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Short-term variability of fish larvae assemblages in Malpelo island, an isolated oceanic island in the Eastern Tropical Pacific

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ABSTRACT

Introduction: Oceanic islands are key biogeographic features that influence the distribution and diversity of marine organisms, particularly in tropical ecosystems. Malpelo Island, located 380 km off the Colombian Pacific coast, is the only oceanic island in the country and a strategic site for assessing ichthyoplankton dynamics in the Eastern Tropical Pacific (ETP).

Objective: To characterize the taxonomic composition and spatial ecological structure of fish larvae assemblages associated with Malpelo Island in the Colombian Eastern Tropical Pacific under prevailing hydrographic conditions. Specifically, to assess differences in species richness, abundance, and diel vertical distribution between insular and adjacent offshore sites. These patterns are interpreted in the context of localized larval retention and vertical migratory behaviors, potentially shaped by insular oceanographic features.

Methods: Short-term variability in larval fish assemblages was evaluated using vertical zooplankton trawls conducted in September 2012 and July 2016 across three depth strata. Fish larvae were identified to the lowest possible taxonomic level, and hydrographic profiles of temperature and salinity were obtained using CTD casts.

Results: A total of 26 taxonomic units representing eight orders and twelve families were recorded. Assemblages near the island included epipelagic and reef-associated taxa such as *Sardinops sagax* and *Anchoa* spp., while offshore stations were dominated by mesopelagic species including *Diogenichthys laternatus* and *Vinciguerria lucetia*. Although larval abundance did not differ significantly between locations (MW; p = 0.38), assemblage similarity was low (45 %) and species turnover high (79 %). Larvae exhibited diel vertical migration, occupying deeper strata (50-100 m) during daylight and ascending to shallower layers (0-50 m) at night, influenced by local thermocline and halocline depth.

Conclusions: These findings highlight the ecological distinctiveness of Malpelo Island and its role in supporting larval fish diversity in tropical oceanic environments. The results provide baseline data for future ecological monitoring and conservation planning in insular marine habitats of the ETP.

Key words: ichthyoplankton; oceanic islands; assemblages; diversity; vertical migration.

RESUMEN

Variabilidad a corto plazo de los ensamblajes de ictioplancton en isla Malpelo, una isla oceánica aislada en el Pacífico Oriental Tropical

Introducción: Las islas oceánicas son elementos biogeográficos clave que influyen en la distribución y diversidad de organismos marinos, especialmente en ecosistemas tropicales. La isla de Malpelo, ubicada a 380 km de la costa pacífica colombiana, es la única isla oceánica del país y constituye un sitio estratégico para evaluar la dinámica del ictioplancton en el Pacífico Tropical Oriental (POT).
Objetivo: Caracterizar la composición taxonómica y la estructura ecológica espacial de los ensamblajes de larvas de peces asociados a la Isla de Malpelo, en el Pacífico Oriental Tropical colombiano, bajo las condiciones hidrográficas predominantes. Específicamente, se evalúan las diferencias en la riqueza de especies, la abundancia y la distribución vertical diaria entre sitios insulares y oceánicos adyacentes. Estos patrones se interpretan en el contexto de mecanismos locales de retención larval y comportamientos migratorios verticales, posiblemente modulados por las características oceanográficas insulares.
Métodos: Se examinó la variabilidad temporal a corto plazo de los ensamblajes de larvas de peces mediante arrastres verticales de zooplancton realizados en septiembre de 2012 y julio de 2016, en tres estratos de profundidad. Las larvas fueron identificadas al nivel taxonómico más bajo posible, y se obtuvieron perfiles hidrográficos de temperatura y salinidad mediante lanzamientos de CTD.
Resultados: Se registraron 26 unidades taxonómicas pertenecientes a ocho órdenes y doce familias. Los ensamblajes cercanos a la isla incluyeron especies epipelágicas y asociadas a arrecifes como *Sardinops sagax* y *Anchoa* spp., mientras que las estaciones alejadas estuvieron dominadas por especies mesopelágicas como *Diogenichthys laternatus* y *Vinciguerria lucetia*. Aunque no se detectaron diferencias significativas en la abundancia larval entre las estaciones (MW; p = 0.38), la similitud entre ensamblajes fue baja (45 %) y el recambio de especies alto (79 %). Las larvas mostraron migración vertical diurna, ubicándose en estratos profundos (50-100 m) durante el día y ascendiendo a capas superficiales (0-50 m) por la noche, influenciadas por la profundidad local de la termoclina y haloclina.
Conclusiones: Estos resultados destacan la singularidad ecológica de la isla de Malpelo y su papel en el mantenimiento de la diversidad larval de peces en ambientes oceánicos tropicales. El estudio aporta datos de referencia esenciales para el monitoreo ecológico y la planificación de conservación en hábitats marinos insulares del POT.

Palabras clave: ictioplancton; islas oceánicas; ensamblajes; diversidad; migración vertical.

INTRODUCTION

Oceanic islands play a vital role in shaping the spatial distribution of marine fauna. These open-ocean enclaves often exhibit enhanced primary productivity and zooplankton abundance compared to surrounding waters, supporting high fish species richness and biomass (Boehlert & Mundy, 1993; Lima et al., 2016; Macedo-Soares et al., 2012; Morato et al., 2010). They also offer favorable environmental conditions for the survival and development of early life stages of both pelagic and resident fish species (Dower & Perry, 2001). The composition of larval fish assemblages associated with oceanic islands appears to be driven by a complex interplay of adult reproductive strategies, local physical and biological conditions, and species-specific ecological and behavioral traits (Boehlert & Mundy, 1993; Harris et al., 2020; Moyano & Hernández-León, 2011; Suthers et al., 2006). In these habitats, the study of vertical and horizontal distribution patterns of ichthyoplankton is central to larval fish ecology, closely linked to local hydrographic processes and diel vertical migration behaviors (Höffle et al., 2013; Leis, 2006; Munk, 2016; Olivar et al., 2018).

The Eastern Tropical Pacific (ETP) is typified by warm, low-salinity surface waters and a shallow thermocline, shaped by the South Equatorial Current and the intrusion of cooler, saline subtropical waters to the NorthWest. Seasonal and interannual dynamics, particularly driven by the El Niño–Southern Oscillation, influence temperature, currents, and biological productivity. Despite seasonal coastal upwelling

that enhances productivity, iron limitation often constrains phytoplankton growth. Below the thermocline, oxygen minimum zones and low pH levels contribute to challenging biogeochemical conditions (Fiedler & Talley, 2006; Kessler, 2006; Pennington et al., 2006; Wang & Fiedler, 2006). The Colombian sector of the ETP comprises the easternmost portion of this region and is part of the Panama Bight marine ecoregion (Amador et al., 2016; Spalding et al., 2007). For most of the year (April–December), this area is influenced by persistent southWesterly winds, fostering surface thermal homogeneity and stratification. Reported hydrographic values include a 21 °C isotherm at 35 m, a 17 °C isotherm at 125 m, and a mixed layer depth of 22 m (Amador et al., 2016; Corredor-Acosta et al., 2020; Rodríguez-Rubio & Giraldo, 2011).

Recent studies in other insular systems have revealed that ichthyoplankton assemblages are often structured by mesoscale oceanographic features such as eddies, fronts, and upwelling zones, which influence larval retention, transport, and survival (Aceves-Medina et al., 2018; Zhang et al., 2021). These features can create localized hotspots of larval abundance and diversity, particularly around submarine ridges and island slopes where vertical mixing and nutrient enrichment occur. For example, research conducted above the Ninety East Ridge in the Eastern Indian Ocean demonstrated that ichthyoplankton abundance was positively correlated with sea surface salinity, temperature, and chlorophyll-a concentration, suggesting that insular productivity gradients play a key role in shaping larval distributions (Zhang et al., 2021). Such findings underscore the importance of integrating hydrographic and biological data to understand larval fish ecology in oceanic island contexts.

Malpelo Island is the sole oceanic island in this Colombian portion of the ETP. It represents the emergent peak of the Malpelo Ridge, a submarine mountain system rising from depths of nearly 4 000 m, featuring a central rocky promontory reaching 300 m above sea level and associated outcrops (Rodríguez-Rubio & Giraldo, 2011). Unlike other oceanic areas in the ETP, biological and ecological data on ichthyoplankton around Malpelo remain limited (Comisión Colombiana del Océano, 2018). This is largely due to research efforts traditionally focusing on neritic and coastal zones (Beltrán-León & Rios-Herrera, 2000; Calle-Bonilla et al., 2017; Escarria et al., 2007; Martínez-Aguilar et al., 2010; Medina-Contreras et al., 2014; Ramírez-Mártinez et al., 2022; Valencia et al., 2024). Nonetheless, recent surveys have reported larvae of *Synchiropus atrilabiatus* (Beltrán-León et al., 2016), and *Diplophos proximus* (Beltrán-León & Ríos-Herrera, 2018), in nearshore Malpelo waters.

In the Colombian Pacific, comparative studies across neritic and oceanic areas—including Malpelo island—have shown that ichthyoplankton composition varies markedly with distance from shore and habitat type (Beltrán-León & Morales-Osorio, 2021). Coastal areas tend to be dominated by Engraulidae and other neritic taxa, while oceanic zones such as Malpelo exhibit higher proportions of mesopelagic families like Phosichthyidae and Bregmacerotidae. These patterns reflect both the biogeographic isolation of oceanic islands and the influence of regional oceanography on larval dispersal and assemblage structure. Understanding these dynamics is essential for assessing the ecological connectivity of insular systems and informing conservation strategies that account for larval transport and recruitment processes.

This study examines the taxonomic composition and spatial ecological patterns of fish larvae assemblages associated with an isolated oceanic island in the Colombian Eastern Tropical Pacific (ETP), under prevailing hydrographic conditions. We hypothesize that ichthyoplankton assemblages near Malpelo Island exhibit significantly greater species richness and abundance compared to adjacent offshore sites. Furthermore, we propose that both areas display comparable diel vertical stratification, with larvae occupying distinct depth strata during daytime and nighttime periods. These patterns are interpreted as evidence of localized retention mechanisms and vertical

migratory behaviors shaped by insular oceanographic features.

MATERIALS AND METHODS

Study area: Malpelo Island (4°00'08" N & 81°36'31" W) lies approximately 380 km off the Colombian mainland (Fig. 1). Designated as a Sanctuary of Fauna and Flora (SFF) in 1995, it forms a critical node within the Eastern Tropical Pacific Marine Corridor (CMAR), a transboundary conservation initiative (Enright et al., 2021; Murillo, 2015). The pelagic environment surrounding Malpelo is shaped by the interaction of three distinct water masses, Superficial Tropical Water (ATS): Characterized by temperatures > 25 °C and salinity < 34, this water mass dominates the upper 100 m and is typical of regions NorthNorth of the equator; Equatorial Surface Water (ASE): With temperatures < 25 °C and salinity > 34, ASE originates from equatorial upwelling and influences surface conditions along the equatorial belt, and Subtropical Subsurface Water (ASSST): Found between 100 and 115 m depth, this water mass exhibits intermediate properties (19-25 °C, 34.6-35.4 salinity) and is likely derived from Central Pacific Water intrusions (Rodríguez-Rubio & Giraldo, 2011). A general description of the surface circulation patterns in the study area during March and September can be found in Valencia et al. (2013).

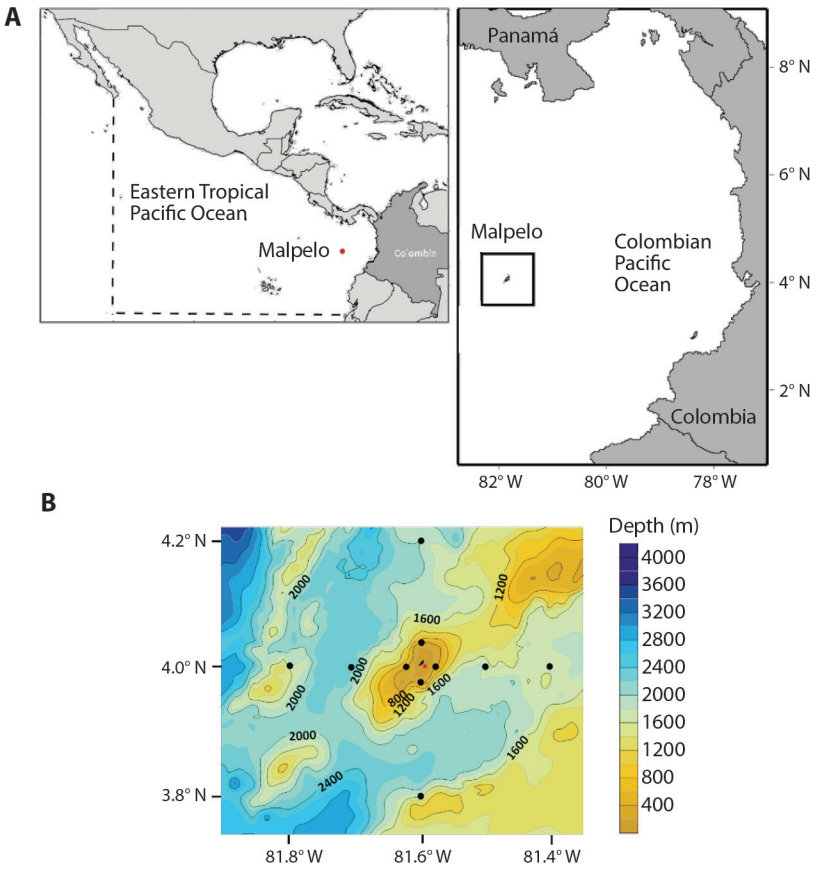

Fig. 1. A. Geographic location of Malpelo Island within the Tropical Eastern Pacific, emphasizing its position in the Colombian Pacific region. **B.** Bathymetric representation of the study area within the Malpelo Fauna and Flora Sanctuary (SFF Malpelo), indicating the positions of biological sampling stations surveyed during the 2012 (black dot) and 2016 (red star) expeditions.

The primary climatological forcing in the study area is driven by seasonal variability in the equatorial trade winds system, which modulates mesoscale circulation patterns and influences regional productivity (Corredor-Acosta et al., 2020; Devis-Morales et al., 2008; Rodríguez-Rubio & Stuardo, 2002; Rodríguez-Rubio et al., 2003). Average surface circulation exhibits meridional characteristics, with southeastward flow observed in March (mean current velocity: 0.59 m/s) and Northward flow in September (mean current velocity: 0.54 m/s) (Rodríguez-Rubio & Giraldo, 2011).

Field methodology: This study was conducted during two oceanographic campaigns involving the collection of stratified vertical zooplankton samples. The first campaign took place aboard the ARC Providencia in September 2012, as part of the ERFEN XV-CPC LI oceanographic cruise. Sampling was performed across a predefined grid comprising ten biological stations. The second campaign occurred aboard the ARC Buenaventura in July 2016, targeting a fixed station located in shallow anchoring zones near Malpelo Island. Sampling was conducted at two-hour intervals between 20:00 h on June 30 and 04:00 h on July 1 (Fig. 1).

Temperature and salinity profiles were recorded from the surface to a depth of 150 m, or to the seafloor in shallow anchoring zones, using a Seabird 19 CTD in 2012 and a YSI-CastAway CTD in 2016. Vertical variability in hydrographic conditions was assessed via continuous profile analyses. Stratified vertical zooplankton sampling was conducted at each station using a 1.9 m long conical net (0.3 m mouth diameter, 250 μm mesh), equipped with a General Oceanic opening and closing system. In the 2012 campaign, tows were performed in three discrete depth intervals: 0-50 m, 50-100 m, and 100-150 m. During the 2016 campaign, modified depth strata were sampled at 0-20 m, 20-50 m, and 50-90 m, tailored to the shallower bathymetry near Malpelo Island. Zooplankton samples were preserved in buffered formaldehyde prepared in seawater at a final concentration of 4 % and transported to the laboratory for taxonomic analysis, and were subsequently sorted, counted, and identified to the lowest feasible taxonomic level using standard ichthyoplankton identification keys (Beltrán-León & Rios-Herrera, 2000; Moser, 1996; Richards, 2005). The identified specimens were deposited in the Zoological Practice Collection of the Department of Biology at Universidad del Valle.

Sampling analysis: Standardized larval fish abundance was calculated according to established protocols (Smith & Richardson, 1977; Moser, 1996), with methodological updates reflecting recent advances in ichthyoplankton survey design (Ma et al., 2025). Abundance was expressed as individuals per square meter (ind/m^2) by dividing the number of larvae collected by the volume of filtered water per tow and subsequently multiplying by the vertical extent of the sampled stratum. Total larval abundance per station was derived by summing the abundance values obtained across all stratified depth intervals.

Species richness of marine fish larvae in the study area was estimated to be using the non-parametric Jackknife one estimator. This approach, which emphasizes the frequency of singleton taxa across sampling units, is particularly suited to ichthyoplankton communities marked by high proportions of rare species and constrained sampling effort (Castilho et al., 2016). By reducing bias associated with underrepresentation of low-abundance taxa, Jackknife 1 provides a robust approximation of expected richness. Its application is especially recommended in tropical aquatic environments, where spatial and temporal heterogeneity frequently limits sampling representativeness (Jaonalison et al., 2020).

Vertical variations in larval fish abundance were evaluated using data from the 2012 sampling campaign. To quantify inter-strata abundance shifts, the Vertical Distribution Index (VDI) was calculated as: VDI = ln (n1/n2), where n1 and n2 represent larval abundances (ind/m^2) in two contiguous depth layers. This index accounts for relative abundance gradients

in the vertical plane and is sensitive to diel fluctuations, given that sampling tows were conducted at various times throughout the day. Additionally, a complementary graphical assessment of larval abundance patterns was conducted at a fixed station during the 2016 campaign. Samples were collected every two hours across three predefined depth strata, enabling temporal resolution of vertical migratory behavior under island-influenced hydrographic conditions.

To characterize the structure and heterogeneity of larval fish assemblages, we applied two complementary ecological diversity indices: Shannon (H') and Simpson (D). The Shannon index, is sensitive to species richness and evenness, making it well-suited for detecting spatial shifts in community diversity (Sponaugle et al., 2002). The Simpson index, by contrast, emphasizes dominance by weighting the most abundant taxa more heavily, providing insight into community resilience and species evenness (Magurran, 2004). These indices have been widely validated in marine ecological studies and are recommended for biodiversity assessments in tropical environments (Cowen & Sponaugle, 2009; Guyah et al., 2021; Paris & Cowen, 2004). To assess statistical differences in diversity and dominance between nearshore and offshore assemblages, we employed a permutation-based comparison using 999 iterations. Permutation tests are non-parametric and distribution-free, making them especially appropriate for ecological datasets that exhibit non-normality and zero inflation (Anderson, 2001). This approach enhances inference quality while minimizing assumptions about underlying data structure.

To compare total larval fish abundance, community composition, and species turnover between nearshore (0.5 km) and offshore (12 km) zones around Malpelo Island, three statistical approaches were employed: the non-parametric Mann-Whitney U test, the Bray-Curtis similarity index, and Whittaker's beta diversity metric. The Bray–Curtis index quantified compositional dissimilarity based on relative abundance data, offering robustness against the disproportionate influence of dominant taxa and suitability for ecological datasets (Hardersen & La Porta, 2023). Whittaker's beta diversity provided an integrative measure of species turnover across spatial units, enabling assessment of heterogeneity and connectivity in pelagic larval assemblages (Maslakova et al., 2022). Both metrics have demonstrated efficacy in recent ichthyoplankton research, allowing for the detection of spatial aggregation, dispersal patterns, and biophysical coupling modulated by environmental gradients (Zhao et al., 2025).

RESULTS

Surface temperature ranged from 26.6 to 27.3 °C across both sampling periods, while surface salinity varied between 30.5 and 32.5 UPS in 2012, and from 33.1 to 33.9 UPS in 2016 (Fig. 2). The 21 °C isotherm and the 34 UPS isohaline were found at shallower depths near Malpelo Island (30 m, 2016 campaign) compared to the surrounding oceanic zone (50 m, 2012 campaign), indicating localized stratification patterns influenced by topographic and hydrographic conditions (Fig. 2).

A total of 93 fish larvae were collected during two oceanographic sampling campaigns around Malpelo island in the Eastern Tropical Pacific: 71 specimens in 2012 and 22 in 2016. These larvae were identified and grouped into 26 taxonomic units (TUs), representing eight orders and twelve families. In 2012, the assemblage was dominated by the family Myctophidae, which accounted for 66.3 % of all specimens (Table 1), with *Diogenichthys laternatus* and *Vinciguerria lucetia* as the most abundant taxa. In contrast, the 2016 assemblage was characterized by a higher relative abundance of the families Engraulidae (27.5 %) and Clupeidae (22.7 %), with *Sardinops sagax* and *Anchoa* sp. as the dominant taxa (Table 1).

The sampling effort yielded a completeness of 78 %, based on a first-order Jackknife richness estimator that projected 33.37 species, compared to the 26 species recorded. This discrepancy suggests that additional sampling could reveal further diversity, particularly

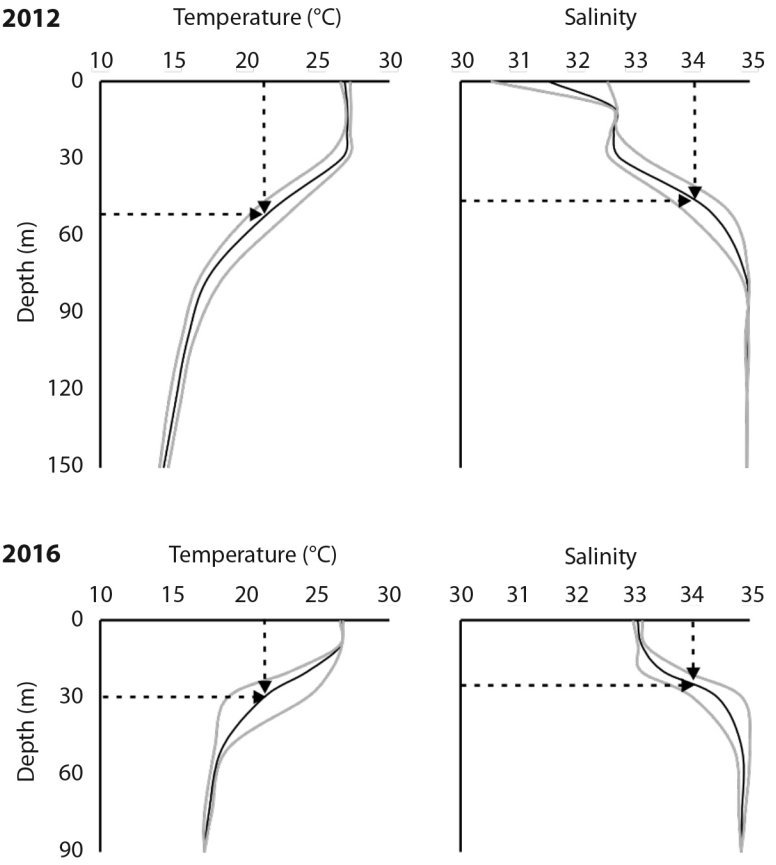

Fig. 2. Vertical variation of temperature and salinity around Malpelo Island during the study period. The average record (black line) and the maximum and minimum records (gray lines) are presented. $n_{2012} = 10$, $n_{2016} = 5$. Dotted line shows depth of 21°C isotherm and 34 UPS isohaline.

among rare or low-abundance taxa. Compositional similarity between zones was relatively low (Bray-Curtis index = 0.41), underscoring pronounced ecological differentiation across the marine landscape. Furthermore, no statistically significant differences in larval fish abundance were detected between nearshore and offshore zones surrounding Malpelo Island (Mann–Whitney test, p = 0.41). However, significant differences were observed in both diversity and dominance metrics. Shannon diversity was notably higher offshore (Shannon index: Inshore = 1.48, Offshore = 2.03, p = 0.001), while dominance was lower offshore as indicated by the Simpson index (Inshore = 0.70, Offshore = 0.79, p = 0.045), suggesting greater evenness and heterogeneity in offshore assemblages. Additionally, β-diversity analysis revealed a high species turnover rate (Whittaker index = 0.71) between the zones, indicating substantial species replacement along an approximately 12 km spatial gradient. This turnover would be strongly influenced by infrequent taxonomic groups (Table 1), implying the presence of environmental discontinuities or oceanographic fronts that may modulate larval distribution patterns in the region.

Fish larvae exhibited distinct diel vertical distribution patterns throughout the sampling periods. During daylight hours, larvae predominantly aggregated within the 50-100 m depth stratum, whereas at night they were

Table 1
Identities of the fish larvae taxonomic units (TU) collected during the 2012 campaign and 2016 sampling at Malpelo island.

Orden	Familia	Especie	2012 AB (%)	2016 AB (%)
Anguilliformes	Muraenidae	TU Sp. 1	1.6	
Clupeiformes	Clupeidae	*Sardinops sagax*		22.7
	Engraulidae	*Anchoa* sp.		18.1
		Cetengraulis mysticetus		9.4
Stomiiformes	Phosichthyidae	*Vinciguerria lucetia*	26.2	9.1
Aulopiformes	Paralepipidae	*Lestidiops neles cf.*	1.6	
Myctophiformes	Myctophidae	*Diaphus* sp.	3.3	
		Diogenichthys laternatus	42.6	9.1
		Hygophum sp.	2.1	
		Lampanyctus sp. 1	1.6	
		Lampanyctus sp. 2	1.6	
		Myctophum sp.	2.1	
		Nannobrachium sp. 1	1.6	
		Nannobrachium sp. 2	1.6	
		Symbolophorus sp.1	1.5	
		TU Sp. 2	1.6	
		TU Sp. 3	1.6	
		TU Sp. 4	2,1	
		TU Sp. 5	1.6	
		TU Sp. 6	3.5	
Gadiformes	Bregmacerotidae	*Bregmaceros bathymaster*	1.6	
Beloniformes	Hemiramphidae	TU Sp. 7	2.1	
Carangiformes	Coryphaenidae	*Coryphaena hippurus*		9.4
Perciformes	Haemulidae	*Anisotremus* sp.		9.1
Blenniformes	Gobiesocidae	*Gobiesox* sp.		4.5
Labriformes	Labridae	*Xyrichthys* sp.		4.5
		poor condition	0.6	4.1

AB: relative abundance (% Larvae/m^2). Phylogenetic organization according to Betancur et al. (2017).

primarily concentrated in the surface layer (0-50 m) of the water column (Fig. 3A). This behavior suggests short-scale vertical migratory movements, likely associated with predator avoidance and foraging efficiency. A similar trend was observed during the 2016 sampling period, when larval abundance peaked in the upper stratum between 20:00 and 02:00, followed by a gradual decline thereafter (Fig. 3B).

DISCUSSION

This study provides the first comprehensive characterization of larval fish assemblages around Malpelo Island, revealing distinct spatial and vertical distribution patterns. The assemblages exhibited high taxonomic diversity, including mesopelagic, epipelagic, and reef-associated taxa, with diel vertical migration modulated by thermocline depth. In oceanic island systems, larval fish assemblages are typically structured by complex interactions among hydrographic conditions, habitat heterogeneity, and dispersal dynamics (Cowen & Sponaugle, 2009; Sponaugle et al., 2002). Around Malpelo Island, elevated species richness and high turnover rates highlight the ecological complexity of the nearshore–offshore gradient. These patterns align with previous findings that island wakes, mesoscale eddies,

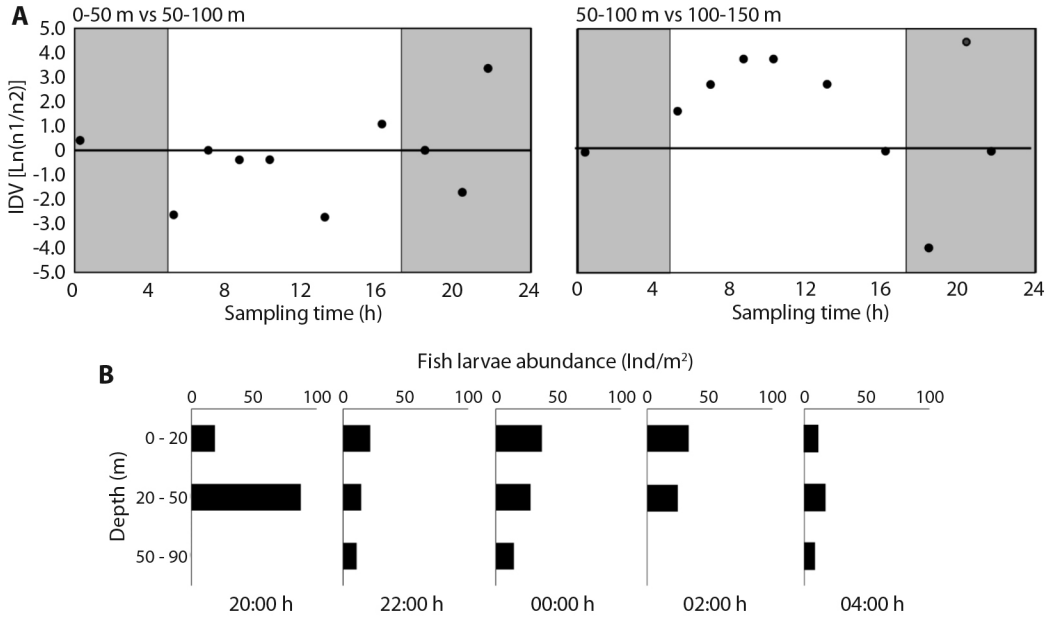

Fig. 3. A. Vertical Distribution Index (IDV) of fish larvae in relation to sampling time at Malpelo Island during 2012. The shaded region indicates the nocturnal period. **B.** Temporal variation in fish larval abundance across three depth strata from June 30 to July 1, 2016, near Malpelo Island, highlighting diel vertical migration patterns.

and bathymetric discontinuities can generate retention zones or dispersal barriers, thereby influencing larval community composition over relatively short spatial scales (Lobel & Robinson, 1986; Macedo-Soares et al., 2012). The pronounced turnover observed between sampling zones may reflect shifts in habitat structure or hydrographic discontinuities that compartmentalize larval habitats, particularly for species with brief planktonic durations or specialized behavioral traits.

The thermal and saline conditions recorded during this study were comparable to those reported by Rodríguez-Rubio and Giraldo (2011) for the second semester of the year. Notably, the thermocline and halocline were shallower near Malpelo Island than in adjacent offshore areas, likely due to the island mass effect on local circulation (de Falco et al., 2022). This phenomenon—where the physical presence of an island obstructs flow and induces vertical compression of water masses—is known to enhance micro-upwelling and nutrient availability, thereby increasing surface chlorophyll-a concentrations (Andrade et al., 2014; Bourdin et al., 2025; Caldeira et al., 2005; Hasegawa et al., 2009; Messié et al., 2020; Rodríguez et al., 2001). Such conditions, combined with the availability of habitat and refugia, contribute to the designation of oceanic island systems as biodiversity hotspots and critical sources of eggs and larvae (Boehlert & Mundy, 1993; Bowen et al., 2013; Cortés, 2012; Cowie & Holland, 2006; de Santana et al., 2020; Hernández-León, 2009; Morato et al., 2010; Requena et al., 2020).

Larval assemblages near Malpelo Island were taxonomically diverse, comprising mesopelagic species such as *Diogenichthys laternatus* and *Vinciguerria lucetia* (Myctophidae), epipelagic taxa including *Sardinops sagax* (Clupeidae) and *Anchoa* sp. (Engraulidae), and reef-associated species like *Anisotremus* sp. (Haemulidae) and *Coryphaena hippurus* (Coryphaenidae). This mixed composition is characteristic of oceanic island environments, where

larval fish from reef, epipelagic, and mesopelagic habitats co-occur due to localized retention and habitat complexity (Boehlert & Mundy, 1993; Hunte et al., 1995; Kitchens & Rooker, 2014; Logerwell & Smith, 2001; Macedo-Soares et al., 2012; Oxenford, 1999; Sassa et al., 2004; Moyano et al., 2009).

Vertical distribution patterns revealed diel migratory behavior, with larvae aggregating at 50-100 m during daylight and ascending to 0-50 m at night. This behavior has been widely documented in both coastal and oceanic systems (Auth et al., 2007; Boehlert & Mundy, 1993; Boehlert et al., 1992; Compaire et al., 2021; Govindarajan et al., 2023; Hawes et al., 2020; Sabatés, 2004; Suntsov, 2002; Suthers et al., 2006). The depth of the thermocline appears to modulate the extent of these movements, serving as a key determinant of larval vertical positioning (Ahlstrom, 1959; Alvarez et al., 2021; Boehlert et al., 1985; Leis, 2006; Moser & Pommeranz, 1999; Smith & Suthers, 1999; Sutton, 2013). Numerous hypotheses have been proposed to explain diel vertical migration, including predator avoidance (Röpke, 1993), prey acquisition (Munk et al., 1989), transport optimization (Ospina-Alvarez et al., 2018; Paris & Cowen, 2004), energetic efficiency (Gray, 1996; Lin et al., 2012), and UV radiation avoidance (Heath et al., 1988).

The dominance of Myctophidae in 2012 may reflect mesopelagic spawning synchronized with stratified upper layers and stable retention conditions (Gartner-Jr, 1991; Rodríguez & Castro, 2000). In contrast, the prevalence of *Sardinops sagax* and *Anchoa* sp. in 2016 near the fixed station appears linked to episodic upwelling and the intrusion of Equatorial Surface Water, as observed in ichthyoplankton studies correlating spawning intensity with nutrient pulses (Beltrán-León & Morales Osorio, 2021; González-Quirós et al., 2003; Twatwa et al., 2005). These taxonomic transitions reinforce Malpelo Island's role as both a larval retention hotspot and a potential node within the Eastern Tropical Pacific Marine Corridor (CMAR). Biophysical modeling studies have shown that larval dispersal across the ETP is modulated by mesoscale eddies and intermittent current reversals, which can create transient corridors for export or retention (León-Chávez et al., 2010; Romero-Torres et al., 2018). Malpelo's steep topography and surrounding stratification may promote localized larval residency, particularly for endemic and low-dispersal species such as *Axoclinus rubinoffi* and *Lepidonectes bimaculatus*, whose life histories suggest high site fidelity and limited recruitment beyond the island's influence (Rojas-Vélez et al., 2021). Collectively, these findings underscore the ecological significance of Malpelo's oceanographic setting and its strategic value for regional conservation planning within the CMAR framework.

Comparative studies from other oceanic islands, such as the Hawaiian archipelago (e.g., Boehlert & Mundy, 1993; Cowie & Holland, 2006), provide valuable context for interpreting our findings. These systems similarly exhibit mixed larval assemblages composed of reef-associated, epipelagic, and mesopelagic taxa, shaped by localized retention, diel vertical migration, and stratification-driven larval positioning. Malpelo Island shares several of these hydrographic and ecological features, including a compressed thermocline and halocline, illustrated in figure 2 through mean water column profiles of temperature and salinity. These patterns suggest vertical compression of water masses due to topographic obstruction, consistent with the island mass effect. However, Malpelo's extreme isolation, steep bathymetry, and location within the CMAR corridor introduce distinct dispersal constraints and endemism dynamics not typically observed in multi-island systems. While the island mass effect is not the central focus of this study, the observed hydrographic structure and high β-diversity between nearshore and offshore assemblages suggest its localized presence. We propose this mechanism as a plausible factor influencing larval retention and spatial turnover, and recommend future studies incorporate detailed hydrographic profiling to further elucidate these dynamics.

Species identification was based on established morphological keys (Moser, 1996;

Richards, 2005), but we recognize that larval stages of several taxa exhibit overlapping traits. Genetic confirmation was not conducted in this study, representing a limitation that future research should address through DNA barcoding approaches (Lira et al., 2023). However, our study reveals that larval fish assemblages around Malpelo Island exhibit distinct spatial and vertical distribution patterns, with mesopelagic species dominating offshore waters and a heterogeneous mix of mesopelagic, epipelagic, and reef-associated taxa concentrated near the island. This compositional gradient mirrors patterns documented around other oceanic islands, underscoring the ecological singularity of insular marine systems. Moreover, the observed diel vertical migration—characterized by larval aggregation in deeper strata during daylight hours and ascent to shallower layers at night—is modulated by the local thermocline depth and reflects behavioral strategies consistent with those reported in both coastal and pelagic environments. These findings reinforce the ecological significance of oceanic islands as biodiversity hotspots and critical habitats for early fish life stages.

To our knowledge, this is the first study to analyze larval fish assemblages around Malpelo Island, addressing a notable gap in ichthyoplankton research for the region, and provide essential baseline data for biodiversity assessments and inform conservation planning within this UNESCO World Heritage Site. Future research should adopt integrative approaches that combine larval ecology, biophysical modeling, and long-term monitoring to elucidate the mechanisms driving assemblage structure and support evidence-based management of isolated island ecosystems in the Eastern Tropical Pacific.

Ethical statement: The authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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