Fisheries Research 173 (2016) 122–127

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Spatial variability of jumbo flying squid (*Dosidicus gigas*) fishery related to remotely sensed SST and chlorophyll-a concentration (2004-2012)

Carlos Paulino*, Marceliano Segura, German Chacón

Instituto del Mar del Perú, Dirección General de Investigaciones en Hidroacústica, Sensoramiento Remoto y Artes de Pesca, Gral. Valle y Gamarra S/N, Chucuito-Callao, Lima, Peru

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form 5 October 2015
Accepted 5 October 2015
Available online 28 October 2015

Keywords:
Dosidicus gigas
Spatial distribution
Jig fishery
Perú
Chlorophyll-a

ABSTRACT

An analysis was performed on the spatial distribution of the industrial Jumbo flying squid fishery within and outside the Peruvian exclusive economic zone (EEZ) in relation to sea surface temperature (SST) and chlorophyll-a (Chl-a). The locations of vessels were derived from the satellite tracking system (SISESAT) of the Instituto del Mar del Perú. Monthly environmental information came from the MODIS sensor of 4 km spatial resolution for the period 2004–2012.

Fishing operations data were divided into three periods based on their distance to shore consequential to the fishing regulations from January 2004 to October 2010, November 2010 to December 2011 and 2012. During the first period, two monthly patterns of spatial distribution were identified; from January to July fishing was along the coast from Paita (05°S) to San Juan de Marcona (15° 22′S) and later it was more concentrated in the northern area between Chimbote and Paita from August to December. In the second period, fishing operations formed small concentrations and widely dispersed points of fishing as a result of fishing restrictions within 80 nautical miles introduced in November 2010. In 2012 the fleet was located outside the EEZ. The highest concentrations of the fleet were found between 30 and 90 nautical miles offshore.

The highest concentrations of squid were located from Paita-Chimbote (05°–09°S) and Callao–San Juan de Marcona (12° 03′–15° 22′S). Fishing operations were conducted in a wide range of SST between 14.1° and 26.8 °C, with the highest incidence in temperatures between 18.4 to 22 °C and with a tendency to be located more frequently in areas with higher temperatures in recent years. Regarding chlorophyll-a, the fleet fished between chlorophyll-a concentrations of 0–9.5 mg/m3 within the EEZ, and from 0.2 to 0.5 mg/m3 outside the EEZ. Distribution patterns of the fleet in relation to anomalies of sea surface temperature in the area El Niño 1 + 2, with respect to latitude and cyclic monthly SST variability, were also observed.

1. Introduction

The Jumbo flying squid (*Dosidicus gigas*) supports a leading Peruvian artisanal fishery as well as a significant fleet of industrial vessels of foreign nations (flags from Japanese, Korean and Taiwanese). The distribution of this resource is wide, because it is a highly migratory species. Its habitat in the Eastern Pacific Ocean, ranges from 60°N and 60°S (Gershanovich et al., 1974; Hatfield and Hochberg, 2007; Ibáñez and Cubillos, 2007; Roper et al., 1984), and to 125°W. In the southern hemisphere, the highest concentrations are located in the oceanic region off of Perú, and in the northern hemisphere in the Gulf of California (Nesis, 1983).

Due to their biological characteristics such as rapid growth, early maturation, short life, high migratory capacity, and complex recruitment patterns (Boyle and Boletzky, 1996) ommastrephid squid populations live in areas characterized by wide oceanographic regimes in oceanic and coastal waters of tropical and temperate latitudes (Anderson and Rodhouse, 2001).

In Perú, the jumbo flying squid fishery has increased activity mainly because of the presence of an industrial fleet consisting of specialized vessels equipped with lighting systems and automatic machines, with storage capacity of 300–1000 t that started their operations in 1991 (Taipe et al., 2001). This was approved by Peruvian regulations for the Operation of Jig Fishery, and later Fisheries Management Plans.

* Corresponding author.
E-mail address: cpaulino@imarpe.gob.pe (C. Paulino).

http://dx.doi.org/10.1016/j.fishres.2015.10.006

According to the Supreme Decree of December 13, 1991, it was stated that fishing operations should be conducted outside 30 nautical miles from the coastline; then in 1993 this was reduced to 20 nm. Subsequently, in 2011 both national and foreign industrial vessels fishing operations were permitted between 80 and 200 nm, this regulation aimed to establish fishing of jumbo flying squid by developing a national fleet and optimizing a specialized industry for direct human consumption.

Fishing takes place mainly at night, for which vessels use powerful lamps to attract the squid (Rodhouse et al., 2001). Halide lamps are suspended above the main deck. Large industrial vessels operate with 150 or more lamps which are 2 kW each; while small coastal vessels often use a single lamp. The lamps typically emit a white light, but sometimes some green lamps are interspersed (Inada and Ogura, 1988). Waluda et al. (2006) used night time visible satellite images from DMSP/OLS, data provided by the NOAA National Geophysical Data Center (NGDC) and data on location of vessels (latitude, longitude and time) was obtained via a regional Collect Location System (CLS) by the Instituto del Mar del Perú (IMARPE) in order to quantify fishing effort of the fishery for *D. gigas* off the coast of Perú and adjacent high seas.

The Peruvian fisheries management has implemented a satellite tracking system called (Sistema de Seguimiento Satelital—SISESAT) for the monitoring, control and surveillance of fishing vessels; data are obtained via satellite tracking using the ARGOS system for better management of aquatic resources, thus allowing for systematic observations (in time and space), of the activities of the jig fishery within and outside the Exclusive Economic Zone.

Since the late 90's, IMARPE depends on daily satellite information for the location (latitude and longitude) in near real time of the industrial fishing fleet and to determine fishing operations, information which serves for research aimed at proper management and sustainability of marine resources.

This paper analyzes the spatiotemporal dynamics of the jig fishery, to identify spatial distribution patterns within and outside the EEZ and their relationship with environmental parameters such as sea surface temperature (SST) and concentration of chlorophyll-a (Chl-a) for the period 2004–2012.

2. Material and methods

The satellite location data of the jig fishery comes from Satellite Tracking System for Ships (SISESAT), which is processed by the Department of Remote Sensing of Instituto del Mar del Perú. This system obtains information from the spatial location (latitude/longitude) of the vessels that have onboard GPS transmitters.

The SISESAT records the location of a boat every hour; this means 24 measurements per day for the same vessel that includes information on the date, time, speed, course direction and name. To determine that a vessel is a squid jigger, critera are assumed based on speed, time spent in a given area and through interviews with researchers on board jigging vessels.

Monthly data of sea surface temperature (SST) and chlorophyll-a, both at 4 km spatial resolution Aqua-MODIS sensor L3 level, distributed by the project website OCEAN COLOR Goddard Space Flight Center (GSFC) was used. The MODIS sensor is located onboard the satellite AQUA PM, which is part of the international mission called Earth Observing System (EOS), in which the National Aeronautics and Space Administration (NASA) participates with other space agencies. Also, average monthly atmospheric data and indices of SST Eastern Pacific (area El Niño 1 + 2 region comprising 0–10° 80–90° south and west), were obtained from the National Oceanic and Atmospheric Administration (NOAA)—National Weather Service Climate Prediction Center for the period 1996–2014.

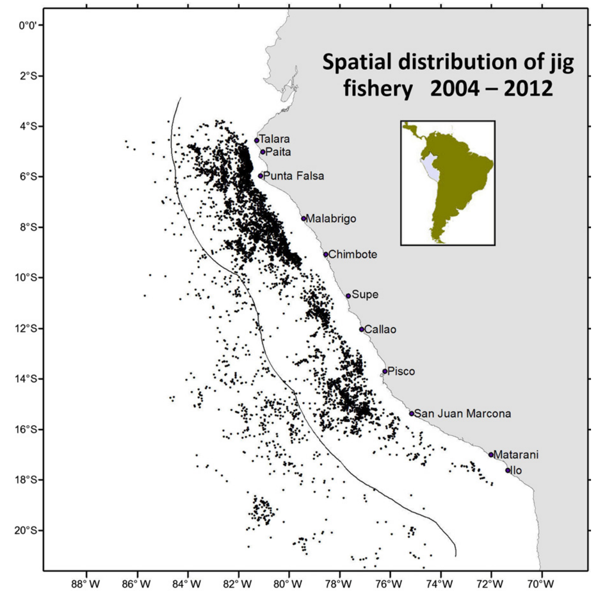

Fig. 1. Study area and spatial distribution of industrial jigging fleet within and outside the EEZ during the period 2004–2012.

From this data set, vector and raster data were generated, which were integrated into thematic layers in a GIS. The resource and environment data were analyzed using R version 3.0.2.

The data analyzed included the dynamics of the fishing fleet in the area of research between Zorritos (03° 47′S) to the southern border of Perú, from 20 to 500 nautical miles from shore. This area is dominated by the Humboldt Current System, which generates cold upwelling, rich in nutrients making this a very productive region (Fig. 1).

Stat plots were generated from the records of the number of fishing operations by Isoparalitoral area polygons created by the imaginary projection of the coastline every 10 nm, the same that are cut every 30 min by the parallel of latitude, to a distance of 300 nautical miles from the coastline, each polygon is coded to facilitate calculations and spatial location (Gutiérrez and Peraltilla 1999), relating to the sea surface temperature, chlorophyll-a, latitude and distance to the coast. Only those isoparalitoral areas containing at least one fishing operation were considered.

3. Results

3.1. Types of jigging fleet by nationality

During the study period, the industrial fishing fleet consisted of 30 foreign vessels authorized to fish. Of this total, 14 were Japanese, 12 Korean and 4 Taiwanese (Table 1). It was noted that during 2004 and 2010 there was a greater number of fishing vessels compared to other years. While in 2011 and 2012 there were 4 vessels conducting fishing operations respectively.

3.2. Annual variability of jig fishery

Fishing operations were recorded from 20 to 495 nm offshore. The annual fleet dynamics were characterized by distinct patterns of spatial distribution and well-defined areas of high concentrations of fishing.

In 2004, fishing operations were conducted between latitudes of 05° to 17°S and from 20 to 308 nm offshore. The largest concentration was located in the north (05°–09°S). Small concentrations were observed outside the Peruvian EEZ. Fishing areas showed a progressive reduction after 2005, most fishing areas in 2005 were