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Satellite tagging of jumbo squid in Chile preliminary results in two sectors

Chile

Satellite tagging of jumbo squid in Chile: preliminary results in two sectors

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The *D. gigas* species is a resource of economic and social importance for the Chilean artisanal fishing sector. Given the importance of this species, it is of most importance to understand its ecological and biological aspects. For this reason, since 2023, the Humboldt II Binational Project, implemented by Subpesca-Chile and the ViceMinisterio de Pesquerías de Perú, implemented by the United Nations Development Program (UNDP), funded a biological study of jumbo flying squid in Chile, conducted by the Fisheries Development Institute (IFOP). One of its specific objectives of this initiative was to establish a tagging program across different regions of the country to investigate and characterize the horizontal and vertical movements patterns of *D. gigas* in Chile.

Materials and methods

<u>Satellite Tagging</u>

The selected device for tagging *D. gigas* specimens was a pop-up satellite archival tag (MiniPAT-390-B, Wildlife Computers, Seattle, USA). The tag is positively buoyant in seawater (Figure 1A). It was attached to the ventral surface of the squid's fin using a customized anchoring system made of polycarbonate and acetal components (Figure 1B). This system comprises translucent polycarbonate plate, secured to the specimen with acetal bolts and nuts, and cushioned with rubber washers to minimize tissue damage. The transmitter was mounted onto the plate and fixed in place using heavy-duty cable ties (Figure 1C). The design was adapted from the methodology described by Stewart et al. (2012) and refined based on guidance from Markaida (pers. comm. 2024).

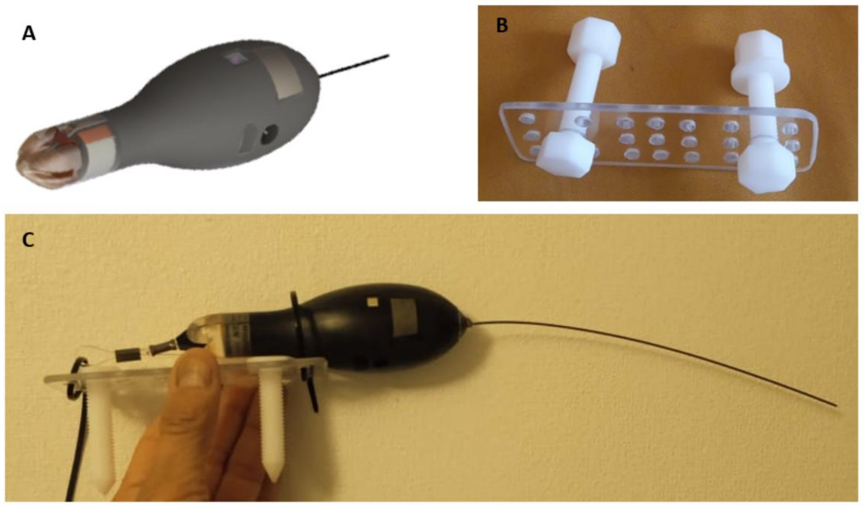

Figure 1. A. Pop-up satellite tag used for tagging *D. gigas*. **B.** Polycarbonate plates with acetal bolts and rubber washers used to attach the transmitter to the squid´s fin. **C.** Fully mounted tag fixed onto the plate prior to deployment.

The sampling interval of the tags was set to 1.25 minutes, allowing for the detection of fine-scale changes in the squids' vertical movement behavior. The temperature sensor was configured with a resolution of 0.1°C, while the pressure sensor was set to a resolution of 0.5 meters, providing high-resolution data on depth profiles.

A standardized selection and handling protocol was implemented to minimize potential impacts of the tagging procedure on the behavior and welfare of the specimens. This protocol was adapted from Gilly et al. (2006) and Stewart et al. (2013).

<u>Tags-data analysis</u>

Following tag detachment, recorded data were transmitted via satellite and archived on the Wildlife Computers platform (https://wildlifecomputers.com/). Once retrieved, data were analyzed to assess the vertical distribution and temperature exposure of each individual throughout its deployment period.

A frequency-based analysis was conducted to quantify the time spent by each squid across discrete temperature and depth intervals. The total time spent within each interval was expressed as a proportion of the total recorded tracking duration, distinguishing between diurnal and nocturnal periods. Day and night phases were determined using a solar position function based on geographic coordinates and time zone, as described by Beauducel (2024).

Depths intervals were structured to cover a range from 1 to 750 meters. The first bin spanned 1-5 m, followed by 10-meter increments up to 100 m, and then 50-meter increments up to 750 m. Temperature values were binned in 0.5°C intervals, ranging from 7°C to 19°C. Additionally, summary statistics - including mean, minimum, and maximum temperature and depth - were calculated for each individual.

Spatial Trajectories

Spatial positioning was estimated using the GTB3algorithm provided by Wildlife Computers. GTB3 is a geolocation model that applies a Bayesian framework to determine the most probable movement path based on light-level (twilight), temperature, and depth data recorded by the tag, as well as environmental data such as sea surface temperature (SST) and bathymetry. Output of the model included individual movement tracks at a spatial resolution of 0.25°.

For a detailed explanation of GTB3 modeling and processing, refer to the Wildlife Computers website.

Environmental Oxygen Profiles

Dissolved oxygen concentrations were derived from the global biogeochemical hindcast dataset provided by Mercator Ocean and distributed through the Copernicus Marine Service

(https://data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_BGC_001_029/description). This dataset is produced by coupling the NEMO ocean model with PISCES biogeochemical model, offering daily temporal resolution and a spatial resolution of 0.25°.

Geolocation estimates for each squid were used to extract a daily vertical oxygen profile up to 1000 meters in depth. The corresponding depth values recorded by the tag were used to match oxygen concentrations along the vertical profile.

Results

A total of four *Dosidicus gigas* specimens were tagged during 2024 - two in Guanaqueros, Coquimbo Region and Lebu, Biobío Region. In Guanaqueros, the first squid was tagged in March and released at coordinates 30.1168°S, -71.4669° W. The second specimen was tagged in October and released at 30.1611°S,71.515° W. In the Biobío Region, tagging was conducted in June, and both individuals were released at 37.5967°S,73.8683°W (Figure 2).

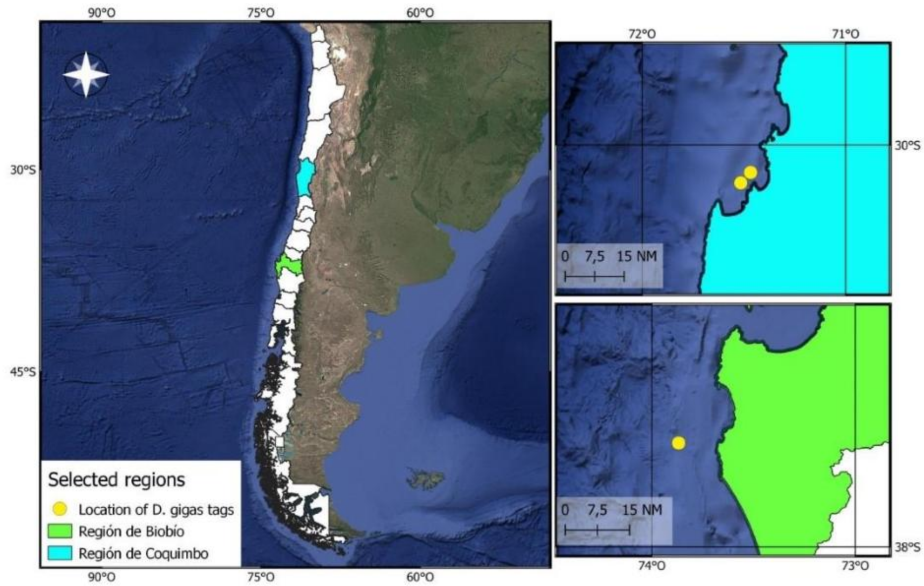

Figure 2. Geographic locations of the tagging sites for *Dosidicus gigas*: Coquimbo and Biobío Regions.

Guanaqueros Squids

Squid-1, tagged off Guanaqueros in March 2024 was tracked for 5 days (Table 1), exhibiting a clear diel vertical migration pattern, with deeper movements during daylight hours. It spent a considerable portion of its time at depths greater than 40 meters (30.3% during the day, 35.8% at night), although it also frequently occupied surface waters (0–5 m), especially at night (15.0%) (Figure 3).

The individual maintained an average depth of 35.6 meters, reaching a maximum of 205 meters. It experienced mean water temperatures of 14.6°C, favoring cooler waters (12.5–13.0°C) during the day and warmer temperatures (17.5–18.0°C) at night (Figure 4). Horizontal displacement was estimated at approximately 100 kilometers in a northwesterly direction, coinciding with a gradual temperature increase (Figure 5).

Throughout its track, the squid remained in relatively well-oxygenated waters (5.5–6.0 mL/L), spending nearly one-fifth of both its daytime and nighttime activity within this oxygen range (Figure 6).

Squid-2, tagged off Guanaqueros in October 2024, was tracked for 6.4 days (Table 1) before a presumed mortality event, indicated by a final recorded depth exceeding 1,500 meters. Throughout the tracking period, the squid maintained an average depth of 111 meters, with vertical movements ranging from 1 to 740 meters (Figure 5).

A diel vertical migration pattern was observed, with the squid occupying shallower depths (20–30 m) during the day and slightly deeper layers (30–40 m) at night. When the water column was segmented into 40-meter intervals, the individual spent 36% of nighttime hours above 40 meters, versus 21.1%

during the day. Below this layer, the squid remained 26.7% of the time during the day and only 10.4% at night (Figure 3).

The mean experienced temperature was 12.2°C, with a range from 5.5°C to 14.4°C. Daytime activity was concentrated in the 14.0–14.5°C range (11.5%), while nighttime behavior peaked in the 13.5–14.0°C range (20.3%) (Figure 4). Horizontally, the squid moved approximately 150 kilometers northwest along the Bahía Coquimbo coastline. As it moved offshore, less frequent deep dives—mirroring the behavioral trend observed in Squid-1.

This individual also showed regular exposure to hypoxic waters near the oxycline. During the day, 13.3% of the time was spent in waters with oxygen levels <1.0 mL/L, increasing to 24.0% in layers below 1.5 mL/L. At night, it spent 10.5% of its time in waters with 1.5–2.0 mL/L and 8.2% in more oxygenated deep layers (5.5–6.0 mL/L) (Figure 6).

Lebu Squids

Squid-3, tagged in June 2024, was tracked for nearly 7 days (Table 1), showing a marked diel vertical migration pattern. It reached a maximum depth of 380 meters and maintained an average depth of 133 meters (Figure 5). During nighttime, it spent 35.5% of its time above 40 meters, particularly in the 1–5 m layer (12.6%), while during the day it occupied these shallow layers only 4.9% of the time. In contrast, deeper waters (>40 m) were consistently used during both diel phases (26.0% at night, 24.5% during the day), with daytime activity concentrated in the 300–350 m layer (7.9%) (Figure 3).

The temperature along its trajectory ranged from 9.0°C to 13.2°C, with a mean of 11.5°C. The squid showed a thermal preference for the 12.5–13.0°C range, spending 30.2% of the nighttime and 7.5% of the daytime within this interval (Figure 4). It moved approximately 150 km in a northwestward direction from Lebu to the Golfo de Arauco.

Environmentally, the squid spent a significant portion of time in hypoxic waters below the oxycline. During daylight hours, 11.8% of its time was spent in waters with <1.0 mL/L oxygen, and 9.6% in the 1.0–2.0 mL/L range. At night, 17.0% of the time occurred in the 0.5–1.0 mL/L range, and 11.2% in well-oxygenated surface waters (>5.5 mL/L) (Figure 6).

Squid-4, also tagged in June 2024, was tracked for 4 days (Table 1), with vertical movements ranging from 1.5 to 422 meters and an average depth of 110 meters (Figure 5). Its vertical distribution closely resembled that of Squid-3. During nighttime, 37.4% of the time above 40 meters and 29.5% below; during the day, 8.1% of the time was spent above 40 meters and 21.6% below. The squid's most used layers were 10–20 meters at night (16.7%) and 100–150 meters during the day (5.9%) (Figure 3).

Thermal preferences were also consistent with those of Squid-3, favoring the 12.5–13.0°C range, where it spent 24.2% of its nighttime and 9.7% of its daytime activity (Figure 4). Horizontally, it moved an estimated 75 km in an offshore direction, influenced by local oceanographic conditions near Punta Lavapié.

Regarding oxygen exposure, Squid-4 predominantly occupied surface waters with oxygen concentrations of 5.5–6.0 mL/L (30% of total time). Time spent in hypoxic waters (<1.0 mL/L) varied with diel phase: 10.7% at night and 5.8% during the day (Figure 6).

Table 1. Identification of individuals recorded with MiniPAT

Squid	Start Time	Final Time	Trajectory duration (hours)	Location names
Squid-1	16/03/2024 08:00	20/03/2024 11:55	98,3	Guanaqueros
Squid-2	23/10/2024 01:58	29/10/2024 11:38	153,8	Guanaqueros
Squid-3	24/06/2024 23:18	01/07/2024 22:32	166,8	Lebu
Squid-4	24/06/2024 23:07	28/06/2024 23:40	96,1	Lebu

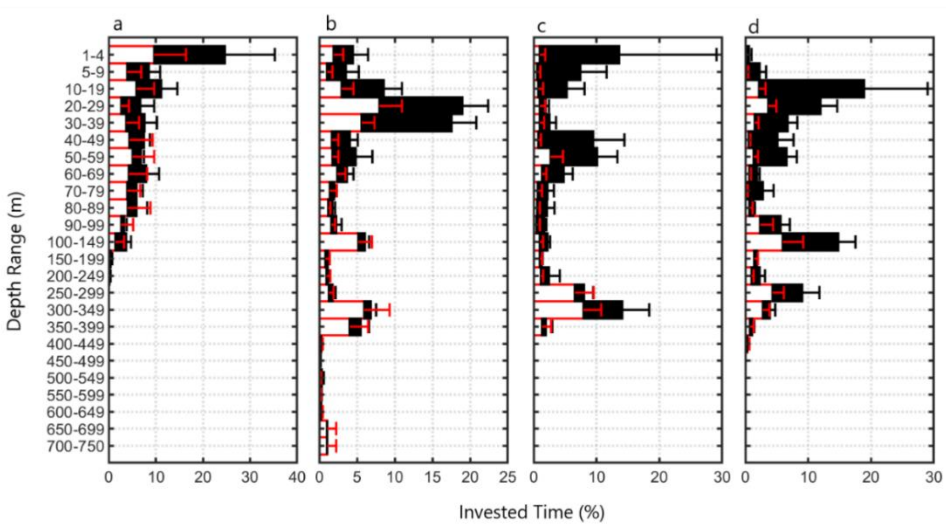

Figure 3. Relative distribution of invested time (%) at different depth intervals by squids from Guanaqueros (Squid-1 (a) and Squid-2 (b)) and Lebu (Squid-3 (c) and Squid-4 (d)). Dark bars correspond to nighttime activity and light bars to daytime activity. Standard deviations are shown in black (night) and red (day).

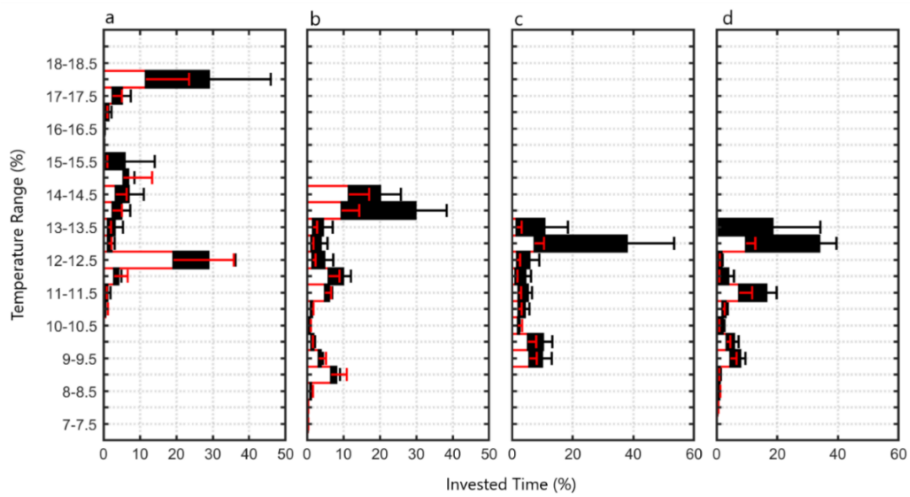

Figura 4. Relative time distribution (%) spent within temperature intervalsby squids from Guanaqueros (Squid-1 (a) and Squid-2 (b)) and Lebu (Squid-3 (c) and Squid-4 (d)). Dark bars represent nighttime activity, and light bars represent daytime activity. Standard deviations are shown in black (night) and red (day). Temperature bins are 0.5° intervals from 7°C to 19°C.

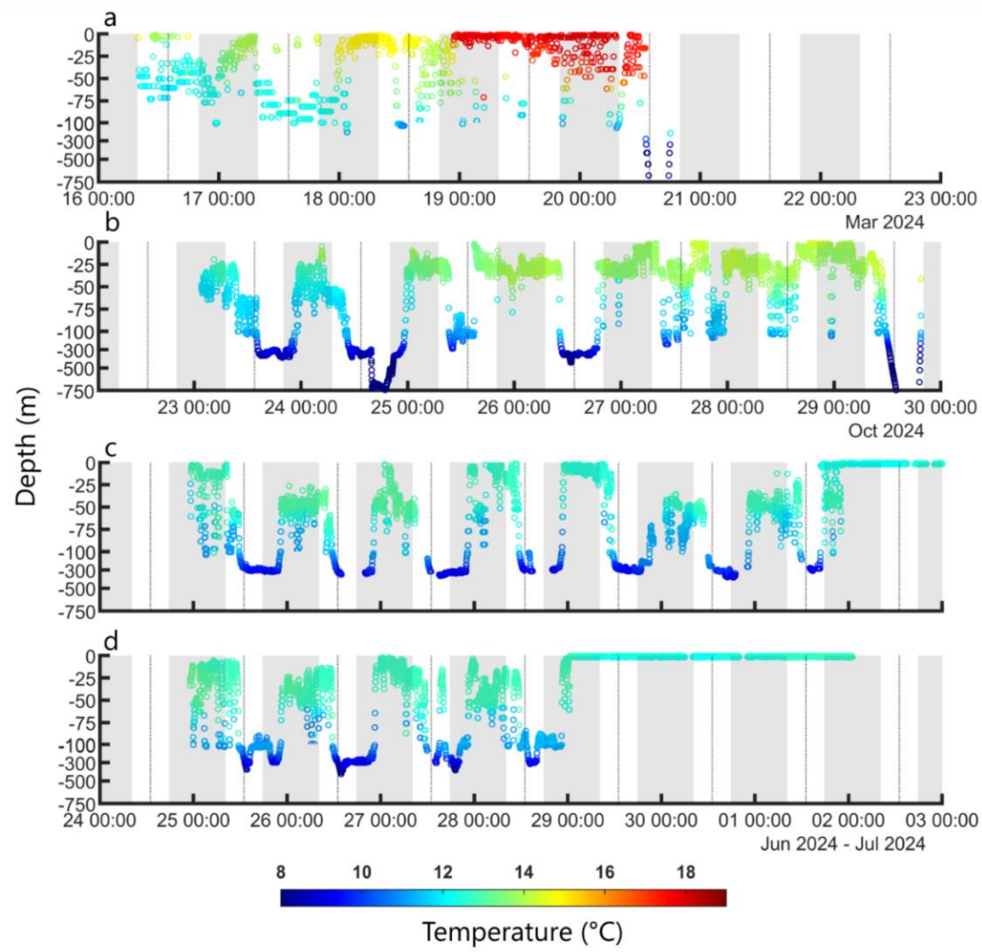

Figure 5. Time series of vertical movements of *D. gigas* tagged in Guanaqueros (Squid-1 (a) and Squid-2 (b)) and Lebu (Squid-3 (c) and Squid-4 (d)). The color scale indicates temperature experience at depth. Gray-shaded areas represent nighttime, while white areas denote daytime. Dashed vertical lines indicate 12:00 pm.

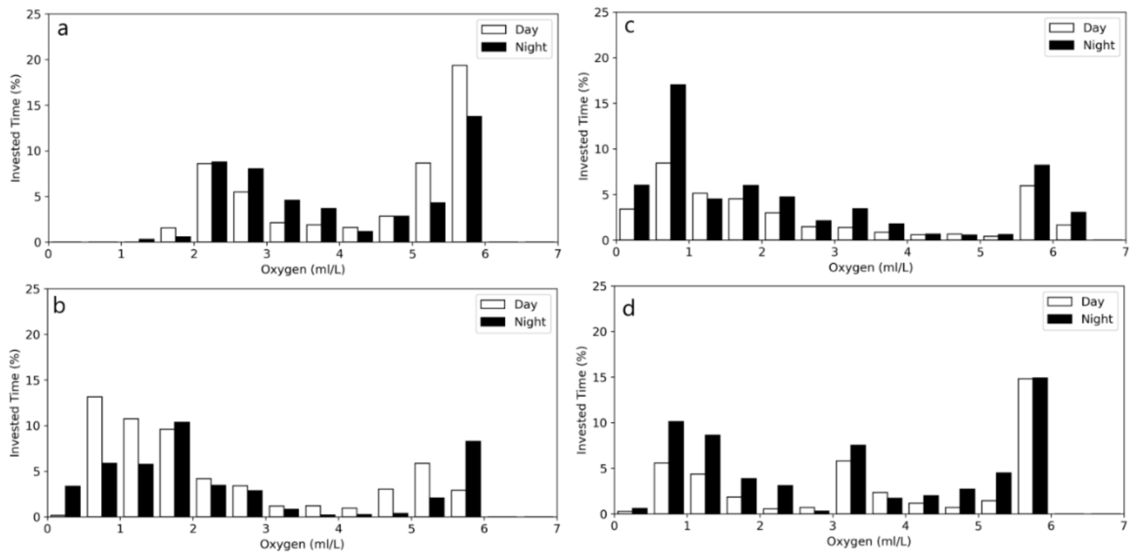

Figure 6. Histogram of oxygen concentrations encountered by tagged *D. gigas* in Guanaqueros (a, b) and Lebu (c, d). Black bars represent nighttime exposure, and white bars represent daytime exposure. Oxygen levels are binned in 1 mL/L intervals.

Discussion

This study provides the first satellite telemetry evidence of diel vertical migration (DVM) in *Dosidicus gigas* in central Chile, based on four individuals tagged in the Coquimbo and Biobío regions. All specimens displayed a consistent DVM pattern—descending to deeper, hypoxic layers during the day and ascending to shallower, warmer waters at night—mirroring patterns previously reported in the Gulf of California, Peru, and Mexico (e.g., Gilly et al. 2006; Sakai et al. 2017).

Despite general similarities, some regional differences were observed. Individuals tagged in Coquimbo often occupied shallow depths even during the day, while those in Biobío exhibited deeper nighttime dives. Oxygen data revealed that squids frequently occupied layers below 2 mL/L and above 5 mL/L, suggesting a preference for conditions near the oxycline. Notably, Squid-1 spent more time in well-oxygenated surface waters, possibly reflecting offshore movement into warmer water masses.

These results suggest that DVM in *D. gigas* is a flexible behavior influenced by environmental factors such as prey distribution, temperature, and oxygen availability. The squid's ability to forage in low-oxygen zones likely supports its rapid growth and opportunistic feeding strategy, as observed in prior dietary studies. Predator avoidance may also influence depth use, particularly given the presence of deep-diving predators such as swordfish and sperm whales.

In summary, the observed behavioral plasticity supports the ecological adaptability of *D. gigas*, enabling it to exploit a wide vertical and geographic range across variable oceanographic conditions.

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