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Jumbo Squid *Dosidicus gigas*: A New Fishery in Ecuador

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ABSTRACT

During 2014 given the relevance of *Dosidicus gigas* in the eastern Pacific and the incentives and possible profits obtained for harvest of jumbo squid, the Ecuador Government decided that *D. gigas* must be a new fishery. So, in this article, the first steps to fishery management and the future directions for jumbo squid fishery in Ecuador are documented. Several recommendations were identified in order to improve the jumbo squid fishery management, such as spatial and temporal distribution, scientific data collection, stock assessment, management strategy, and proposal of fishery management in the Galapagos Islands. This review identified as priority a fishery management plan for jumbo squid in the region.

KEYWORDS
Management strategy; stock assessment; artisanal fleet; Galapagos islands

1. Introduction

Knowledge about distribution of *Dosigicus gigas* (D'Orbigny 1835) in the eastern Pacific has showed that the species has changed its distribution range in the region. In the northern hemisphere jumbo squid has been reported from California to Alaska, USA and from Mexico (Gulf of California) to Costa Rica. In the southern hemisphere the species has been reported and commercially caught from Peru to Chile. The causes of this new distribution are not clear and they have been discussed in the literature (Field et al., 2007, 2008; Alarcón-Muñoz et al., 2008; Keyl et al., 2008; Rodhouse, 2008; Ibañez et al., 2015). The species has increased the scientific attention of its presence and interaction with the components of the ecosystems. Simultaneously, the availability of *D. gigas* has changed the fishing pressure on marine resources traditionally harvested (e.g., shrimps, fishes), representing an alternative fishery (Morales-Bojórquez et al., 2001a).

In Ecuador, the studies of identification and taxonomic classification of squid began during April–June, 1979 on board from R/V Tohalli (Instituto Nacional de Pesca, Ecuador), squid were caught using an automatic jigging system. The species found in the Ecuadorian coasts and insular zone from Galapagos Islands were *D. gigas*, *Sthenoteuthis oualaniensis*, and *Ommastrephes bartramii*. New survey researches were made on board R/V Shinko Maru 2 during November–December, 1992 (Ecuadorian coasts), and during September–November, 1993 (Ecuadorian coasts and Galapagos Islands), these squid were also caught using an automatic jigging system. The data showed that the *D. gigas* is mainly distributed off the southern coasts of Ecuador bordering with Peru. A new research survey was implemented during 1995, using small boats with outboard motors; this fleet is commonly referred to as an artisanal fleet, the fishing gear was hand jigs. This study also identified the zone with highest abundance, which was located bordering with coastal waters of Peru. Recently, biological information was updated in order to propose a new fishery in Ecuador. This new information is provided in this paper and has not been published previously. In recent review about world squid fisheries the presence of *D. gigas* in the Ecuadorian coasts, and the related fishing activity in the region were not documented (Arkhipkin et al., 2015b). For *D. gigas*, in terms of biological and fishery data there is limited information with respect to its presence in Ecuadorian waters. Consequently the species is poorly known in the area, although several inferences and hypotheses about of its population dynamics are assumed to be similar to those observed for the southern stock in Peruvian waters.

Given the relevance of jumbo squid in the eastern Pacific and the incentives and possible profits obtained for harvest of jumbo squid, during 2014 the Ecuador Government decided that *D. gigas* must be a new fishery. Fishery management of jumbo squid is complicated, the availability and abundance of this resource shows high

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instability and variability in biomass, these changes have been reported for *D. gigas* in Mexican, Peruvian, and Chilean waters (Rodhouse et al., 2006; Zúñiga et al., 2008; Tafur et al., 2010; Ibañez et al., 2015). For Ecuadorian waters must have a squid fishery management very different to other sites in the eastern Pacific. Ecuador must manage jumbo squid in its Economic Exclusive Zone (EEZ) and around the Galápagos Islands, this archipelago is a marine protected area (MPA), consequently the fishery management must consider movements of jumbo squid in and out, as well as between MPA and the EEZ. Regulations should protect the stock from intensive fishing effort in MPA, where the species would be especially vulnerable if open access squid fishery is applied (open access is the condition where access to the fishery is unrestricted). The fishery management regulations must consider that the yield for the artisanal and industrial fleet must be optimum to prevent the jumbo squid fishery from overcapitalization. This can occur when the amount of harvesting capacity in a fishery exceeds the amount needed to harvest the desired amount at least cost, such a case was observed in the Gulf of California, Mexico (de la Cruz-González et al., 2011). Hence, in this paper, the first steps to manage the fishery are outlined, as well as the future directions for the jumbo squid fishery in Ecuador are documented.

2. Distribution in ecuadorian waters

Jumbo squid is mainly distributed in the Gulf of Guayaquil, and high densities have been observed from July to October in Santa Elena, although the species is also abundant in the border with Peruvian waters. In the northern region, the abundance of jumbo squid is scarce, although its presence has been observed in Manabí (Bahía de Manta) and Esmeraldas (border with Colombia) (Figure 1). Jumbo squid is also distributed in the Galapagos Islands mainly in Isabela and San Cristóbal Islands; the abundance in this insular zone is unknown (Figure 1).

During 2014 the identified fishing areas were classified into three zones with different availability. According to catch records obtained from the EEZ in Ecuador, the main fishing ground was located in the southern region from Punta Santa Elena to the border with Peru. The second area with low catch records was identified in the central Pacific area of Ecuador, mainly from Punta Santa Elena to Bahía de Manta. While third zone was located in the northern region from Esmeraldas to the border with Colombia, in this area the availability of jumbo squid was lower (Figure 1). This information was obtained from jumbo squid harvested from artisanal fishery of Ecuador, and the industrial fishery of Japan, this fleet has high mobility on long-distance, and consequently it pursues *D. gigas* in Ecuadorian waters. This fleet targets large catches of jumbo squid outside the Peruvian and Ecuadorian EEZ.

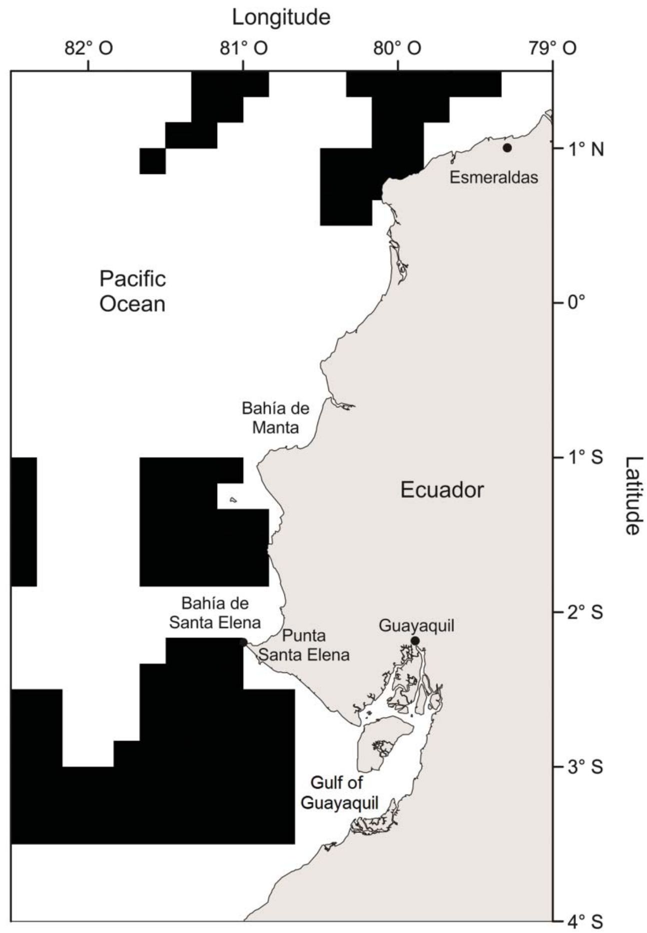

Figure 1. Spatial availability of jumbo squid *Dosidicus gigas* for artisanal and industrial fleets in the Ecuadorian Pacific Ocean. The black areas indicate the fishing zones during 2014.

3. Fishing gear

Although the captures of jumbo squid have been partially monitored the changes in biomass and vulnerability are unknown. From 1995, the artisanal fishery uses hand jigging as fishing gear. Additionally, artisanal fleet captures jumbo squid as bycatch using drift nets (mesh size 5 in.). Arkhipkin et al. (2015b) reported that *Loligo vulgaris* and *L. forbesi* were also caught as bycatch for gill nets and trammel nets. In Ecuador, jumbo squid is commonly used as bait for drifting longlines, these fishing gears targets species as dolphinfish (mahi mahi), billfish (it refers to the fishes of the families Xiphiidae and Istiophoridae), sometimes incidentally sharks are caught.

4. Data collection

For jumbo squid caught in Ecuadorian waters, limited data were collected during 2013 and 2014. For management purposes the availability of biological and fishery data are crucial for managing the fishery. Monitoring program for jumbo squid must be improved in temporal scale and in terms of quantity of data. Effort should be focused on generating and increasing biological data for age determination (statoliths), growth modeling, collection of gonads for histological analysis, and stomachs for food and feed studies (Bazzino et al., 2010), the sample size of variables, such as mantle length (ML), and mantle weight, while at the same time the landings of jumbo squid must be monitored. For this biannual period (2013–2014) the data were collected on a monthly basis; nonetheless for biological and demographic studies the recommended data must be collected on a fortnight basis (Hernández-Herrera et al., 1998; Morales-Bojórquez et al., 2001b). If these data can be obtained, then fishery modeling can be possible, and important management quantities such as vulnerable biomass and biological reference points can be estimated, thus providing a much better understanding of the population dynamics of jumbo squid in Ecuador waters and its interaction with jumbo squid of Peruvian waters.

A brief and non-quantitative description of ML frequency distributions for 2013 and 2014 showed that the individuals caught were not larger than 50 cm ML. In

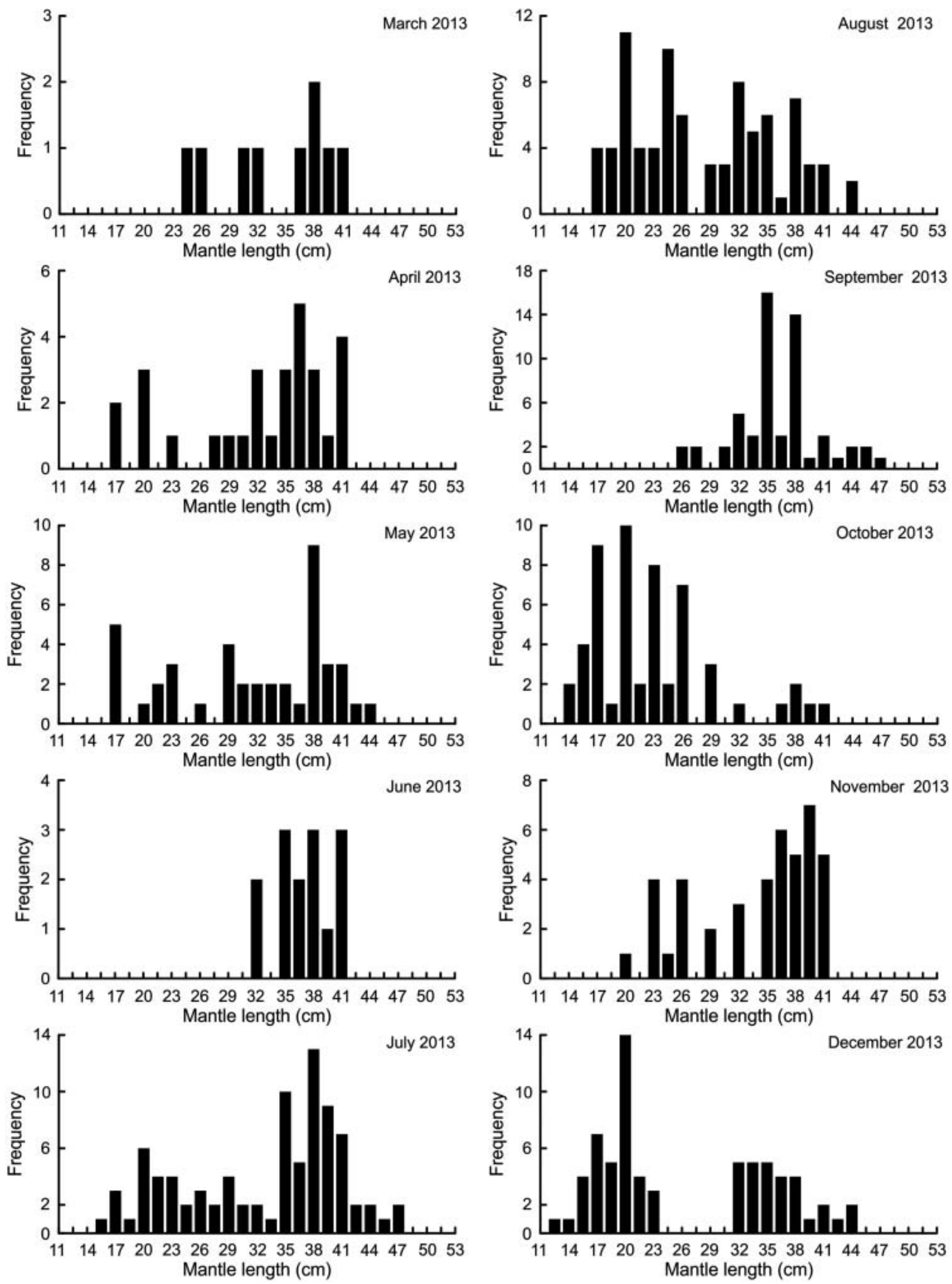

Figure 2. Monthly mantle length frequency distribution for *Dosidicus gigas* in the Ecuadorian Pacific Ocean during 2013.

addition, for both years the presence of small individuals from 14 to 20 cm ML were commons from November to December (Figures 2 and 3). The monthly ML frequency distributions of 2013, showed that there is a group of individuals between 32 and 41 cm ML throughout year, except during October (Figure 2). Small individuals (presumably recruits) were observed during July, August, and October–December, the ML for this group varied from 14 to 23 cm (Figure 2). For 2014, the monthly ML frequency distributions was similar to those described

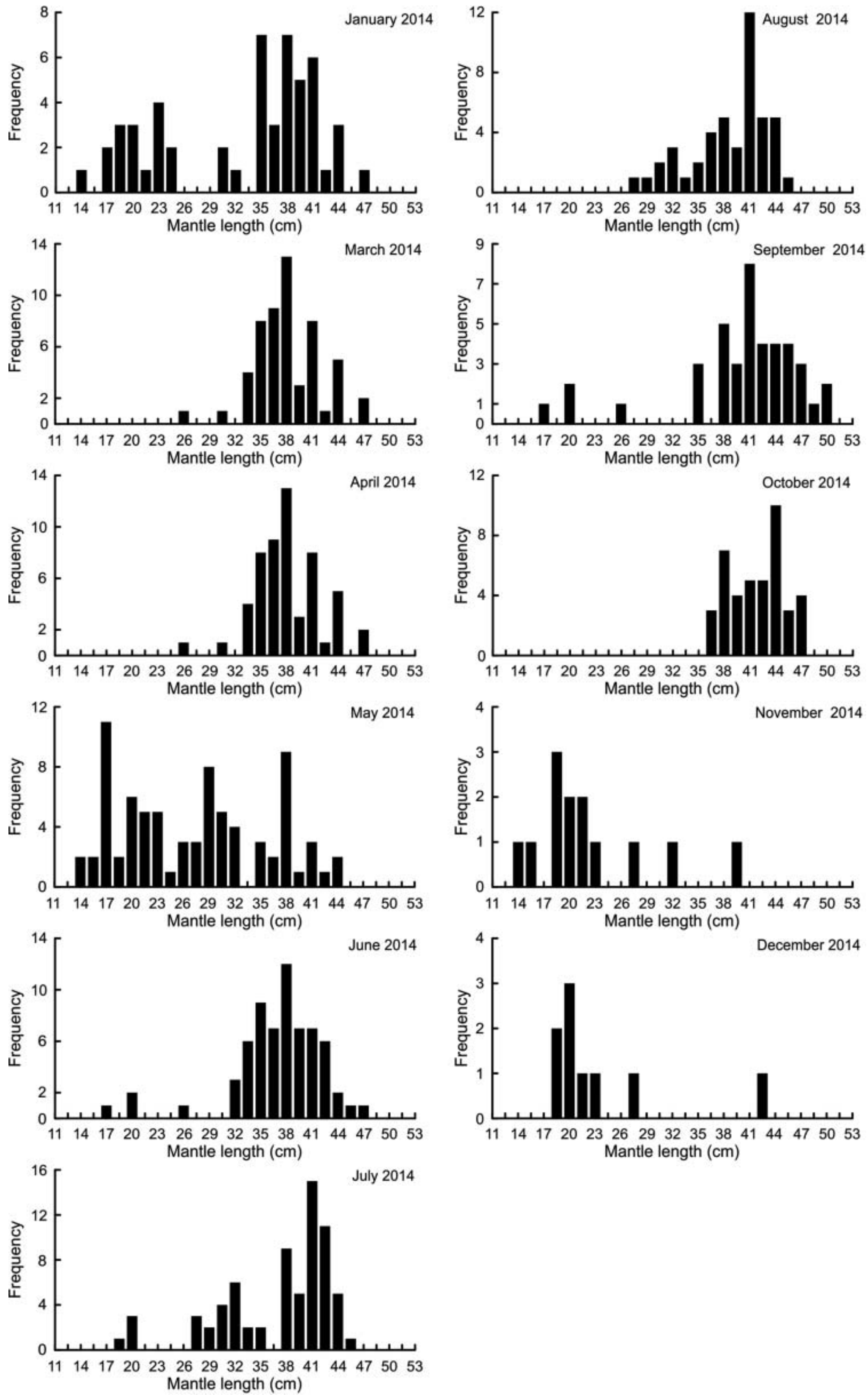

Figure 3. Monthly mantle length frequency distribution for *Dosidicus gigas* in the Ecuadorian Pacific Ocean during 2014.

for 2013, the presence of smaller individuals were recorded for January, May, November, and December. Individuals larger than 32 cm ML were observed throughout year, except during November and December (Figure 3).

Changes in mantle weight (kg) during 2013 showed that the average mantle weight (AMW) was 0.71 kg, and during September the heavier AMW was estimated (1.0 kg) (although individuals with ML heavier, up to 2.0 kg AMW were observed in January, April, and September). AMW diminished during October and December, these values were 0.24 and 0.45 kg, respectively. The mantle weight data (AMW) were non-informative in terms of tendencies and temporal changes (Figure 4A). In contrast, during 2014 increasing monthly AMW was observed from May onward (0.45 kg) to October (1.2 kg). In that year AMW was 0.81 kg, and lower AMW values were observed during November (0.20 kg) and December (0.26 kg) (Figure 4B).

5. Stock assessment

According to Arkhipkin et al. (2015b) the highest concentrations of *D. gigas* in Peru have been recorded bordering with Ecuadorian waters (3°20′S), while lower distribution concentrations have been observed in more southern Peruvian waters. Comparatively, the ML frequency distribution in the Gulf of Guayaquil, Ecuador shows small individuals, they were less than 50 cm ML.

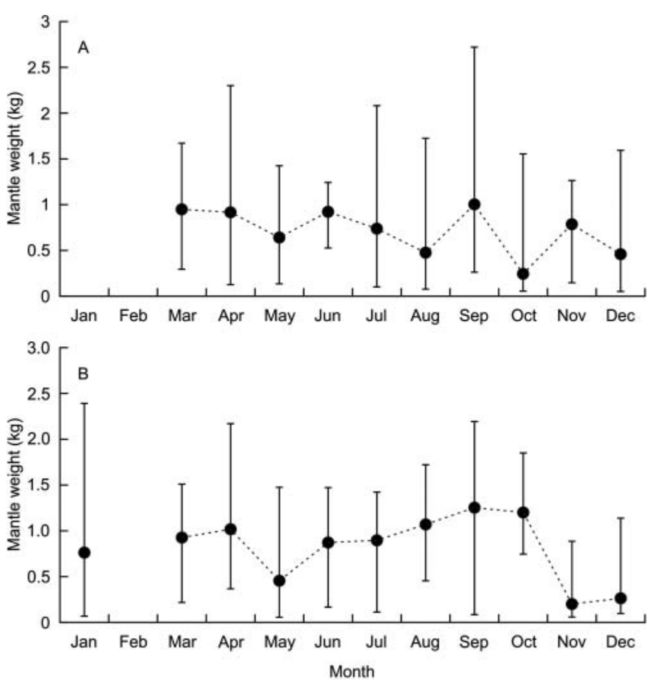

Figure 4. Monthly average mantle weight for *Dosidicus gigas* in the Ecuadorian Pacific Ocean during 2013 (A) and 2014 (B).

In comparison, the squid observed in Peruvian waters were harvested between 30 and 89 cm ML, and during 1996–2000 fishing seasons the average ML varied between 23 and 42 cm ML (Arkhipkin et al., 2015b). In Chilean waters (29°–34° S) the ML frequency distribution has been reported varying from 77 to 103 cm ML (Fernández and Vásquez, 1995), and from 20 to 90 cm ML during July 2003 to February 2004 (Ibañez and Cubillos, 2007; Ibañez et al., 2015). Thus a gradient in ML was observed in the southern hemisphere, the smaller individuals were located in Ecuador, and larger squid in Chile. The numbers of cohorts of *D. gigas* in Ecuadorian waters are unknown. This information is relevant for fishery management, the presence of one single cohort or multiple cohorts in the population is related to reproductive success, strong age-classes, and the total and vulnerable biomass. Reports in Peruvian waters showed that the variability between cohorts changed from 0 to 6 annual cohorts (Keyl et al., 2011). For the Gulf of California, Mexico the number of cohorts has varied from 2000 to 2009 between 1 and 3 cohorts (Velázquez-Abunader et al., 2012). A limited number of cohorts have also been reported for Chilean waters. During research cruises in the winter of 1993 and the spring of 1994 the ML frequency distributions of *D. gigas* in this region showed two cohorts in Chilean jumbo squid (Chong et al., 2005).

Several studies on age and growth *D. gigas* have been published for different regions in the eastern Pacific. Recently, Zepeda-Benitez et al. (2014) reported an apparent pattern difference in growth between specimens in the southern and northern hemispheres. Jumbo squid showed asymptotic growth in the California Current and Gulf of California (Markaida et al., 2004; Mejía-Rebollo et al., 2008; Zepeda-Benitez et al., 2014). In contrast, regions from Costa Rica Dome, Peruvian and Chilean waters showed squid growing according with non-asymptotic patterns (Argüelles et al., 2001; Chen et al., 2011, 2013). The reasons for these differences are unclear, although Nigmatullin et al. (2001) suggested that the difference could be influenced by complicated intraspecies structure of *D. gigas* along the latitudinal gradient in the Eastern Pacific. They suggested the presence of three groups on the basis of ML: one small-sized group with male and female ML varying from 13 to 26 cm and 14 to 34 cm, respectively; a medium-sized group of males and females with ML from 24 to 42 cm and 28 to 60 cm, respectively; and a third group with individuals from 50 to 120 cm ML, where they noted that in this last group the females were larger than males. Arkhipkin et al. (2015a) hypothesized on the environmental influence of Peruvian waters possibly affecting growth pattern and lifespan of jumbo squid. They suggested that the water temperature (warmer water) has influence on early maturation when the squid is small in size, thus influencing its 1-year lifecycle. In contrast, if colder waters are present in the Humboldt Current, then a delayed maturation process occurs and larger sizes are observed in the population, increasing the lifecycle to 1.5- to 2-years.

Given that the population dynamics of jumbo squid in Ecuadorian waters is unknown. There is a hypothesis that attempts to explain the seasonal presence of jumbo squid in Ecuadorian waters. The hypothesis suggests that the temporal changes in availability of the jumbo squid in northern areas (Esmeraldas) to southern zones (Gulf of Guayaquil) is determined by the Humboldt Current System (HCS). The cause being due to incursion of cold waters in the coastal zones of Ecuador thereby promoting changes in spatial and temporal distribution of jumbo squid. Consequently, the population dynamics of jumbo squid in Ecuador should be similar to those reported in northern areas of coastal Peruvian waters (Puerto Pizarro), this region is the most important fishing ground of Peru. The description of ML frequency distributions for *D. gigas* caught in Ecuadorian waters are showed in Figures 2 and 3. Changes in average ML were observed throughout time, and the presence of smaller individuals were evident in the region. In comparison, off of Peruvian waters the ML of jumbo squid harvested were larger than those caught in Ecuador at a latitudes of 3° S (border with Peru), 4° S and 5° S (Figure 5). The presence of jumbo squid in the Ecuadorian coasts is assumed as an incursion of *D. gigas* from Peruvian waters.

This hypothesis is supported by reports in prior studies of changes in distribution of *D. gigas* in the California Current System. Pearcy (2002) reported that during 1997–98 El Niño event, jumbo squid were observed in abundant numbers off the California coast, as well as in coastal waters off of Oregon and Washington states. Including incursions of jumbo squid around Vancouver Island, Canada (Cosgrove, 2005) and Gulf of Alaska, USA (Wing, 2006). Changes in distribution were also reported for the central Gulf of California, Mexico during 1997–1998 El Niño event, the species migrated from Gulf of California to the western coast of the Mexican Pacific, and the jumbo squid that was established in Bahía Magdalena, Baja California Sur had a higher abundance and the landings were greater than usually observed (Morales-Bojórquez et al., 2001a). This extensive expansion of the geographical range of the jumbo squid, has generated two hypotheses that have been widely discussed. The first hypothesis is that jumbo squid temporal distribution variation is due to changes in the California Current System; this hypothesis is supported by climate and oceanographic data associated to changes in the oxygen minimum zone (Stewart et al., 2013). The second is attributable to changes associated with overfishing of top fish predators thereby modifying the species composition in the northern areas of the California Current System (Brodeur et al., 2006; Field et al., 2007; Zeidberg and Robison, 2007; Watters et al., 2008). Consequently, the distribution of jumbo squid throughout its range is characterized by irregular migratory incursions of large numbers of squid into new areas where its presence was uncommon, absent or not reported. In Ecuadorian waters the HCS influences the oceanographic conditions in this area. The general oceanography of the HCS is characterized by a predominant northward flow of surface waters of sub-Antarctic origin and by strong upwelling of cool nutrient-rich subsurface waters of equatorial origin. Occasionally during El Niño events, the nutrient-supply engine of the HCS is interrupted by influx of warm and nutrient-depleted equatorial waters; the northward flow of cool nutrient-rich waters is suppressed and upwelling intensity is often reduced (Marín et al., 2001; Pagès et al., 2001; Simeone et al., 2002). According to artisanal landings of jumbo squid during 2014 in the oceanic waters of Ecuador, including Gulf of Guayaquil, the temporal and spatial availability of jumbo squid during January–April 2014 was low (catch < 1000 t), with only one peak of high availability during July–October (catch > 2000 t), while the months from May–June and November–December the catch varied between >1000 t and < 2000 t (Figure 6).

6. Jumbo squid fishery management

During 2014, the jumbo squid was recognized and authorized as a new fishery in Ecuadorian waters. The management rules were approved by the Ecuadorian Government, assuming a passive management (agreement 080 Ministerio de Agricultura, Ganadería, Pesca y Acuacultura; http://www.viceminis terioap.gob.ec/ subpesca1955-acuerdo-ministerio-no080-

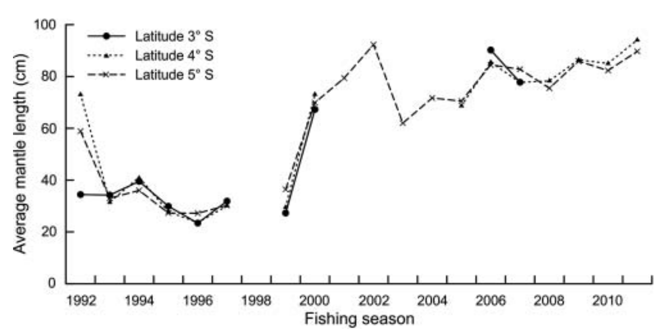

Figure 5. Average mantle length for *Dosidicus gigas* caught in Peruvian waters to fishing seasons from 1992 to 2011. The variability in average mantle length for latitude 3°, 4°, and 5° S are shown. Data source obtained from Arkhipkin et al. (2015b).

pesqueria-de-calamar-gigante.html/acuerdo-ministerio-no080-pesqueria-de-calamar-gigante). The jumbo squid was caught as bycatch by drift gillnets and used as bait for the billfish fishery; the new management rules in the agreement 080 recommends that jumbo squid must be used for human consumption. The fishing effort is controlled by just allowing 36 fishing licenses distributed in 30 for artisanal fleet, and 6 for commercial fishing vessels, each vessel must have an observer on board for collection of biological and fishery data. Thus, the fishery of jumbo squid has begun in Ecuador but data at present is limited from past or recent commercial fishery landings. The data gap includes information regarding catch records, or even basic biological data such as: maturity stage, ML, and mantle weight. Thus, the jumbo squid fishery in Ecuador is based on passive management. In summary, this means that the jumbo squid fishery in Ecuador is presently managed without a specific management plan whereby all aspects of the management process are not detailed (Pereira and Hansen, 2003; Williams and Blood, 2003).

Passive management can be work when uncertainties are small (Hilborn and Walters, 1992). The jumbo squid fishery must be managed taking into account at least under two different geographic locations: (a) the coasts of the Ecuadorian Pacific, and (b) the MPA around the Galapagos Islands, where organizations of artisanal fishermen are demanding licenses for this new squid fishery. Studies about estimates of total and vulnerable biomass are relevant because they allow for understanding of changes in production of the stock and its maintenance in the population (Lawrence and Bazhin, 1998), this knowledge will improve fishery management in the region. The jumbo squid fishery management could be complicated considering that the populations of jumbo squid in the Ecuadorian Pacific could show a metapopulation structure (the stock is shared with Peru), rapid individual growth, high mortality, migration (the conservation and management of transboundary stock) and variable recruitment. Thus, knowledge about the population dynamics of jumbo squid and its basic biology is necessary, otherwise there is a high risk of unsustainability of this fishery activity in Ecuador.

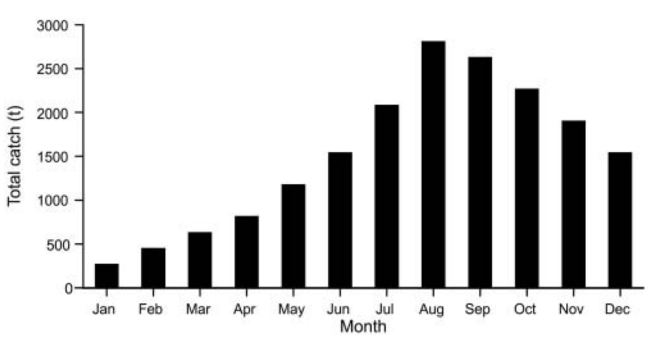

Figure 6. Monthly landing data of *Dosidicus gigas* caught in Ecuadorian waters during fishing season, 2014.

This fishery began with limited biological information and fishery data, using conservative management rules based on restrictions in fishing effort as management tactic; this can be acceptable in this initial phase of the fishery. For Ecuadorian waters the jumbo squid fishery needs an active management. This provides additional safety since it uses alternative models that are consistent with historical experience to identify a policy that offers some balance between probing for information versus caution about losses in short-term yield and long-term overfishing (Hilborn and Walters, 1992). The change and development from passive to active management must consider and do the following: (a) identify alternative stock response hypotheses; (b) develop models for future learning to test hypotheses; (c) Identify alternative policy options; (d) Assess what further steps are necessary by estimating the expected value of perfect information; (e) formalize comparisons of options using tools of statistical decision analysis; (f) develop performance criteria for comparing options (Hilborn and Walters, 1992); (g) identify adaptive management strategies (Walters, 1986; 1998); and (h) a clear and complete management procedure with well-defined goals or objectives for the jumbo squid fishery. The process should involve all Ecuadorian stakeholders where they must evaluate the probability of the consequences of various management actions, including no action. The information will be useful to apply an active management in the Ecuadorian Pacific, because the species must be managed in different way to those used in Peruvian waters because the jumbo squid fishery has begun without a fishery management plan, since it is based on passive management and limited fishery data.

7. Management strategy and biomass estimates

In Chile, a more conservative management policy was adopted, here the jumbo squid fishery management is based on a modifiable total allowable catch that is estimated from landings from the last 10 years (Arkhipkin et al., 2015b). Unfortunately, these landings were based on numbers caught not on biomass estimates for *D. gigas*. Hence, in this country actual biomass is unknown and statistical methods are not reported. Nevertheless, in the short-term this management rule may be useful, although in the long-term it is not generally recommended. For a sustainable management policy and to diminish risk associated to the variability, instability and change in the availability and abundance of this species better data are needed. This will allow a better management strategy, and for this purpose the biomass estimates of jumbo squid are fundamental.

In Peruvian waters the jumbo squid fishery has been managed by quotas from 1991. The biomass estimates have been supported by catch-per-unit effort (CPUE) data used in production models (Arkhipkin et al., 2015b). Biomass estimates based on acoustic methods have been used from 1999, and recently a Schaefer biomass dynamic model has been implemented, this method was found to be useful to estimate total biomass, as well as providing a reference point for maximum sustainable yield and optimal effort (Arkhipkin et al., 2015b). Given that the jumbo squid fishery is managed through annual quotas by the Peruvian government, a scientific observers program has been implemented aboard fishing vessels to monitor fishing activities and collect scientific data of jumbo squid; additionally a satellite tracking system for surveillance and control is mandatory for industrial fleet.

Fishery management of jumbo squid necessarily requires biomass estimates (total and vulnerable). Squid fisheries such as *Illex argentinus* and *D. gigas* have a management strategy based on constant proportional escapement, it is defined as the number of spawners alive at the end of the fishing season as a proportion of those that would have lived had there been no fishing (Hernández-Herrera et al., 1998; Morales-Bojórquez et al., 2001b, 2001c). For jumbo squid from Mexican Pacific (including Gulf of California) the management strategy is based on proportional escapement (40%), this was adopted from Argentine shortfin (*Illex argentinus*) fishery from Falkland Island (Nevárez-Martínez and Morales-Bojórquez, 1997). For jumbo squid fishery from the Gulf of California the management strategy has been successfully implemented, this target escapement is useful as a tool for the control of the fishing effort. In Ecuador the jumbo squid fishery began based on 36 fishing licenses, apparently this is a very low fishing pressure compared to Mexico. In Mexico the fishing effort during 1996–1997 fishing season reached 2000 licenses for artisanal fleet and 98 licenses for commercial fishing vessels (shrimp trawlers of various characteristics adapted with hand jigs to the fishing of *D. gigas*) (Morales-Bojórquez et al., 2001a). An advantage of constant proportional escapement is that at least two alternative management strategies can be implemented: (1) limits the number of licenses and determines allowable levels of fishing effort prior to the start the fishing season; or (2) limits the length of the fishing season, this is accomplished by monitoring the stock during the fishing season, and determining whether the fishing season needs to be shortened (Beddington et al., 1990; Rosenberg et al., 1990; Basson and Beddington, 1993; Basson et al., 1996). The target of proportional escapement allows for avoiding recruitment overfishing, it is limits the fishery in such a manner that exploitation of fishery resource does not exceed an intensive level that compensatory stock responses are insufficient to maintain a normal pattern of recruitment (Hilborn and Walters 1992). Consequently, the proportional escapement is directly related to the total biomass of the squid, the adult squid (spawners) are very important for fishery management, and fishing control management rules must avoid fishing pressure that reduces the spawning biomass produced by a year class over its lifetime below the spawning biomass of its parents.

Although the statistical methods applied to biomass estimates of jumbo squid were initially based on commercial CPUE and depletion models (Morales-Bojórquez et al., 2001a, b; Morales-Bojórquez y Nevárez-Martínez, 2002). New proposals have been developed according to biology and population dynamics of jumbo squid (e.g., rapid individual growth, variability in the number of cohorts by fishing season, sudden changes in spatial distribution). Thus, several specific modelling tools for stock assessment of jumbo squid in Ecuadorian waters can be applied; brief summaries of these modelling methods are described as follows.

7.1. *Single-cohort biomass model*

For the jumbo squid fishery in the Gulf of California, Mexico, the biomass estimated supported a single-cohort biomass model (approx. 190,000 t), and the control fishing effort was based on proportional escapement applied to regulate the number of licenses allowed for two fleets (artisanal and vessel fleets) (Hernández-Herrera et al., 1998).

7.2. *Biomass estimated from multi-fleet model*

Morales-Bojórquez et al. (2001b) reported estimates of biomass (approx. 82,000 t) of *D. gigas* using a multi-fleet model; this included indices of relative abundance from three fleets in the Gulf of California (two artisanal fleets and one vessel fleet).

7.3. *Depletion models*

These statistical approaches (Leslie-De Lury models) are based on commercial CPUE data, the main assumption is that the CPUE is proportional to the abundance of jumbo squid. They have been shown to be useful for estimating recruitment of *D. gigas* (Morales-Bojórquez and Nevárez-Martínez, 2002). Several estimates of catchability and recruitment have been computed, including an improved estimation of catchability based on two-component-mixture probability distribution (Morales-Bojórquez et al., 2008).

7.4. Survey research

Biomass of jumbo squid has also been estimated using survey research data and by using estimators based on stratified random sampling, and swept area by strata. The first method yielded an estimate of 85,513 t, while the second method indicated yields of 118,170 t (Nevárez-Martínez et al., 2000). Biomass estimates can also be obtained from acoustic methods (Arkhipkin et al., 2015b).

7.5. Mark-recapture data

Morales-Bojórquez et al. (2012) based on mark-recapture data of jumbo squid in the Gulf of California estimated a biomass of 20.2 million squid during October 2001, and 132.6 million of individuals during April 2002. This method is completely dependent of the number of recaptures and its implementation is not easy. The use of mark-recapture data can be an alternative to other statistical procedures for estimating abundance of *D. gigas* and can be used when CPUE data applied to depletion models or estimates from survey research are not available.

7.6. Catch-at-length analysis

Recently, for jumbo squid from the Gulf of California, annual changes in abundance were also estimated from catch-at-length models, analyzing the catch expressed in number of individuals. Nevárez-Martínez et al. (2006, 2010) analyzed these data using a model with assumptions of equilibrium. In contrast, Morales-Bojórquez and Nevárez-Martínez (2010) also analyzing these data assuming non-equilibrium, and using a model that includes stochastic individual growth. In both cases, a time series of outputs such as total abundance, vulnerable biomass, recruitment, fishing mortality, and harvest rate were computed.

7.7. Biomass dynamic models

These models share most data requirements and assumptions with production models. Unlike production models they do not assume stocks are in equilibrium. They are an attempt to acknowledge the time lags occurring between removals of biomass by fishing and growth in biomass due to the intrinsic productivity of squid stock. They try to explain changes in total abundance through indices of relative abundance (e.g., CPUE, acoustic index, survey research) as a function of the removal of biomass by fishing, the biomass in the previous time period and the growth in biomass. The growth in biomass is commonly expressed as a function of the biomass in the previous time period and of a few parameters describing the productivity of the stock (Hilborn and Walters, 1992; Haddon, 2001). For Peruvian waters the Schaefer dynamic model was used, and important management quantities such as carrying capacity (3×10^6 t), intrinsic growing rate (1.7), maximum sustainable yield (1.3×10^6 t), optimal effort (87×10^3 fishing days), and average catchability (1×10^{-5}) were estimated (Arkhipkin et al., 2015b).

Because of the wide fluctuations reported in abundance and availability of *D. gigas* in the California and Humboldt Currents Systems (Morales-Bojórquez et al., 2001a; Arkhipkin et al., 2015b), and its high natural mortality associated to its recent spatial distribution, this kind of fishery is classified as highly unstable (Rodhouse et al. 2006; Morales-Bojórquez et al., 2001a). This is reflected as changes in the recruitment to the fishery, as well as in the variability of the catch (Nevárez-Martínez et al., 2006). The success of this new squid fishery in Ecuador depends on the choice of management strategies based on an adequate knowledge of the population dynamics of the species, and its changes in biomass and availability for the fishing fleets in Ecuadorian waters. Consequently, the estimates of recruitment in the current fishing season are the reference points in the management strategy. Hence, the estimates of abundance and recruitment of jumbo squid in Ecuadorian waters can be based on experiences of previous specific methods applied to *D. gigas*. Additionally, the use of several stock assessment methods are necessary, because alternative biomass models must be analyzed, while taking into account the uncertainty in abundance estimates, different methodological approaches and data. This information can improve the advice given to stakeholders and fishery managers.

Jumbo squid management implementation in the EEZ of Ecuador could be different to those implemented in the insular area of Galapagos Islands. The management plan for conservation and sustainable use of the Galapagos Marine Reserve (http://www.unesco-ioc-marinesp.be/uploads/documentenbank/0fced0e8a056110335ca46e8038a84ae.pdf) recognizes the fishing activity of almost 600 fishermen organized in cooperatives, the fishing effort includes around 270 crafts including canoes, boats and fiberglass boats. Several types of fishing gear are used in the Galapagos Islands, and they have been classified into four types: (a) nets, (b) diving, (c) collection, and (d) lines and hooks. In addition, the artisanal fishing activities in the archipelago has regulations and specific laws of surveillance and control (e.g., permitted and prohibited fishing methods, requirements to be an artisan fishermen, licensing and permits for artisan fishing, transportation and commerce).

Fortunately, the management plan for conservation and sustainable use of the Galapagos Marine Reserve has been successfully functional in the context that it provides an excellent example of collaboration among community members; these include the Ecuadorian government, fishermen, environmental groups and scientists. The framework of the current management plan avoids conflicts and negative consequences of mismanagement, moreover it gives support to co-management approach excluding weak enforcement and ineffective institutional arrangement based on top-down and centralized control, increasing the robustness of management decisions and changing the traditional command control authority (Holling and Meffe, 1995; Chuenpagdee and Jentoft, 2007; Gibbs, 2008). Nonetheless, in the years to come the jumbo squid fishery in the Galapagos Islands must have a clear fishery management objective (e.g., maximum sustainable yield, maximum economic yield, or maximum social yield), and the management strategy could be different in this region, possibly based on small quotas. Whilst that the regulations of jumbo squid in the costal zones of Ecuador could be based on proportional escapement similar to that of Mexico (Morales-Bojórquez et al., 2001a). This difference in management is suggested because the insular area is represented by artisanal fishery, and the perspective of maximizing employment and social equity would be an attractive policy in the region. Nevertheless, overcapitalization of this fishery should be avoided (de la Cruz-González et al., 2011). In this context the maximum economic yield and management strategy based on quotas could be optimal (Hilborn, 2007). These decisions are crucial and represent a challenge for stakeholders and fisheries authorities of the Ecuador.

8. Future directions

The Permanent Commission of the South Pacific (CPPS) is the regional maritime agency that coordinates marine policies of its member countries: Chile, Colombia, Ecuador and Peru, promoting the conservation and sustainable use of natural resources and the environment for the benefit of their peoples (http://cpps-int.org). The CPPS holds periodical meetings since transboundary species is a recurrent topic, mainly in fisheries (e.g., hake, Chilean jack mackerel). Jumbo squid is a marine resource that has and is crossing Peruvian and Ecuadorian waters, and joint biomass estimates could be necessary, the most important fishing ground of jumbo squid is in the border with Peru. If the species is harvested without knowledge of its abundance, ML and age structure, reproductive cycle and basic demography, then the resource could be mismanaged and overexploited in Ecuador. These have potentially negative repercussions that could also be observed in Peru causing overfishing, this is observed when the harvest rate produces a loss of the stock that is greater than the biomass gained due to growth, it also is defined as harvesting too many squid before they are matured, so that the replenishing potential is restricted (Hilborn and Hilborn, 2012); or recruitment overfishing (harvest pressure characterized by a greatly reduced spawning stock) (Myers et al., 1994). Additionally, the squid fishery in Ecuador needs to avoid overcapitalization (Clark, 1977). The jumbo squid has rapid response to environmental conditions (Markaida and Sosa-Nishisaki, 2001; Markaida, 2006), particularly to El Niño events where changes in the Humboldt Current System affects distribution ranges of the jumbo squid. Thus affecting abundance, temporal residence, and all these may have impacts on the reproductive patterns of *D. gigas* (Boyle and Rodhouse, 2005; Markaida, 2006; Tafur et al., 2010).

According to the previous background, the jumbo squid fishery in Ecuador must be managed using a fishery management plan. The advantages of using this approach is that according to Cochrane (2002) provides a formal framework between a fisheries authorities and interested parties. In this arrangement partners in the fishery and their respective roles are identified, it includes details with agreed objectives for the fishery and specifies the management rules which apply and provides other details about the fishery which are relevant to the task of managing the fishery. Therefore, we suggest that the jumbo squid fishery could begin with a joint management or co-management improving the governance (Carlson and Berkes, 2005; Thompson, 2008; Berkes, 2009). This approach can be used in the marine and coastal zone from Ecuador, because in Galapagos Islands the management plan for conservation and sustainable use (including fishing activity) of this archipelago is implemented; in contrast the management rules for the jumbo squid industrial fishery of Ecuador has not been defined.

Finally, the jumbo squid fishery began in Ecuador during 2014, and limited data have been collected, they had been initially focused on measurements of total weight, ML and landing records, including basic biological data such as visual determination of maturity stages, stomach contents and sex ratio. Additionally, stock assessment approaches and sampling design must be defined in order to collect specific data. Estimates of biomass, relative abundance, age and growth in the region, harvest rate and fishing mortality, the recruitment period and the number of cohorts in Ecuadorian waters are necessary to improve fishery management. A collaboration among Instituto Nacional de Pesca (Ecuador) and

Ecuadorian Universities, non-governmental organizations, fishery national governmental agencies (e.g., IMARPE, Peru; INAPESCA, Mexico; IFOP, Chile) are crucial to share experiences, academic knowledge and costs of regional research in attaining as sustainable fishery of jumbo squid.

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