

REPORT OF WORKING GROUP 23 ON *COMPARATIVE ECOLOGY OF KRILL IN COASTAL AND OCEANIC WATERS AROUND THE PACIFIC RIM*

The Working Group on *Comparative Ecology of Krill in Coastal and Oceanic Waters around the Pacific Rim* (WG 23) convened its first meeting on October 24, 2008 under the co-chairmanship of Drs. William Peterson and Song Sun. At least 16 persons attended the full workshop with perhaps the same number attending portions of the workshop. A list of those who attended the complete workshop can be found at the end of this report (*WG 23 Endnote 1*). A draft of the agenda was reviewed and adopted without changes (*WG 23 Endnote 2*).

AGENDA ITEM 2

Summary of research – Country reports

One member from each PICES member country provided a 30-minute summary of past, present and future research related to krill species in local waters, with emphasis focused on *Euphausia pacifica* and *Thysanoessa* spp. Although the presentations are not available on the PICES website, anyone interested in a certain talk can e-mail the author or Co-Chairman, bill.peterson@noaa.gov, to request a copy.

Canada

Dr. David Mackas informed the Working Group that the earliest work on life cycle, growth rate and production of *E. pacifica* in the Strait of Georgia was by Heath (1970, Ph.D. thesis). Coastwide surveys of ichthyoplankton in 1980 were used to summarize krill cohort structure and growth (Fulton *et al.* 1982). A thesis by Summers (1993) explored growth of *Thysanoessa spinifera*. Studies of long-term variations in abundance of *E. pacifica* and *T. spinifera* have been carried out by Tanasichuk (1998); Dr. Mackas tracks long-term changes in abundance from his sampling program off the west coast of Vancouver Island, including the study of cross-shelf transport and retention mechanisms, and patchiness and their causes have been investigated recently. Dr. Steve Romaine (DFO, Institute of Ocean Sciences) has developed algorithms for calculating the patch structure of krill from acoustic surveys in the Strait of Georgia. Strengths of the Canadian program are: spatial distribution, population dynamics, and a long time series. Gaps include the need for work on live animals, especially for rates of metabolism and reproduction, and the study of mechanism(s) of population regulation, including reproduction, predation and parasites.

China

Dr. Song Sun stated that the dominant species in Chinese waters are *Euphausia pacifica* and *Pseudeuphausia sinica*. Most of the work in China is focused on sampling and experimental work in the Yellow Sea and the East China Sea, but with some research on the Antarctic krill *Euphausia superba*. *Euphausia pacifica*, along with the copepod *Calanus sinicus*, are the dominant species in both the Yellow and East China seas, and thus receive most of the research attention. Major research cruises were carried out monthly in summer and quarterly in winter to determine krill distribution and abundance. They are most abundant in the middle of the relatively shallow Yellow Sea (maximum water depths of about 90 m) with a maximum in adult biomass in the autumn. Maxima in abundances of eggs are in the spring, similar to that reported for the northeast coast of Japan. Egg production experiments showed that spawning is most intense in March–May, averaging about 40 eggs per female in April and May. A major piece of research needed is to understand how the adults survive the very warm summer months when surface waters in the Yellow Sea can exceed 25°C. Apparently the adults reside in the deeper (and colder) waters of the Yellow Sea and migrate each night to the base of the pycnocline to feed on phytoplankton.

Japan

Dr. Yuji Okazaki presented an “*Overview of krill biology and ecology in the western North Pacific*”. He reported on the krill fishery off the east coast of northern Japan – the fishery takes place from February to May and is well-regulated. Krill are harvested mostly for the aquaculture industry but some are dried for human

consumption. In terms of research, the published work of Taki on distribution (including vertical distribution), abundance and growth was reviewed. Some new work on egg production was presented showing that *Euphausia pacifica* can lay eggs during temperatures as low as 5°C in April, at the time of the spring bloom; the major spawning season is April–May; egg production measurements have been made April–July, with an average output of approximately 60 eggs per female. Dr. Okazaki also reviewed Japanese work on *Thysanoessa* spp. and noted that they seldom make up more than 10% of the total euphausiid biomass. New work is now being prepared for publication on *Thysanoessa* by Taki and Kim from Hokkaido University. The available historical data were reviewed, and Dr. Okazaki noted that the euphausiids from the Odate collection have not been analyzed but cautioned that the small mouth of the Norpac net may have resulted in low catches of krill. Collections from the PH-line (off Hokkaido) are being processed for eggs and larvae, and taxa that likely do not avoid plankton nets. Future work is planned to concentrate on sampling along the A-line which will focus on comparison of krill in nets of various sizes (bongo vs. MOHI net), and on growth rate experiments.

Korea

The Korean report was given by Dr. Hyoung-Chul Shin. Surveys of krill in Korean waters have been conducted by the National Fisheries Research and Development Institute (NFRDI) on a bimonthly basis but these samples have not been processed for krill eggs, larvae, juveniles or adults. Surveys of krill in the Yellow Sea in spring and fall were reported by Yoon (2000). Distributions seemed to be controlled more by temperature than by chlorophyll. Dr. Shin also reported on some work carried out at a nuclear power plant – the screens for water intake used for the cooling towers can at times be clogged with *Euphausia pacifica* – we heard a report on this at the krill Topic Session on “*Life history and ecology of euphausiids in coastal and oceanic waters around the Pacific Rim*” (S2) (Chae, PICES XIV). The potential is great for additional work on krill in Korean waters and plans are being discussed that may lead to new work on distribution, abundance, feeding, egg production, and growth. Ships are available for surveys and in-house expertise exists for identification of krill as well as the use of acoustics during krill surveys that could be used to estimate krill biomass and patch structure. There is also expertise on lipid analysis that would help clarify krill’s role in the food chain.

Russia

Dr. Yury Zuenko stated that there are no scientific programs focused on euphausiids in Russia. However, euphausiids are (and were always) studied as a part of the zooplankton community. General information is available on zooplankton resources, distribution, species composition, and biology of the main species, including euphausiids, in the Far-Eastern Seas and Northwest Pacific. Within regional ecosystem-based programs, the Pacific Research Institute of Fisheries and Oceanography (TINRO-Centre) conducts annual surveys of zooplankton (sometimes twice in a year) over the Okhotsk Sea and western Bering Sea, and off the Kuril Islands. From time to time (once in 3–4 years) the northern Japan Sea is surveyed. Foreign EEZs are surveyed within bi-lateral programs with Japan and the U.S.A. (previously also with the Democratic People’s Republic of Korea (North Korea) and China). Again, although krill are not the target species, they are collected in the plankton nets but probably only the eggs and larvae are collected quantitatively. Although many samples have been collected, many need to be analyzed, giving the opportunity for joint collaborative work. There are as yet no plans for any experimental work although such work could move forward with proper training.

U.S.A.

Ms. Tracy Shaw reviewed the research that has been carried out in the California Current, Gulf of Alaska and Bering Sea by as many as 30 investigators. Her comprehensive talk covered work in the laboratory on vital rates, including developmental times, bioenergetics, physiology and respiration, feeding, growth and reproduction. Field work on age structure, seasonal cycles of spawning, seasonal and interannual variations in brood sizes, and growth were compared. She also reviewed synthesis activities planned by the U.S. GLOBEC program.

AGENDA ITEM 3

Gaps and plans for research

WG 23 prepared an outline which listed the gaps in knowledge and plans for research that will fill those gaps. The Working Group discussed what research needed to be done to produce a synthesis and comparison of the ecology, life history and population dynamics of krill around the Pacific Rim. Also discussed was the possibility of using krill in NEMURO models that would compare zooplankton population dynamics in waters around the Pacific Rim (see for example a recent paper by Terui and Kishi (2008), Population dynamics model of Copepoda (*Neocalanus cristatus*) in the northwestern subarctic Pacific. Ecological Modeling 215: 77–88.)

A final report was given by Dr. Micho Kishi, Hokkaido University, Japan. He reviewed progress on his and his student's work on incorporating krill into the NEMURO modeling framework. The model has stage-specific feeding rates, with larvae feeding on two size-classes of phytoplankton, and juveniles and adults feeding on both phytoplankton and on copepods. Developmental rates and transition times between stages follow data in Ross (1982). The model seemed to do a reasonable job in tracking the seasonal cycles of abundance of eggs, larvae, juveniles and adults, given the agreement between the model and observations of Taki (2004), and reported by Dr. Okazaki in Japan's report (Agenda Item 2).

AGENDA ITEM 3

Gaps in krill research that need to be filled

1. Standardization of sampling through use of the same nets, or, if this is not possible, the need for "catchability coefficients" of krill by various types of nets. Better estimates of abundance and biomass are needed in order to be able to make regional comparisons.
2. Size of animals in different regions and seasonal differences in size; comparative length-weight regressions.
3. Feeding habits and diets through experimental work on living animals and through use of lipid biomarkers and stable isotopes.
4. Aggregations of krill. This needs more study – what are the advantages to an individual for staying within a swarm? Are there physiological benefits? More night sampling is needed.
5. Age of adults. More work is needed to explore the utility of the lipo-fuscin method of age-determination.
6. Sampling in critical habitats. Are there "critical habitats" that we are not sampling and which need more study? Suggested examples include the Japan/East Sea, particularly in Korean waters, Monterey Bay (CA), Heceta Bank (OR), Unimak Pass (AK), Northeast Japan.
7. Use of acoustics to estimate biomass and patch structure.
8. Modeling of krill.
9. More measurements of egg production rates in relation to temperature and chlorophyll.
10. A project that looks at population structure using modern techniques of microsatellites or SNPS is needed to determine the degree to which populations of *Euphausia pacifica* are connected.
11. An interest was expressed in setting up a "krill library" where all important publications could be available. This would include theses, cruise reports, and grey literature. Ideally, all would be available in English.
12. All participants expressed interest in having a set of digital photographs of krill life cycle states that could be used in presentations. Also, any video clips showing krill aggregations would be of interest as well. These could all be stored on the same website where the "krill library" was maintained. The need to find a "home" for this material, perhaps on the PICES webpage was discussed.

AGENDA ITEM 4

Exchange of scientists, graduate students and post-docs

The Working Group discussed the potential for an exchange of scientists, graduate students, and post-docs in order to learn from one another how best to sample euphausiids and how to conduct experimental work on

living krill. Also discussed were any cruise plans for 2008–2009 that would benefit from international cooperation; possible visits to other laboratories; and the possibility of convening “hands-on” practical workshops during which the Working Group would teach students and other scientists how to carry out experimental work with krill

AGENDA ITEM 5

General discussion

A portion of the general discussion was set aside to hear a talk by Dr. Jaime Jahncke on “*Krill related studies in the Gulf of the Farallones, California*”. This contribution was to be a poster presented during the Poster Session of main PICES Annual Meeting but seemed that it would be useful to include it during our meeting. The talk included discussion of a large research program that is working on spatial and temporal relationships between krill and seabirds that nest on island in the Gulf of the Farallones, located offshore of San Francisco. Of particular interest is krill patchiness and patch size and how this relates to forage opportunities for the sea birds, in particular the Cassin’s auklet.

Most of the remaining time was devoted to a general discussion of the krill workshop planned for the GLOBEC Open Science Meeting to be held in Victoria June 2009. The workshop, entitled “*Krill biology and ecology in the World’s oceans*”, is being organized by Dr. Peterson along with Drs. Angus Atkinson, Bettina Meyer and Jaime Gómez-Gutiérrez (*WG 23 Endnote 3*). The objective is to convene a gathering of krill biologists and ecologists from around the world to discuss the life history and population dynamics of all krill species. These discussions were first initiated at the 4th International Zooplankton Production Symposium in Hiroshima, Japan, May 2007. A number of Working Group members agreed to submit abstracts for the GLOBEC meeting – Yuji Okazaki, Song Sun, Hyoung-chul Shin, David Mackas and William Peterson.

WG 23 Endnote 1

WG 23 participation list

Members

Se-Jong Ju (Korea)
Hyung-ku Kang (Korea)
David Mackas (Canada)
Yuji Okazaki (Japan)
William T. Peterson (Co-Chairman, U.S.A.)
C. Tracy Shaw (U.S.A.)
Hyoung Chul Shin (Korea)
Song Sun (Co-Chairman, China)

Observers

Harold Batchelder (U.S.A.)
Hongsheng Bi (U.S.A.)
Jaime Jahncke (U.S.A.)
Michio J. Kishi (Japan)
Bernard Megrey (U.S.A.)
Jennifer Menkel (U.S.A.)
Tom Wainwright (U.S.A.)
Yury Zuenko (Russia)

WG 23 Endnote 2

WG 23 meeting agenda

1. Welcome and introductions
2. Summary of past, present and future research related to krill species in local waters
3. Discuss the gaps and plans for research that will fill those gaps.
4. Discuss the potential for an exchange of scientists, graduate students, and post-docs.
5. General discussion

WG 23 Endnote 3**Proposal for a 2-day workshop at the GLOBEC Open Science Meeting in June 2009 in Victoria, Canada, on “Krill biology and ecology in the World’s oceans”**

Chairs: Angus Atkinson (UK), Jaime Gómez-Gutiérrez (Mexico), Bettina Meyer (Germany) and William Peterson (U.S.A.)

Objective: To convene a gathering of krill biologists and ecologists from around the world to discuss the life history and population dynamics of all krill species. This is timely because krill have been important elements of a number of the GLOBEC core programs and a great deal has been learned from the GLOBEC fieldwork that needs to be synthesised. These discussions were first initiated at the 4th International Zooplankton Production Symposium, in Hiroshima, May 2007. At that meeting we convened a workshop and were overwhelmed with presentations (42 oral and poster presentations) and attendance (approx 100 participants). A product of the meeting was a special issue of selected papers from the Symposium to be published in *Deep-Sea Research II*; the special issue is now in the final editing phase. A total of 18 research papers have been found to be acceptable for publication.

Aims of the proposed GLOBEC OSM Workshop include:

- For workers on different species to get together to discuss methods/approaches that have proved effective for one species. Then we can see whether they can be applied to other euphausiid species.
- To make sure there is a degree of harmony (or at least that there is no serious disconnect) in their approaches. It is also to improve technical aspects of specific methods.
- To generate ideas for future collaborations, for example laboratory/seagoing exchanges of personnel and of exchange and pooling of datasets to address wider-scale issues.
- To produce a tangible product, to show where krill research is at the moment, hurdles to progress and potential solutions. We suggest that an overview type paper in MEPS/review length journal (authored *e.g.*, by all participants) would be excellent.

We propose a 2-day workshop, with the first day being a series of short 10-minute presentations with, say, a 5-minute discussion around each (15 minutes total). These presentations would have some data (obviously) as examples, but would aim to give more of a flavour of the state of the research in their own lab/research group in relation to the session theme, with some questions, future directions and “hooks” to start the discussion. The second day could then be devoted to framing particular themes and issues for more detailed discussion, then breakout groups, *etc.*, before coming together at the end to talk about how we are all going to put together the written product. We expect active participation by young investigators and graduate students.

The Table below shows some topics that may be valid, with some potential speakers/contributors. This is clearly incomplete and of course there is some overlap across themes. Also note that some topics, *e.g.*, modelling and genetics, are blended across several themes. An alternative approach would be to have them as separate, defined themes.

Topic	Possible speakers	Notes
Controls on Distribution	Peterson, Zhou, Goodall-Copestake, Atkinson	- To what extent are euphausiids drifters in ocean currents? - Use of advective models to understand distribution, - Role of swimming/vertical migration in dictating distribution, - Combining historical datasets for a larger-scale understanding of distribution, - Contrasting controls in upwelling areas, S Ocean, N Atlantic and N Pacific Genetic approaches to stock separation – functional and genetically defined sub-pops.
Determining absolute biomass and abundance	Demer, Watkins/Fielding, Nicol	- How reliable are nets and acoustics in determining absolute abundance/biomass? - Can we make better efforts to combine them?

Topic	Possible speakers	Notes
Behaviour	Kaartvedt, Yen, Kawaguchi, Brierley	<ul style="list-style-type: none"> - Role of laboratory/experimental studies, - Sensory biology, - Role of underwater cameras/ROVS, <i>etc.</i> - Role of moored instrumentation and advanced acoustics (<i>e.g.</i>, to determine swimming/migration speed in <i>M. norvegica</i>, <i>etc.</i>).
Reproductive biology	Gómez-Gutiérrez, Cuzin	<ul style="list-style-type: none"> - What affects reproductive output? - Food quantity/quality effects and egg condition/viability, - Spawning periodicity – field and histological approaches.
Larval biology	Meyer Shaw/Feinberg	<ul style="list-style-type: none"> - Critical phases concept, - Alternative developmental pathways (<i>e.g.</i>, intermediate/missed stages), - What can we learn from inter-species comparisons?
Ecophysiology and Energy budget	Ross/Quetin, Daly, Taeshke, Tarling, Jarman, Teschke	<ul style="list-style-type: none"> - What dictates moulting frequency? - Is moulting a “pacemaker” for maturation/spawning? - Issues with measuring rate processes in euphausiids, - Cues for seasonal behaviour (hormones <i>vs.</i> external cues) experimental and genetic approaches, - What are main unknowns in the energy budget - does not knowing them matter? - Role of lipids across different krill species – are their common themes?
Feeding and diet	Passmore, Schmidt, Stuebing, Kaartvedt	<ul style="list-style-type: none"> - Evaluation of emerging methods (<i>e.g.</i>, immunoassays, quantitative genetics), - Value of combined methods, - Application from one species (<i>e.g.</i>, paired mandible method for <i>M. norvegica</i>) to others, - Evaluating specific issues with gut contents, feeding incs, FA biomarkers, stable isotopes.
Population parameters: Growth rate Mortality rate	Pinchuk, Feinberg/Shaw, Gómez-Gutierrez, Mortality rate expert needed	<ul style="list-style-type: none"> - “Standardising” IGR approaches, - Methods to evaluate length frequency data, - Comparison of growth rates across euphausiid species, - Methods of determining mortality rate, - Sources of mortality: predation versus parasitism/pathogens/“old age”.
Developing whole/partial life cycle models	Hofmann, Tarling, Fach, Murphy	<ul style="list-style-type: none"> - Where are we at with the various species? - Identifying key knowledge gaps and how to address them.
Schooling and vertical migration	Zhou, Kaartvedt, Tarling, Mangel/Alonzo, Hofmann, Sourisseau/Simard	<ul style="list-style-type: none"> - Inter-species comparison of extent of schooling/vertical migration, - Behaviour and characteristics of schools, - Advantages and disadvantages of schooling (including modelling approaches), - Variability in DVM and costs/benefits (including modelling approaches), - DVM and schooling as mechanisms for retention/efficient swimming.
Future impacts on euphausiids	Kawaguchi, Ross	<ul style="list-style-type: none"> - Changes in temperature/ice cover/food/ phenology/ph – approaches to predicting the future, - Timescale of change and rates of adaptation to change, - Other challenges: pollution, UV, harmful algal blooms, <i>etc.</i>