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# Biological and Fishery Parameters of Jumbo Squid (*Dosidicus gigas*) in the Colombian Pacific, a Resource without Directed Fishing Exploitation

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**Abstract:** The distribution range of the jumbo squid (*Dosidicus gigas*) has increased over the past few decades; it is now found in the entire Eastern Pacific Ocean and is considered an important species in the small and large fisheries of Chile, Perú, Ecuador, Costa Rica and Mexico but not in the Pacific region of Colombia. Three night-fishing campaigns were conducted over a year in the coastal Baudó-San Juan environmental unit, adjacent to the Bajo Baudó Encanto de Manglares Regional Integrated Management District in Chocó, at three locations 20 km, 35 km, and 45 km from the coastline to establish the availability and viability of jumbo squid as an alternative to the target species of artisanal fisheries in the Colombian Pacific. Night fishing sets were conducted at 60 m and 200 m depth at each sampling station to assess some of the biological parameters of the jumbo squid population (mantle length-ML, weight, growth and size at sexual maturity). Most catches were obtained in February and March. Growth was isometric, the average catch size was 24.3 cm ML, size at sexual maturity ($L_{50}$) was 23.25 cm ML, estimated maximum size ($L\infty$) was 39.9 cm ML, the growth constant (K) was 0.83, and mortality due to experimental fishing was 26 cm ML. According to our results, the jumbo squid fishery in the Colombian Pacific artisanal fishery would be viable during the first months of the year.

**Keywords:** small scale fisheries; nekton; cephalopods; eastern pacific; panama bight; chocó



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## 1. Introduction

The jumbo squid (*Dosidicus gigas*) is a cephalopod species of the Eastern Pacific Ocean (EPO) whose distribution range has increased over the past few decades [1,2]. This fishing resource is of considerable interest in the region [3], with average annual catches of 874,723 t between 2015 and 2019 [4,5]. It has been reported that the average longevity of the jumbo squid in the EPO is less than a year and that it presents rapid growth rates [6–9]. This is an opportunistic predatory species that can feed on fishes, crustaceans, and squids. It is preyed upon by sharks, tunas, dorados, billfishes, and marine mammals [9–14], and is therefore a key component of trophic dynamics in pelagic environments [15,16].

This species has been scarcely studied in the Colombian Pacific; scientific studies only include a fishing expedition undertaken in 1997 which deployed 65 fishing sets from February to December, reporting MLs between 14 and 45 cm, with a total of 4772 kg of jumbo squid captured during 254.3 h of an effective fishing effort [17]. Although jumbo squids are an important fishing resource for industrial and artisanal fishing operations in Peru, Ecuador, Costa Rica, and Mexico [3–5], this species is not considered of interest for targeted fisheries in Colombia. However, it has been selected as a promising species [18], as it could represent a new income alternative for local artisanal fishers, considering that their average monthly income is around USD 200, below other countries in the region such as Peru (USD 300) and Chile (USD 728) [19].

The artisanal fishing contribution for the northern Colombian Pacific was estimated at 1030.4 t in 2021, representing only 9.5% of landings in the Pacific region of Colombia (10,857.7 t) and 1.7% of landings in the country (62,143.6 t) [20]. Small-scale fisheries in this region are directed mainly towards pelagic and demersal fishes (e.g., *Scomberomorus sierra*, *Brotula clarkae*, *Thunnus albacares*, *Euthynnus lineatus*, *Bagre pinnimaculatus*, *Lutjanus guttatus*, *Cynoscion albus*, *Cynoscion phoxocephalus*, *Caranx caninus*, *Caranx caballus*, *Seriola rivoliana*, *Lutjanus peru*, and *Mugil cephalus*) that are captured using fishing gear such as handlines, longlines, and gillnets [20–22]. Shallow-water crustaceans (*Xiphopenaeus riveti* and *Penaeus occidentalis*) and mollusks associated with tidal canals and mangrove forests (*Anadara similis* and *Anadara tuberculosa*) are also caught in lower amounts [20].

The jumbo squid is an oceanic species [9,10,23] whose abundance, size, and reproductive cycle are strongly associated with mesoscale oceanographic variability [24–26]. For this reason, its availability is highly variable over spatial and temporal scales [27,28]. Although this is the most abundant oceanic cephalopod species in the coastal area of the EPO [9,10,29], it is more abundant in tropical areas with active upwelling processes such as the Costa Rica Dome (4°–11° N, 90°–100° W), where Chinese squid-jigging vessels catch from 2.3 to 19.4 t/day [6,30]. The jumbo squid was recently identified as a new artisanal and industrial target species in the exclusive economic zone of the Ecuadorian Pacific, with landings of 300 t/month to 1800 t/month, and the border area between Ecuador and Colombia is an active fishing area for this resource [31]. However, artisanal fishing catch records for this species in the Colombian Pacific were only 1.1 t/year in 2021, representing 0.1% of the total artisanal fishing catches for the region in terms of biomass [20].

In this study, we describe biological and fishery characteristics of jumbo squid in the central northern region of the Colombian Pacific and address the following questions: (1) What size are the jumbo squid specimens present in the central northern region of the Colombian Pacific? (2) At what distance from the coast are more individuals captured? (3) Is jumbo squid abundance constant throughout the year in this area? (4) What size are the jumbo squid at sexual maturity and at mortality by experimental fishing in the central northern region of the Colombian Pacific? We hypothesized that the jumbo squid population inhabiting the central northern region of the Colombian Pacific can support a small-scale fishing effort by the artisanal fleet. Answering these questions will provide new information on biological aspects of the jumbo squid in the tropical area of the EPO and will allow us to determine its viability as an alternative resource for artisanal fisheries in the central northern region of the Colombian Pacific.

## 2. Materials and Methods

### *2.1. Study Area*

The Colombian Pacific makes up the easternmost area of the Eastern Tropical Pacific Ocean (ETPO) and is part of the Panama Bight (Figure 1). Oceanographic dynamics are influenced by the intra-annual displacement of the intertropical convergence zone, an atmospheric process that modulates the development of coastal upwelling in the Gulf of Tehuantepec (Mexico), Gulf of Papagayo (Costa Rica), and Panama Bight (Panama–Colombia) [32,33]. The influence of coastal upwelling in this region largely determines the temporal variability in thermal and saline conditions. Two oceanographic periods have been identified in the Colombian Pacific: a period of cold water and high surface salinity in January–April and a period of warm water and lower surface salinity between May and December [34,35].

A particular characteristic of the Colombian Pacific is that precipitation levels can reach 8000 mm/year, with a multimodal pattern defined by periods of intensification in April–June and September–December, and a weakening in January–March and July–August [36,37]. High precipitation feeds an extensive hydrological network that modulates the spatial variation in surface salinity [38,39]. The surface circulation pattern is determined by the influence of the North Equatorial Countercurrent and the South Equatorial Current that feeds a coastal current flowing northward, known as the Colombian Current, which is approximately 180 km wide and 250 m deep [40,41]. The continental platform presents a variable width, with a maximum of 50 km in the south, whereas to the north it extends between 5 km and 10 km from the coastline [42].

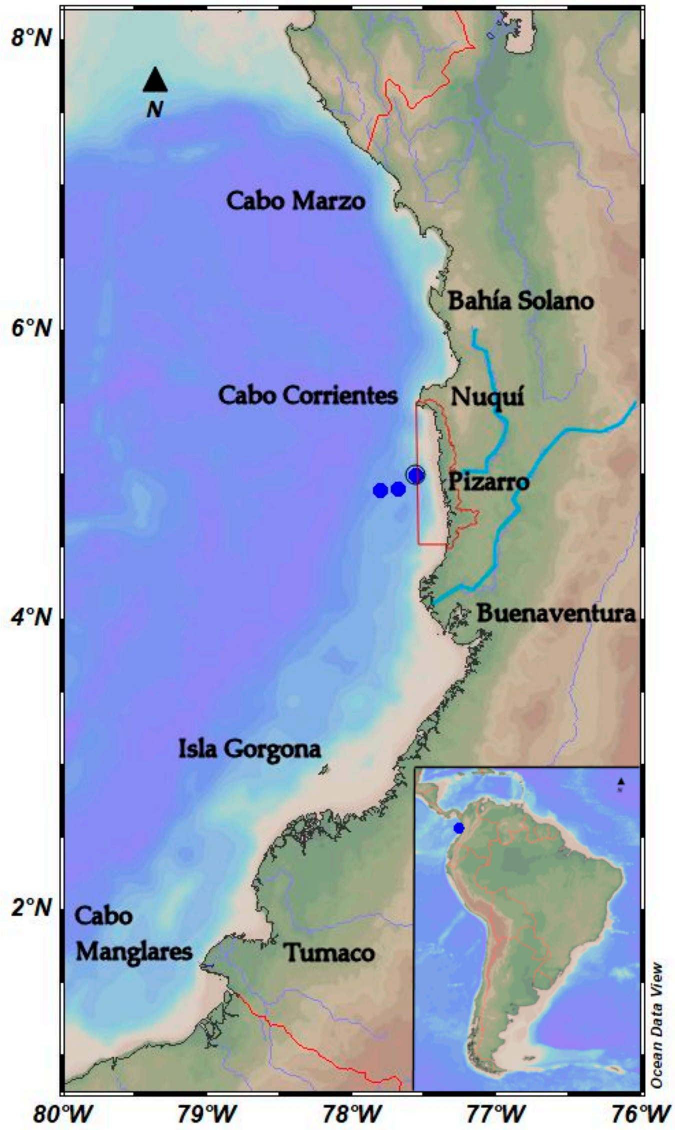



**Figure 1.** Location of the study area in the Colombian Pacific. Distance to the coast: E1, 20 km; E2, 35 km; E3, 45 km.

## 2.2. Experimental Fishing

Experimental fishing for jumbo squid was undertaken in the central northern Colombian Pacific, in the coastal Baudó-San Juan environmental unit associated with the Bajo Baudó Encanto de Manglares Regional Integrated Management District (DRMI EMBB). The municipality of Pizarro, located at the river mouth, was designated as the launching port. Night fishing for squid was carried out monthly between December 2021 and November 2022 at three sampling sites located at different distances from the coast (Figure 1). The first site was located 20 km from the coast (200 m depth) and was selected in consideration of an empirical reference for the vertical migration range of *D. gigas* [43], the second site was located 35 km from the coast (>400 m depth), and the third site was located 45 km from the coast (>800 m depth).

We used a boat equipped with two manual jigging reels, on which the fishing line was wound, one night/site/month. Nylon fishing lines with branch lines bearing five lures each and a sinker at the end were used and 11 fluorescent squid jig lures (13 cm in length with double layer squid hooks) were deployed for three hours during each fishing effort. The temperature and salinity of the water column were measured with a YSI Castaway CTD profiler prior to fishing. The fishing site was illuminated for 1 h using two 60 watt spotlights. Three fishing lines were then deployed at different depths, considering the reported tendency of squid to move vertically during the night [43], keeping the spotlights lit; the first line was deployed at 200 m depth, the second at 60 m depth, and the third was used as a handline in the upper 50 m.

### *2.3. Biological and Fisheries Characteristics*

Captured individuals were placed in a cooler on ice and transported to the laboratory in the municipality of Pizarro, where the dorsal mantle length (ML, 1 mm precision), fin length, total weight (TW, 0.1 g precision), and gonadal weight (GW, 0.1 g precision) of each specimen were measured. Individuals were dissected to obtain internal organs and the macroscopic developmental stage of the gonads was recorded [44]. The size frequency distribution was analyzed, the monthly average catch size (ACS) was estimated, and the frequency distribution of the gonadal developmental stages was assessed. A one-way analysis of variance was undertaken to compare the ACS obtained at the three sampling sites, after verifying normality assumptions, using post hoc Bonferroni tests for multiple comparisons.

The TW–ML relationship was evaluated by fitting a potential curve to the data, using the equation TW = aMLb. The Elefan I routine in the Fisat II program was used to establish the $L\infty$ and K growth parameters [45], where $L\infty$ is the asymptotic mantle length and K is the growth coefficient per year. The φ′ index [46], defined as $\varphi' = \log 10K + 2 \log 10L\infty$, was used to explore differences between growth parameters found in previous studies and this study. Natural mortality (M) was calculated as $\log M = -0.0066 - 0.279 \log (L\infty) + 0.6543 \log (K) + 0.463 \log (T)$ [47], where $L\infty$ and K are growth parameters and T is the annual average temperature in the habitat in °C. Fishery-dependent mortality (F) per year, exploitation rate (E) per year, catch, and stock abundance were calculated using a virtual population analysis (VPA) based on longitude [48] in the Fisat II program, incorporating values of longitude of catches in the $L\infty$, K, and M parameters, and the a and b parameters of the TW–ML relationship.

Length at sexual maturity was calculated using gonadal development records, based on fitting a logistic model describing the proportion of mature females as a function of size as follows: $PL = [1 + \exp - (a - bL)] - 1$, where PL is the proportion of mature females at size L, and a and b are constants estimated using generalized linear models. Mean size at sexual maturity was defined as $L_{50} = a/b$; individuals were classified as mature or immature; and the random variable followed a binomial distribution. This approximation is equivalent to maximizing the following log-likelihood function: $L(a,b) = S\ k \ln(P) + (1 + h)\ln(1 - P)$, where k is a variable indicating female maturity (=1) or immaturity (=0), and P is the maturity logistic function. Finally, the gonadosomatic index (GSI) was calculated as GSI = GW/TW and the temporal variation in the GSI was assessed with a generalized additive model (GAM).

## 3. Results

The surface temperature during the study period ranged from 27.1 °C to 27.9 °C. The thermocline depth (21 °C isotherm) was 5 m in March and 40 m in June. A total of 747 individuals were caught, with a total landing weight of 272.15 kg. The greatest catches occurred in February (95 kg); the sampling site 45 km from the coast was the location with greatest number of individuals and greatest biomass caught (Figure 2). Although catches in March were similar to those obtained in February, the abundance of individuals caught at the two outer sampling sites (35 km and 45 km from the coast) was similar, which suggests that jumbo squids were closer to the coast during this period (Figure 2). It should be noted that the lowest abundances were recorded at the sampling site 20 km from the coast (located at the 200 m isobath). No squid were caught at any of the sampling sites in November and December (Figure 2).

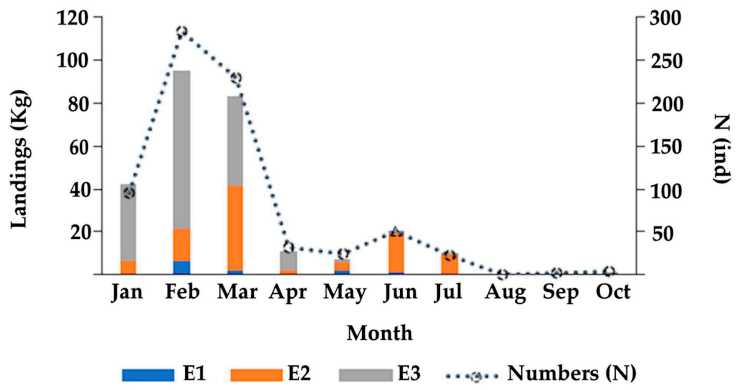
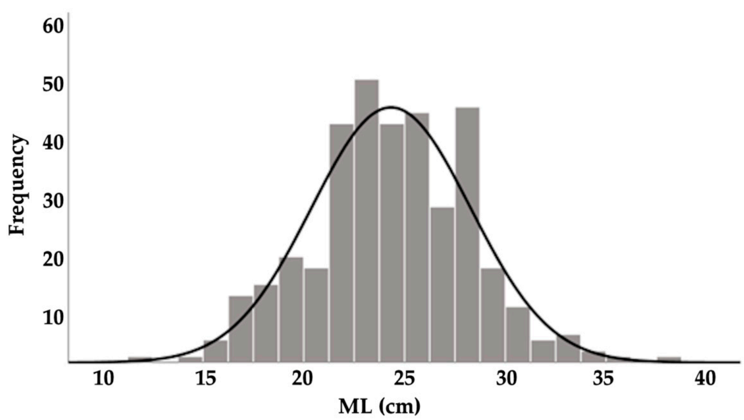



**Figure 2.** Temporal and spatial variations of jumbo squid, *Dosidicus gigas*, catches in the central northern Colombian Pacific. No specimens were caught in November and December. Distance to the coast: E1, 20 km; E2; 35 km; E3, 45 km.

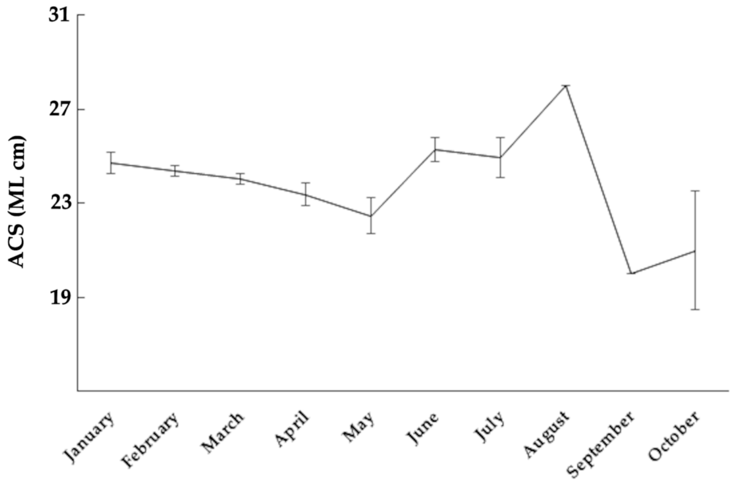
Captured jumbo squid ranged in size from 11.8 cm to 38.0 cm in mantle length (ML) (Figure 3A); the average catch size (ACS) was 24.2 ± 3.9 cm. The ACS ranged from 23.0 cm to 25.0 cm ML between January and July; the greatest ACS was recorded in August (27.5 cm) and the lowest in September and October (20.5 cm–21.0 cm). The greatest variability in ACS records was obtained in October (18.5 cm to 23.5 cm ML, Figure 3B). The spatial variation in catch size in the study area showed that the ACS was significantly greater ($p < 0.05$) at the sampling station located 45 km from the coast, whereas there were no significant differences between the other two sampling stations.

A subsample of 379 individuals were sexed, of which 97% were females (ML: 11.8 cm to 38.0 cm) and 3% were males (ML: 16.4 cm to 31.8%) (Figure 4A). Fifteen percent of females were in stage I (ML: 11.8 cm to 34.5 cm), 30% were in stage II (ML: 15.1 cm to 32.9 cm), 47% were in stage III (ML: 14.5 cm to 38.0 cm), and 8% were in stage IV (ML: 22.1 cm to 35.8 cm) (Figure 4A). On the other hand, of the 11 males sexed, 9% were in stage III (ML: 23.1 cm), 45.5% were in stage II (ML: 17.0 cm to 24.6 cm), and 45.5% were in stage I (ML: 16.4 cm to 24.6 cm) (Figure 4A). Only two individuals could not be sexed (14.5 cm ML and 19.2 cm ML). The temporal variation in the GSI showed that jumbo squid females had the greatest gonadal development from January to March (Figure 4B). However, gonadal development stage III was the most frequently found during the entire sampling period, although gonadal development stage II was most frequently found in February, July, and October; 54% of individuals were classified as mature and 46% as immature.




**A.**

**Figure 3.** *Cont.*




**B.**

**Figure 3.** (**A**) Size frequency distribution of *Dosidicus gigas* in the central northern Colombian Pacific during the study period. (**B**) Temporal variation in the average catch size (ACS) of *Dosidicus gigas* in the central northern Colombian Pacific during the study period. The mean and standard error are shown.

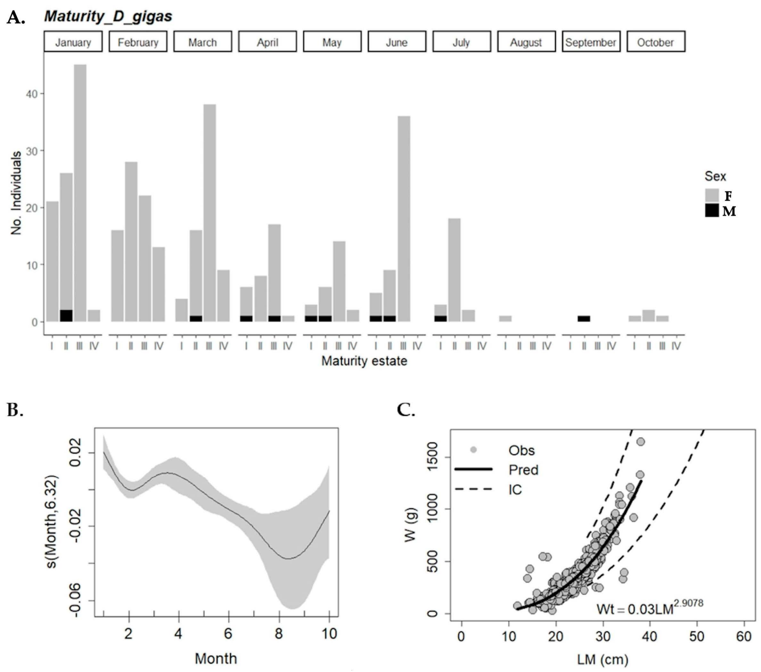
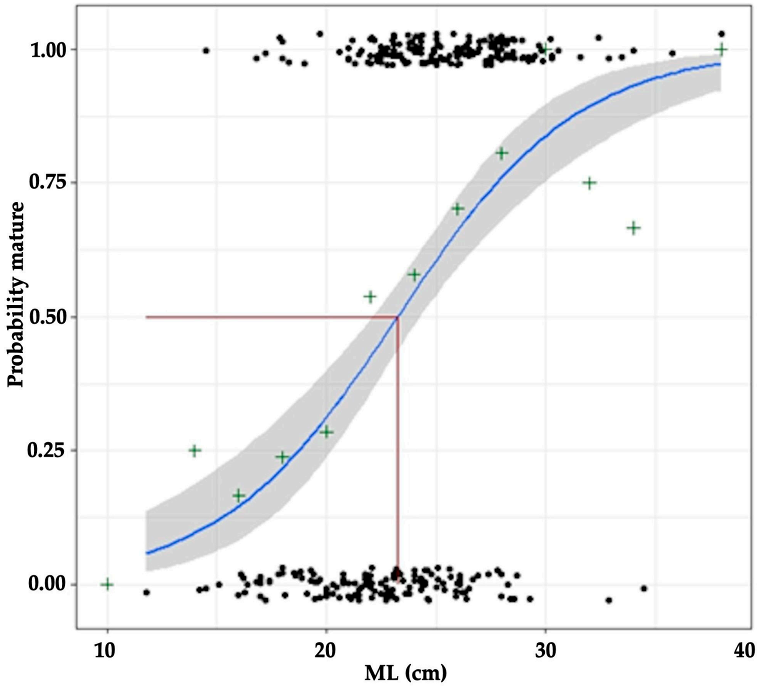



**Figure 4.** (**A**) Monthly maturity estate, (**B**) temporal variation in GSI and (**C**) ML (cm)-weight (g) relationship ($R^2$ = 0.82) of jumbo squid *Dosidicus gigas* in the central northern Colombian Pacific during the study period. F (female), M (male). The gray shadow and dotted lines indicate 95% confidence intervals.

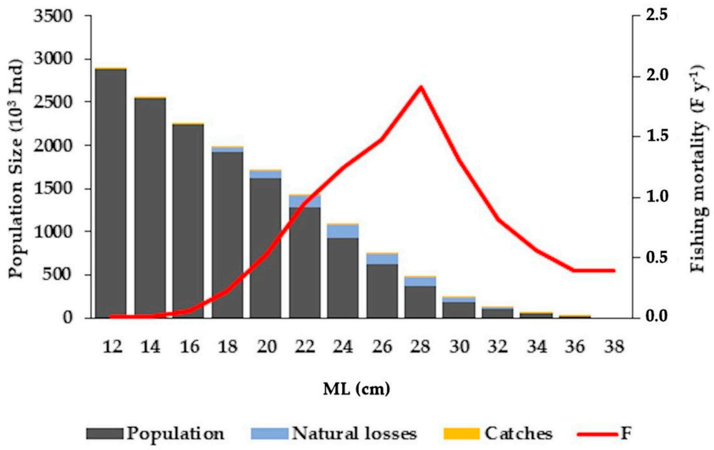
Growth was isometric ($p > 0.05$, $R^2 = 0.82$) (Figure 4C); the asymptotic length (L∞) was 39.9 cm ML; the mean growth coefficient (K) was 0.83 $y^{-1}$; and the growth performance index (φ′) was 3.12. The length at first capture (Lc) was 15.43 mm ML, the natural mortality (M) was 1.4 $y^{-1}$, the fishing mortality (F) was 0.4 $y^{-1}$, the total mortality was 1.8 $y^{-1}$, and the exploitation rate (E) was 0.22.

The size at sexual maturity of *D. gigas* females in the study area was 23.3 cm (Figure 5A); 55.2% of captured individuals measured more than the $L_{50}$. The VPA (Figure 5B) showed that with the fishing effort used here (11 baits/3 h), fishing mortality began to occur at

18 cm ML and increased gradually to reach the greatest effect at 26 cm ML, when it was equal to natural mortality, and it was greater than natural mortality at 28 cm ML.




A.




B.

**Figure 5.** (**A**) Maturity probability at $L_{50}$ of *Dosidicus gigas* females. Green crosses indicate the location of each class size in 2 cm intervals. (**B**) Virtual population analysis (VPA) based on experimental captures of *Dosidicus gigas*. Red line indicates fishing mortality (F $y^{-1}$).

## 4. Discussion

The results of this study show that jumbo squids can be found in the study area during at least 10 months of the year, with the greatest catches from January to March. Although the spatial coverage of our study limits extrapolation of observed sizes to the real stock size composition, the observed mean mantle size of 24.2 cm suggests that the *D. gigas* population present in the central northern Colombian Pacific belongs to the population of small-sized individuals (Table 1) that has been identified as dominant in the warm tropical waters of the EPO [10]. Jumbo squid exhibit a wide spatial variability in size throughout their geographic range of occupancy; in the southern (Chile–Peru) and northern zone (Mexico–USA) larger-sized specimens, mean MLs between 50.0 cm and 70.0 cm are reported, while in the central zone (Costa Rica) small-sized specimens with MLs between 25.0 and 30.0 cm are present [49–53]. According to molecular studies carried out on individuals captured in Mexico and Peru, size variations exhibited by jumbo squids along their distribution range could be the result of high phenotypic plasticity in this species [54]; size differences are not related to intrapopulation genetic differentiation [55,56], but to local variations in environmental conditions and food availability [26,57,58].

Jumbo squid specimens caught in the central northern Colombian Pacific consisted mainly of females, which comprised up to 97% of catches. According to sex ratios reported for Chile, Peru, Ecuador, Costa Rica, and Mexico [30,31,52,59–63], females usually represent over 70% of catches, probably as a consequence of the selectivity of fishing gear used [57]. Although the size at recruitment of male *D. gigas* could not be established for the central northern Colombian Pacific, the estimated size at recruitment of females ($L_{50}$ = 23.3 cm ML) was lower than the size reported for tropical areas in the EPO (Ecuador $L_{50}$ = 32.4 cm ML [64], Costa Rica $L_{50}$ = 29.7 cm LM [30]), as well as in areas in the northern and southern limits of its distribution (Peru $L_{50}$ = 54.2 cm ML [49], Mexico > 38 cm ML [65]).

**Table 1.** Biological and fishery parameters of *Dosidicus gigas* reported in the Eastern Pacific regions. Sizes: ML range, average size in parentheses. [*] this study.

| Country | Size (ML cm) | $L\infty$ (ML cm) | K ($y^{-1}$) | $L_{50}$ (ML cm) | M ($y^{-1}$) | F ($y^{-1}$) | Reference |
|---|---|---|---|---|---|---|---|
| Chile | 22.5–83.70 | 98 | 1.5 | 64.6 | - | - | [49,53] |
| Peru | 52.0–55.0 (38.4 ± 6.3) | - | 1.5 | 54.2 | - | - | [29,31,49] |
| Ecuador | 23–42 | - | 0.51 | 32.4 | - | - | [8,31] |
| Colombia | 11.8–38.0 (24.2 ± 3.9) | 39.9 | 0.83 | 23.3 | 1.4 | 0.4 | [*] |
| | 14–45 | - | - | - | - | - | [17] |
| Costa Rica | 25–30 | - | 0.83 | 29.7 | - | - | [30,49] |
| Mexico | 58–70 | 95 | 1.1 | >38 | 1.65 | 0.44–3.6 | [50,66] |

Jumbo squids exhibit year-round reproductive activity in the central northern Colombian Pacific; however, the greatest proportion of mature females was recorded between January and March. This same trend was reported for the Costa Rica Dome [30] and the Gulf of California [66], whereas in Ecuador, the greatest proportion of mature females was recorded in May and between October and November [64], and in Peru and Chile, more mature females in coastal areas were recorded in August and November [67–69]. According to histological evidence, *D. gigas* reproduction is not seasonal, so mature individuals can be found year-round [9,10,30], although in regions with marked seasonal variability in environmental conditions such as Chile, Peru, and Ecuador, two periods of greater numbers of mature females associated with summer and winter have been reported [10,57,59,62,69–71].

A strong relationship between environmental temperature, growth rate, and reproductive development has been identified for jumbo squid [56,59,61], with faster somatic growth and lower recruitment size when development occurs in warm environments, such as those found in the central northern Colombian Pacific, compared with colder subtropical environments or areas associated with upwellings, such as the Humboldt Current (Chile–Peru), the Costa Rica Dome, or the Gulf of California. Although the $\varphi'$ index found in this study was lower (3.12) than what has been reported for other populations (>4.0) [50,66], the mean catch size was greater than the size at maturity ($L_{50}$) in our study area, which is a necessary condition to endorse the use of a fishing resource. However, as these two values were similar, a permanent monitoring of these population parameters would be necessary when implementing a targeted jumbo squid artisanal fishery in the central northern Colombian Pacific.

The availability and viability of jumbo squid as an alternative resource for artisanal fishing in the study area could strengthen the economy of the fishing communities in the region and help reduce fishing pressure on other resources that have been strongly affected, as such as the main commercial fish species landed in the Colombian Pacific. However, based on the results of the VPA and considering the established population parameters, we propose that, although these squid are present in the area, the results are not conclusive to recommend using squid as an alternative resource for local fishermen. In order to define whether its stock is sufficient to sustain a fishing effort directed by an artisanal fleet, it would be advisable to survey the available biomass considering the seasonal and spatial attributes observed in this study with respect to abundances in the first months of the year and the differences of captures respect to distance to the coast.

The results of this study increase knowledge about the fishing biology of jumbo squid in the Colombian Pacific and the ETP and could become a reference to establish a potential management plan for this resource in the Colombian Pacific. However, research efforts on this species must be increased on key topics such as population structure, migration, spatial distribution, and other significant biological parameters to establish the spatiotemporal dynamics of this resource in the studied region.

**Author Contributions:** Conceptualization, A.G.; Data curation, J.J.G. and N.L.; Formal analysis, D.F.C.-R. and A.G.; Funding acquisition, A.G.; Investigation, D.F.C.-R., J.J.G. and N.L.; Methodology, D.F.C.-R. and A.G.; Project administration, N.L. and A.G.; Supervision, A.G.; Visualization, D.F.C.-R. and N.L.; Writing—original draft, D.F.C.-R.; Writing—review and editing, A.G. and D.F.C.-R. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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