

UC San Diego

Research Final Reports

Title

Ecology and Trophic Interactions of Jumbo Squid (*Dosidicus gigas*) in the California Current Ecosystem

Permalink

<https://escholarship.org/uc/item/54z8h284>

Authors

Gilly, William
Field, John

Publication Date

2012-03-15



California Sea Grant College Program Final Report

Filed March 15, 2012

Project Information

Year

NOAA Grant No.:

Number R/OPCFISH-06

Start Date: 3/1/2008

Completion Date: 2/28/2012

Title Ecology and Trophic Interactions of Jumbo Squid (*Dosidicus gigas*) in the California Current Ecosystem

Project Leader

Last Gilly

First William

Init

Institution Stanford University

Department Hopkins Marine Station

Address 120 Oceanview Blvd.

City Pacific Grove

State CA

Zip 93950

Phone 831-655-6219

Fax 831-375-0793

Email lignje@stanford.edu

Position Title Professor

Project Leader

Field

John

Research Fisheries Biologist

NOAA NMFS SWFSC

Fisheries Ecology Division

110 Shaffer Rd.

Santa Cruz

CA

95060

8314203907

8314203977

john.field@noaa.gov

Project Hypothesis

Humboldt squid have recently demonstrated a range expansion into the waters off California from the previous northern extent of their range in Mexico. In this new environment, we expected the vertical and horizontal migratory behavior and the diet to be generally similar those previously documented in Mexico. However, we also expected significant differences in diet and reproductive activity, with potentially great impacts on ecosystems in the California Current System. In particular, consumption of numerous ecologically and economically important species could greatly affect both nearshore and offshore environments and fisheries in the California Current System. We hypothesize that mechanisms driving the range expansion include tolerance of environmental variability and flexibility in diet.

Project Goals and Objectives

We aim to understand Humboldt squid behavior and ecology in its new environment in the northern California Current System. We will characterize movement, both vertically in the water column, and horizontally alongshore and offshore, and also investigate the population structure, diet, feeding habits and species interactions in nearshore and offshore environments. We will also investigate the reproductive status of Humboldt squid in California waters in order to assess whether spawning is occurring. This work will enable us to better assess the impacts this species is having on local ecosystems and fisheries.

Briefly describe project methodology

We will complete our project objectives through a combination of sampling, tagging, assessment of stomach contents and reproductive status, aging and modeling. We sample Humboldt squid by fishing with luminescent jigs and dissect them either shipboard or in the laboratory to assess reproductive status, sex, and size. Statoliths are sectioned and polished to allow counting of growth rings to establish age. Further dissection and enumeration and weight of stomach contents provides information on diet. We also attach electronic pop-up archival transmitting (PAT) tags to large, healthy animals. Data from these tags demonstrate swimming patterns as well vertical habitat usage (depth, temperature). To further understand the environment in which Humboldt squid live, we measure water properties to 500 meters at our sampling sites using an oceanographic profiler that logs salinity, temperature, depth, oxygen concentration and fluorescence.

Describe progress and accomplishments toward meeting goals and objectives.

We have sampled nearly 900 Humboldt squid from California, Oregon, Washington and British Columbia. In addition to size, sex, and sexual maturity, stomach contents have been analyzed from these samples. Numerically, the most abundant prey are lanternfish, although squid also eat a large amount of Pacific hake, squid, several rockfish (*Sebastes*) species, and even salmon smolts in Washington. We have also developed genetic methods for identifying fish prey from bones collected from squid stomachs. We identified 98 unique species (or genera, if no species assignment was possible), including 71 fishes, 22 cephalopods and 5 pteropods. In addition, 6 rather broad classes of crustaceans were encountered. Seven of the 98 species

were identified only through DNA analysis, but these included larger, important fish -- pink salmon, arrowtooth flounder, lingcod, Pacific cod, yellowtail rockfish, widow rockfish, and speckled rockfish (*S. ovalis*). The abundance and diversity of fish in the diet contrasts strongly to the situation in the Gulf of California and Pacific Baja coast where fewer than 10 species of fish were consumed.

We tagged nine squid and have obtained useful data from six. We have estimated the migration of these squid by comparing the depths and temperatures sampled by the tags to local bathymetry and remotely sensed sea surface temperatures and creating a model of daily movement. In addition, we have analyzed vertical movement in California, particularly with association to the oxygen minimum zone (OMZ). We have compared vertical movement and diet in California with previous studies in Mexico in order to identify behavioral differences in the two locations. We also examined CalCOFI zooplankton collections, studied temperature-dependence of early development of Humboldt squid embryos, and mapped potential spawning habitat off California. We found no evidence of spawning in California waters, but a vast potential spawning environment exists seasonally (July-October) several hundred miles offshore.

Through a synthesis of results based on sampling, apparent growth rates and tagging, we have developed a model for a putative feeding of Humboldt squid up the US Pacific coast in early summer that reaches the Olympic Peninsula and Vancouver Island by late summer. We propose a return migration then occurs to the south to take animals to warmer waters that are suitable for spawning and permissive for development of the pelagic embryos.

PROJECT MODIFICATIONS: Explain briefly any substantial modifications in research plans, including new directions pursued and ancillary research topics developed. Describe major problems encountered and how they were resolved.

In fall 2009 we had a very successful field season and were able to work out of Monterey Bay, as compared to 2008 where we worked primarily out of Bodega Bay (due to boat availability). Although we had hoped to tag and sample more squid in fall 2010, Humboldt squid essentially vanished in California coastal waters. Based on our work in the Gulf of California, we believe this was a result of an El Niño event during the winter of 2009-2010.

We also carried out a pilot project in September 2009 that involved tagging squid off Washington with acoustic pingers that could be detected by the POST receiver array in that area. This was the first time this approach was used with a migrating, oceanic squid. Squid were found to move south at the end of the summer and did not appear to remain in a coherent school between tagging and detection (6 to 32 days).

We have added quantitative analysis of MBARI video data to complement data from archival tags in characterizing the vertical distribution of squid during daytime and the environmental features that define their habitat. We are also using these data to define the seasonality of relative abundance of Humboldt squid in the Monterey Bay area and to devise a model that predicts actual numbers of Humboldt squid in the Monterey Bay area.

Our work in 2011 primarily involved data analysis. We have submitted three manuscripts to scientific journals based on tagging data and one on diet data. We will be submitting additional manuscripts on abundance estimates and relations to oceanographic conditions, including El Niño. A PhD thesis will also be prepared based on data generated by this project (scheduled defense in May 2012).

PROJECT OUTCOMES: Briefly describe data, databases, physical collections, intellectual property, models, instruments, equipment, techniques, etc., developed as a result of this project and how they are being shared.

Throughout the course of this project we have given many seminars for academic institutions and other venues. In 2011-12 we presented our work at three conferences (PICES, Monterey Bay National Marine Sanctuary Currents Symposium and Ocean Sciences). We have also engaged in numerous public outreach events in association with our Squids-4-Kids outreach project. This has involved many visits to California schools, educational conferences and major public science-events in a number of locations, including San Francisco (Bay Area Science Festival) and Washington, DC (USA Science and Engineering Festival).

We have submitted four manuscripts to peer-reviewed journals based on this study, and we will submit two more in the near future. Julia Stewart is completing her PhD dissertation, which will result in a Stanford University thesis as well as further publications. Our project has received much attention by television, radio and print media.

IMPACTS OF PROJECT: Briefly describe how this project has contributed to a discipline; to developing human resources; to developing physical, institutional or information resources; technology transfer; and society beyond science and technology. Please notify CASG of impacts that occur after your project ends; CASG may contact you after your project ends to learn about additional impacts that occur over time.

Our interest in well managed fisheries using the best available science is reflected in our efforts to understand the behavior and ecology of Humboldt squid in our local waters. Currently, Humboldt squid is not a commercial fishery in California, but results from our study can help design the management plan if such a fishery were to develop in the future. Further, as we have documented that Humboldt squid eat a variety of economically important fished species (including market squid, rockfish species, Pacific Hake, and salmon), our work can help manage already-existing fisheries on which Humboldt squid prey. We consulted with NOAA in Seattle on our studies in conjunction with modifications being

designed for the hake acoustic surveys that were being confounded by the presence of large numbers of squid.

BENEFITS, COMMERCIALIZATION, AND APPLICATION OF PROJECT RESULTS: Please list any companies, agencies, organizations or individuals who have used your project results, scientific/technical advice, etc., and provide names, emails and phone numbers. Briefly describe how results were used and quantify results and socioeconomic benefits, if possible.

Productive contacts have developed with local fishing communities in Half Moon Bay and Ft. Bragg, CA. Half Moon Bay has an active charter vessel fishery for Humboldt squid when they are locally abundant, and our interactions with fishermen were documented in a KQED Quest production, "The Fierce Humboldt Squid" (April, 2008). An online follow-up story appeared on the Quest website in August, 2010 ("What Happened to the Humboldt Squid?"). The Ft. Bragg community is interested in developing a commercial fishery for Humboldt squid, and we have been advising them on ecological aspects of the squid, and we will continue to work with them in the future.

We have also begun to explore the composition of the Humboldt squid digestive gland with a NOAA lab in Seattle, because this large organ is extremely rich in omega-three fatty acids which could be commercialized as human dietary supplements or an additive to aquaculture feed. Commercial contacts have been established with a Norwegian fish-oil company, a German seafood company and a San Francisco-based company that are interested in developing new products from a Humboldt squid fishery.

ECONOMIC BENEFITS generated by discovery, exploration and development of new, sustainable coastal, ocean and aquatic resources (i.e., aquaculture, marine natural products, foods, pharmaceuticals).

Issue-based **forecast capabilities** to predict the impacts of a single ecosystem stressor, developed and used for management (i.e., climate change, extreme natural events, pollution, invasive species, and land resource use).

Commercialization of products based on the digestive gland, a tissue currently discarded by fisheries and rich in omega-three fatty acids, will likely play out in the coming years. It may be useful for both human pharmaceuticals and as an ingredient to feeds used in the aquaculture industry. We will be working with Mark Drawbridge, Hubbs Seaworld, and Mike Rust, NOAA Seattle, who are studying feasibility of using squid discards in aquaculture feed for white seabass and yellowtail in a California experiment. Unfortunately, the current lack of Humboldt squid in California waters during the last 2 years has led to a cut-back in those efforts.

Understanding how the presence of Humboldt squid relates to seasonal environmental changes, both acute like El Nino and longer-term oscillations and warming, will help to assess its impacts on local ecosystems. We are attempting to account for the seasonality of Humboldt squid presence in the Monterey Bay area (during non El Nino years) based on relevant environmental features including upwelling, oxygen at depth, and shallow temperatures.

Tools, technologies and information services developed (i.e., land cover data, benthic habitat maps, environmental sensitivity index maps, remote sensing, biosensors, AUVs, genetic markers, technical assistance, educational materials, curricula, training).

Publications (list in appropriate category below) Each listing should be a stand-alone bibliographic reference, including all authors' names. For each Publication type, specify title, authors, date and journal details, where appropriate (repeat headers as necessary).

Technical Reports

Title	Authors	Date
-------	---------	------

Conference Papers, Proceedings, Symposia

Conference	CALCOFI Conference 2007: JUMBO SQUID (DOSIDICUS)	Location	San Diego, CA	Date	Novmeber 2007
Title	Symposium Introduction: Jumbo Squid (Dosidicus gigas) Invasions in the Eastern Pacific Ocean.	Authors	JC Ffield		
Conference	PICES-2010: North Pacific Ecosystems Today, and	Location	Portland, OR	Date	10/28/2010
Title	Adaptability and plasticity of Humboldt squid, Dosidicus gigas, in conjunciton with environmental peturbation	Authors	WFF Gilly and U Markaida		
Conference	PICES-2010: North Pacific Ecosystems Today, and	Location	Portland, OR	Date	10/28/2010
Title	Foraging ecology of the Humboldt squid in the California Current	Authors	JC Field, KA Baltz, W Matsubu, GE Gillespie, JS Stewart, WF Gilly and WA Walker		
Conference	Monterey Bay National Marine Sanctuary Currents	Location	Marina, CA	Date	4/9/2011
Title	Humboldt squid migration in the California Current System	Authors	JS Stewart, WF Gilly and JC Field		
Conference	PICES 2011: Mechanisms of Marine Ecosystem	Location	Khabarovsk, Russia	Date	10/14/2011
		Authors			

Title	Movement patterns and foraging ecology of Humboldt squid in the California Current System	Authors	JS Stewart, WF Gilly, JC Field		
Conference	2010 Ocean Sciences Meeting	Location	Portland, OR	Date	2/24/2010
Title	Seasonal Abundance of Humboldt Squid in Monterey Bay in Relation to Upwelling	Authors	JS Stewart		
Conference	2012 Ocean Sciences Meeting	Location	Salt Lake City, UT	Date	February 2012
Title	Modelling marine predator migration during range expansion	Authors	JS Stewart, EL Hazen, DG Foley, SJ Bograd and WF Gilly		

Peer-reviewed journal articles or book chapters

Journal	J. Acoustl Soc Amer	Issue Num	123	Page Num	1318__1	Date	3/1/2008
Title	Controlled and in situ target strengths of the jumbo squid Dosidicus gigas and identification of potential acoustic scattering sources	Authors	KJ Benoit-Bird, WF Gilly, WWL Au and B Mate				
Journal	J. Mar. Biol. Assn. U.K.	Issue Num	88	Page Num	759-770	Date	6/25/2008
Title	Natural egg mass deposition by the Humboldt squid (Dosidicus gigas) in the Gulf of California and characteristics of hatchlings and paralarvae	Authors	DJ Staaf, S Camarillo-Coop, SHD Haddock, AC Nyack, J Payne, CA Salinas-Zavala, BA Seibel, L Trueblood, C Widmer and WF Gilly				
Journal	Geophys. Res. Lett.	Issue Num	35	Page Num	doi:10.10	Date	6/28/2008
Title	Oxygen declines and the shoaling of the hypoxic boundary in the California Current	Authors	SG Bograd, CG Castro, E DiLorenzo, DM Palacios, H Bailey, W Gilly and FP Chavez				
Journal	CalCoFI Rep.	Issue Num	49	Page Num	90-103	Date	12/1/2008
Title	Food and feeding of jumbo squid Dosidicus gigas in the central Gulf of California during 2005-2007	Authors	U Markaida, WF Gilly, C Salinas-Zavala, R Rosas-Luis and JAT Booth				
Journal	Prog. Oceanography	Issue Num	86	Page Num	59-71	Date	1/18/2010
Title	Horizontal migrations, vertical habitat utilization and diet of the jumbo squid (Dosidicus gigas) in the Pacific Ocean off Baja California Sur, Mexico	Authors	G Bazzino, WF Gilly, U Markaida, CA Salinas-Zavala and J Ramos-Catillejos				
Journal	Mar Ecol Prog Ser	Issue Num	418	Page Num	165-178	Date	11/18/2010
Title		Authors	DJ Staaf, RI Ruiz-Cooley, C Elliger, Z Lebaric, B Campos, U Markaida and WF Gilly				

Non-peer Reviewed Reprints**Publications, Brochures, Fact Sheets****Books & Monographs****Handbooks, Manuals, Guides**

Electronic publications: (non-print formats).

Maps, Charts, Atlases**Theses, dissertations**

Estructura polacional, movimientos horizontales y migraciones verticales del calamar gigante, Dosidicus gigas, en el Golfo de California	Gaston A. Bazzino	CIBNOR, La Paz, Baja California Sur, Mexico	June 2008
Reproduction and early life history of the Humboldt squid	Danielle Joy Staaf	Stanford University	August 2010

Newsletters, periodicals**Program reports (annual/biennial, strategic plans, implementation plans)****Educational Documents**

Fisheries: Squid Fisheries (http://gilly.stanford.edu/materials.html)	DJ Staaf, JS Stewart	2011	▲
			▼

Topical Websites and Blogs

http://gilly.stanford.edu/outreach.html	DJ Staaf, JS Stewart, JC Field, KA Baltz, WF Gilly	2009-present	▲
			▼

Miscellaneous documents (not listed above).

MEDIA COVERAGE: Select 'Yes' or 'No'. If yes, describe any radio, TV, web site, newspaper, magazine coverage your project has received. Send original clippings or photocopies to the Sea Grant Communications Office.

KQED TV, QUEST, San Francisco CA, 4/1/2008: The Fierce Humboldt Squid (15 min segment) (<http://science.kqed.org/quest/video/the-fierce-humboldt-squid/>)

MEDIA NOTES: Brief description of the type media coverage your project has received.**DISSEMINATION OF RESULTS:** List any other ways in which results of your project have been disseminated. Indicate targeted audiences, location, date and method.

National Science and Engineering Festival, Washington DC, Oct 2010. Our outreach program described below (Squids 4 Kids) participated in this 2-day event that attracted over 100,000 visitors. W. Gilly also participated in the "Nifty Fifty" program that provides speakers with exciting scientific programs to middle and high schools in the DC area for a talk and informal meetings with students. This program will be repeated in April, 2012, and we will again be participating in these ways.

Gulf of the Farallones Jumbo Squid Soiree, San Francisco, CA, Nov 2011. Lecture, hands-on squid dissection, print making (<http://farallones.noaa.gov>)

WORKSHOPS AND PRESENTATIONS: A brief description of location, date, time, topic, number of attendees and name of presenter.

"Voices of the Bay" marine educators workshops, held in collaboration with Monterey Bay National Marine Sanctuary (NOAA) in 2009-2011. Activities include a research cruise on a NOAA vessel, plankton tow, CTD casts, squid jigging. 25 participants per year, presented by W. Gilly and graduate students J. Stewart and D. Staaf. <http://sanctuaries.noaa.gov/education/voicesofthebay.html>

Jasper Ridge field station, Stanford University, 3/1/2011 and 12/13/2011, 12:00, Humboldt squid ecology and climate effects, 40 attendees each presentation by W. Gilly

Hopkins Marine Station, Pacific Grove, CA, July 2011, Summer Scholar's Institute on John Steinbeck funded by National Endowment for Humanities (in collaboration with San Jose State Univ.). 25 humanities and science teachers participated in a 3 week seminar, one of which was devoted entirely to marine biology and sustainable fisheries issues. 25 participants, presented by W. Gilly

COOPERATING ORGANIZATIONS: List those (e.g., county or state agencies, etc.) who provided financial, technical or other assistance to your project since its inception. Describe the nature of their cooperation.**Federal Organizations**

Monterey Bay National Marine Sanctuary, Monterey, CA

Monterey Bay National Marine Sanctuary Foundation, Monterey, CA

Regional Organizations

Pacific Fisheries Management Council

State Organizations

California Wetfish Producers Association

Noyo Harbor District, Fort Bragg, CA

Nongovernment Organizations

David and Lucille Packard Foundation

International Organizations

North Pacific Marine Science Organization (PICES)

CIBNOR, Guaymas(Sonora) and La Paz (Baja California Sur), Mexico

Industry Organizations**Academic Organizations**

Monterey Bay Aquarium Research Institute, Moss Landing, CA

Sea Grant Organizations

Oregon Sea Grant, A cooperative effort to track the Humboldt squid invasion in Oregon (R/RCF-29), S. Heppel, Oregon State University

Other Organizations

Monterey Bay Aquarium

INTERNATIONAL IMPLICATIONS: Does your project involve any colleagues overseas or have international implications?

Humboldt squid constitutes a major fishery in Mexico, and we are closely connected with a number of collaborators in the Mexican states of Baja California, Baja California Sur and Sonora. In these locations we work with academic researchers, researchers at technical institutes, fishermen and producers. Further, we have attended scientific conferences and given seminars in Mexico, Russia, France, and Sweden, and have collaborated with researchers in Canada.

AWARDS: List any special awards or honors that you, or any co-project leaders, have received during the duration of this project.**KEYWORDS: List keywords that will be useful in indexing your project.**

squid, ecology, fisheries, diet, tagging, migrations, life history

PATENTS: Please list any patents or patent licenses that have resulted from this project, and complete the patent statement form available on the web site.**NOTES: Please list any additional information in the notes area****FOR ALL STUDENTS SUPPORTED BY THIS GRANT, PLEASE LIST:**

Volunteer Count 10

Graduate Student Info