SCIENTIFIC COMMITTEE
THIRD REGULAR SESSION

13-24 August 2007
Honolulu, United States of America

CLIOTOP/PFRP WORKSHOP: THE ROLE OF SQUID IN PELAGIC MARINE ECOSYSTEMS

WCPFC-SC3-EB SWG/IP-12

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CLIOTOP/PFRP Workshop: "The Role of Squid in Pelagic Marine Ecosystems"

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Squid play a central role in marine pelagic food webs by linking the massive biomass of the micronekton, particularly myctophid fishes, to many oceanic top predators, particularly tunas and billfishes (Figure 1). Characterized by short life spans and fast growth rates, squid can be expected to respond more readily to environmental change than perhaps any other mid-trophic-level organism in the open ocean. As part of the broader CLIOTOP[1] initiative aimed at "identifying the impact of both climatic variability and fishing on the structure and function of open ocean ecosystems," five working groups were established (see Maury and Lehodey 2005 for a full description). Working Group 3 (Trophic Pathways in Open Ocean Ecosystems) developed a number of objectives to understand the "trophic pathways that underlie the production of tunas and other oceanic top predators." As squid are the central link in many, if not most, pelagic ecosystems, a concerted effort is needed to better understand what might occur in changing oceanographic conditions.

Of all the components of the pelagic ecosystem leading to top predators such as the tunas, squid are perhaps the least understood. This is in part due to their ability to avoid capture by conventional marine sampling techniques. Other factors, such as their complex taxonomy compounded by their relatively fast digestion in predator stomachs, have meant that detailed information on their role in many ocean ecosystems is lacking. Nevertheless, new technologies, including those to track their movements (*e.g.* archival and satellite tags) and biochemical techniques to identify their presence in the tissues of their predators (*e.g.* stable isotope and fatty acid analysis), are helping to resolve some of the questions surrounding this group.

With encouragement and sponsorship from CLIOTOP and PFRP, a workshop was held immediately following the 2006 PFRP Principal Investigators meeting at the Imin Conference Center at the University of Hawaii. The workshop aimed was to bring together squid ecologists working across diverse oceanographic regions and ecosystems from the Pacific, Atlantic, and Indian Oceans to summarize relevant information on key

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[1] In 2004, the international research program GLOBEC (Global Ocean Ecosystem Dynamics) (http://www.globec.org/) implemented a regional program called CLIOTOP (Climate Impacts on Oceanic Top Predators). CLIOTOP aims to identify, characterize, and model the key processes involved in the dynamics of oceanic pelagic ecosystems in a context of both climate variability and change, and intensive fishing of top predators. The goal is to improve knowledge and to develop a reliable predictive capacity for single species and ecosystem dynamics at short-, medium-, and long-term scales.

pelagic squid species and how changing oceanographic conditions may affect their role as prey, and in some cases, as predator. The focus of the workshop was:

- To consider the role of squid in pelagic ecosystems that support tunas and other upper-level predators;
- To consider how climate change might impact squid populations and the ecosystem;
- To consider the recent range expansions of *Dosidicus gigas* in the Pacific Ocean, especially in terms of its effects on the ecosystems;
- To identify research needs for large pelagic squid to meet the goals of GLOBEC-CLIOTOP and to identify potential research proposals.

The workshop hosted 21 oral and 5 poster presentations by researchers from several countries, including Australia, Canada, Chile, France, Great Britain (including the Falkland Islands), Japan, Mexico, Portugal, and the USA (east and west coasts) (Figure 2).

The workshop featured four main themes: biology and ecology, trophic links, climate impacts, and modeling. A final session, led by the moderators from each theme, reviewed the outcomes from each theme and highlighted potential future research proposals. A detailed report on this workshop, including extended abstracts from each presenter and summaries of the discussions and conclusions, is being prepared by the conveners. The report will be published as part of the GLOBEC Report series later this year. A brief summary of the workshop follows.

Theme summaries

Biology and Ecology

The biology and ecology theme highlighted the unique life histories of oceanic squids. Many of the presentations concentrated on the jumbo or Humboldt squid, *Dosidicus gigas*, an ommastrephid species that has undergone a massive biomass and range expansion in recent years in the eastern Pacific Ocean. This species is the target of the world's largest cephalopod fishery, yet relatively little is know of its natural behaviors. Discussion centered on the potential reasons for the range expansion. The apparent wide tolerance of this species to temperature, the oxygen minimum layer, and CO_2 concentration, its migratory capacity, and its generalist feeding habits have enabled this species to expand its range, possibly in response to a warming trend in the Pacific Ocean. Data was presented on the vertical and horizontal distribution of adults and the distribution of paralarvae, and on some of its unique physiology, morphology, and reproductive biology. The importance of nektonic squid as biological pumps, transporting substantial amounts of resources between ecosystems, and the susceptibility of these processes to alteration by climate change, was discussed.

Trophic Links

Pelagic squids are key predators and prey in the ecosystem. Cephalopod prey are important components of the diet of large pelagic fishes in the central North Atlantic, the eastern Pacific, and elsewhere (data for the Indian Ocean were not presented at the workshop). Squid are voracious predators, and ecosystem effects of *D. gigas* range expansions were illustrated by predation data on commercially-important pelagic fishes in Chile and groundfishes in the California Current. Vertically-migrating myctophid fishes and a galatheid crustacean, *Pleuroncodes planipes*, dominate the diet of *D. gigas* in the Gulf of California and adjacent waters (Figure 3). Biochemical techniques such as fatty acid and stable isotope analyses have become popular for identifying squid in the diets of large fishes, such as swordfish, and for elucidating their role in the ecosystem.

Climate Impacts

By the end of the next century global mean sea surface temperatures are expected to rise substantially, and climate change may impact ecosystems via complex effects on squid populations. Studies of loliginid squid have provided evidence that increasing temperatures could result in complex interacting effects on egg development time, hatchling size, growth rate, life span, feeding rate, survival, and movements. Changes in physical parameters, such as wind stress, air temperature, SST, and mixed layer depth, can explain trends in stock size and distribution of *Todarodes pacificus* in the western Pacific Ocean. Neon flying squid *Ommastrephes bartramii* was found to respond quickly to environmental and ecosystem changes caused by climate change and the fishery, and may have affected ecologically-related species. The El Niño Southern Oscillation (ENSO) is thought to influence the abundance and population structure of *Dosidicus gigas* in the Gulf of California. Also, increasing CO_2 in the atmosphere and the resultant acidification of ocean waters can have sublethal effects on respiration physiology and reduced scope for activity of *D. gigas*, which could affect the animals' ability to catch prey and escape predators.

Modeling

Not only are cephalopods important components of pelagic ecosystems, their economic importance, evidenced by fisheries landings, has increased rapidly over the past thirty years. A modeling study of 17 Large Marine Ecosystems (LMEs) estimated that approximately 10 to 30% of the fishery landings and market values may pass through the cephalopod biomass pool. Because generations are essentially non-overlapping, modeling of squid population dynamics (and coincident impacts on ecosystems) reduces to predicting recruitment success. Environmental signals are expected to have a strong effect on spawning and hatching success and on growth and survival of early life stages. A review of approaches to modeling spatiotemporal patterns in squid life history, distribution, abundance, and fisheries, and to identify relevant research questions in relation to *D. gigas* was presented. An Ecopath with Ecosim model for central Chile was used to estimate the potential impact of predation by *D. gigas* on pelagic and demersal fishes in that region. Increased abundance of that species in Chile between 2000 and 2005 could have had a moderate to strong impact on hake via predation, but not on common sardine and anchovy.

Perspectives

There was informal consensus at the workshop that an international research effort was needed to better understand the jumbo squid and its role in structuring the pelagic and mesopelagic ecosystems within its range. Understanding of the reasons for rapid, massive range expansions by cephalopods is lacking, and the opportunity to study this phenomenon in *D. gigas* may lead to a better understanding of other oceanic ommastrephids, such as *Ommastrephes bartramii* and *Sthenotheuthis oualaniensis*, in the Pacific and other oceans.

The ability to respond rapidly to variations in environments and to changing oceanographic conditions and their plasticity in biological parameters implies that pelagic cephalopods might serve as useful ecological indicators of ecosystem change.

References

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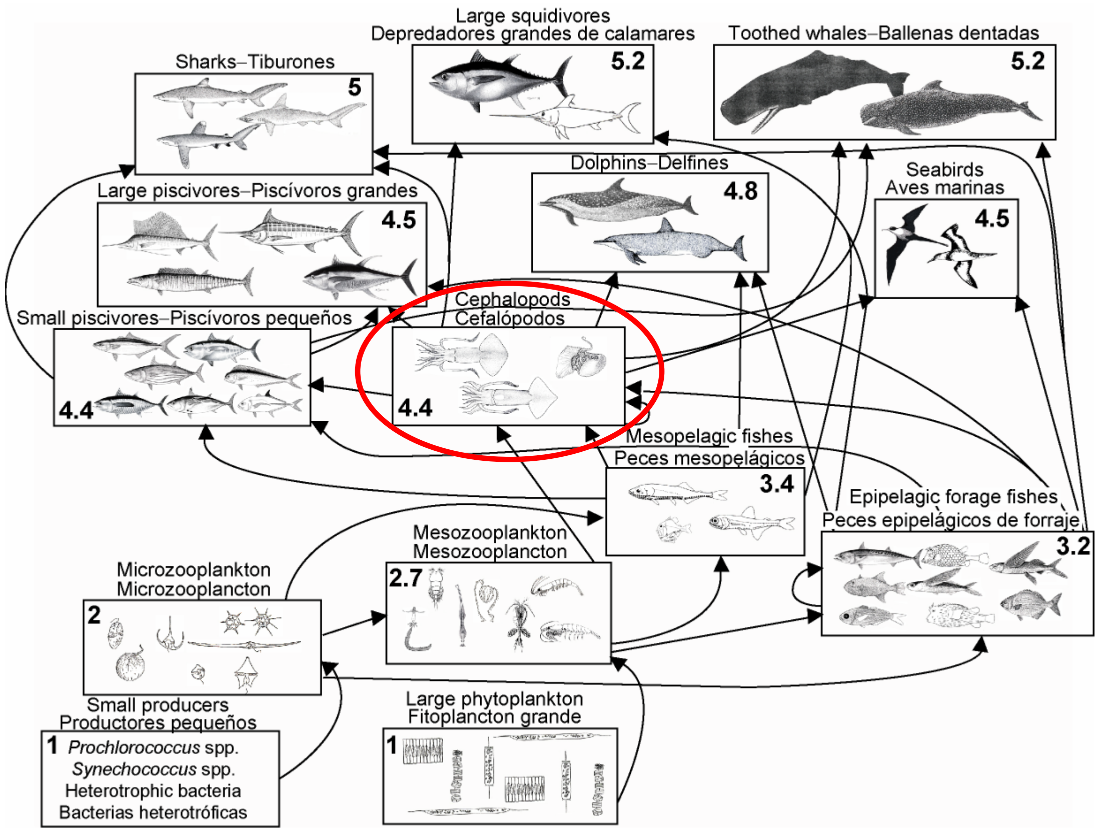

Figure 1. Simplified food-web diagram of the pelagic ecosystem in the tropical eastern Pacific Ocean, with cephalopods highlighted (after Olson and Watters 2003). The numbers inside the boxes indicate the approximate trophic level of each group.

Figure 2a. Group photo of workshop participants.

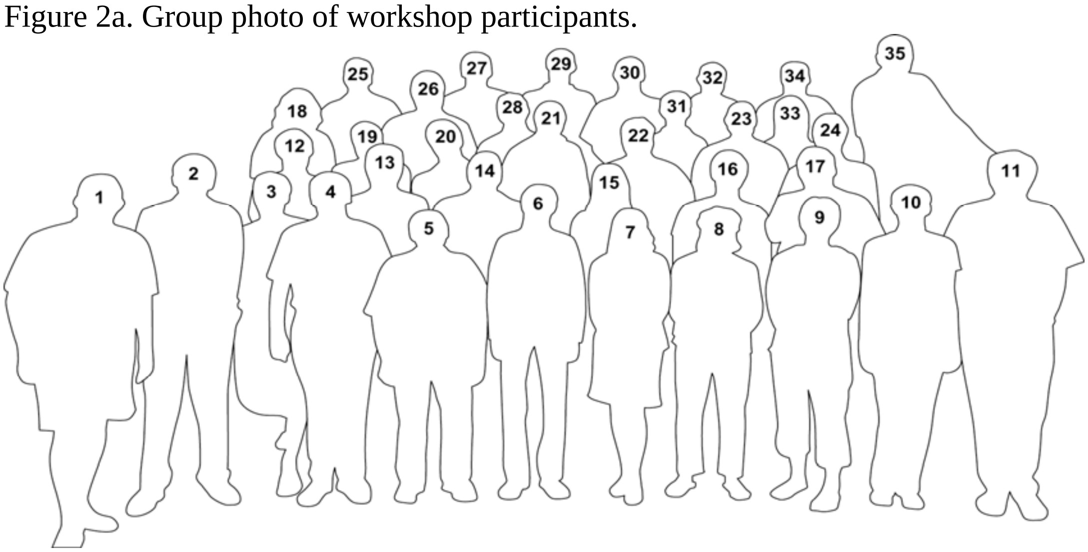

Figure 2b. Workshop participants: 1, Frances Juanes; 2, George Jackson; 3, Rui Rosa; 4, Ron O'Dor; 5, Robert Olson; 6, Reka Domokos; 7, Susana Camarillo-Coop; 8, Brittany Graham; 9, Bridget Ferriss; 10, Inna Senina; 11, John Sibert; 12, Taro Ichii; 13, William Walsh; 14, William Boecklen; 15, Mary Hunsicker; 16, Anders Nielsen; 17, Felipe Galván-Magaña; 18, Heidi Dewar; 19, Richard Young; 20, Brian Popp; 21, Enzo Acuña; 22, César Salinas-Zavala; 23, Pierre Klieber; 24, Eric Hochberg; 25, Unai Markaida; 26, Enrique Morales-Bojórquez; 27, Patrick Lehodey; 28, Hugo Arancibia; 29, Jock Young; 30, Kenneth Baltz; 31, Molly Lutcavage; 32, Matthew Parry; 33, Valerie Allain; 34, Graham Pierce; 35, William Gilly (Not photographed : Yasunori Sakurai and Alexander Arkhipkin)

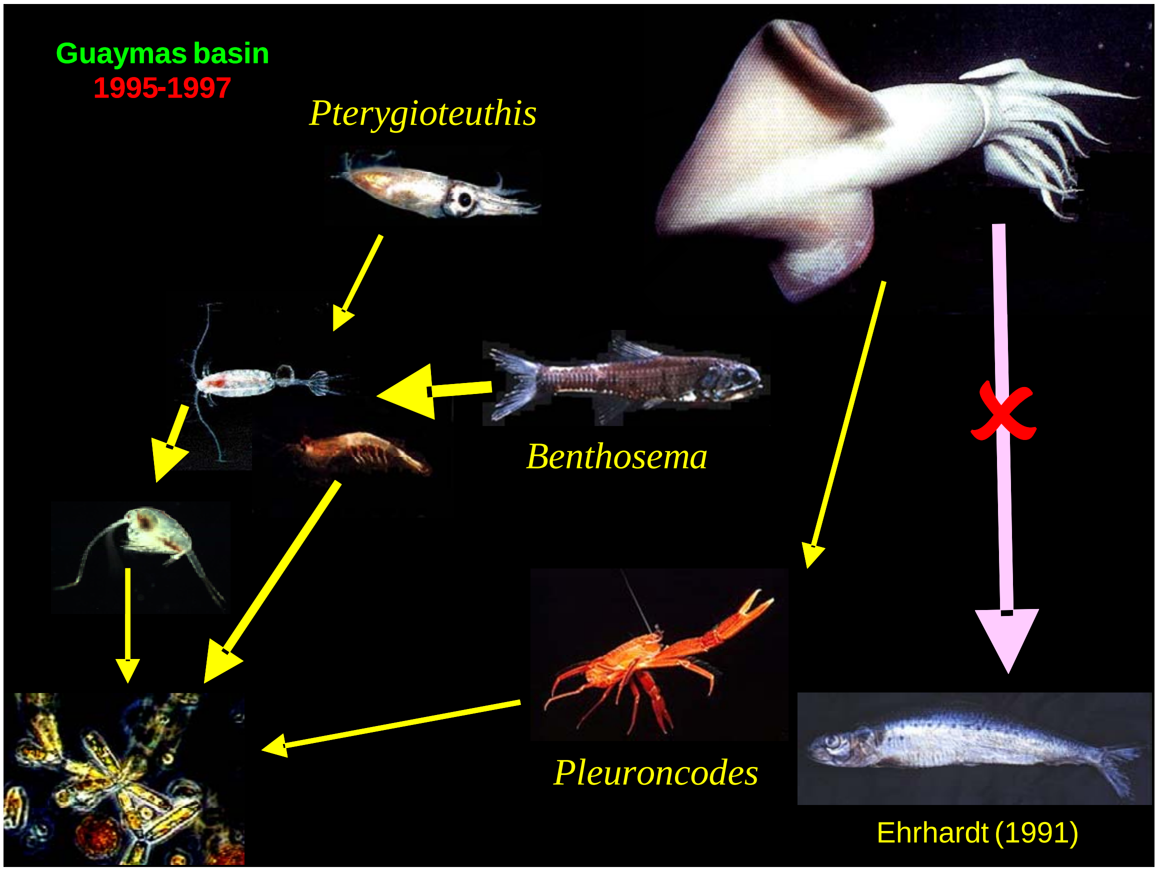

Figure 3. Food habits of jumbo squid *Dosidicus gigas* in the Guaymas basin of the Gulf of California, Mexico (Markaida and Sosa-Nishizaki 2003). Predation on fishery resources as sardines, anchovies, and shrimp is very limited (note deleted path to sardines, largely postulated by Ehrhardt 1991). Courtesy of Unai Markaida.