

10th MEETING OF THE SCIENTIFIC COMMITTEE

26 to 30 September 2022, Seoul, Korea

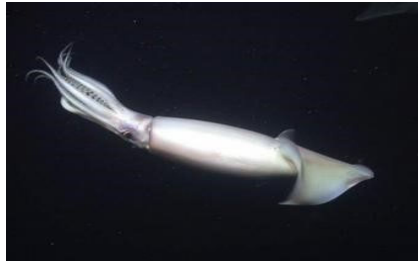
SC10-SQ13_rev3

Proposed squid species profile

Squid Working Group

Code: GIS

Scientific name: *Dosidicus gigas*



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Sonja Heinrich, 2004

Taxonomy

Phylum	Mollusca
Class	Cephalopoda
Order	Oegopsida
Family	Ommastrephidae
Genus and species	<i>Dosidicus gigas</i> (d'Orbigny, 1835)
Scientific synonyms	None
Common names	Humboldt squid, jumbo flying squid, jibia, calamar rojo, calamar gigante, pota.
Molecular (DNA or biochemical) bar coding	Recent phylogenetic studies of mitochondrial DNA have confirmed that the jumbo flying squid <i>Dosidicus gigas</i> belongs to the Ommastrephinae subfamily (Pardo-Gandarillas et al., 2018a). Species identification through DNA barcodes available in the Barcode of Life Data System (BOLD), at: http://www.boldsystems.org https://www.boldsystems.org/index.php/Public_SearchTerms?query=%22Dosidicus%20gigas%22[tax] , see in Public Data to access DNA sequences



Species characteristics

Global distribution and depth range

Dosidicus gigas is a common species to the Eastern Pacific, ranging from Alaska to Southern Chile (58°N – 45°S), and to 140°W at the equator (Figure 1) (Nesis 1983, Nigmatullin et al., 2001, Roper, Nigmatullin and Jereb 2010, Arkhipkin et al., 2015, Ibáñez et al., 2015). Its range is stretched meridionally and is semi-oceanic (Nigmatullin et al., 2001).

Adult squid undergo diel vertical migration with a night lift to the 0-200 m water layer, plunging in the daytime to 800-1000 m and deeper (Yatsu et al., 1999; Nigmatullin et al., 2001, Gilly et al., 2006, Bazino et al., 2010, Sakai et al., 2017, Csirke et al., 2018).

Distribution within South Pacific area

Straddling stocks occur off the coasts of Peru, Chile and Ecuador. Proportions inside and outside Exclusive Economic Zones (EEZs) are unknown but trends have shown an increase of abundance in the high seas when coastal numbers are high. Large aggregations have been found in the zone of divergence of the Peruvian Oceanic current (17-22° S) (Nigmatullin 2002). *Dosidicus gigas* is commonly found along the entire Peruvian coast, occupying areas that can be located between 10 and more than 500 nautical miles (nm) away from the coast (Csirke et al., 2015), however large concentration occurs along the coast of northern Peru (Taipi et al., 2001). Off Chile, the *D. gigas* fishery is carried out in an extensive area from 32°30'S to 40°S and from the coast to 84°W (Fernandez & Vasquez 1995, Cubillos et al., 2004, Ibáñez et al., 2015).

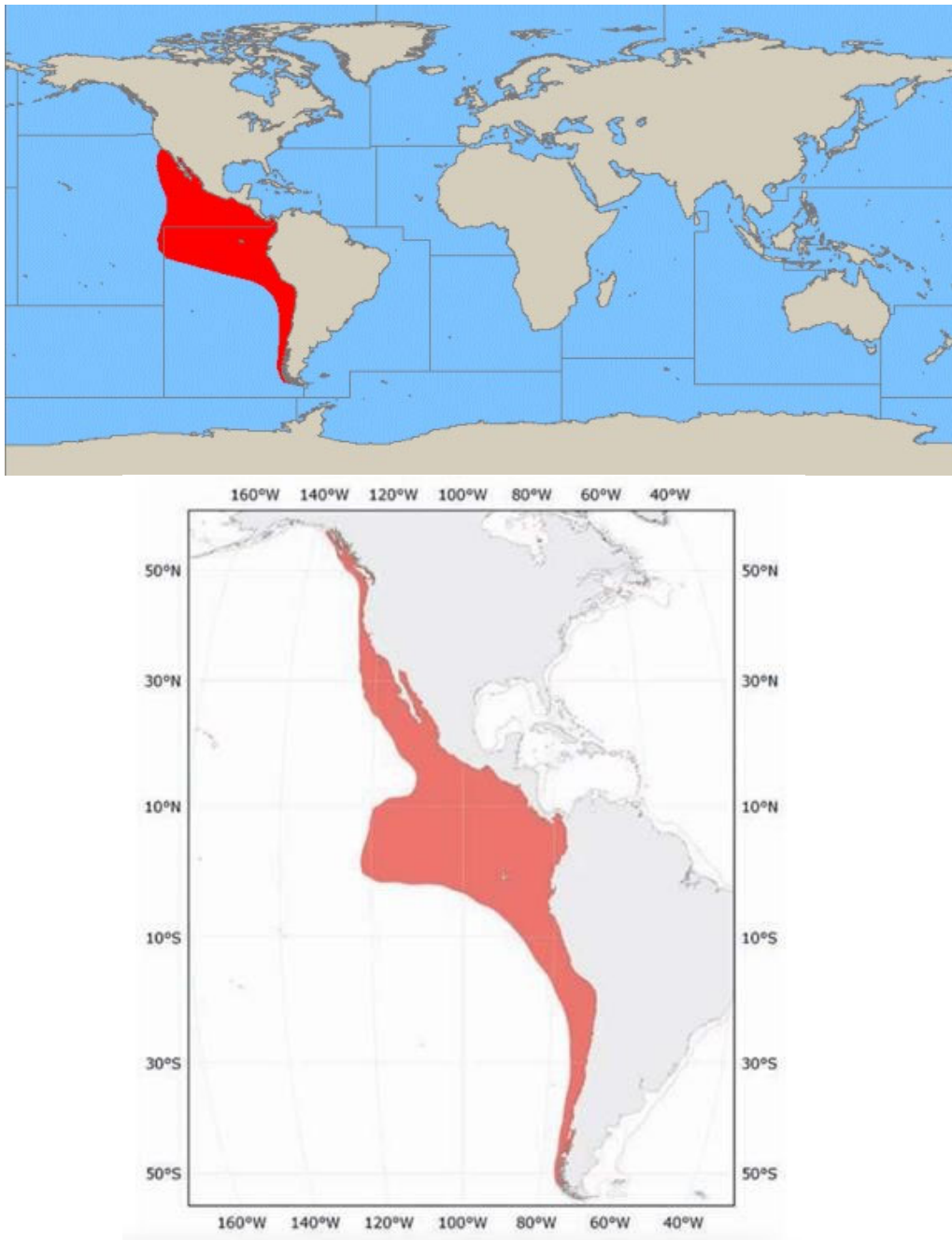


Figure 1. Known distribution of *D. gigas*. Source: Roper, Nigmatullin and Jereb (2010).

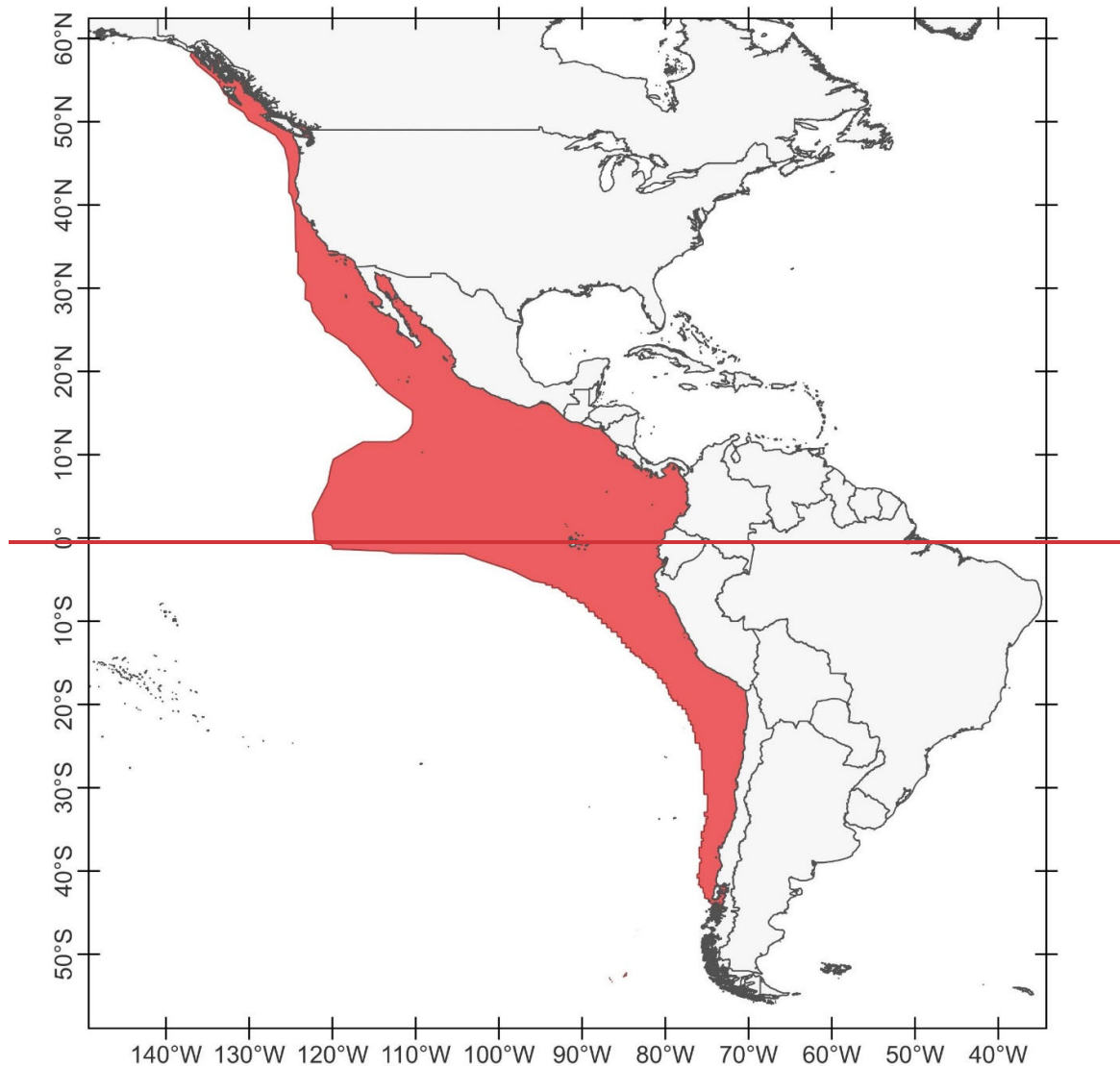


Figure 1. Known distribution of *D. gigas* along the Eastern Pacific (based on Nigmatullin et al., 2001, Roper, Nigmatullin and Jereb 2010, Ibáñez et al., 2015).

General habitat and behaviour

Dosidicus gigas is a pelagic species inhabiting the areas offshore of the continental shelves, from the surfaces to depths of at least 1200 m (Nigmatullin et al., 2001). It can aggregate into schools that vary during the ontogeny (juvenile schools, 20-40 individuals; subadults schools, 20-200 individuals; adult schools, 2-5 to 10-12 individuals).

Population units and intraspecific groups

Based on biogeographic studies, some authors proposed the existence of at least two stocks or population units of jumbo flying squid throughout its range in the Eastern Pacific Ocean, one in the northern hemisphere and another in the southern hemisphere (Wormuth 1976, 1998, Nesis



1983, Clarke & Paliza 2000). This was also reported based on genetic studies (RADPs and mtDNA markers) confirming that jumbo flying squid off Mexico (NE Pacific) and off Peru and Chile (SE Pacific) belong to different populations, separated long enough to accumulate significant genetic differences (Sandoval-Castellanos et al., 2007, 2009, 2010, Staaf et al., 2010). All the studies carried out to date (nuclear and mtDNA) are consistent in finding a low general genetic diversity, which suggests a demographic expansion between the last glacial period and the current interglacial period (Sandoval-Castellanos et al., 2010, Ibáñez et al., 2011; Ibáñez & Poulin 2014; Sánchez et al., 2016, 2020). Low levels of genetic diversity in marine animals with large population sizes are unusual and generally occur in those that have undergone drastic reductions in population size, bottlenecks, or founding events and are in processes of demographic expansion (Haye et al., 2014, Oyarzún et al., 2016; Pardo-Gandarillas et al., 2018a, b, c). In this sense, the historical variation of primary productivity along the Humboldt Current System would have caused historical fluctuations in the population size of *D. gigas* and in its range of distribution (Ibáñez et al., 2011; Ibáñez & Poulin 2014). Consequently, today large squid populations are the result of relatively recent population expansions, as their genetic diversity has not yet reached new levels of equilibrium (Ibáñez et al., 2011; Ibáñez & Poulin 2014).

On the other hand, Nigmatullin et al. (2001) identified and described three intraspecific groups present in both the northern (Bazino et al., 2007, Markaida 2006) and southern hemispheres (Arguelles et al., 2001, 2008, 2017, 2018, Arguelles & Tafur 2010, Arguelles & Taïpe 2018, Liu et al. 2013, 2013a, Li et al., 2016, 2017, Arkhipkin et al., 2015, Csirke et al., 2015), distinguishable by their maximum size and by the size at which males and females reach sexual maturity, with somewhat different ranges and environmental preferences, which partially overlap. Some authors mentioned that this only represents a great phenotypic flexibility of this species (Hoving et al., 2013, Ibáñez et al. 2015). Molecular studies based on RAPDs and mitochondrial markers, carried out with specimens of different stages of sexual maturity collected in Peru and Mexico, did not show that these groups present genetic differences (Sandoval-Castellanos et al., 2009), but a low (1.7%) but significant genetic differentiation between small and large phenotypes was evidenced based on mtDNA (Sánchez et al., 2006). It is worth mentioning that these markers do not have sufficient resolution to detect genetic differentiation (e.g., between phenotypic groups) produced in recent times.

The size variation observed in *D. gigas* is possibly a phenotypic response closely linked to environmental conditions that interfere with the ontogeny of this species, changing the population structure and geographic distribution, according to the cohort that is influenced by temperature and other environmental variables (Liu et al., 2010, Bazzino 2014; Chen et al., 2011, 2014; Arkhipkin et al., 2015. Ibáñez et al., 2015). Ibáñez et al. (2015) hypothesize that epigenetic effects driven by sea temperature during embryonic development would be responsible for this high flexibility in size at sexual maturity in *D. gigas*. ~~Phenotypic plasticity and flexibility have been observed in temperate marine species that experience large temporal and spatial variation in habitat temperature (Piersma & Drent 2003, Somero 2005). In this context, epigenetic forces appear to be a central mechanism promoting developmental plasticity, as environmental factors such as temperature and nutrition have been shown to influence genome methylation patterns in marine invertebrates, altering gene expression rates (Somero 2005, Harvey et al. 2014). In the case of *D. gigas*, spawning ground water temperature and food quality of paralarvae could be important in determining final mature size (Ibáñez et al. 2015). It has been evidenced that the size of newly hatched paralarvae is smaller when water~~



~~temperature is higher (>17°C), reaching maturity at smaller size and age (Pecl & Jackson 2008, Arkhipkin et al. 2015).~~

Also, Nigmatullin et al., (2001) have indicated the possibility that squid groups maturing at different sizes represent genetically discrete units, even at the subpopulation. Thus, genetic studies using more variable molecular markers (that could reflect variations in short-time, a fine-scale structure between regions, and adaptive differentiations) are needed to clarify possible population structuring.

Biological characteristics

Morphology: According to Nigmatullin et al. (2001), in terms of many of the important morphofunctional characteristics, that is, in the development of the jet propulsion system, fins, gladius, brain, statocysts, statoliths, etc. *Dosidicus gigas* has no substantial differences from the other four genera of Ommastrephinae (*Ommastrephes*, *Sthenoteuthis*, *Euclideantheuthis* and *Hyaloteuthis*). They can be distinguished by the absence of large mantle skin photophores (only minor photophores are present), by the absence of eye and intestinal photophores in paralarvae (which are present in juveniles and subadults), and by elongated and attenuated arm ends. The arms of *D. gigas* have up to 200 pairs of suckers. The gladius is a typical ommastrephid type and characterised by double marginal ribs on the rachis, long lateral plates, being arc-like bent on the short stem, and the drop-like callus of the hypostracum on the ventral side of cone flages (Bizikov, 1996).

Dosidicus gigas has a conical-cylindrical mantle whose greatest radius is not always located in the open part, but often reaches its maximum near the middle portion. This does not seem related to gonadic growth or maturation, since it is also observed in immature specimens. The radius of the mantle is reduced gradually towards the area of insertion of the fins, ending as a conical tip. The edge of the base of the mantle in its ventral portion slightly turns outwards and upwards, between the cartilages that join the mantle with the siphon.

The fins have a rhomboid shape. The siphon is strong and muscular, with deep invagination and anterodorsally rounded. The foveola - the cleft that gives space to the siphon at the back of the head - has on average seven longitudinal grooves and four to five secondary folds on either side. The cartilage that joins the mantle with the head has an inverted T-shape bifurcation, which is a typical characteristic of the Ommastrephidae family.

The head is generally wider in the back, with two large, very conspicuous globular eyes, without eyelids (Oegopsida) and placed on the sides of the head with an anterior projection. There is a proportionally large and strong beak.

The eight arms are practically identical, except for the right or left IV arm of the males, which is hectocotylized (copular organ), whose protective membrane is remarkably thick and has 13 holes on one side.

The ends of the arms are narrow and have 100 to 200 tiny suckers. In the corneal rings of the larger suckers there are from 8 to 25 little teeth. In the tentacular club the suckers are arranged in four rows. The tentacles are thinner than the arms and twice the length. The color of the skin can range from pale pink to purple, passing through brown (Ehrhardt et al., 1986, Roper et al., 2010).



Dosidicus gigas are monocyclic, so they have only one reproductive season during their life. There is a distinct peak in spawning during spring and summer in the southern hemisphere (Nigmatullin et al., 2001). In Peruvian waters spawning extends throughout the year, with a main spawning peak during October to January, and a secondary peak in July and August. (Tafur & Rabi 1997, Tafur et al., 2001). Individual spawning periods are long and intermittent (batch spawning) (Nigmatullin et al., 2001), and energy sourcing for reproduction is mainly from concurrent food intake (Chen et al., 2020). Spawning takes place both over the continental slope and in adjacent oceanic areas. It is presumed that spawning takes place in the near-surface water layer. In the Gulf of California, egg mass was found in warm waters (25-27°C) at a depth of 16 m. The egg mass resembled a semi-transparent grey cloud, with dimensions ranging from 3-4 m for the major equatorial diameter (Staaf et al., 2008).

Dosidicus gigas has a flexible and opportunistic behaviour (Markaida 2006b) which allows it to respond quickly to environmental variability (Rodhouse & Nigmatullin 1996); which is manifested in changes in the distribution, abundance, growth rate, size at maturity and longevity associated with the availability of food and oceanographic conditions (Arguelles et al. 2008).

Dosidicus gigas grows quickly and does not live for more than 2 years having an average life span of ~1 year (Arkhipkin & Murzov 1986, Masuda et al., 1998, Arguelles et al., 2001; Nigmatullin et al., 2001, Markaida et al., 2004, Liu et al., 2013, Goicochea-Vigo et al., 2019), although, some very large individuals can live for 18 months to 2 years (Nigmatullin et al., 2001). Liu et al. (2010) determined that *D. gigas* can live between 1.5 to 2 years, research developed by reading statoliths. However, other investigations have determined that this species can live up to 2.6 years, depending on its ontogenetic development (Keyl et al., 2010, Arkhipkin et al., 2015).

Regarding the size at maturity, Nigmatullin et al., (2001) have reported three population groups each with different maturity ranges. Squid with small size at maturity (130-260 mm and 140-340 mm for males and females respectively), squid with medium size at maturity (240-420 and 280-600 mm for males and females respectively) and squid with large sizes at maturity (> 400-500 and 550-650 to 1000-1200 mm for males and females respectively). These groups have been reported by Tafur et al. (2018) for the period 1989-2016 who estimated the average mantle size or length at first maturity for smaller specimens with an average first maturity of 201 mm (with annual estimates between 91 and 336 mm) in males and 306 mm (with annual estimates between 186 and 447 mm) in females. And for larger specimens, first maturity was estimated as 514 mm for males and 642 mm for females. In EEZ off the coast Chile, only individuals with large size at maturity (565 and 638 mm of mantle length for males and females respectively) were found (Liu et al., 2010).

Embryonic development lasts for 6-9 days at 18°C. The mantle length (ML) at hatching averages 1.1 mm (Yatsu et al., 1999). In another study, Sakai et al. (2018) observed the early stages of embryonic development of jumbo flying squid under controlled conditions and determined that at 20°C the eggs hatched 6.5 days after spawning. Ontogenesis includes the following phases: paralarvae (1-10 mm ML), juvenile (15-100 mm ML), sub-adult (150-350 mm ML), and adult (400-1000 mm ML), with three transitional periods. During these periods the morphology, food spectrum, and ecological status of the squid change (see Nigmatullin et al., 2001).



The maximum potential fecundity was estimated at 32 million oocytes, and this potential is closely related to female size (Nigmatullin & Markaida 2008).

Role of species in the ecosystem

Dosidicus gigas is thought to play an important role in oceanic food webs. They are prey to a variety of predators such as pelagic fish, marine birds, and mammals. Juveniles are preyed upon by large carnivorous fish, small tuna, squid, and gulls; sub-adults are preyed upon by dorado, snake mackerel, yellowfin tuna, and other large tunas, fur seals; and adults by sharks, swordfish, striped marlin, sperm whales and pilot whales (Nigmatullin et al., 2001 Ibáñez et al., 2015). Sperm whale stomach contents from the southeast Pacific have shown that *D. gigas* is their main prey (Clarke et al., 1988). Before the moratorium on commercial whaling, the biomass of *D. gigas* consumed by exploited sperm whales in the eastern Pacific was estimated to be nearly 10 million tonnes (Clarke et al., 1988).

Studies in the Gulf of California have reported that the jumbo squid feeds predominantly on mesopelagic fishes such as myctophids. Pteropods, micronekton squid, megalopae, and euphausiids have also been reported in the stomachs of jumbo squid (Markaida 2006a).

Dosidicus gigas prey in the Southeast Pacific appears similar to that in the Gulf of California. A predominance of myctophids was observed, however, the gonostomatid *Vinciguerria lucetia* was the second in fish prey importance (Shchetinnikov 1989). The jumbo flying squid in the northern Peruvian Current system consume high percentages by weight of mesopelagic fish, such as *Vinciguerria lucetia*, *Lampanyctus* spp., *Myctophum nitidulum*, *M. aurolaternatum* and *Diogenichthys laternatus*, as well as cephalopods, including their own species (cannibalism), the squid *Abraliopsis affinis*, the nautilus *Argonauta* spp., several species of Loliginidae, and other invertebrates such as euphausiidae and the squat lobster *Pleuroncodes monodon* (Alegre et al., 2014).

In the northern system of the Humboldt Current, small jumbo squid (<400 mm) are distributed mainly offshore, where they feed mainly on mesopelagic fish. As they grow, they move closer to shore and increase their consumption of other cephalopods. However, off Peru, unlike other systems, *D. gigas* does not occupy very coastal waters where there is a large biomass of anchoveta. This would indicate that the jumbo flying squid cannot enter coastal waters that have low oxygen saturation at the surface. Although jumbo flying squid can feed in deep hypoxic water, they require normoxic surface water afterward. Therefore, the oxygen concentration can limit the coexistence of both species and then impede predator-prey interactions. Large squid move farther offshore (without reaching the oceanic range of smaller jumbo squid) and increase their consumption of squid (including jumbo flying squid) and euphausiids. Consumption of euphausiids is quite low considering their availability, indicating that *D. gigas* may seek out more energetic prey. Jumbo flying squid feeding behavior is opportunistic and is affected by ontogenetic migration and most likely by oxygen conditions. In addition, there is great variability between individuals and differences in jumbo flying squid life history strategies highlight the high degree of plasticity of the jumbo flying squid and its high potential to adapt to environmental changes (Alegre et al., 2014).

Dosidicus gigas are recognized as voracious and adaptable predators of a broad range of prey including small crustaceans and fishes at early life stages and shift to micronekton, larger fishes, and cephalopods (including cannibalism) as they grow (Nigmatullin et al., 2001; Alegre et al.,



2014). Ontogenetic changes in the morphology of the capture apparatus (e.g., arms and beaks) seem to reflect the increasing capacity to seize or bite different size spectrum of prey (Franco-Santos & Vidal, 2014; Gong et al., 2018). Prey size increases as the squid grow (Schchetinnikov, 1989). Prey size, on average, is commonly between 5-7 cm and occasionally larger 10-15 cm for larger adult squid (Markaida & Sosa-Nishizaki 2003). A high occurrence of cannibalism (up to 70%) has been observed (Markaida 2006a).

Stable isotope analyses have complemented stomach content studies, suggesting that larger adult squid consumed prey of a higher trophic position than myctophids (Ruiz-Cooley et al., 2006). However, in Peruvian waters the high inter individual variability of nitrogen isotope with mantle length indicates that *D. gigas* can prey on a high variety of resources at any stage of their life cycle (Lorrain et al., 2011, Arguelles et al., 2012), indicating that *D. gigas* has a high potential to adapt to environmental changes.

Imarpe studies show that in the period 2004-2017, of a total of 67 groups of identified prey, the ones with the highest average percentage in weight for the entire period were cephalopods with 42.33%, including their congeners (14, 50%), mesopelagic fish with 25.43%, among which *Vinciguerra lucetia* (13.05%) and the Myctophidae *Lampanyctus* sp. (4.63%), *Myctophum* spp. (2.46%) and other Myctophidae (5.29%). Other important components of the jumbo flying squid diet are the munida (*Pleuroncodes monodon*) and the Euphausiidae, which on average represented 5.04% and 4.39% by weight of the stomach content, respectively. Species of commercial interest such as anchoveta (*E. ringens*) and hake (*Merluccius gayi*; Guichenot, 1848) were found as prey with low weight percentages (with averages for the entire period of 4.44% and 0.20%, respectively) (Csirke et al., 2018).

The majority of the feeding records of *D. gigas* are descriptive (Fernández & Vásquez, 1995; Ibáñez et al., 2008). Few studies have found that *D. gigas* collected off the Chilean coast do not show feeding differences related to their sexual and ontogenetic condition (Ulloa et al., 2006, 2012; Pardo-Gandarillas et al., 2014). Apparently, variability in stomach contents occurs on a seasonal and geographic scale, possibly due to changes in prey availability in the Humboldt Current System ecosystem (Chong et al., 2005; Pardo-Gandarillas et al., 2014, Bruno et al., 2021).

Presence of parasites

Parasitic fauna associated with *D. gigas* caught in oceanic and coastal waters in Central Chile (32°S-40°S) is composed by cestode larvae: *Hepatoxylon trichiuri* (Holten, 1802) (abundance of 2.6 and prevalence of 70.2%), *Tentacularia coryphaenae* Bosc, 1802 (0.1 abundance, 5.6% prevalence), plerocercoid *Tetraphyllidea* (9.1 abundance, 83.1% prevalence), *Pelichnibothrium speciosum* Monticelli, 1889, *Anisakis* Type I (0.06 abundance, 6.5% prevalence) and *Anisakis* type II (0.52 abundance, 17.7% prevalence). Among the parasite species mentioned, *H. trichiuri* is a newly recorded parasite of *D. gigas* in the latitudes of the southeast Pacific. Other taxa were previously described for *D. gigas* inhabiting Ecuador, Peru, and northern Chile (Shukhgalter & Nigmatullin, 2001). However, genetic studies have been suggested to identify larval nematodes associated with the jumbo squid as there is limited information about these taxa and they are difficult to identify visually (Pardo-Gandarillas et al., 2009). The composition and abundance of the parasite communities of *D. gigas* are different between oceanic and coastal waters off of Chile, which could be explained by the type of diet of *D. gigas* in each zone (Pardo-Gandarillas et al., 2014).

In 254 mantles of *D. gigas* in Puerto Lomas (15°26' S to 75°03' W), Arequipa, Peru, 5 taxa of endoparasitic helminths were found as part of the community of parasitic helminths: Didymozoidae



gen. sp. no indet., *H. trichiuri*, *T. coryphaenae*, *A. simplex*, and *A. physeteris*. *T. coryphaenae* is the species with the highest prevalence (56.29%) and average abundance (1.68%), this being the one with the highest quantity found in the mantle muscle. Helminths of zoonotic importance are represented by *A. physeteris* (Prevalence: 50%) and *A. simplex* (Prevalence: 15.74%). No relationship was observed between the prevalence of *A. physeteris* and *A. simplex* and the ML of the host. A linear relationship was only found with the ML of the jumbo flying squid and the prevalence of *T. coryphaenae*. Similarly, the prevalence of *A. physeteris* and *T. coryphaenae* did not show a linear relationship with the weight of the host's mantle. Only the prevalence of *A. simplex* showed a linear relationship with the weight of the mantle. It was determined that there is no relationship between the mantle length (ML) and mantle weight (MW) of *D. gigas* and the abundance of the parasites found. The average ML (cm) between parasitized and non-parasitized squid with the three parasitic helminths is the same for *T. coryphaenae*, *A. simplex* and *A. physeteris* evaluated. The values obtained for the zoonotic helminth species *A. simplex* and *A. physeteris* show a decrease in mean abundance when both species are found together. The prevalence of the 2 zoonotic species *A. simplex* and *A. physeteris* during 2009 in Puerto Lomas was higher compared to 1981-1989, 2003-2004 and 2008-2009 (Céspedes et al., 2011).

Impacts of Fishing

Habitat damage

There is likely to be minimal if any damage to the habitat due to the highly selective type of fishing methods (jiggers) that are mostly employed.

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