2012 Yeosu Workshop on "Beyond Dispersion"

by William Stockhausen, Sukyung Kang and Carolina Parada

A 1-day workshop on "*Beyond dispersion: Integrating individual-based models for bioenergetics and behavior with biophysical transport models to predict influences of climate change on recruitment processes in marine species*" was held on May 20, 2012, immediately following the 2nd International Symposium on "*Effects of Climate Change on the World's Oceans*" convened in Yeosu, Korea. Future climate change is expected to influence the abundance and distribution of marine fish species in complex ways, including changes in the local environmental characteristics and transport pathways experienced by early life stages that are typically pelagic, such as eggs and larvae. To date, numerous coupled biophysical models (CBPMs) with individual-based model (IBM) subcomponents have been developed to study the influence of oceanographic transport patterns on dispersion of early life stages and recruitment variability in marine fish species. In many of these models, advective oceanographic processes are hypothesized to be the main determinant of recruitment variability; simulated individuals in the models are regarded primarily as passive particles or drifters and "success" is judged by the relative number of simulated particles that end up being advected to suitable juvenile nursery grounds. While these models represent a significant step in our ability to understand and predict the effects of climate change on recruitment, they ignore important effects (temperature/salinity stress, food availability, *etc*.) on growth and survival associated with the environmental conditions encountered by (simulated) individuals along their drift trajectories. Although bio-energetics models typically include such effects and can be used to address the impact of local environmental variation on the growth and survival of eggs and larvae, few bioenergetics models have been targeted toward early marine life stages, few CBPMs incorporate bioenergetic considerations, and fewer still have been used to address the potential impact of climate change on marine species. The workshop was intended to discuss the state-of-the-art for incorporating IBMs within CBPMs, together with current challenges and future directions.

The workshop consisted of 5 presentations in the morning followed by a productive afternoon discussion period. Altogether, 19 people participated in the workshop. In addition, it featured what had to be the largest banner of all sessions and workshops (Fig. 1).

Following initial remarks by workshop co-conveners, Sukyung Kang and William Stockhausen, the first invited speaker, Myron Peck (University of Hamburg, Germany), discussed recent advances in, and future challenges to, integrating physiology, behavior and physical constraints into coupled IBMs/CBPMs for the early life stages of marine fish. In a wide-ranging talk, he highlighted the diverse physiological mechanisms and responses to environmental conditions that need to be accounted for in modeling the growth and survival of early (and later) life stages of marine fishes on an individual basis. These include direct effects of temperature and size on growth and survival through egg development rates, hatching success, size-at-hatch, yolk sac utilization rates, routine metabolism

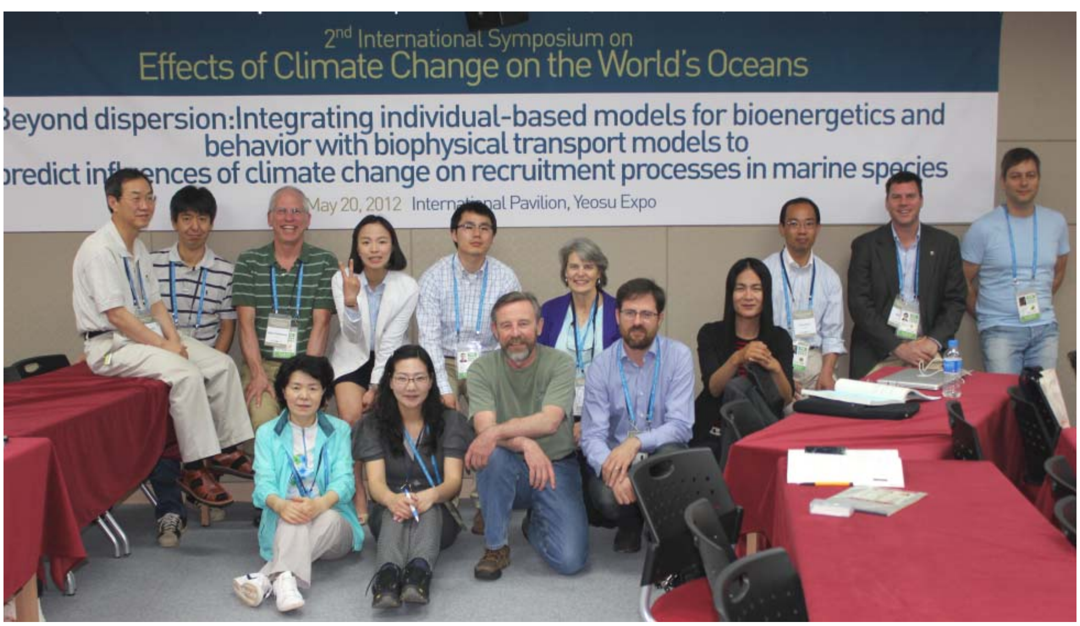

Fig. 1 The workshop: participants and banner (photo credit: Sukgeun Jung).

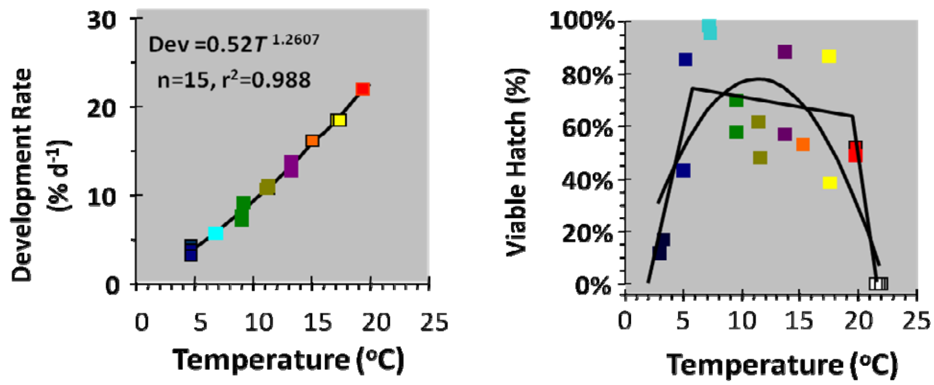

Fig. 2 Effects of temperature on egg development rates and hatching success in Baltic herring (Clupea harengus) (based on Peck et al., 2012).

rates and swimming speed (*e.g*., Fig. 2). Parental effects on egg survival, environmental effects on success of the first feeding, changes in diet composition and prey energy content, flexibility in foraging behavior, and species interactions were also discussed. The importance of increased knowledge of the growth physiology of target species and the need for modelers to conduct sensitivity studies to identify critical model parameters were stressed among his recommendations.

Shin-Ichi Ito (Tohoku National Fisheries Research Institute, Japan), the second invited speaker, discussed the need to incorporate feeding and spawning migrations in models for growth and survival of marine fishes. He presented results from a comparison of such models for Japanese sardine (*Sardinops melanostictus*) in the western North Pacific (Fig. 3) and highlighted the importance of confronting observed spatial patterns (based on field data) with multiple alternative models because different behavioral mechanisms can give rise to similar spatial patterns. Authors of the recounted study were able to eliminate two of four hypothesized behavioral mechanisms for observed sardine feeding migrations from further consideration; however, they were unable to discriminate between the remaining two mechanisms, even though the behavioral bases for these models were quite different (predator avoidance *vs*. extended kinesis). He also presented a rather novel approach, based on artificial neural networks, to "forcing" a spawning migration pattern when hypothesized behavioral mechanisms were inadequate to reproduce observed movement patterns.

Fittingly (given the venue), the other speakers presented talks featuring models and data relevant to Korean marine systems. Jung-Jin Kim (Pukyong National University, Korea) used a coupled IBM/CBPM to infer current seasonal spawning grounds for Korean common squid (*Todarodes pacificus*) in the western Pacific from field data for larval occurrence. He then used IPCC model runs to drive a regional ocean model to predict changes in spawning grounds under future climate change. Sukgeun Jung (Jeju National University, Korea) presented preliminary results for a coupled IBM/CBPM for Pacific anchovy (*Engraulis japonicus*) in Korean waters. And finally, Min-Jung Kim (National Fisheries Research and Development Institute, Korea) presented results from diet studies on Pacific anchovy in the southern coastal waters of Korea. Her talk highlighted the spatiotemporal and ontogenetic variability in anchovy diets in southern Korean waters due to variability in prey species composition and abundance, plasticity in feeding strategies, and ontogenetic differences.

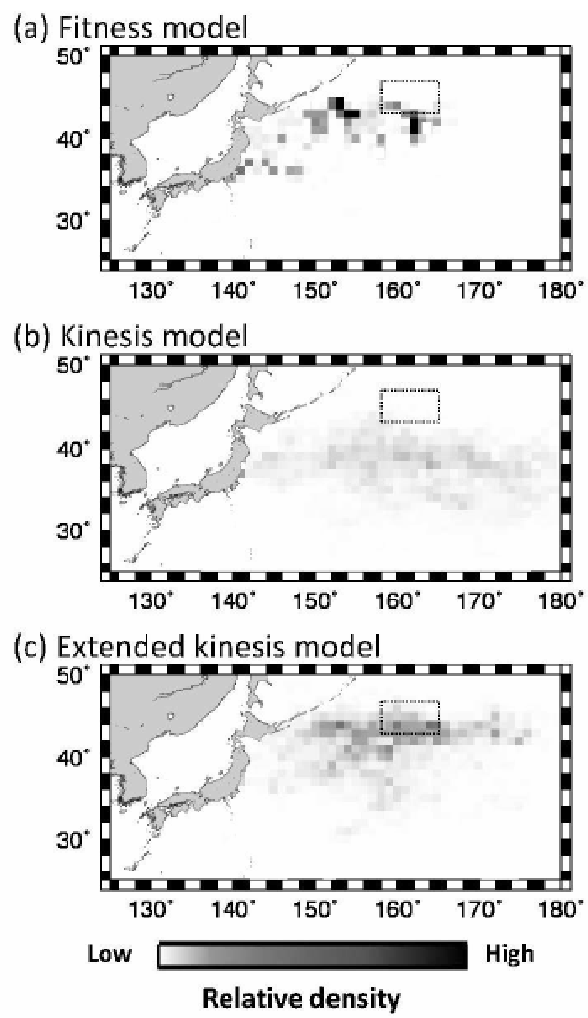

Fig. 3 Results from three alternative feeding migration models for Japanese sardine (from Okunishi et al., 2012).

A key outcome from discussions following the presentations was the recognition that one aspect of the impact of future climate change on species abundance and distribution patterns will occur through changes in the growth rates, and subsequent survival, of individuals. However, these changes may not be predictable from simple statistical relationships based upon (current) growth rates and expected changes in temperature. Instead, it is likely that future changes will be due to the dynamic interaction of several factors, including indirect effects on the abundance, composition, and relative energy content of key prey species. These indirect effects will act in concert with direct effects such as changes in water circulation patterns and temperature that will influence the spatial overlap and metabolic processes of predators and prey. Thus, one important recommendation stemming from the discussions was that IBMs used to predict the impact of future climate change on species abundance and distribution should incorporate mechanistic bioenergetics models that account for effects of changes in prey abundance, energetic content and species composition on individual growth rates. Workshop participants also acknowledged a general lack of data on the physiology of many fish and shellfish species, even for commercially- and/or ecologically-important ones, as well as a scarcity of marine physiologists who could potentially address these issues.

A list of additional recommendations from the workshop include:

- incorporating life cycle closure within physiologically-based models to capture climate impacts on various life stages (and identify potential climate-driven bottlenecks to recruitment), with a recognition of stage-specific differences in growth physiology, diets, and tolerance to environmental factors;
- increasing process-level understanding of the factors controlling fish migration patterns, particularly spawning migrations, and the environmental factors that regulate behaviorally-mediated movements or the evolution of observed behaviors of different life stages; and
- conducting more basic, controlled laboratory experiments on the growth physiology of species, including those designed to capture the interactive effects of multiple factors (*e.g*., temperature *x* prey species *x* pH).

For more details on some workshop-related research, see:

Okunishi, T., S.-I. Ito, D. Ambe, A. Takasuka, T. Kameda, K. Tadokoro, T. Setou, K. Komatsu, A. Kawabata, H. Kubota, T. Ichikawa, H. Sugisaki, T. Hashioka, Y. Yamanaka, N. Yoshie and T. Watanabe. 2012. A modeling approach to evaluate growth and movement for recruitment success of Japanese sardine (*Sardinops melanostictus*) in the western Pacific. Fish. Oceanog. 21: 44–57. doi: 10.1111/j.1365-2419.2011.00608.x.

Peck, M., P. Kanstinger, L. Holste, and M. Martin. 2012. Thermal windows supporting survival of the earliest life stages of Baltic herring (*Clupea harengus*). ICES J. Mar. Sci. 69(4): 529–536.



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Dr. Sukyung Kang (kangsk@nfrdi.go.kr) is a Fisheries Oceanographer with the National Fisheries Research and Development Institute (NFRDI), Korea. She has been a member of the North Pacific Anadromous Fish Commission (NPAFC) for Korea for the last five years and was a member of the joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish. Her research interests include the impacts of climatic and oceanographic variability on small pelagic fish, as well as the use of otolith chemistry information for stock identification and habitat characteristics of fishes.

Dr. Carolina Parada (cparada@inpesca.cl) is a Research Scientist at the Fisheries Research Institute (INPESCA) in Chile and a Research Associate to the Geophysical Department at the University of Concepción-Chile. She is also one of the Principle Investigators in the modeling component of the North Pacific Research Board's Gulf of Alaska Integrated Ecosystem Research Program. Carolina has been working with biophysical models since 1999 and applying these models to larval drift, connectivity and pre-recruitment variability studies for various pelagic and benthic species in different regions. Her work focuses on biophysical modeling and links to population dynamics and the environment, and transport and connectivity of small pelagic and highly migratory species in the Humboldt Current system. Her current research interests include ecosystem modeling focused on the impact of climate variability and change on fish populations and their fisheries.