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Description of food sources used by jumbo squid *Dosidicus gigas* (D'Orbigny, 1835) in Ecuadorian waters during 2014

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A B S T R A C T

Jumbo squid, *Dosidicus gigas*, is a species endemic to the eastern Pacific. Its distribution ranges from the Gulf of Alaska to Chile. These squids are important components of the ecosystem, as they are prey to sharks, billfishes, and marine mammals, and active predators of myctophid fishes, other squids and crustaceans. In Ecuador, *D. gigas* is a potential resource for industrial and artisanal fisheries, but they are often by-catch in artisanal fisheries that use trammel net and gill-netting methods. Due to the importance of *D. gigas* as prey and predator, we performed this exploratory research to describe the composition of their diet and identify their most important prey. A total of 167 squids were sampled in Santa Rosa, Salinas, Ecuador from May to December 2014. Squids ranged between 17.5 and 52 cm ML, and our results showed an average size of 40 cm ML. According to the %IRI the diet was mainly composed of fish and squids. Two myctophids, *Lampanyctus* sp. and *Myctophum* sp., were important food resources. Our results showed that there was no difference between food resources, and the sex, size, and maturity of squids in our sample. Cannibalism also occurs on small to large *D. gigas*, and is influenced by availability of other prey in the surface waters during fishing activity.

1. Introduction

The jumbo squid *Dosidicus gigas* is an abundant and widely distributed species in the eastern Pacific ranging from the Gulf of Alaska to southern Chile (Nigmatullin et al., 2001; Field et al., 2007; Keyl et al., 2008). It inhabits the water column from 0 m to more than 1500 m (Nigmatullin et al., 2001). In the northern hemisphere, it is known to migrate from the south to the north (Gilly et al., 2006; Field et al., 2013) and in the southern hemisphere the migration occurs in the opposite direction (from north to south) (Keyl et al., 2008). These migratory movements have been related to the location of feeding areas, abundance of prey resources, and the change in the oxygen minimum layer (Seibel, 2013).

D. gigas is an important predator in the ecosystem of the Pacific Ocean, as they prey on mesopelagic fish, cephalopods and crustaceans (Markaida and Sosa-Nishizaki, 2003; Markaida, 2006; Markaida et al., 2008; Rosas-Luis et al., 2011; Alegre et al., 2014). Their feeding activity is characterized by a voracious form of predation, ingesting a great variety of prey and inorganic materials (Markaida and Sosa-Nishizaki, 2003). These interactions with a large number of predators and prey, makes *D. gigas* a key species in the transfer of energy and biomass from the basic levels to top predators (Rosas-Luis et al., 2008). The diet and feeding habits of *D. gigas* have been described in the Gulf of California by Markaida et al. (2008), in the California Current by Field et al. (2007), in Peru by Rosas-Luis et al. (2011) and Alegre et al. (2014), and in Chile by Ulloa et al. (2006). These descriptions show a diet composed of fish, with myctophids being the most important prey, followed by pelagic crustaceans, cephalopods (other *Teuthida* species), pelagic gastropods (Pteropods), and cannibalism (Ibáñez and Keyl, 2010). All of these studies concluded that *D. gigas* exhibits a generalist feeding behaviour and is able to feed on the most abundant prey in the ecosystem.

This squid is preyed upon by many fish, marine mammals and birds in the northern hemisphere (Nigmatullin et al., 2001; Galván-Magaña et al., 2013), and there are reports of some additional predators, such as sharks, that prey on *D. gigas* in the Ecuadorian Pacific (Polo-Silva et al., 2007, 2009; Estupiñan-Montaño et al., 2009). Due to the lack of information on the biological aspects of *D. gigas* in the Ecuadorian waters, and their importance as prey, we examined its diet for eight months during 2014. We gathered data on the size, sex ratio and maturity stage of specimens, to improve our knowledge of this species feeding ecology in Ecuador.

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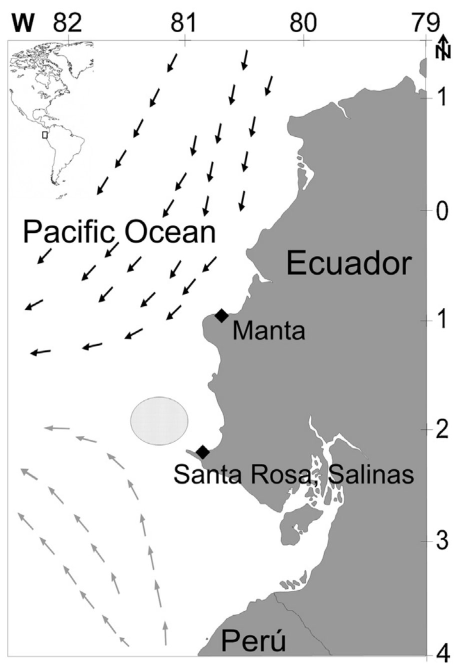

Fig. 1. Fishing port of Santa Rosa in Ecuador where samples were taken. The circle shows the main fishing area of the artisanal fleet where *Dosidicus gigas* was caught. Grey arrows represent the flux of the Humboldt Current, and dark arrows represent the flux of the Equatorial Counter Current (Fiedler and Talley, 2006).

2. Materials and methods

2.1. Sample collection

D. gigas stomach samples were collected from the fishing port of Santa Rosa, Salinas, Ecuador from May to December 2014 (Fig. 1), from the individuals captured by local fishermen. The artisanal fleet fishes from night time to dawn around 50 nautical miles from the coast, and *D. gigas* were caught incidentally in the trammel nets. In the long line fisheries, squids are collected for commercial purposes by fishermen when their usual commercial species, *Thunnus*, *Katsuwonus*, shark or billfishes, are not available. Squids were put on ice after capture.

2.2. Measurements

When squid arrived at the fisheries port, we selected squids with intact stomachs and measured the mantle length (ML) to the nearest millimeter. We weighed the complete body to the nearest gram (body weight DW), determined the sex and classified the maturity stage as immature, maturing, or mature, according to Lipinski and Underhill (1995). The stomach was weighed and the visual fullness index assigned: 0 (empty), 1 (few remains), 2 (half–full), 3 (almost full), 4 (completely full) (Breiby and Jobling, 1985). Stomachs were transported on ice to the Marine Resources Laboratory at the Universidad Laica Eloy Alfaro de Manabí, Manta, Ecuador.

2.3. Sample size sufficiency

To evaluate the sample we generated a randomised cumulative prey curve using the vegan package (Oksanen et al., 2010) in R statistical software (R Development Core Team, 2010). We used the lowest taxonomic level of each prey and excluded prey items that occurred in only one stomach. When the curve approached the asymptote, the number of samples was considered sufficient to describe the diet (Hurtubia, 1973). When the asymptote was not evident we fitted a straight line to the last 4 points and compared the slope of the line with a line of slope zero, with the asymptote indicated when the lines did not differ significantly (Bizzarro et al., 2007).

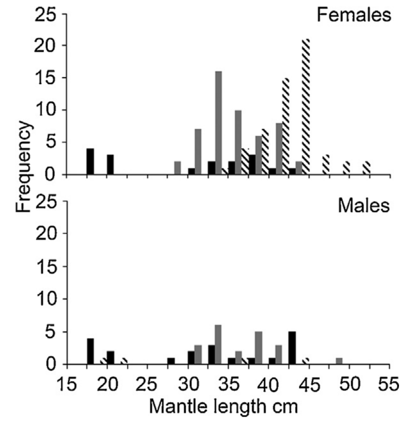

Fig. 2. Frequency distribution of females and males by mantle length grouped into 5 cm intervals of *Dosidicus gigas*. Black bars represent immature individuals, gray bars are maturing, and hatched bars are mature.

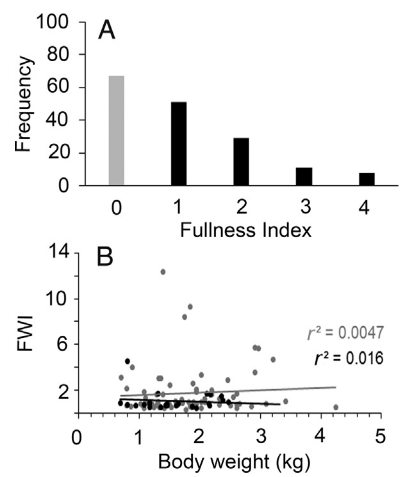

Fig. 3. Stomach fullness of *Dosidicus gigas* from Ecuador in 2014. (A) Frequency distribution of stomach fullness index, grey bars represent the empty stomachs and dark bars represents stomachs with food remains. (B) Relationship between fullness weight index (FWI) and *Dosidicus gigas* body weight. Black circles represent males and grey represent females.

2.4. Diet analysis

Stomach content weight (SCW) and fullness weight index (FWI = (SCW × 100)/(BW–SCW) (Rasero et al., 1996) were calculated for all squids with food remains. The correlation between FWI and BW was also tested.

Stomach contents were separated and identified to the lowest possible taxonomic level under a dissecting microscope (60–120 magnification), and the most conspicuous prey items were weighed to the nearest 0.01 g. Fish sagittal otoliths were identified consulting García-Godos (2001), cephalopod beaks were identified using of Clarke (1962), Iverson and Pinkas (1971), Wolff (1982, 1984), and Clarke (1986). Crustaceans were identified based on their exoskeleton and by referring to Sars (1899).

Frequency of occurrence, and numeric and gravimetric methods were used to quantify the diet. Frequency of occurrence (%FO) was calculated as the percentage of squid that fed on a certain prey. The number of individuals of a certain prey relative to the total number