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Jumbo squid (*Dosidicus gigas*) landings in the Gulf of California related to remotely sensed SST and concentrations of chlorophyll *a* (1998–2012)

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ABSTRACT

The jumbo squid *Dosidicus gigas* supports an important fishery in the central region of the Gulf of California, Mexico. However, in recent years, landings of this species in the port of Guaymas, Sonora has declined significantly. We examined monthly landing records from January 1998 through March 2012 and related this record to monthly sea surface temperature (SST) and chlorophyll *a* from satellite imagery and coastal upwelling index (CUI) in the fishing area as proxies of inter-annual changes in the epipelagic habitat. Results indicate that jumbo squid catches were high between June 1999 and December 2004 (328,903 t) associated with an extended period of prevailing cold SSTs (La Niña 1999) and high chlorophyll *a* concentrations with intense CUI. From January 2005 through March 2012, a progressive catches decrease; landings were about 31.8% of previous captures (104,829 t). Decline is associated with a progressively warmer habitat with less chlorophyll *a* and considerably lower CUI. Six fishing surveys carried out into the central Gulf of California with jig sampling indicate that jumbo squid tend to be in regions with low SST and high chlorophyll *a*, confirming its association with cold and productive areas.

1. Introduction

The ommastrephidae squid *Dosidicus gigas* (jumbo squid, Humboldt squid, or "calamar gigante" in Spanish) supports a large local fishery in the central Gulf of California, Mexico. This fishery, operating since 1974, targets a fast-growing, short-lived squid species with capacity to migrate vertically and horizontally and rapidly responding to changing environmental conditions (Benoit-Bird and Gilly, 2012; Ehrhardt et al., 1983; Markaida et al., 2004, 2005; Nigmatullin et al., 2001). It is not surprising that, like other squid fisheries, landings of this species in Mexico show large year-to-year fluctuations (Sakurai et al., 2000). In the Gulf of California, giant squid are captured in feeding grounds off Santa Rosalia, Baja California Sur and Guaymas, Sonora. Its distribution has been related to seasonally alternate upwelling regions along both coasts of the gulf (Markaida and Sosa-Nishizaki, 2001), where intense upwelling along the west coast of the mainland occurs from December through May, and less intense upwelling occurs along the east coast of the Baja California Peninsula during the rest of the year (Santamaria-del-Angel et al., 1994; Lluch-Cota, 2000).

The jumbo squid fishing fleet in Guaymas consists of ~500 small open boats (~7 m, regionally known as pangas), each operated by 2 or 3 fishermen, and ~50 modified shrimp trawlers (10–15 m) operated by 10–15 fishermen. Jumbo squid are fished by manual jigging during one-night trips in small boats and four or five nights in modified shrimp trawlers. This small boat fleet typically capture about 80% of the total catch landed at Guaymas (Juan Pedro Vela, Mexican Council for the giant squid for the State of Sonora, pers. comm.). Currently, there is no stock assessment; minimal management is applied to the fishery. Governmental fishery management is based on fishing permit limits, intending to maintain a relatively constant proportional escape of 40% of residual biomass remaining to spawn (Morales-Bojórquez et al., 2001). There are no catch quotas or fishing season or minimum squid dorsal mantle length permitted for the catch. This may reflect the inherent difficulties in managing a highly variable population, and the difficulty of accurately predicting biomass of this squid, using standard methods of stock assessment models (Morales-Bojórquez et al., 2001; Nevárez-Martínez et al., 2006). An efficient fishery management plan for the fishery should include considerable knowledge about spatial-seasonal distribution and abundance associated with regional oceanography and its intrinsic variability (Rodhouse, 2001).

Jumbo squid inhabits the productive waters of the Eastern Pacific (45°S–45°N) and are directly influenced by the climatic variability associated with ENSO (Nigmatullin et al., 2001). El Niño 1997–98 off Peru severely reduced jumbo squid catches (Taipe et al., 2001; Waluda and Rodhouse, 2006; Waluda et al.,

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2006). In the Gulf of California, El Niño 1997–98 had a similar impact on jumbo squid population structure and decrease in commercial catches (Markaida, 2006; Morales-Bojórquez and Nevárez-Martínez, 2010; Morales-Bojórquez et al., 2001). These observations suggest that variability of squid catches may be predictable, using a set of environmental variables, such as sea surface temperature (SST), particularly related with recruitment strength and abundance (Rodhouse, 2001; Waluda and Rodhouse, 2006). However, attempts to correlate squid distribution during and between El Niño events and SST in the Gulf of California have yielded no conclusive results (Nevárez-Martínez et al., 2000; Brito-Castillo et al., 2000).

We correlated the official monthly landings reported at the port of Guaymas with monthly satellite imagery of SST and concentration of chlorophyll *a* in the traditional fishing area in the central Gulf of California from January 1998 through March 2012. This period includes multiple ENSO signals: the intense El Niño 1997–98, La Niña 1999 and the weak El Niño 2009–10 (http://www.esrl.noaa.gov/psd/enso/mei/). Since this species has the fastest rate of growth among the ommastrephidae squid that particularly feed on myctophids, a class of small, short-lived fish with rapid responses to environmental changes (Markaida and Sosa-Nishizaki, 2003; Markaida et al., 2004), we hypothesised that capture of squid near Guaymas will follow seasonal pulses of phytoplankton productivity indicated by SST and concentrations of chlorophyll *a*. Additionally, we carried out six surveys with jigging samplings to capture jumbo squid inside and outside traditional fishing areas, associating catches to the remotely-detected environmental variables.

2. Materials and methods

2.1. Fishery data (1998–2012)

Monthly jumbo squid landings from January 1998 through December 2010 were obtained from the Mexican National Fisheries and Aquaculture Agency (CONAPESCA) http://www.conapesca.sagarpa.gob.mx. Monthly catches for 2011 and 2012 were obtained directly from the Federal Fishing Office (Subdelegación Federal de Pesca) at Guaymas, Sonora. From 2003 onwards, data from CONAPESCA for Sonora represent jumbo squid landings in Guaymas since almost the entire landings in this State occur in this port. Part of the summer landing reported in Guaymas may also come from shrimp fishing fleets jigging off Santa Rosalia near the coast of the Baja California Penisula. From official statistics published online it is not known the specific origin of the monthly landings before 2003. Catches are reported for the entire country; however, from 1999 through 2002 more than 99% of the total catch came from the Mexican coast of the Pacific and more than 89% was landed in Baja California Sur and Sonora. Specifically for 1998, it is reported that jumbo squid expanded southward along the eastern coast of the State of Baja California Sur reaching around the peninsula to Bahia Magdalena on the west coast of Baja California Sur, where 32,000 t of jumbo squid were captured (Morales-Bojórquez et al., 2001). This represents more than the total of the official figures reported for the Mexican coast of the Pacific; therefore in the present analysis it is assumed that during 1998 no jumbo squid were landed in Guaymas.

Information from CONAPESCA combines the commercial landing from trawlers adapted for jumbo squid fishing and the small boats fleet (pangas). Size-frequency of dorsal mantle length and other relevant biological information is not available from official sources, but information about dorsal mantle length from 1997 through 2008 can be found elsewhere (Morales-Bojórquez and Nevárez-Martínez, 2010; Nevárez-Martínez et al., 2010).

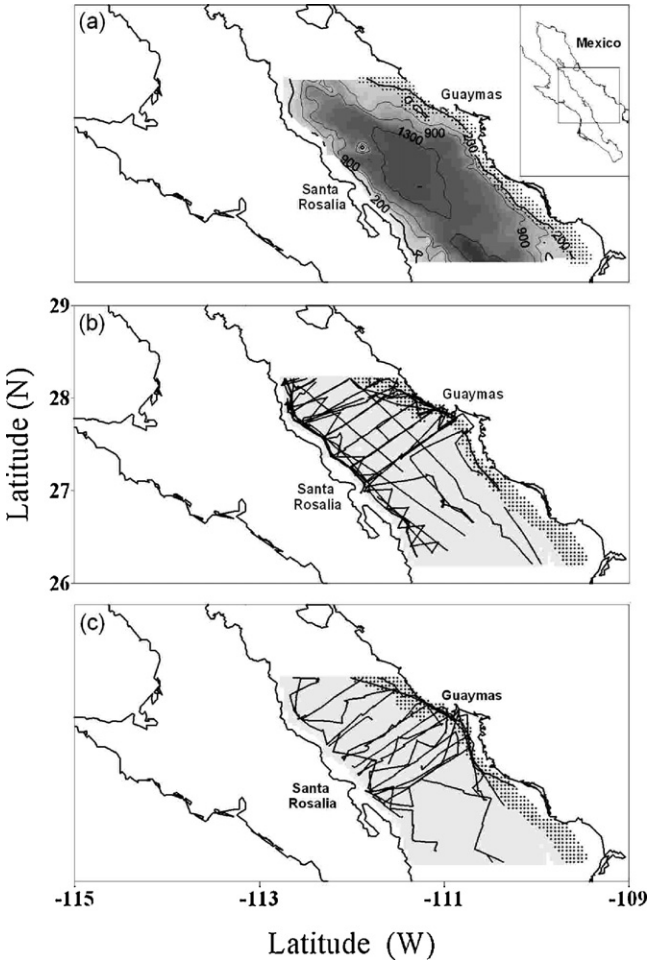

Fig. 1. (a) Guaymas jumbo squid fishing area where the remotely-sensed 30-day composite SST and chlorophyll *a* data were analysed shown as dotted pattern (>50 and <300 m depth). Shadowed area is the study area with bathymetry (m) where six surveys were carried out and where remotely-sensed SST and chlorophyll *a* 8-day data was compared with the area where jumbo squids were captured. (b) Survey tracks in November 2005, January 2007, and November 2011. Shadowed area is the study area. (c) Survey tracks in July 2007, March 2010, and September 2010. Shadowed area is the study area.

2.2. Remotely sensed sea surface temperature and chlorophyll a data

Satellite remotely-sensed night SST (°C) and concentrations of chlorophyll *a* (mg m^{-3}) data for 1998 were obtained from the Jet Propulsion Laboratory and data for 1999 from NASA http://podaac.jpl.nasa.gov and http://oceandata.sci.gsfc.nasa.gov/SeaWiFS). The monthly dataset is 4 km resolution from the composite Advanced Very High Resolution radiometer (AVHRR) and monthly, spatial 9 km resolution from the composite Sea-viewing Wide Field-of-view Sensor (SeaWIFS). Night SST and chlorophyll *a* data from January 2000 through March 2012 were obtained from MODIS-Terra (Moderate Resolution Imaging Spectro radiometer). Data is monthly at 4 km resolution (http://oceandata.sci.gsfc.nasa.gov/MODIST/).

2.3. Selecting remotely-sensed SST and chlorophyll a data using bathymetric data

Surface remotely-sensed information covered an area 50–300 m depth from 26°45′N to 28°32′ N on the far offshore and coastal area near Guaymas, traditional fishing area of this squid. Most of the fishing activity is restricted to areas shallower than 300 m (Fig. 1a).