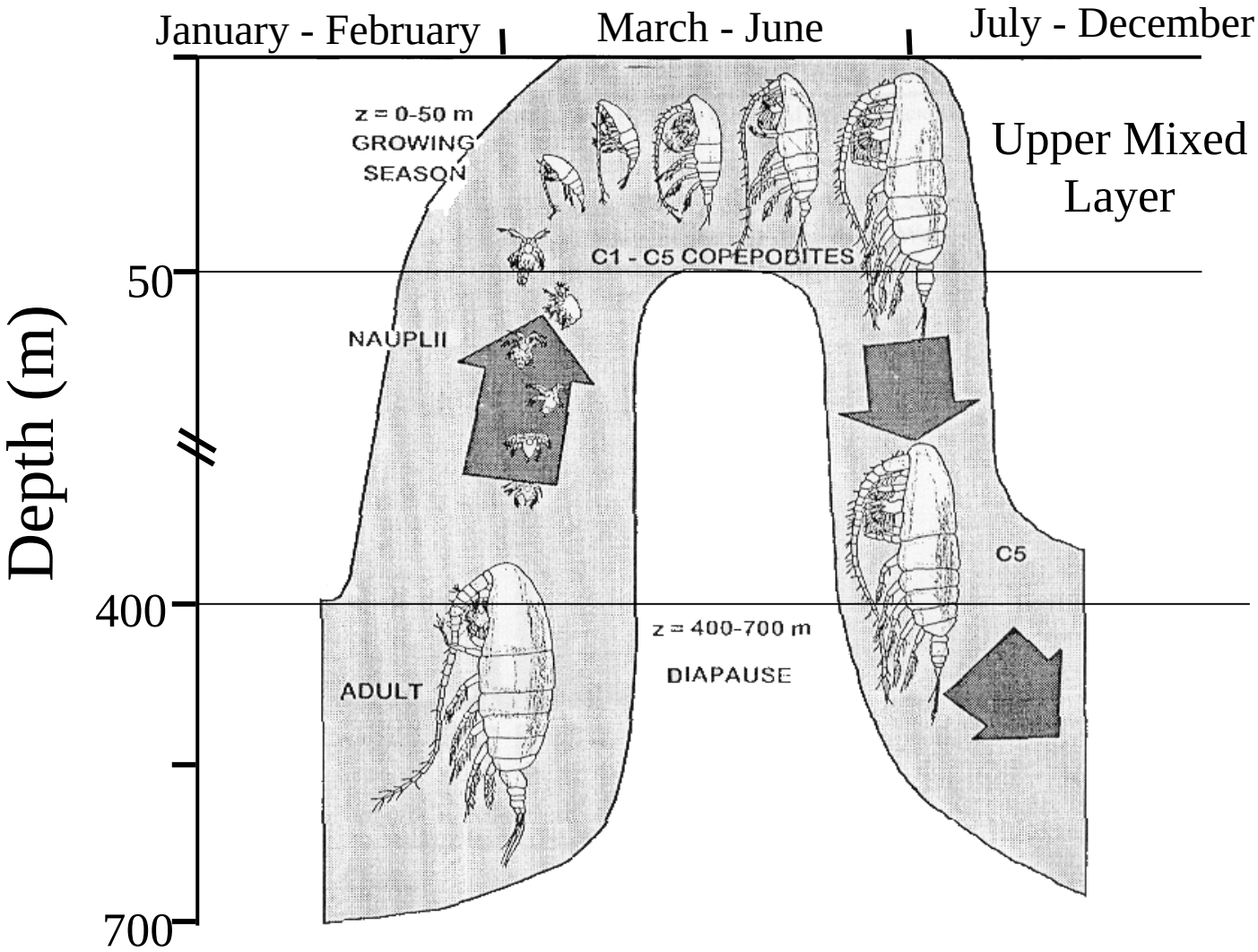
g = acceleration of gravity

ρ = density

Mean Biomass of major calanoids by month

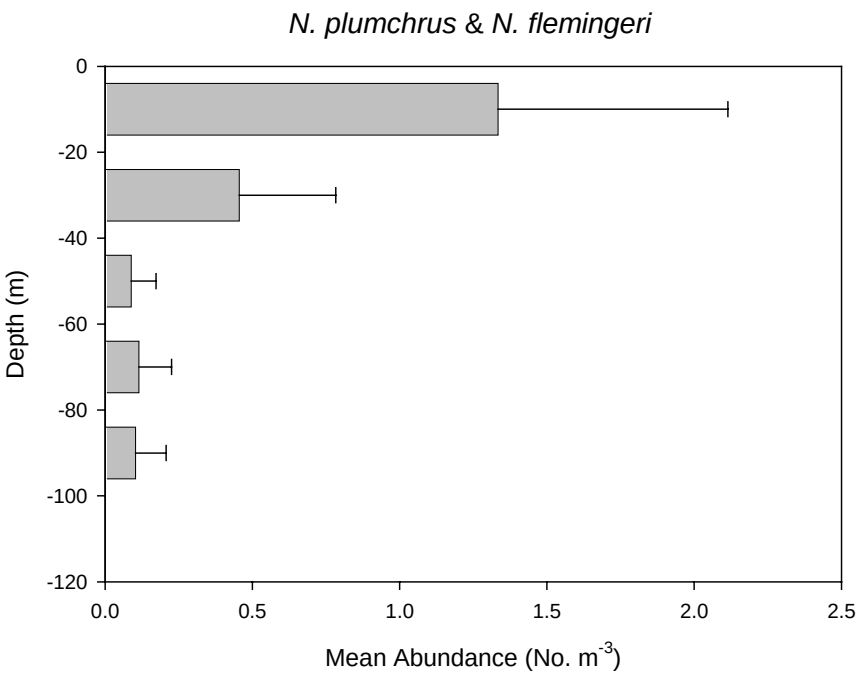


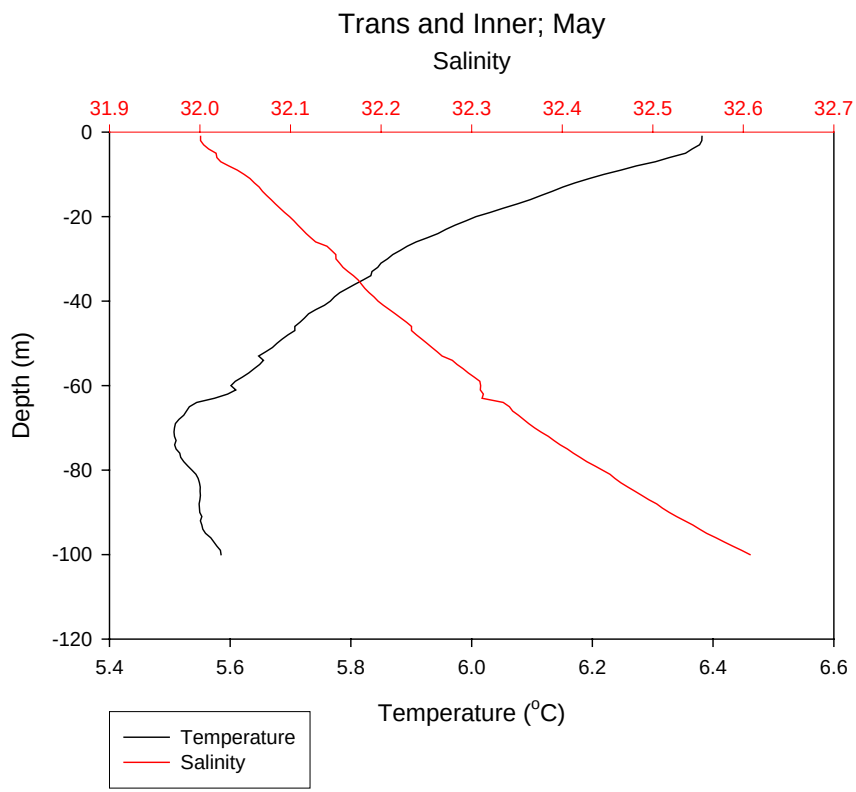
Neocalanus flemingeri plumchrus life cycle

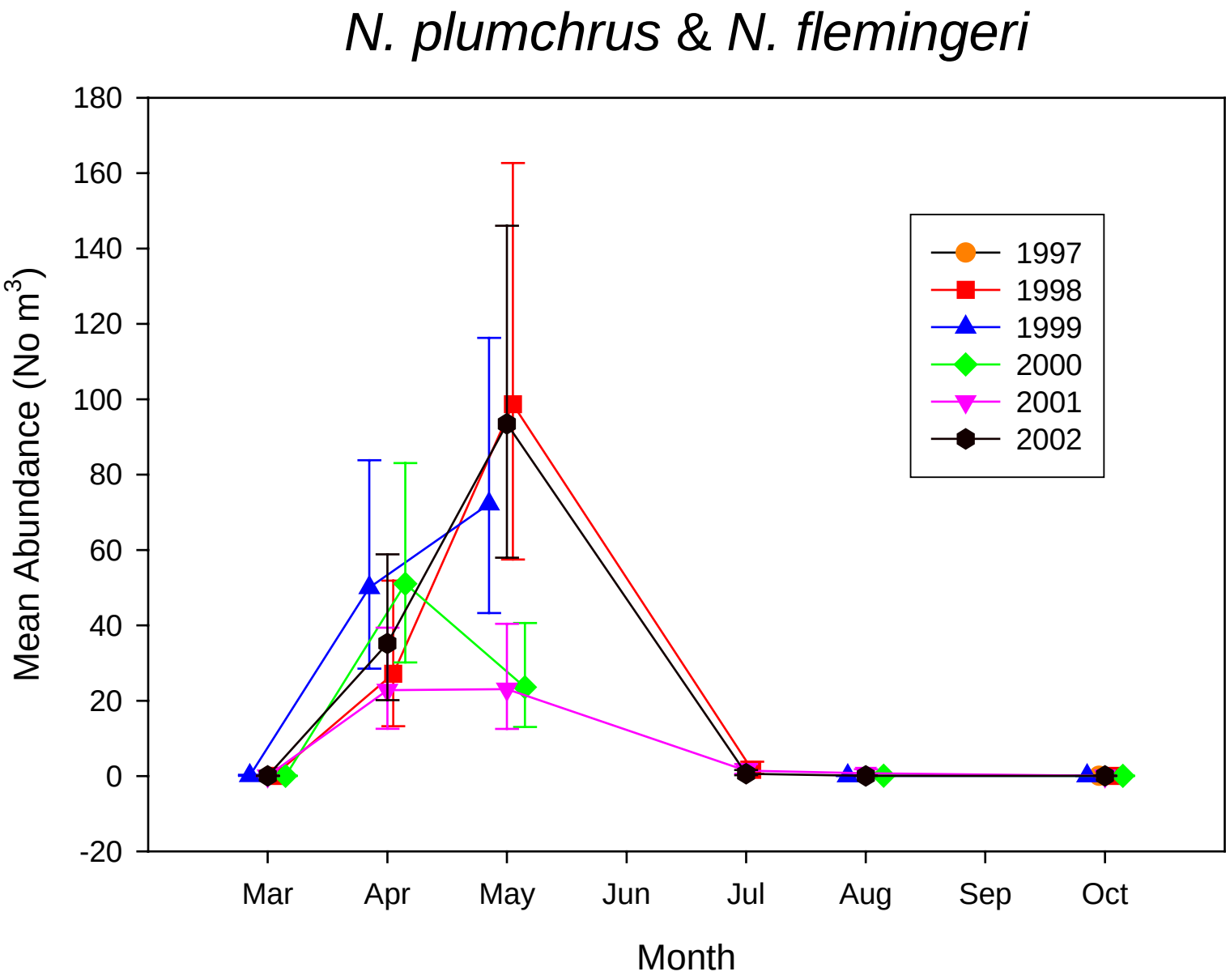


Modified from Mackas et al. (1998)

Average depth distribution for *Neocalanus flemingeri*, May, 1998 – 2002
Average salinity and temperature distribution, May 1998 – 2002.






N. plumchrus & N. flemingeri
Mean Abundance (No m3)
180
160
140
120
100
80
60
40
20
0
-20
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month
1997
1998
1999
2000
2001
2002

Neocalanus characteristics on the GOA shelf

- The *Neocalanus flemingeri* is an oceanic animal, its distribution is not constrained by a physiological response to oceanic salinity.
- They reside in the upper wind-mixed layer during their growth phase and are therefore mixed across the shelf.
- They dominate the zooplankton biomass during May.
- They undergo their largest growth per animal in April – May – June. April – May – June is therefore a critical foraging period.
- They are integrators of production conditions for the critical period (April – May – June).
- There are significant interannual differences in mean abundance and biomass during May.

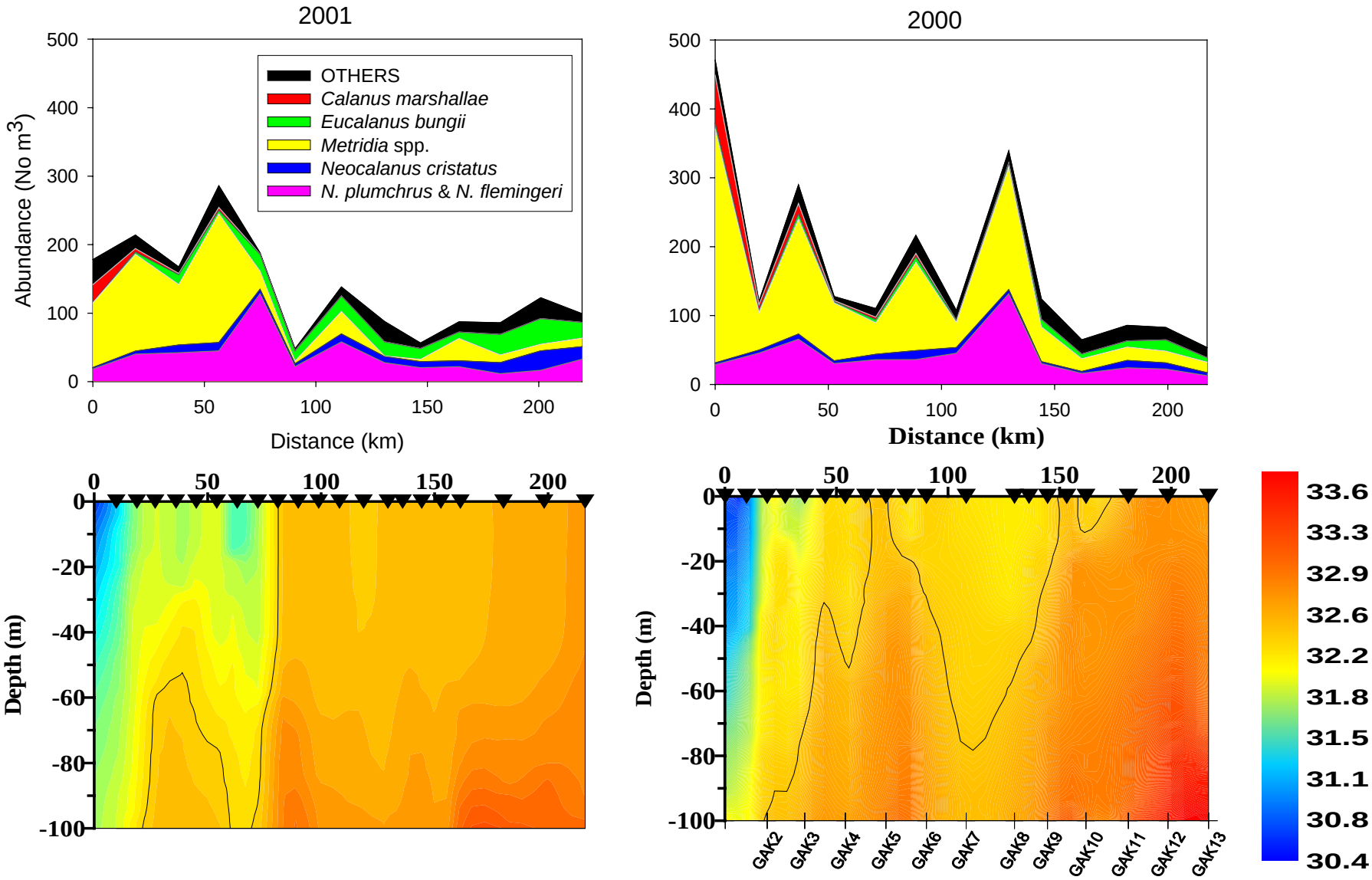
Total Redundancy: 31%; Canonical R: 0.55; p = 0.00582

Correlation between major water column properties and abundance of *Neocalanus plumchrus-flemingeri* during May, 1998 - 2002	
Upper Mixed Temperature	-0.031527
Lower Mixed Temperature	0.217810
Mean Water Column Temperature	0.176241
Potential Energy (Stability)	-0.270128
Upper Mixed Salinity	**-0.423168**
Lower Mixed Salinity	**-0.448230**
Mean Salinity	**-0.445252**

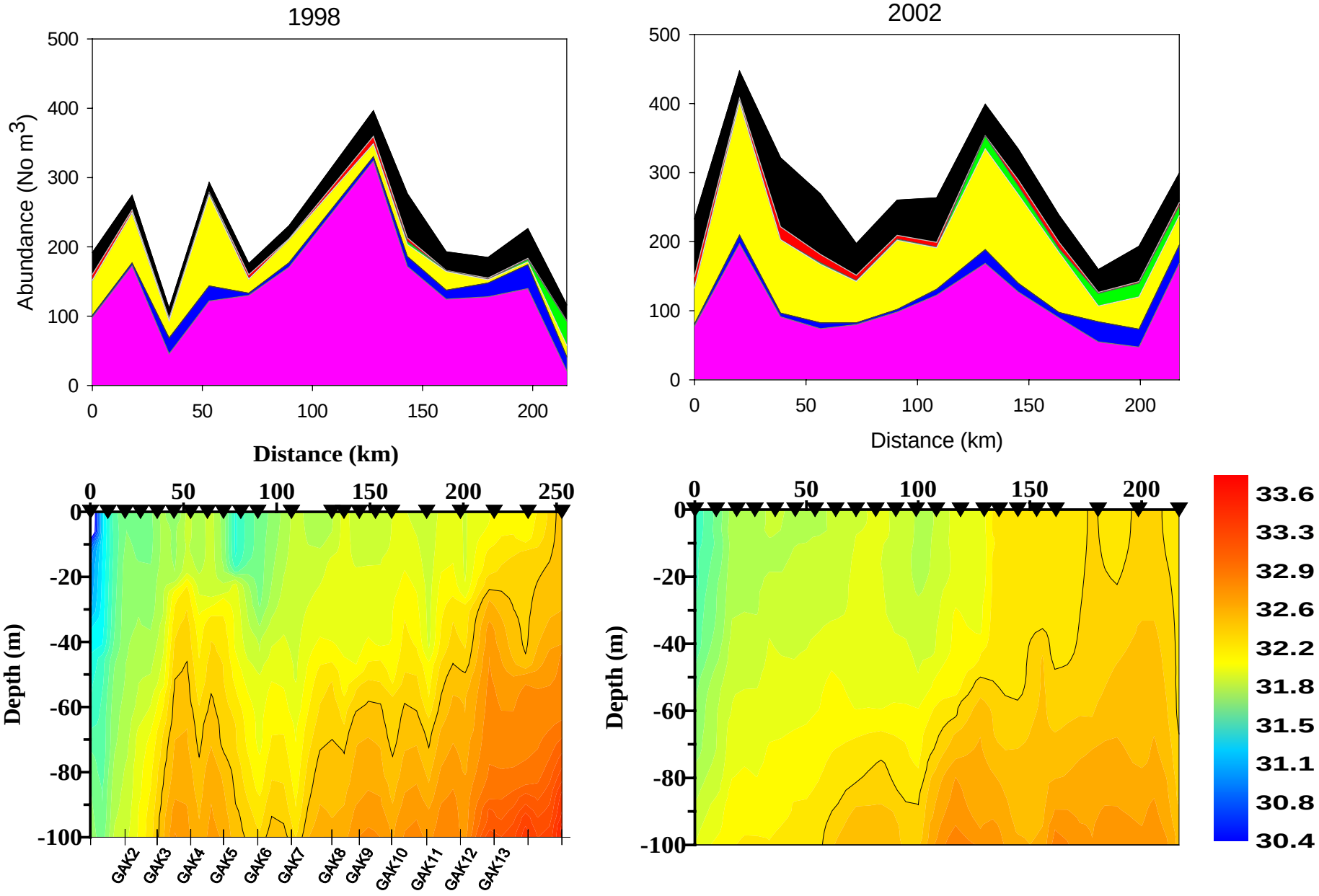
Total Redundancy: 63%; Canonical R: 0.79; p = 0.0000027

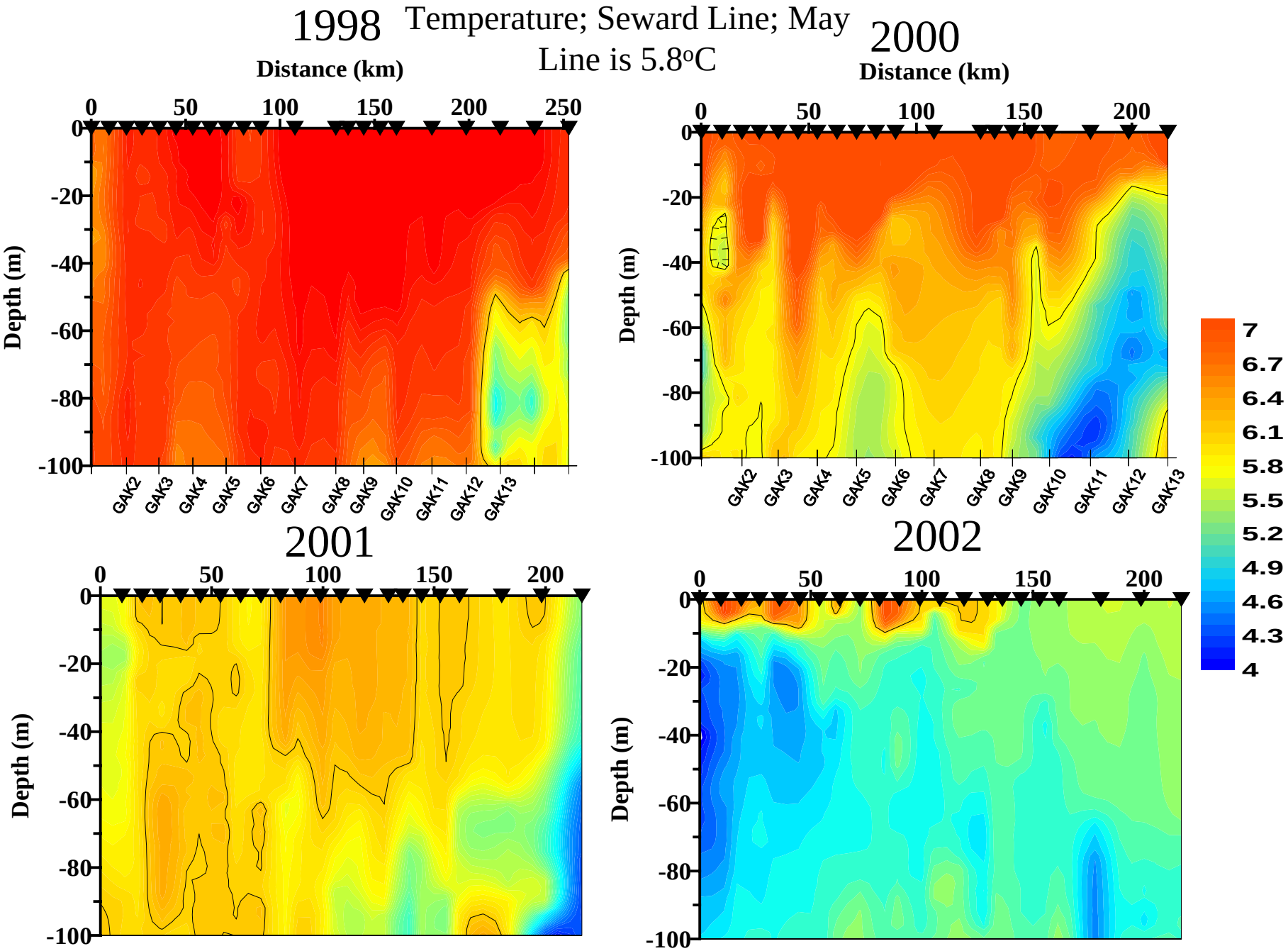
Correlation between major water column properties and abundance of *Neocalanus plumchrus-flemingeri* during May, 1998 – 2002; outer nine stations	
Upper Mixed Temperature	0.025283
Lower Mixed Temperature	0.421468
Mean Water Column Temperature	0.343750
Potential Energy (Stability)	-0.223003
Upper Mixed Salinity	**-0.757058**
Lower Mixed Salinity	**-0.768888**
Mean Salinity	**-0.783464**

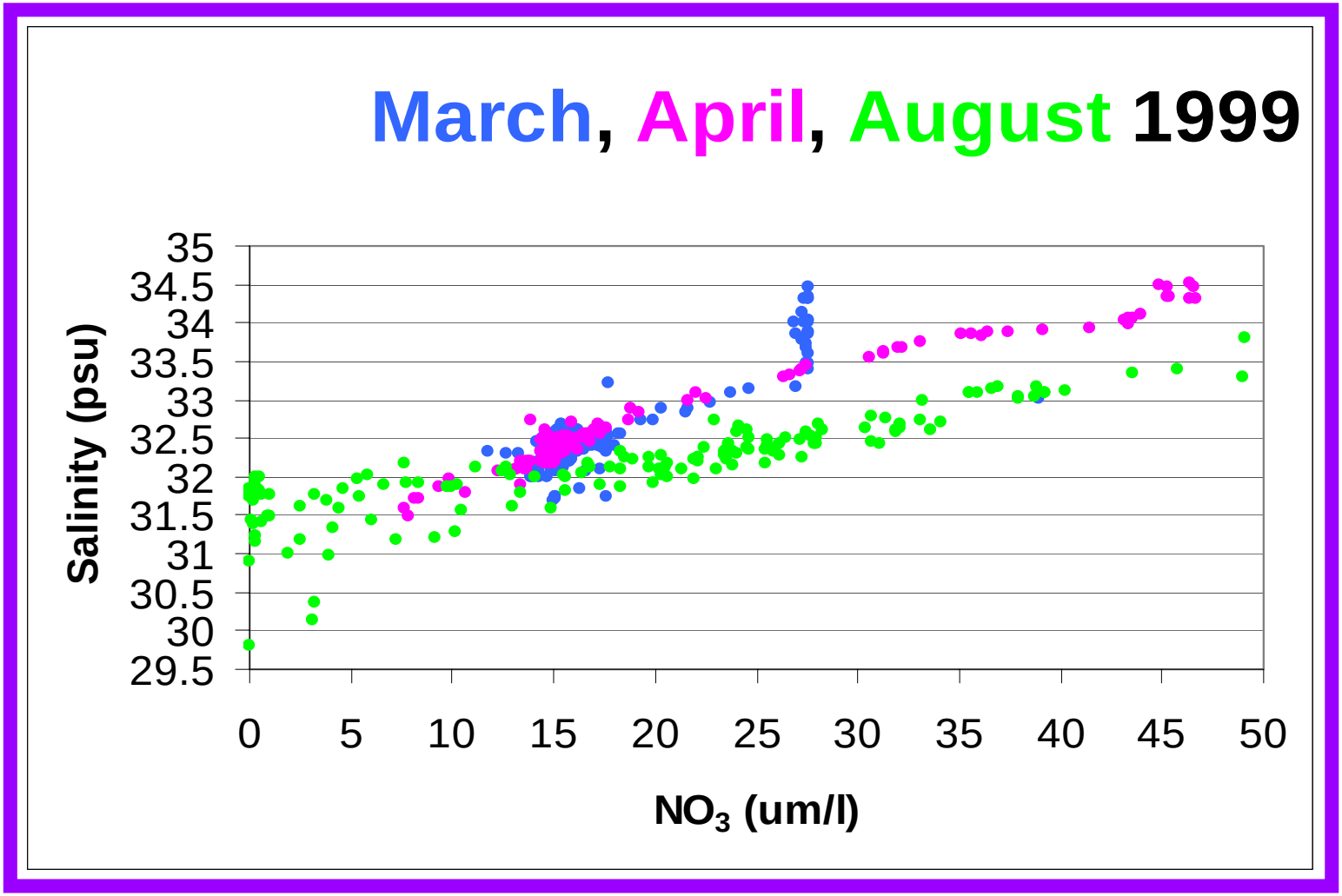
Salinity and Copepod abundance; Seward Line; May
Line is 32.4



Salinity and Copepod abundance; Seward Line; May
Line is 32.4

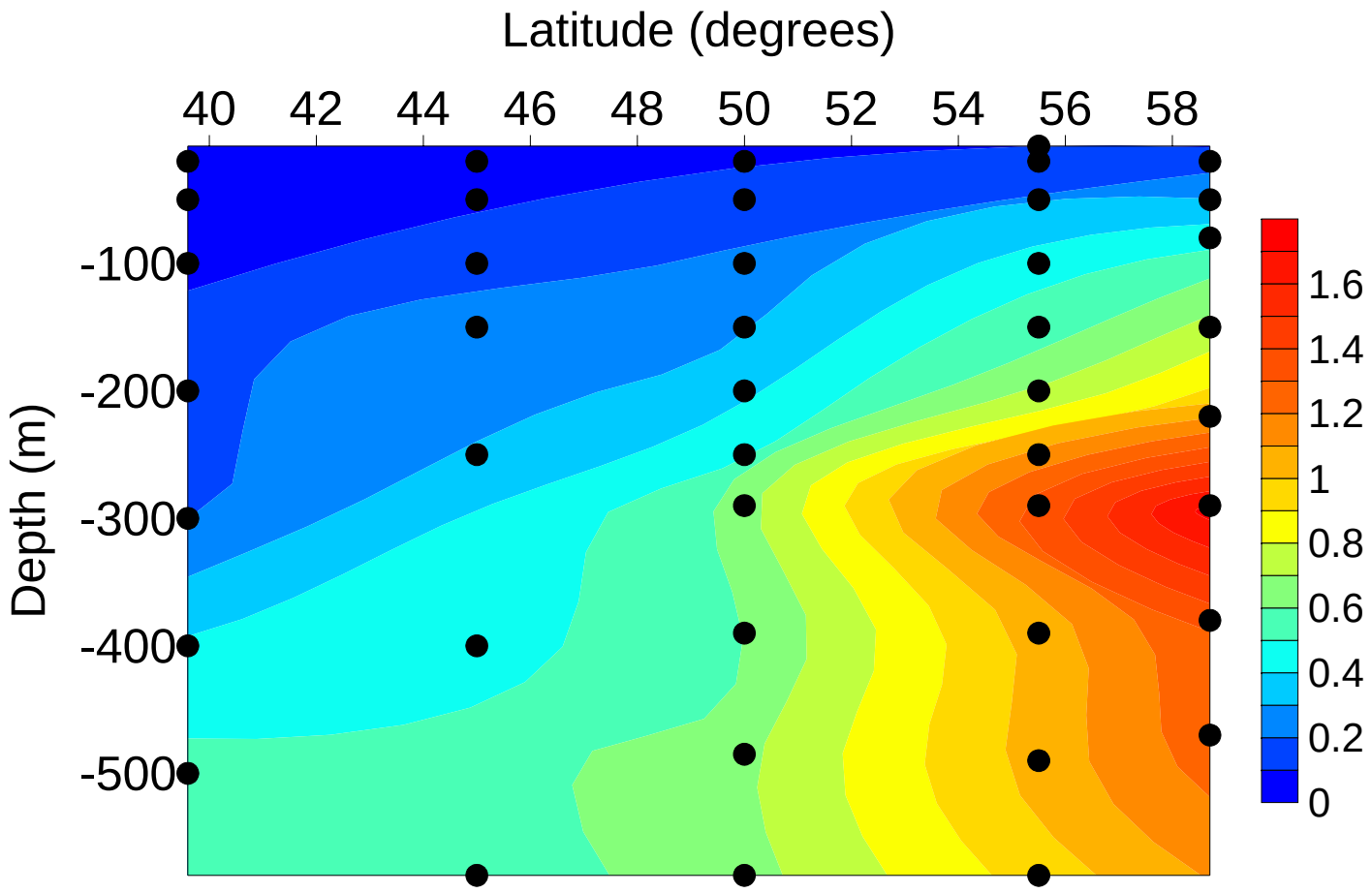


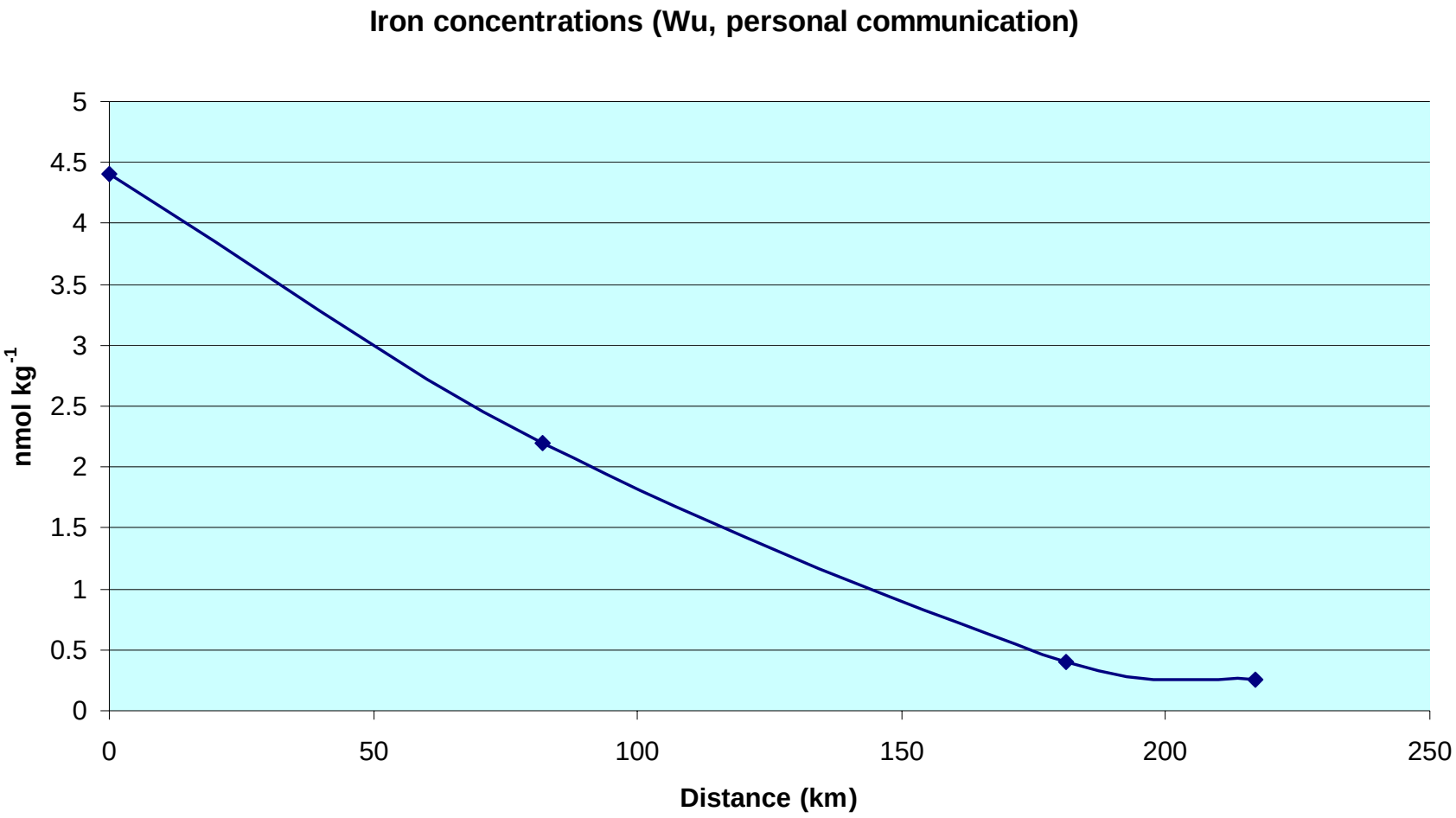

1998
Temperature; Seward Line; May
Line is 5.8°C
2000
2001
2002
Distance (km)
Depth (m)
0
50
100
150
200
250
-20
-40
-60
-80
-100
GAK2
GAK3
GAK4
GAK5
GAK6
GAK7
GAK8
GAK9
GAK10
GAK11
GAK12
GAK13
7
6.7
6.4
6.1
5.8
5.5
5.2
4.9
4.6
4.3
4



From a poster at ASLO, 2000, by Childers, Whitledge, Stockewll, Weingartner, Danielson, Coyle: Major nutrient distributions in relation to the physical structure of the Gulf of Alaska shelf.

Iron concentrations (nmol/kg) from Ocean Station P to the Gulf of Alaska shelf break (Martin et al., 1989)





Wu, Jingfeng: measured iron on the Seward Line in the upper mixed layer during May, 2004

Summary of observations

1) Copepod abundance is strongly and negatively correlated to salinity.
2) Copepod abundance shows little or negative correlation to water column stability.
3) Copepod abundance shows little or no correlation to upper mixed temperatures.
4) When copepod abundance is low, intrusion of oceanic water onto the shelf constrains the mixing zone to a narrow band near the outer edge of the coastal current.
5) When copepod abundance is high, the mixing zone is spread across the shelf from the coastal current to the shelf break front.
6) Macronutrient concentrations are positively correlated to salinity.
7) Iron concentrations are near threshold detection levels in the mixed layer at the shelf break but about an order of magnitude higher in the Alaska Coastal Current.

Conclusion

Although a consistent negative correlation is observed between the abundance of major copepod species and salinity, enhanced productivity due to greater water column stability (as postulated by the Optimum Stability Window hypothesis) is not supported by observations.

Observations suggest that elevated production occurs in the mixing zone between oceanic and ACC waters. Conditions which broaden the mixing zone will result in elevated copepod abundance and biomass.

The most likely explanation for the observations is that mixing between high-nutrient, low-iron oceanic water and high-iron, low-nutrient ACC water promotes elevated primary production in the mixing zone, leading to elevated production of zooplankton forage.

A strong Aleutian Low is likely to promote zooplankton production on the shelf by increasing the volume of freshwater runoff on the shelf, thus injecting iron into the system, broadening the mixing zone and elevating production across the shelf.

Thank you

Other participants in the LTOP project:

Physical Oceanography
Tom Weingartner
Tom Royer
Seth Danielson

Nutrients - Phytoplankton
Terry Witledge
Dean Stockwell

Zooplankton
Alexei Pinchuk
Russell Hopcroft

Fish
Lew Halderson
Jennifer Boldt

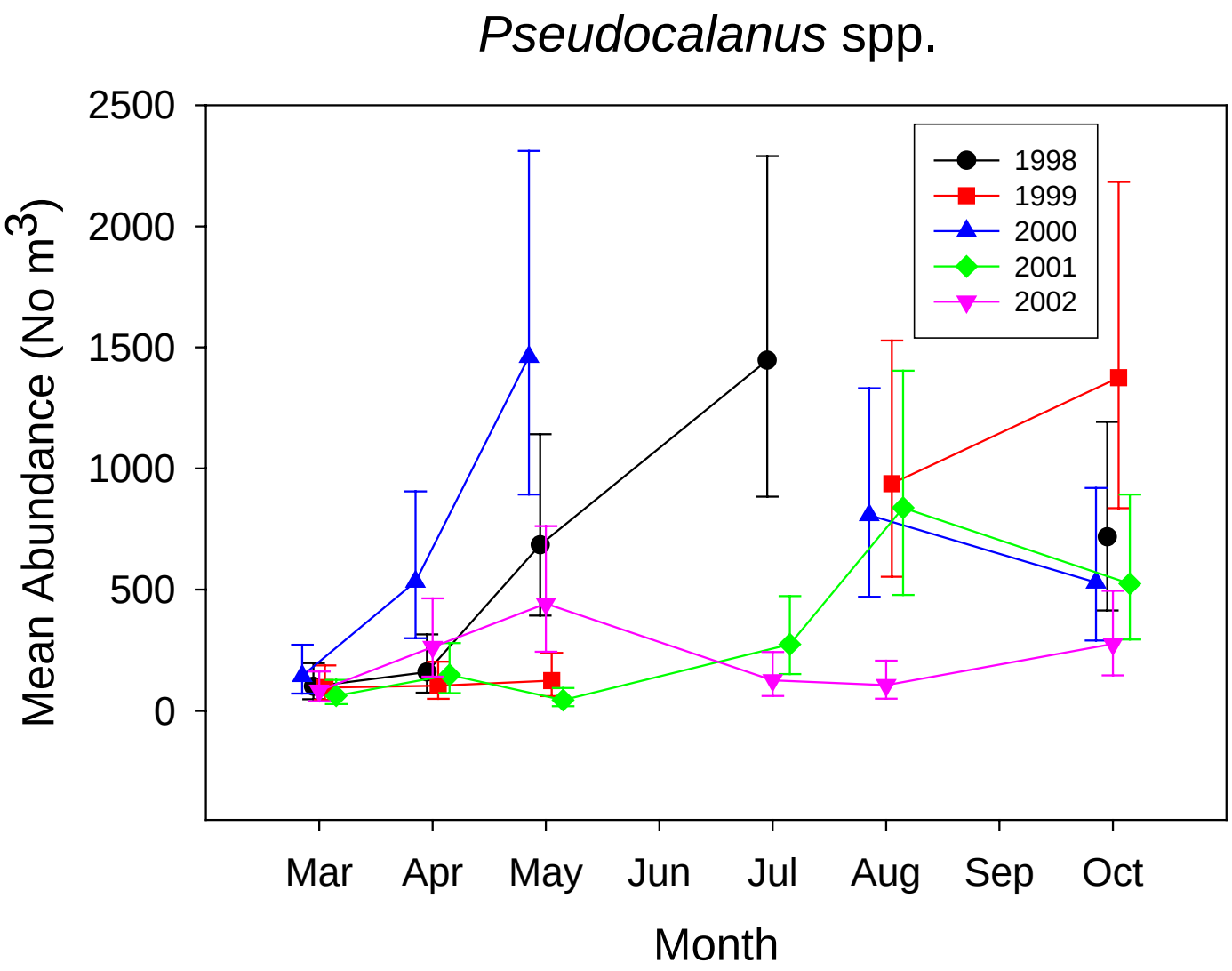
Questions?

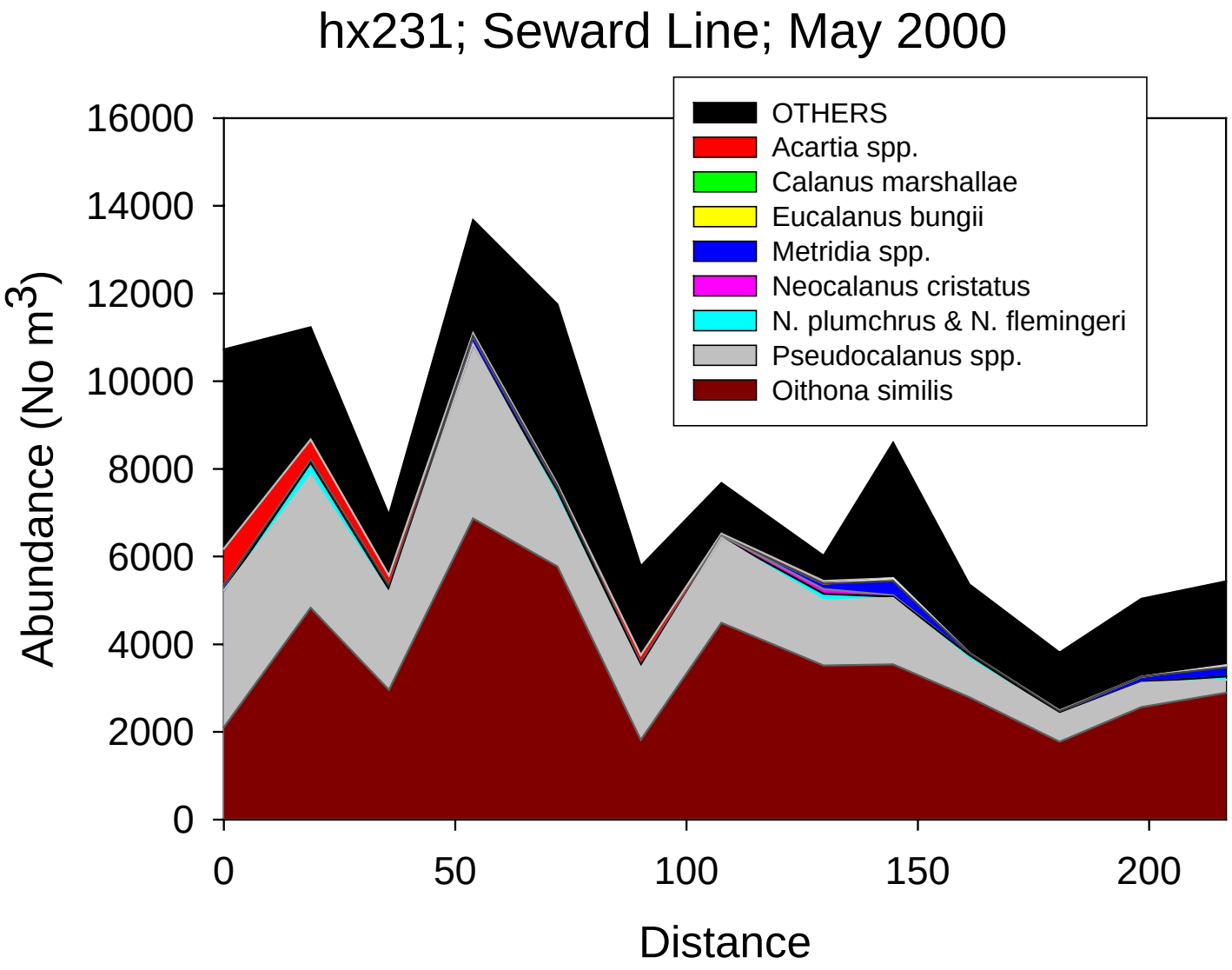
Total Redundance: 61%; Canonical R: 0.71; p = 0.00000

Correlation between major water column properties and abundance of *Pseudocalanus* spp. during July and August, 1998 - 2002	
Upper Mixed Temperature	0.121350
Lower Mixed Temperature	0.653928
Mean Water Column Temperature	0.454451
Potential Energy (Stability)	0.270545
Upper Mixed Salinity	-0.413925
Lower Mixed Salinity	-0.554767
Mean Salinity	-0.549876

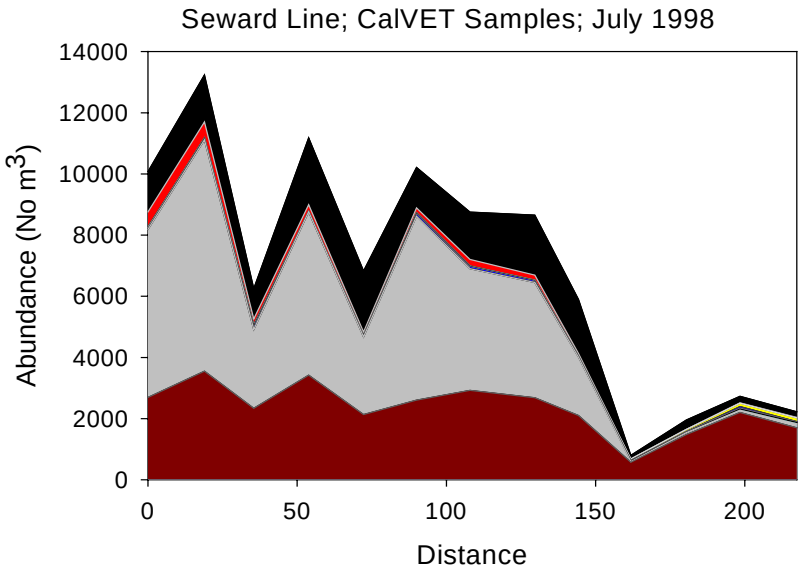
Total Redundance: 62%; Canonical R: 0.79; p = 0.00000

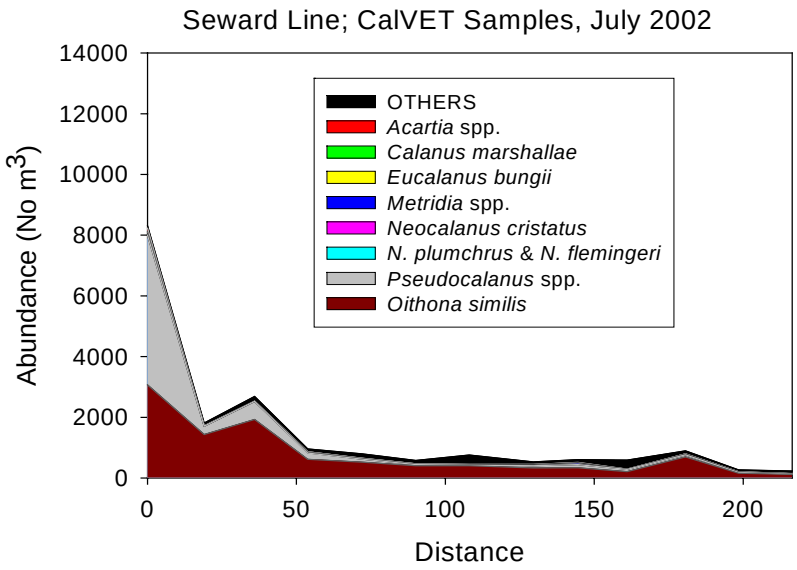
Correlation between major water column properties and abundance of *Pseudocalanus* spp. during May, 1998 - 2002	
Upper Mixed Temperature	0.404935
Lower Mixed Temperature	0.251569
Mean Water Column Temperature	0.282027
Potential Energy (Stability)	0.295794
Upper Mixed Salinity	-0.571260
Lower Mixed Salinity	-0.614358
Mean Salinity	-0.580635

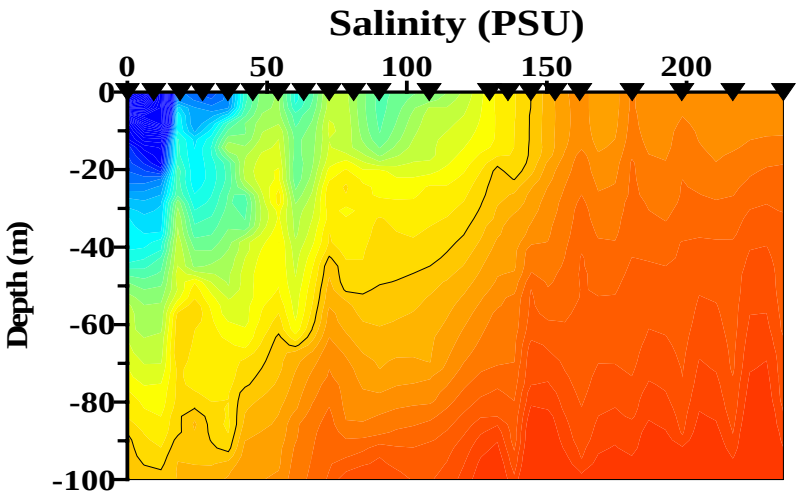

Pseudocalanus spp.
Mean Abundance (No m3)
2500
2000
1500
1000
500
0
1998
1999
2000
2001
2002
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month

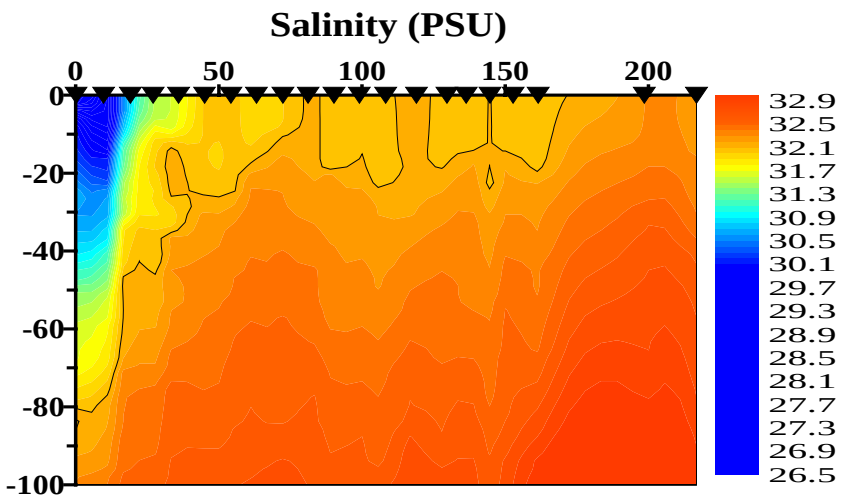

hx231; Seward Line; May 2000
OTHERS
Acartia spp.
Calanus marshallae
Eucalanus bungii
Metridia spp.
Neocalanus cristatus
N. plumchrus & N. flemingeri
Pseudocalanus spp.
Oithona similis
Abundance (No m3)
16000
14000
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
Distance

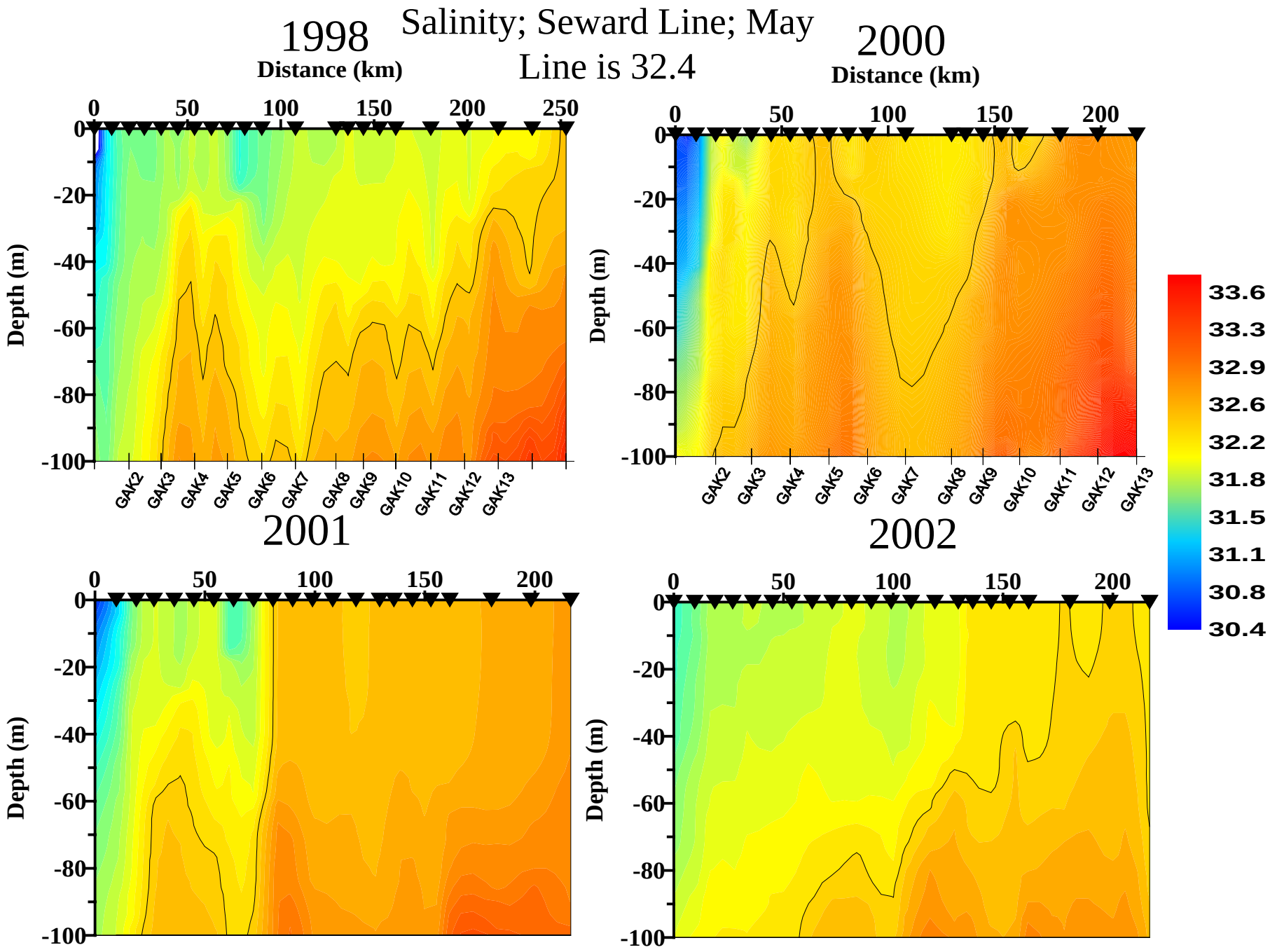
CalVET samples on Seward Line
July 1998 and July 2002
Salinity Line is 32.1



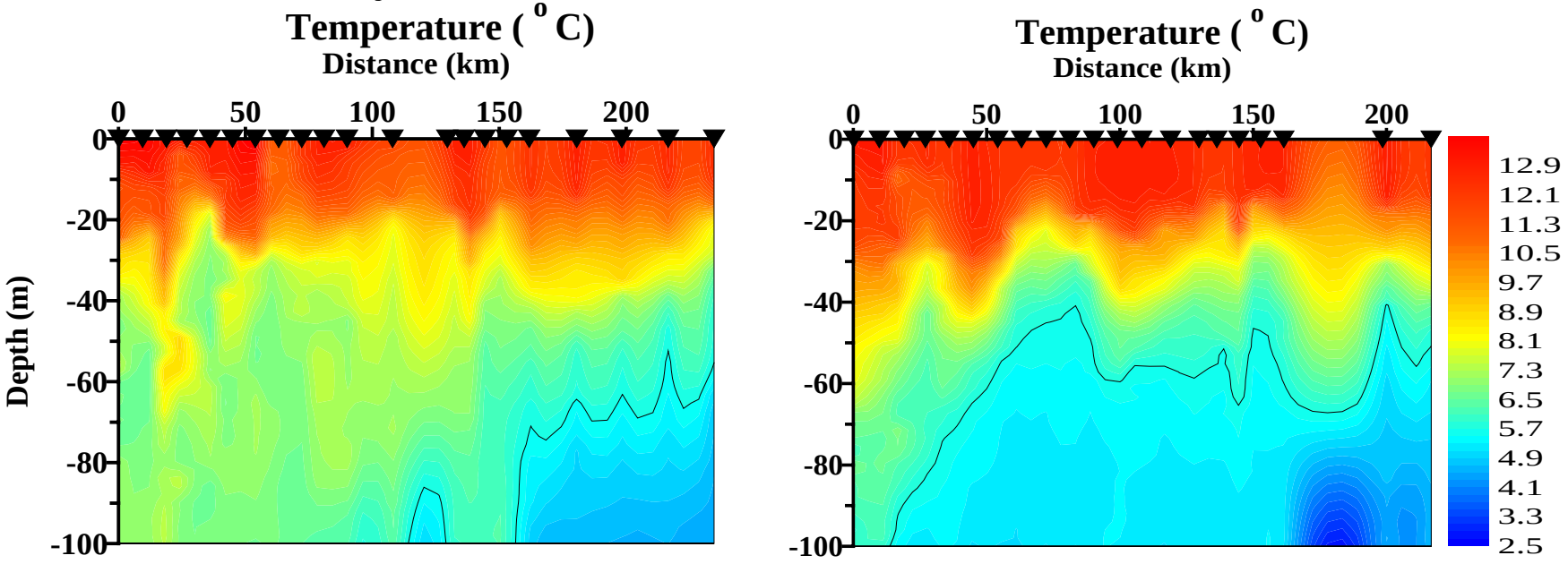


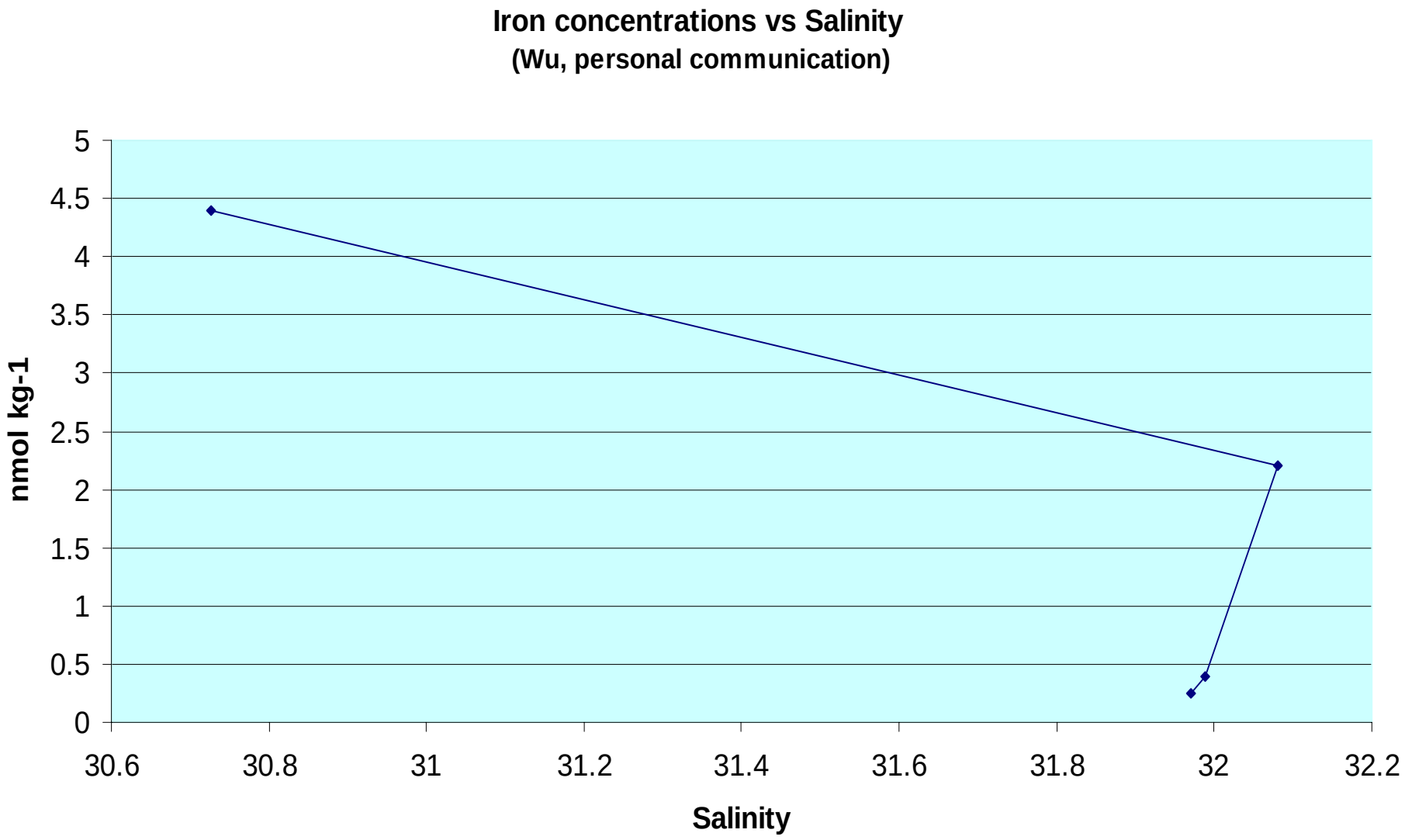




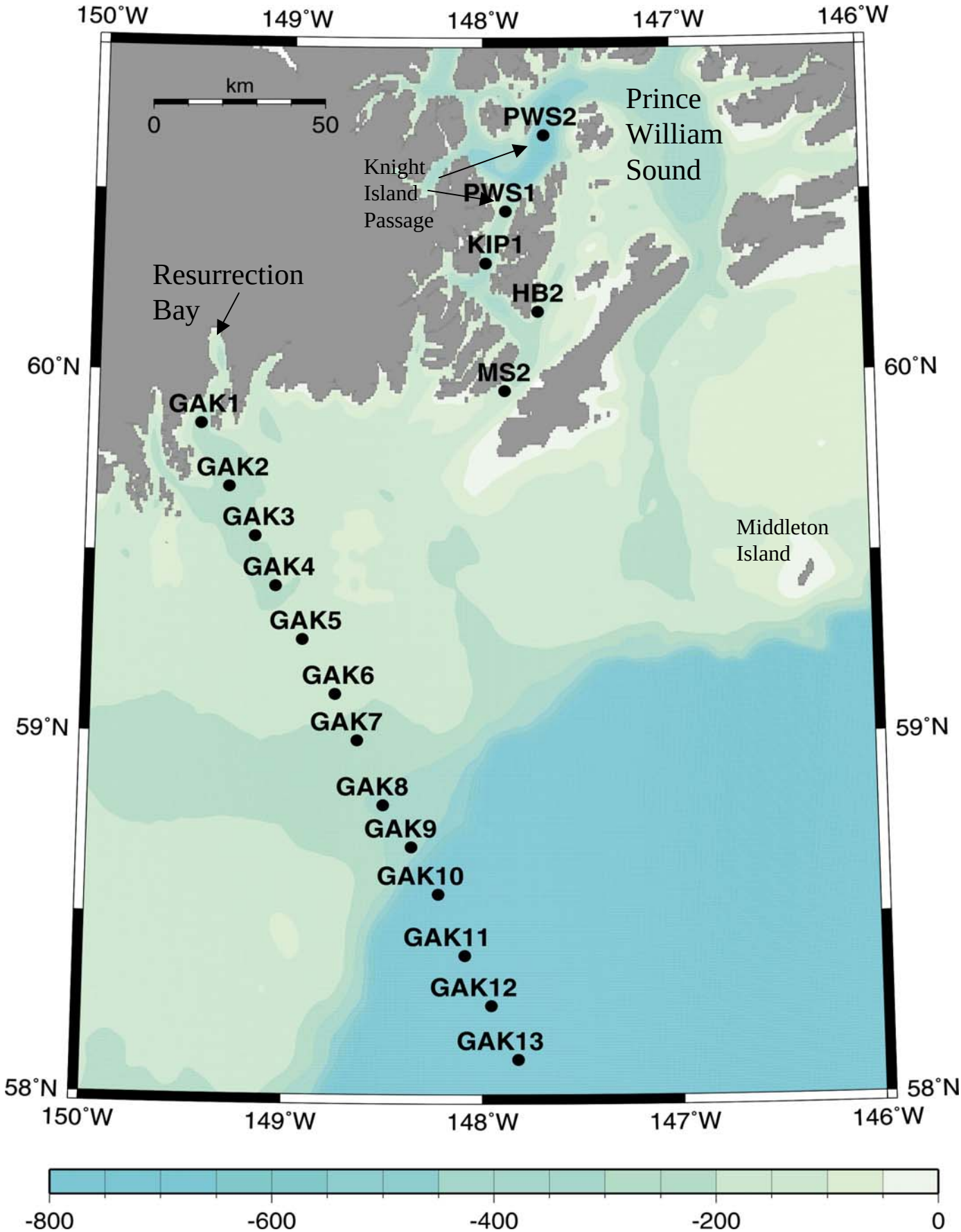

Salinity; Seward Line; May
Line is 32.4
1998
2000
2001
2002
Distance (km)
Depth (m)
0
50
100
150
200
250
-20
-40
-60
-80
-100
GAK2
GAK3
GAK4
GAK5
GAK6
GAK7
GAK8
GAK9
GAK10
GAK11
GAK12
GAK13
33.6
33.3
32.9
32.6
32.2
31.8
31.5
31.1
30.8
30.4

July 1998 Temperature Line = 5.7°C July 2002





Lowest iron concentration is associated with salinity under 32.


150°W
149°W
148°W
147°W
146°W
km
0
50
Prince
William
Sound
PWS2
Knight
Island
Passage
PWS1
KIP1
HB2
Resurrection
Bay
60°N
MS2
GAK1
GAK2
GAK3
GAK4
GAK5
GAK6
GAK7
GAK8
GAK9
GAK10
GAK11
GAK12
GAK13
Middleton
Island
59°N
58°N
-800
-600
-400
-200
0