Development of ontogenetically migrating copepods in the Western Subarctic Gyre

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T. Kobari[1], A. Ueda[1], D. K. Steinberg[2], M. Kitamura[3] & A. Tsuda[4]

[1]Faculty of Fisheries, Kagoshima University
[2]Virginia Institute of Marine Science
[3]Japan Agency for Marine-Earth Science and Technology
[4]Ocean Research Institute

East-West difference of ocean conditions

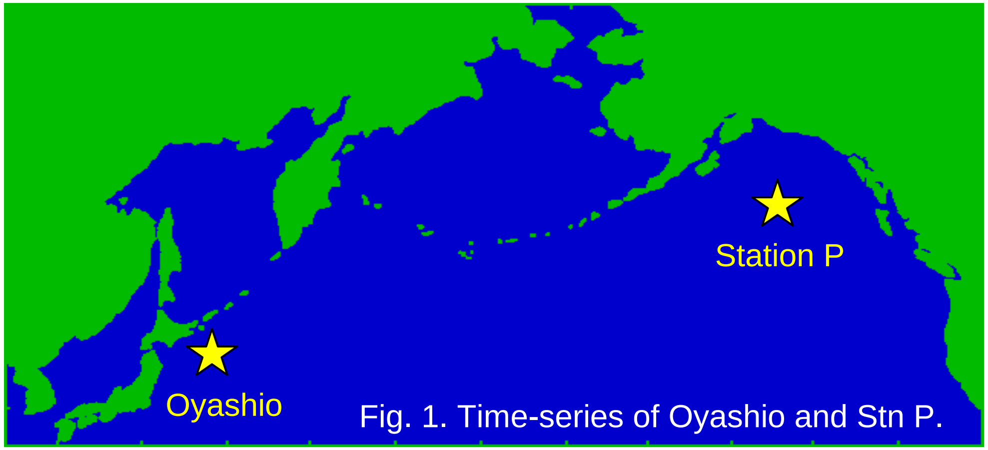

Fig. 1. Time-series of Oyashio and Stn P.

For the last few decades, extensive zooplankton samplings have been conducted at Station P in the center of Alaskan Gyre and in the Oyashio at the westernmost of subarctic Pacific Ocean. We have recognized that oceanographic conditions and plankton ecosystems are different between the east and west.

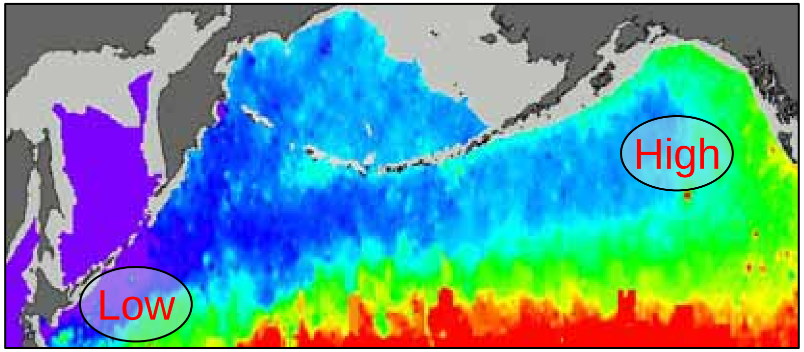

Fig. 2. Mean water temperature in 0-500 m determined with CTD (from Dr. K. Tadokoro).

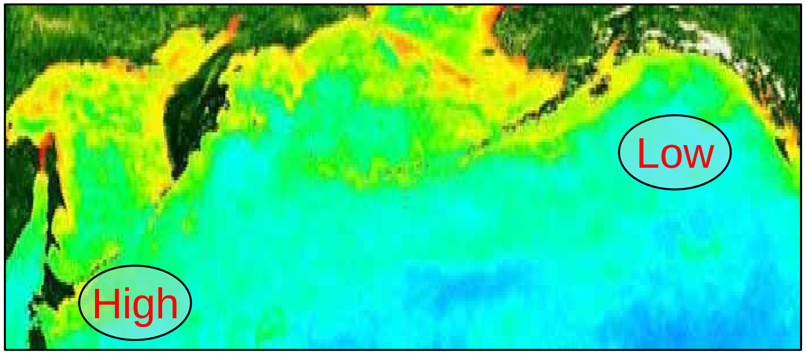

Fig. 3. Satellite image of sea surface chlorophyll a (from NASA).

For example, water temperatures in the Oyashio are colder than those at Station P. In the Oyashio, massive phytoplankton bloom occurs from April to May every year. Although primary production increases during June to July, Station P is characterized by high nutrients and low chlorophyll conditions throughout the year.

Geographical difference of copepod community

Table 1. Geographical comparison of copepod community between the east and west. *Note that some fractions of *Neocalanus flemingeri* show a 2-year life cycle.

	Oyashio (Site H)	Gulf of Alaska (Station P)
Predominant copepods	*N. cristatus*	*N. plumchrus*
Copepod body size	Large	Small
Life span		
Neocalanus spp.	1 year*	1 year
Eucalanus bungii	1-2 year	2-3 year
Surface appearance		
Neocalanus spp.	January - August	February - August
Eucalanus bungii	April - August	June - August

Reflecting the ocean conditions, zooplankton community shows a geographical difference between the east and west.

- Predominant copepods are *N. cristatus* in the west and *N. plumchrus* in the east.
- Generally, copepods in the western site have a larger body length and weight.
- Shorter life span and longer surface appearance are evident for *E. bungii* in the west, but life cycles of *Neocalanus* are conservative between the two sites.

Therefore, we need to know how their development is changed by ambient temperature and food concentration.

Samplings….too sparse!

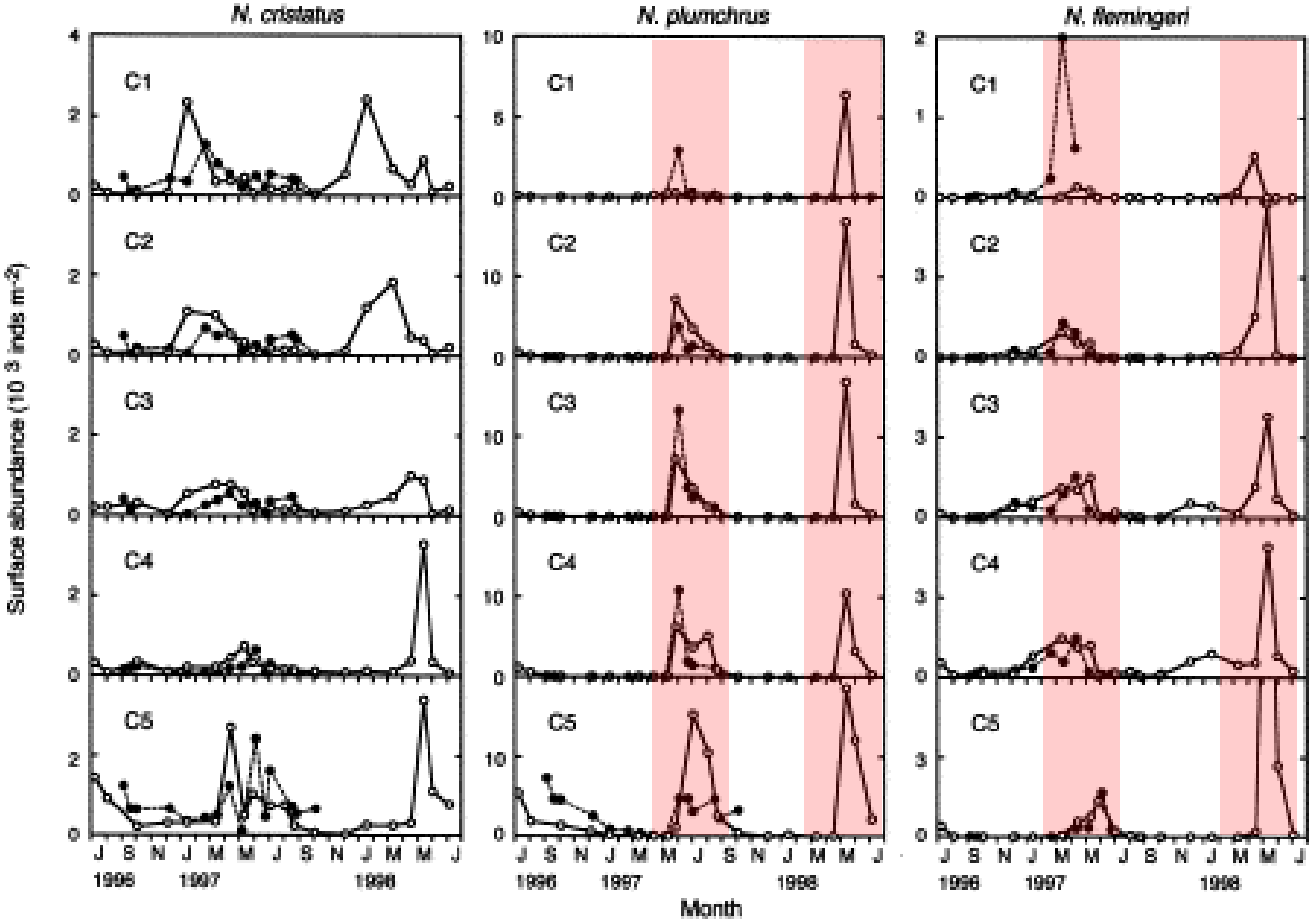

Fig. 4. Monthly changes in population structures of *Neocalanus* copepods at the western site (Kobari et al. 2003).

- To date, oceanographic observations and zooplankton samplings have been conducted biweekly to monthly at these monitoring sites, excepted for some snapshots or campaigns.
- However, such samplings are too sparse to evaluate subsequent development because these copepods make a distinct cohort to develop in a few months, like *N. flemingeri* and *N. plumchrus*.

Objectives

In the present study, we investigate

- ➢ Population structure
- ➢ Depth distribution

of the ontogenetically migrating copepods based on high frequent samplings.

We try to evaluate "surface development" of the populations in the Western Subarctic Gyre

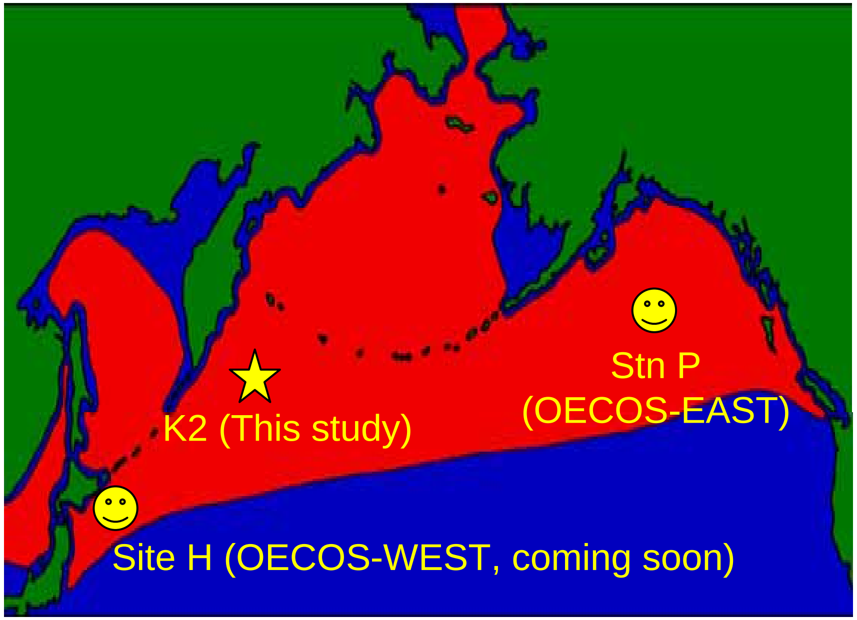

Fig. 5. Geographical distribution of ontogenetically migrating copepods (red-colored).

Sampling station

- ❑ JAMSTEC Time-Series, K2
- ❑ 47˚N, 160˚E (WSG)

Sampling period

- ❑ July to August, 2005 (18 days)
- ❑ June to July, 2006 (44 days)

Zooplankton samples

- ❑ NORPAC (0.1mm mesh openings)
  Population structure in 0-150 m
- ❑ IONESS (0.35mm mesh openings)
  Depth distribution down to 1000 m

Population structure (EB/NC)

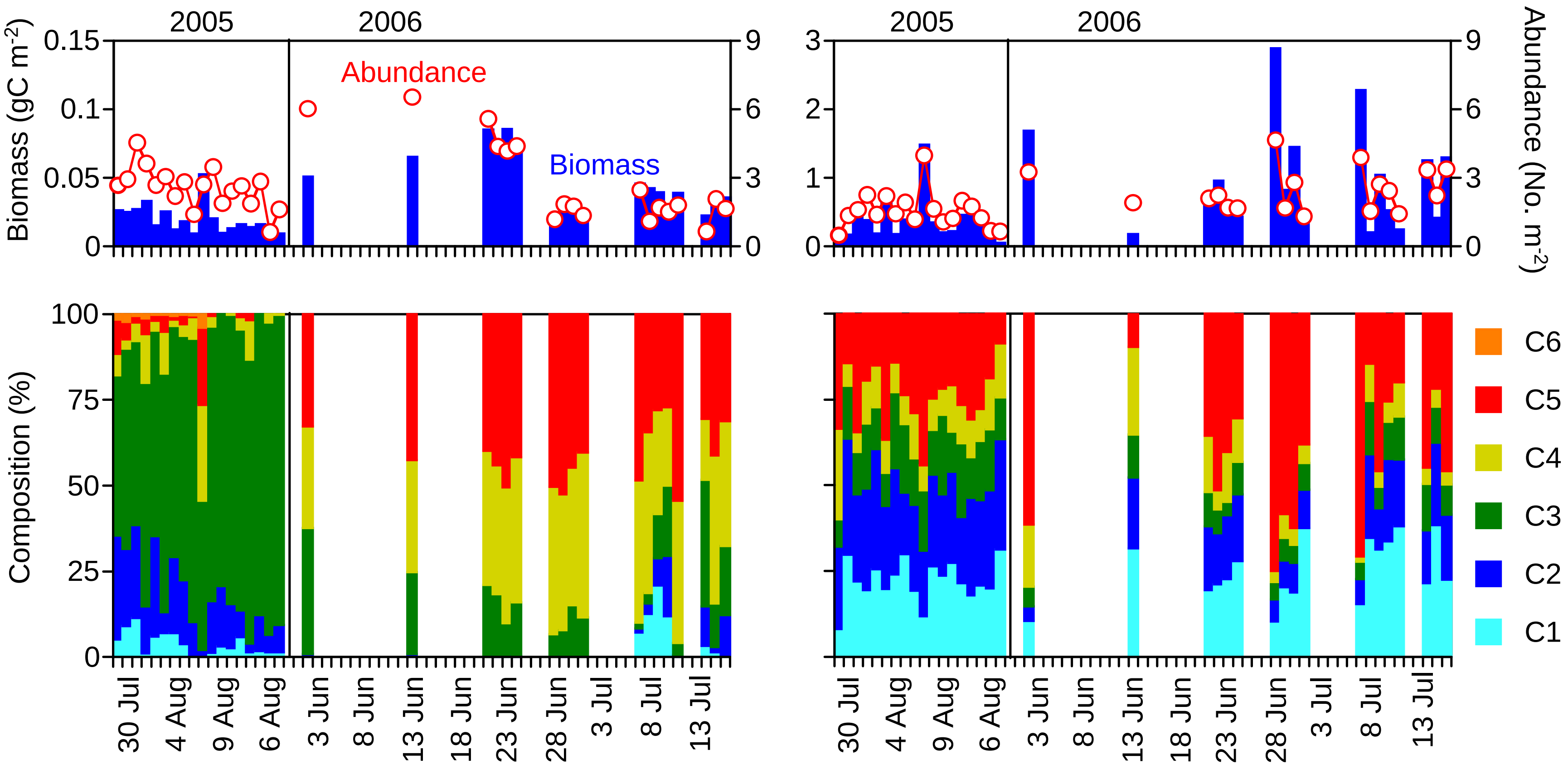

Fig. 6. Temporal changes in abundance, biomass and stage composition of copepodites for *E. bungii* (left) and *N. cristatus* (right) at K2.

- Seasonal pattern was unclear for abundance and biomass of both species.
- Late copepodite stages of *E. bungii* were predominant in June, because of the emergence from dormancy at depth. C1 appeared in mid-July to early August, indicating recruitment from nauplii. Decreasing early copepodites, subsequent development into C3 to C5 was evident during August.
- Temporal pattern was not clear for stage composition of *N. cristatus* over the study period, showing some cohorts with different birth date.

Population structure (NF/NP)

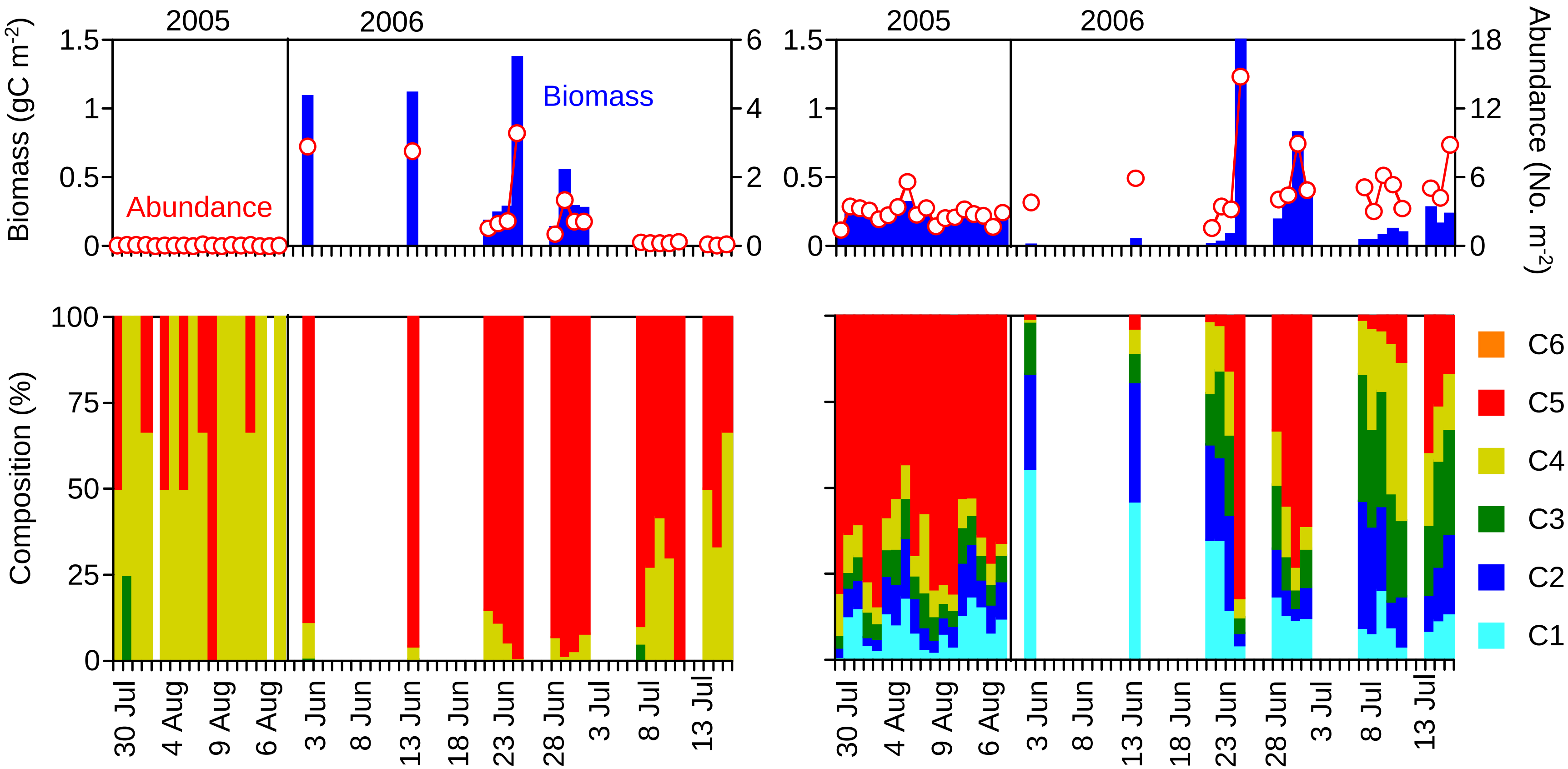

Fig. 6. Temporal changes in abundance, biomass and stage composition of copepodites for *N. flemingeri* (left) and *N. plumchrus* (right) at K2.

- Abundance and biomass of *N. flemingeri* were high during June, while the temporal pattern was unclear for *N. plumchrus*.
- *N. flemingeri* was predominated by C4 and C5 during July to August, indicating the end of surface development seasons.
- *N. plumchrus* showed subsequent development from early to late copepodite stages during June and C5 dominated the population during August.

Weighted Mean Depth

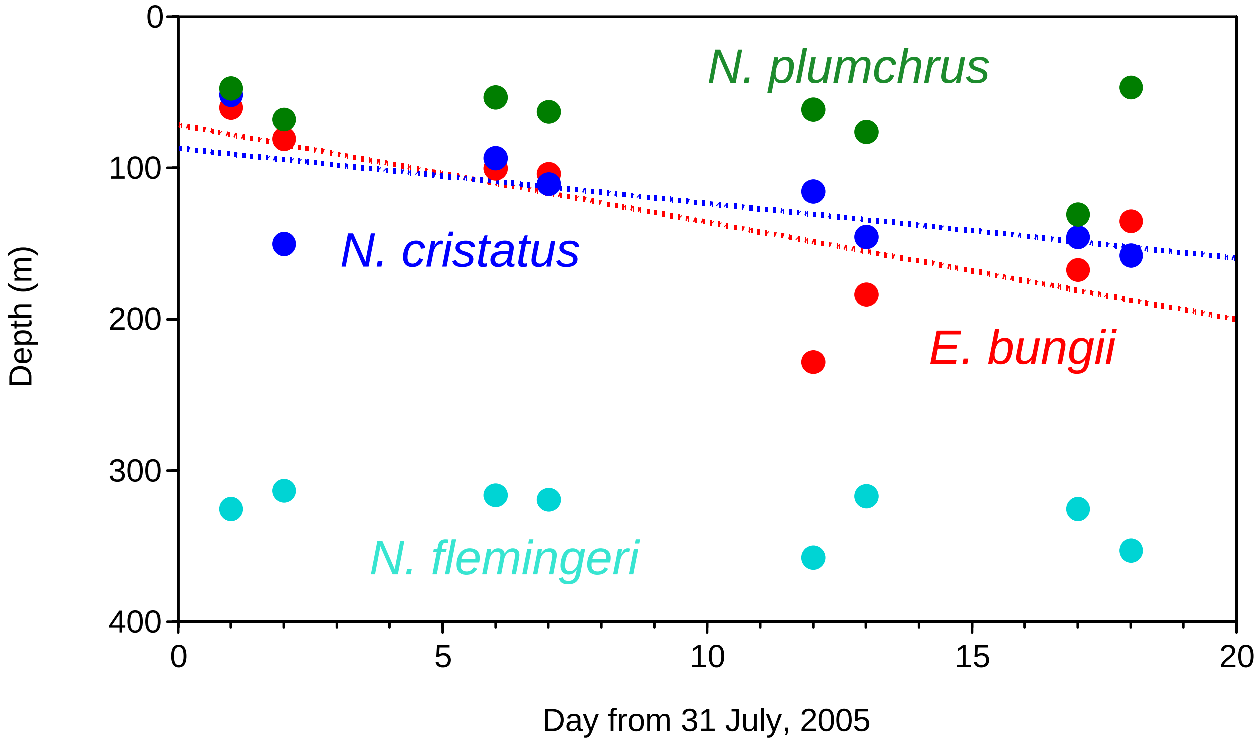

Fig. 7. Temporal changes in weighted mean depth (m) of vertical distributions for the ontogenetically migrating copepods at K2 during August.

- Most predominant stage of *N. plumchrus* was C5 and they resided at the surface. This shows that they are toward the end of surface development seasons.
- C6 females of *N. flemingeri* were found at mesopelagic depths, and thus they would start dormancy.
- *E. bungii* (red) and *N. cristatus* (blue) gradually increased weighted mean depths, indicating the beginning of ontogenetic downward migration to mesopelagic layers for overwintering.

Geographical comparison

Table 2. Geographical comparison of ocean conditions and life cycle timing for the ontogenetically migrating copepods. OY: Oyashio. WSG: Western Subarctic Gyre. GoA: Gulf of Alaska.

	OY (Site H)	WSG (K2)	GoA (Stn P)
Ocean conditions			
SST (˚C)	0.2 - 22.0 *1	3.0 - 9.5 *2	5.6 - 13.9 *3
Chlorophyll *a* ($\mu g\ L^{-1}$)	0.1 - 19.0 *1	0.8 - 1.0 *2	0.1 - 0.6 *3
Increasing season of PP	Apr - May *1	Jun - Jul *2	Jun - Jul *3
Surface development seasons			
Eucalanus bungii	Apr - Sep	Jul - Aug	Jul - Sep
Neocalanus cristatus	Jan - Aug	? - Aug	Jan - Sep
N. flemingeri	Mar - Jun	? - Jun	Feb - Jun
N. plumchrus	May - Aug	Jun - Aug	May - Aug

*1: Saito et al. (2002). *2: Harrison et al. (1999). *3: Miller et al. (1984).

- Western Subarctic Gyre shows comparable ocean conditions to Gulf of Alaska, but lower chlorophyll and delayed primary production than Oyashio.
- Assuming surface development seasons from C1 recruitment to downward migration, *E. bungii* and *N. plumchrus* in the Western Subarctic Gyre indicate comparable life cycle timings to those in the Gulf of Alaska.
- Although we have no samples before June, the timings of downward migrations for *N. cristatus* and *N. flemingeri* are similar between the populations of the Western Subarctic Gyre and Gulf of Alaska.
- *N. flemingeri* develop at the surface before *N. plumchrus*, thus surface development seasons are segregated between the two species.
- Therefore, these copepods indicate comparable surface development between Western Subarctic Gyre and Gulf of Alaska.

Growth estimation

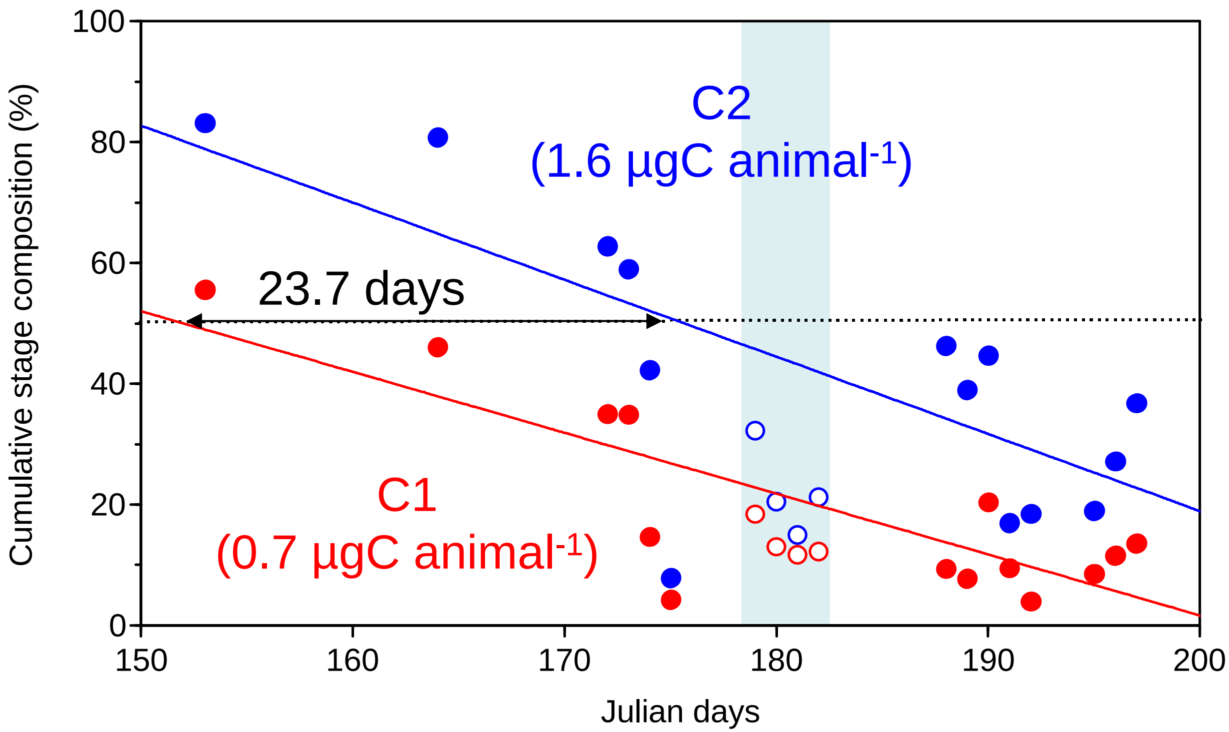

Fig. 8. Temporal changes of stage composition for *N. plumchrus* from early June to mid July 2006. Regression lines are superimposed for C1 and C2, excepted for the data points in the end of June when warm and saline water mass appeared.

- Subsequent development was evident for C1 and C2 of *N. plumchrus* because their proportions were gradually declined.
- Cluster analysis shows that population structure in the end of June is different due to the appearance of warm and saline water mass.
- Applied regression lines to the decline of cumulative stage compositions excepted for data in this period, intersecting points at 50% indicate that half of the population develops into the next stage.
- Based on this assumption, stage duration of C1 is computed to be 23.7 days.
- According to data-sets previously shown by Ueda-san, animal carbon weights of C1 and C2 were 0.7 and 1.6 μgC, respectively. Finally, growth rate of C1 is estimated to be 0.03 day^{-1}.

Comparison to models

Table 3. Comparison of growth rate for C1 estimated from field observations and global models. MR: Molting rate method. AC: Artificial cohort method. CB: Combined MR and AC method. BC: Body carbon. WT: Temp.

Exp. method Model dependent	Spp.	Stage duration (day)	Growth rate (day^{-1})	Source
Field observation				
Natural cohort	NP	24	0.03	This study
MR	NP/NF	6 - 80	0.02 - 0.21	Liu & Hopcroft (2006)
AC	NP/NF	8 - 90	0.05 - 0.18	Liu & Hopcroft (2006)
Neocalanus model				
BC (MR)	NP/NF	-	0.07	Liu & Hopcroft (2006)
BC (AC)	NP/NF	-	0.05	Liu & Hopcroft (2006)
BC (CB)	NP/NF	-	0.06	Liu & Hopcroft (2006)
Global model				
WT	NP	-	0.06 - 0.07	Huntley & Lopez (1992)
WT & BC	NP	-	0.23 - 0.26	Ikeda & Motoda (1978)
WT & BC	NP	-	0.10	Hirst & Sheader (1997)
WT & BC	NP	-	0.27 - 0.28	Hirst & Lampit (1998)

- Our estimates are lower than those observed in molting and artificial cohort experiments in the coastal Gulf of Alaska. It may be resulted from food limitation on copepod growth in the Western Subarctic Gyre where chlorophyll is much lower than coastal Gulf of Alaska.
- Growth rates are comparable for *Neocalanus* model proposed by Liu and Hopcroft but large overestimation for global models which are constructed by coastal copepod species.

Conclusion

- ✓ Surface development seasons are segregated between *Neocalanus flemingeri* (before June) and *N. plumchrus* (from June to August) in the Western Subarctic Gyre.

- ✓ Seasonal timings of C1 recruitment and downward migration for *E. bungii* in the Western Subarctic Gyre are comparable to those in Gulf of Alaksa but later than those in the Oyashio.

- ✓ Stage duration lasts 23.7 days for C1 of *N. plumchrus*, and thus the carbon specific growth rate is estimated to be 0.03 day^{-1}.

- ✓ Our estimate is lower than those determined with the molting rate and artificial cohort experiments conducted in the coastal Gulf of Alaska, indicating food limitation in the Western Subarctic Gyre.

- ✓ Global models of copepod growth rate are inappropriate for *Neocalanus* copepods due to the large overestimation.

Acknowledgement

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