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Fish Larval Assemblage Associated with an Eastern Tropical Pacific Coral Reef: Seasonal and Interannual Variability

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Abstract: The seasonal and interannual temporal variation in the composition, richness, diversity, and similarity of fish larval assemblages associated with an Eastern Tropical Pacific (ETP) coral reef system was studied in March (cold water) and September (warm water) during the years 2017, 2018, and 2019. Throughout the study period, we collected 4779 fish larvae and identified 88 taxa, encompassing 46 families. This increased the total number of recorded fish taxa for the region to 146. Fish larvae were collected by daytime and nighttime surface trawls, using a bongo net 30 cm in diameter and 180 cm in length, equipped with mesh sizes of 300 and 500 µm. The species diversity and abundance of ichthyoplankton over this ETP coral reef changed by intra-annual variation of the hydrological conditions of the upper layer of the sea. Six significant assemblages were identified (SIMPROF, $p < 0.05$), each one associated with each sampling period (ANOSIM, $R = 0.764$); *Cetengraulis mysticetus*, *Diaphus pacificus*, *Anchoa* sp., *Anisotremus* sp., *Bremaceros bathymaster*, *Oligoplites saurus*, *Caranx* sp., *Seriola* sp., Gobiidae sp., *Microgobius* sp., and *Synodus evermanni* were the species that contributed to dissimilitude between groups. Canonical correspondence analysis revealed significant associations between specific larval fish taxa abundance and temperature, salinity, dissolved oxygen, and zooplankton biomass. Overall, the assemblage of ichthyoplankton in this ETP coral reef system is sensitive to seasonal changes in water column hydrographic conditions.

Keywords: Colombian Pacific; coral reef; community composition; diversity; ichthyoplankton

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1. Introduction

The Eastern Tropical Pacific (ETP) has unique environmental characteristics for marine life. Specifically, the abiotic conditions in the region were modulated by the combined effects of seasonal and regional fluctuations in local environmental and oceanographic factors across a range of spatial and temporal scales [1–4]. The Colombian Pacific Ocean (CPO) is in the easternmost sector of the ETP, and there are different types of marine coastal ecosystems, including rocky shores, sandy beaches, estuaries, mangrove forests, and coral reefs, which support a wide variety of fishes with a wide range of life history strategies [5,6].

Coral reefs are highly biodiverse ecosystems and host the richest communities of fish species on the planet [7–9]. In general, fishes have a life cycle with two different phases: the first pelagic larval phase, which allows them to disperse, and the second demersal or pelagic

adult phase [10,11]. Fish larvae are a phase of great interest in marine ecology research because of the replenishment of populations, the connectivity or exchange of individuals between them, and the understanding of fish dispersal patterns, and in general, a wide range of ecological processes of these populations depend largely on the understanding of the dynamics of the larval stages [12,13]. Therefore, studies on variations in the abundance and composition of fish larval assemblages are necessary to understand the dynamics of the fish populations present on coral reefs.

In coastal marine environments, variations in environmental conditions at different time scales can modulate the attributes of fish larval assemblages [14], such that during an annual cycle, which incorporates different hydrographic conditions, changes in their composition and abundance have been reported [15–19]. In general, the spatiotemporal variation in physical factors generally contributes the most to the biological responses of marine communities. For example, fluctuations in circulation, water column stability, turbidity, salinity, oxygen, and temperature can determine the viability of a particular species and consequently modulate the composition of a set or assemblage [20–23].

To date, research efforts on reef fishes in the ETP have focused on both the adult and larval stages [7,16,24–29]; however, in the CPO, efforts have focused mainly on adults [30–36]. In this region of the ETP, only two studies have analyzed larval fish assemblages, the first of which was carried out by Calle-Bonilla et al. [37], who evaluated the role of surface circulation in the movement of fish larvae associated with coral reef environments on Gorgona Island during two contrasting oceanographic periods; the other one was carried out by Ramírez et al. [38], who evaluated the temporal variability in the assembly of fish larvae associated with a coral reef formation on Gorgona Island on a daily (day–night) and monthly scale.

In this study, we hypothesize that seasonal oceanographic and climatic variability determines the composition and abundance of the fish larval assemblage associated with coral formations in the Colombian Eastern Tropical Pacific. To test this hypothesis, we assessed the responses of ichthyoplankton assemblages associated with well-developed coral reef formation to the intra-annual and interannual variability of hydrographic conditions. Specifically, we addressed the following questions: (1) Does ichthyoplankton abundance and community composition differ among the intra-annual contrasting oceanographic periods described for this region? (2) Is the composition of the fish larval assemblage similar on an interannual scale? (3) What are the main environmental factors affecting the abundance and community composition of fish larvae in this coral reef formation?

2. Materials and Methods

2.1. Study Area

The Colombian Pacific Ocean is an integral part of the eastern region of the ETP. In this region, the most developed coral reefs are located on the eastern side of Gorgona Island (2°58′ N–78°11′ W) (Figure 1), on the continental shelf of Colombia's southern Pacific region, 36 km from the mainland. This area, declared a National Natural Park in 1984, has an average air temperature of 27 °C (varying between 24 °C and 30 °C), and the annual rainfall ranges between 4000 mm and 8000 mm, distributed in two rainy periods, the most intense between April and November, and a second less intense period between December and March [39]. Two contrasting oceanographic periods have been described for this locality, the first from May to December with low surface salinity values and a deep thermocline (c.a. 47 m), and the second from January to April with high surface salinity and a shallow thermocline (c.a. 7.5 m), with a semi-diurnal tide that can reach a maximum recorded height of 5.7 m [40].

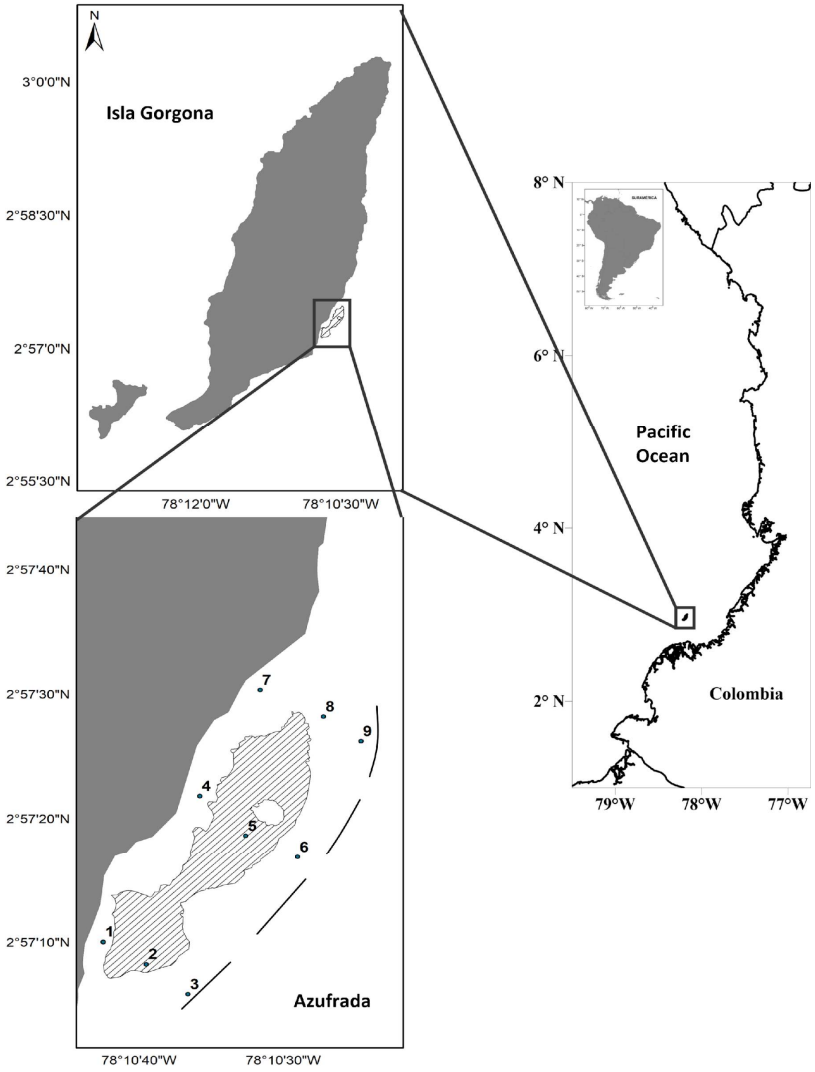


Figure 1. Geographical location of Gorgona Island and sampling stations on the La Azufrada reef. The area of the La Azufrada reef plain and slope, the position of La Azufrada on Gorgona Island, and the position of Gorgona Island in the Eastern Tropical Pacific are highlighted.

Gorgona Island has a great variety of coastal habitats [41], among which the coral formations of La Azufrada, Playa Blanca, El Muelle, La Ventana, and Farallones stand out as habitats for diverse marine fauna [7,42–44]. All these coral formations have a low impact from anthropogenic activities, and the La Azufrada coral reef is considered one of the largest and most well-developed coral reefs in the ETP [44]. The coral reef is 780 m long and 80–180 m wide, and it is formed mainly by coral species of the Pocilloporidae family, although there are also coral species from Psammocoridae, Agariciidae, and Poritidae families represented by genera such as *Psammocora*, *Pavona*, *Porites*, and *Gardineroseris* [43,44].

2.2. Field Sampling

Since 2007, the pelagic environment of the La Azufrada coral reef has been monitored twice a year as part of the protected area's oceanographic monitoring program, which consists of a sampling grid of nine equidistant stations over the reef (Figure 1). For this study, only samples collected during March and September 2017, 2018, and 2019 were used during the cold and warm oceanographic periods, which have been described for this location of the ETP [37,40,45–48].

Discrete water samples were collected at a depth of 1 m using a Niskin bottle (General Oceanics®, Miami, FL, USA) and temperature, salinity, and dissolved oxygen were recorded using a YSI ProQuatro handhel multiparameter probe (YSI, Yellow Springs, OH, USA), chlorophyll-a was recorded using an *Aqua*Fluor handheld fluorometer (Turner Designs, San José, CA, USA), and water column transparency using a Secchi disk (General Oceanics, Miami, FL, USA). Fish larvae were obtained by day and night surface (1 m) trawls of 5 min duration, using a bongo net of 30 cm diameter and 180 cm length, equipped with 300 and 500 µm pore meshes, with flowmeters (Hydro-Bios, Altenholz, Germany) calibrated to quantify the volume of filtered water. Samples were fixed in a formalin solution (formalin–seawater) at a final concentration of 4% for transport to the Oceanographic Sciences Laboratory of the Universidad del Valle. All samples were reviewed to separate fish larvae from each zooplankton sample, and taxonomic identification was carried out to the closest possible species level, following the guidelines [49,50]. The identified species were deposited in the Zoology Teaching Collection of the Universidad del Valle.

2.3. Data Analysis

To quantify the zooplankton biomass, half of the sample collected with the 300 µm mesh was concentrated on cellulose filters that were previously dried and weighed. The samples were dried at 60 °C for 24 h and weighed on an analytical balance with a precision of 0.0001 g; the dry biomass was determined by the weight difference.

To reduce the effect of day and night variation in the structuring of the data matrix of fish larvae in the water column of the La Azufrada coral reef, the day and night records made during each sampling campaign were taken together. In addition, the information obtained with the 300 µm and 500 µm nets was consolidated, assuming that they were complementary sources of taxonomic information [51].

Temperature, salinity, dissolved oxygen, chlorophyll-a, zooplankton biomass, and fish larval abundance were compared between periods and years of study (summing the cold and warm periods for each year) using a non-parametric Kruskal–Wallis test (KW) with Bonferroni correction and a post hoc Tukey rank test. The representativeness of the sampling effort was established from the construction of rarefaction curves for the study period and the expected richness was defined from Clench's nonlinear estimator, which predicts that the probability of finding a new species will increase (up to a maximum) as the sampling effort increases, that is, the probability of adding new species eventually decreases, but field work increases it [52]. The community attribute indices Shannon and Simpson were used to describe the diversity of the assemblages, and a comparison was made between periods by resampling 1000 replicates using the bootstrap technique.

The composition of the assemblage was described based on the Bray Curtis similarity index, defined from the abundance matrix of species with a frequency of occurrence equal to or greater than 5%. Transformation was performed using the log (x + 1) function to reduce the abundance effect of dominant species. The average clustering algorithm was used to construct a similarity dendrogram, and the similarity profile routine (SIMPROF) was used to establish the significance of the clusters. Moreover, the contribution of species within the clusters generated in the similarity analysis was established using the similarity percentages (SIMPER) routine in PRIMER v6.0® software. Finally, to determine whether there were differences in fish larval assemblage composition between study periods, a one-way abundance matrix similarity analysis (ANOSIM) was used to evaluate the differences in the composition of fish larval assemblages between study periods (totally different assemblages when *R* values are between 0.75 and 1) [53].

Finally, the relationships between the established assemblage composition and local environmental conditions (temperature, salinity, chlorophyll-a, and dissolved oxygen)

were explored using a canonical correspondence analysis (CCA) carried out with the free ecological software Past® v3.12. CCA is a multivariate association analysis that maximizes the degree of correlation between fish larval abundance and physicochemical parameters.

3. Results

3.1. Fish Larval Assemblage Composition

A total of 4779 fish larvae were captured, of which 4556 (95% of the total), belonging to 88 species and 46 families, were identified during the six study periods. In our study, 41 species were first recorded in the La Azufrada coral reef, increasing the number of larvae of fish species associated with the coral formations of this locality to 162 taxa (Table 1, Supplementary Materials File S1). During the cold oceanographic period (March), the families with the highest relative abundance were Engraulidae (51.36%), Myctophidae (14.14%), and Carangidae (8.75%), and the species with the highest relative abundance were *Cetengraulis mysticetus* (Günther, 1867), *Diaphus pacificus* Parr, 1931, and *Bregmaceros bathymaster* Jordan and Bollman, 1890. During the warm oceanographic period (September), the families with the highest relative abundance were Engraulidae (25.99%), Bregmacerotidae (21.67%), and Haemulidae (16.47%), and the species with the highest abundance were *C. mysticetus*, *B. bathymaster* and *Anisotremus* sp.

Table 1. Taxa of fish larvae reported for Gorgona Island and the La Azufrada coral reef.

Authors	Taxa Reported	New Records	Accumulated Taxa
Escarria et al. [54]	35	35	35
Calle-Bonilla et al. [37]	29	29	64
Ramírez et al. [38]	87	57	121
Gallego et al. [this research]	88	41	162

The sampling representativeness was above 86% (Clench's nonlinear estimator) and the species richness and diversity varied significantly among the study periods and years, being higher in March 2018 and September 2019 than in the rest of the periods and years evaluated (Table 2).

Table 2. Diversity and richness indices by period evaluated.

Periods	Richness (d)	Diversity H′ (nats/ind)
March_2017	1.64	2.25
September_2017	1.80	2.90
March_2018	2.23	4.38
September_2018	1.71	2.99
March_2019	1.98	2.34
September_2019	2.59	4.20

Larval density (ind/100 m^3) did not show significant differences between the study periods, except between March and September 2018. Zooplankton biomass (g/100 m^3) was significantly higher in March 2019 than in the other periods evaluated (Figure 2). A non-significant positive correlation was established between larval density and zooplankton biomass ($R = 0.14$, $p < 0.05$; Figure 3) in the study area, suggesting that zooplankton biomass did not have a dominant effect on larval density.

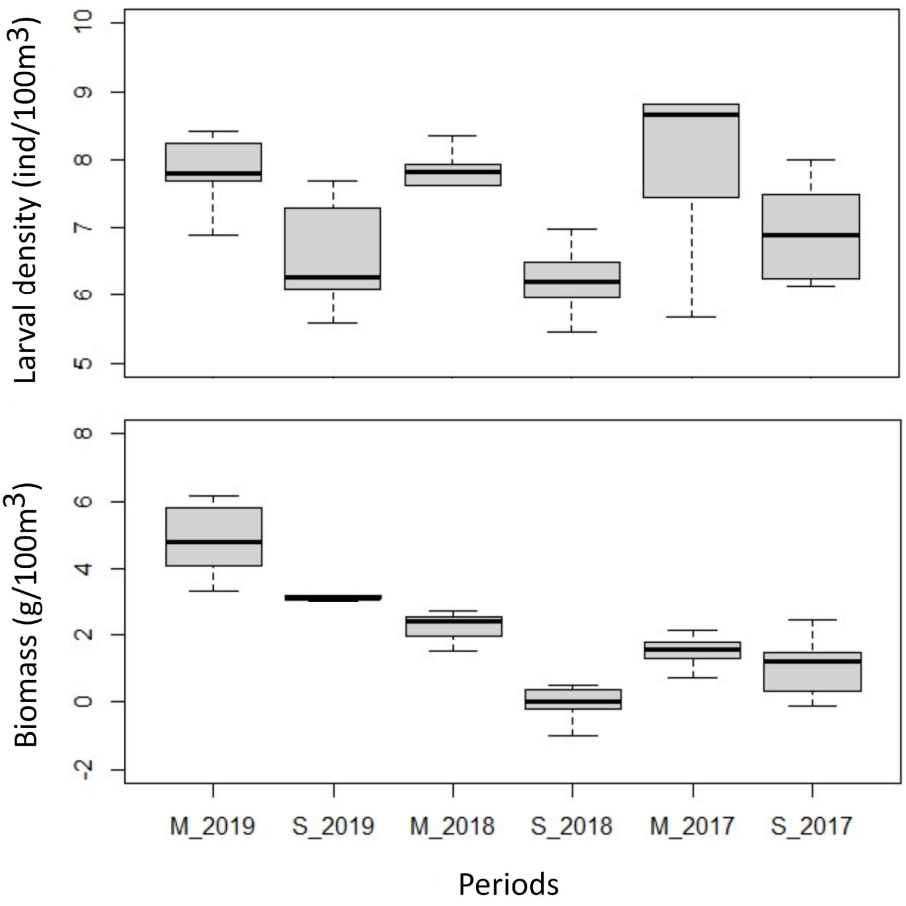


Figure 2. Zooplankton biomass and fish larval density present in the water column associated with the La Azufrada coral reef during March and September 2017 to 2019. The y-axis is in logarithmic scale.

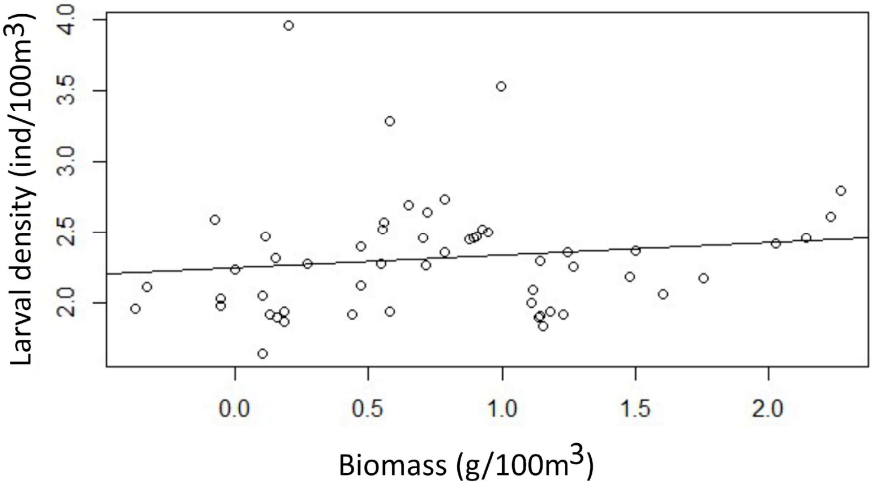


Figure 3. Spearman correlation showing the relationship between zooplankton biomass and larval density in the study area. The two axes are in logarithmic scale.

Based on the analysis of similarity between periods and years, six significant groups (I, II, III, IV, V, and VI) were established (SIMPROF, $p < 0.05$), with dissimilarity percentages between groups above 65% (Figure 4). Each established group consisted of nine sampling stations in each study period. Group I (March-2018) was established due to the contribution of *C. mysticetus*, *D. pacificus*, *Anchoa* sp., and *Anisotremus* sp. (SIMPER, 57.36% similarity), which showed a tendency to cluster with those of group II. Group II (March-2017) was formed by the contribution of species such as *Anchoa* sp., *C. mysticetus*, *B. bathymaster*, and

O. saurus (SIMPER, 72% similarity). Group III (March-2019) was formed owing to the contribution of species such as *C. mysticetus*, *Caranx* sp. *Seriola* sp., and *Anisotremus* sp. (SIMPER, 70% similarity) (Figure 4).

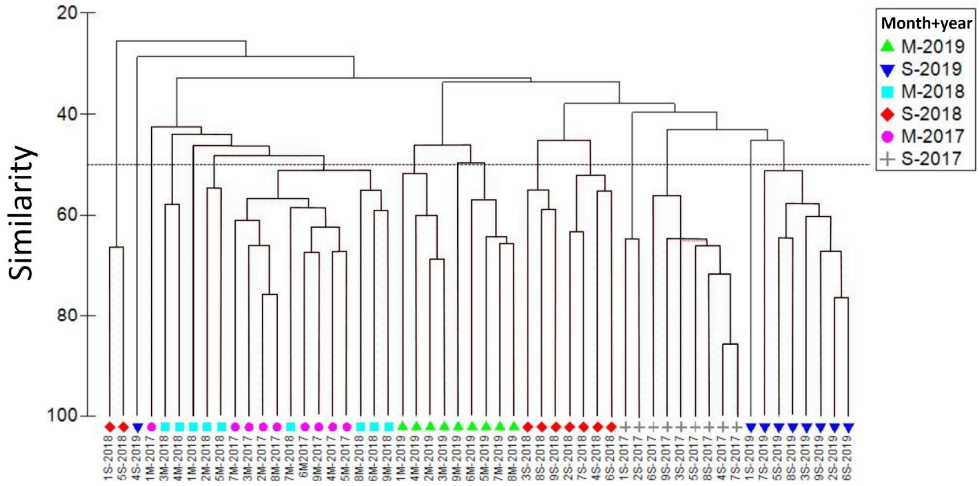


Figure 4. Similarity dendrogram of the fish larval assemblage present in the water column associated with La Azufrada reef in the March-September periods between 2017 and 2019. The first term is the station number (1 to 9) and sampling month (M: March, S: September). The last term is the year (2017, 2018, or 2019).

Group IV (September-2018) was formed due to the contribution of *B. bathymaster*, Gobiidae sp. 6, *Anisotremus* sp., and Gobiidae sp (SIMPER, 62.65% similarity). On the other hand, group V (September-2017) was established due to the contribution of species such as *Anisotremus* sp., *C. mysticetus*, *Microgobius* sp., and *S. evermanni* (SIMPER, 58.72% similarity) and group VI (September 2019) was formed due to the contribution of *C. mysticetus*, *Anisotremus* sp., Gobiidae sp. and *Caranx* sp. (SIMPER, 49.0% similarity). Finally, the ANOSIM similarity analysis indicated that there was a difference between assemblages from all periods (overall $R = 0.764$, $p < 0.1$) (Table 3).

Table 3. One-way ANOSIM, with sampling periods (month + year).

Groups	*R*	*p*
M-2019, S-2019	0.752	0.1
M-2019, M-2018	0.921	0.1
M-2019, S-2018	0.859	0.1
M-2019, M-2017	0.903	0.1
M-2019, S-2017	0.791	0.1
S-2019, M-2018	0.837	0.1
S-2019, S-2018	0.682	0.1
S-2019, M-2017	0.962	0.1
S-2019, S-2017	0.601	0.1
M-2018, S-2018	0.757	0.1
M-2018, M-2017	0.287	0.1
M-2018, S-2017	0.849	0.1
S-2018, M-2017	0.856	0.1
S-2018, S-2017	0.576	0.1
M-2017, S-2017	0.896	0.1

3.2. Ambient Conditions

The mean sea surface temperature ranged between 28.4 ± 0.13 °C (March 2017), 28.8 ± 0.13 °C (September 2017), 27.4 ± 0.24 °C (March 2018), 27.7 ± 0.09 °C (September

2018), 25.8 ± 0.29 °C (March 2019), and 27.5 ± 0.13 °C (September 2019); no significant differences were found for SST between oceanographic periods (KW, $p > 0.05$). The mean sea surface salinity range included 29.6 ± 0.03 (March 2017), 25.2 ± 0.45 (September 2017), 26.7 ± 0.18 (March 2018), 26.1 ± 1.14 (September 2018), 30.7 ± 0.44 (March 2019), and 30.3 ± 0.13 (September 2019); there were significant differences between March and September 2017 (KW, $p > 0.05$). The maximum temperature and salinity values were recorded in September 2017 and March 2019, respectively (Table 4).

Table 4. Physicochemical parameters recorded in the water column associated with La Azufrada coral reef during March and September between 2017 and 2019. T: temperature, S: salinity, DO: dissolved oxygen, μ: mean, S.D.: standard deviation, Min: minimum value recorded, Max: maximum value recorded, n = 9.

Parameters	Statistics	M-2017	S-2017	M-2018	S-2018	M-2019	S-2019
T (°C)	μ	28.4	28.8	27.4	27.7	25.8	27.5
	S.D.	0.13	0.13	0.24	0.09	0.29	0.13
	Min	28.3	28.7	27.2	27.5	25.4	27.4
	Max	28.7	29.1	27.8	27.8	26.2	27.8
S (PSU)	μ	29.6	25.2	26.7	26.1	30.7	30.3
	S.D.	0.03	0.45	0.18	1.14	0.44	0.13
	Min	29.6	24.2	26.5	23.1	30.1	30.0
	Max	29.7	25.7	27.0	26.7	31.4	30.4
DO (ml/L)	μ	5.6	6.7	5.9	4.9	8.9	6.7
	S.D.	0.20	0.50	0.80	0.46	0.24	0.63
	Min	5.2	6.1	5.3	4.1	8.6	6.0
	Max	5.8	7.5	7.4	5.5	9.3	7.9

The average dissolved oxygen at the sea surface range included 5.6 ± 0.2 mL/L (March 2017), 6.7 ± 0.5 mL/L (September 2017), 5.9 ± 0.8 mL/L (March 2018), 4.9 ± 0.46 mL/L (September 2018), 8.9 ± 0.24 mL/L (March 2019), and 6.7 ± 0.63 mL/L (September 2019). The average sea surface pH range included 7.8 ± 0.06 (March 2017), 8.5 ± 0.06 (September 2017), 8.5 ± 0.08 (March 2018), and 8.3 ± 0.1 (March 2019). The lowest dissolved oxygen value was recorded in September 2018, and the highest pH value occurred in September 2019 (Table 4).

3.3. Relationships Between Fish Larval Assemblages and Environmental Variables

The first two ordination axes of the canonical correspondence analysis (CCA) explained 67% of the total variance in the fish larval assemblage present in the water column associated with the La Azufrada coral reef. Salinity, chlorophyll-a, zooplankton biomass, pH, and dissolved oxygen were inversely related to axis 1 ($p < 0.05$), whereas chlorophyll-a, temperature, and pH were inversely related to axis 2 ($p < 0.05$) (Table 5, Figure 5).

Bregmaceros bathymaster, *Ophichthus zophochir*, *Bathycongrus macrurus*, *Antennarius sanguineus*, *Gobiesox* sp., *Lythrypnus* sp., *Achirus* sp., and *Coryphaena hippurus* were directly related to chlorophyll-a and pH, whereas *Anchoa* sp., *Anisotremus* sp., *Auxis* sp., and *Opistognathus panamensis* were directly correlated with temperature. Finally, most of the species identified in the study periods and years evaluated were directly correlated with salinity, dissolved oxygen, and zooplankton biomass, such as *Cetengraulis mysticetus*, *Gobiidae* sp., *Oligoplites saurus*, *Caranx* sp., *Chromis* sp., and *Lampanyctus parvicauda* (Figure 5).

Table 5. Correlation values of each variable with respect to the first two axes in the canonical correspondence analysis. The first two ordination axes explain 67% of the total variance. $p < 0.05$. T: temperature (°C), S: salinity (UPS), DO: dissolved oxygen, Chl-a: chlorophyll-a.

	Axis 1	Axis 2
Variance explained	36.27	31.42
T (1 m)	0.45	−0.42
S (1 m)	−0.19	0.44
DO (1 m)	−0.43	0.56
pH-1 m	−0.10	−0.13
Chl-a (1 m)	−0.45	−0.32
Biomass	−0.59	0.45

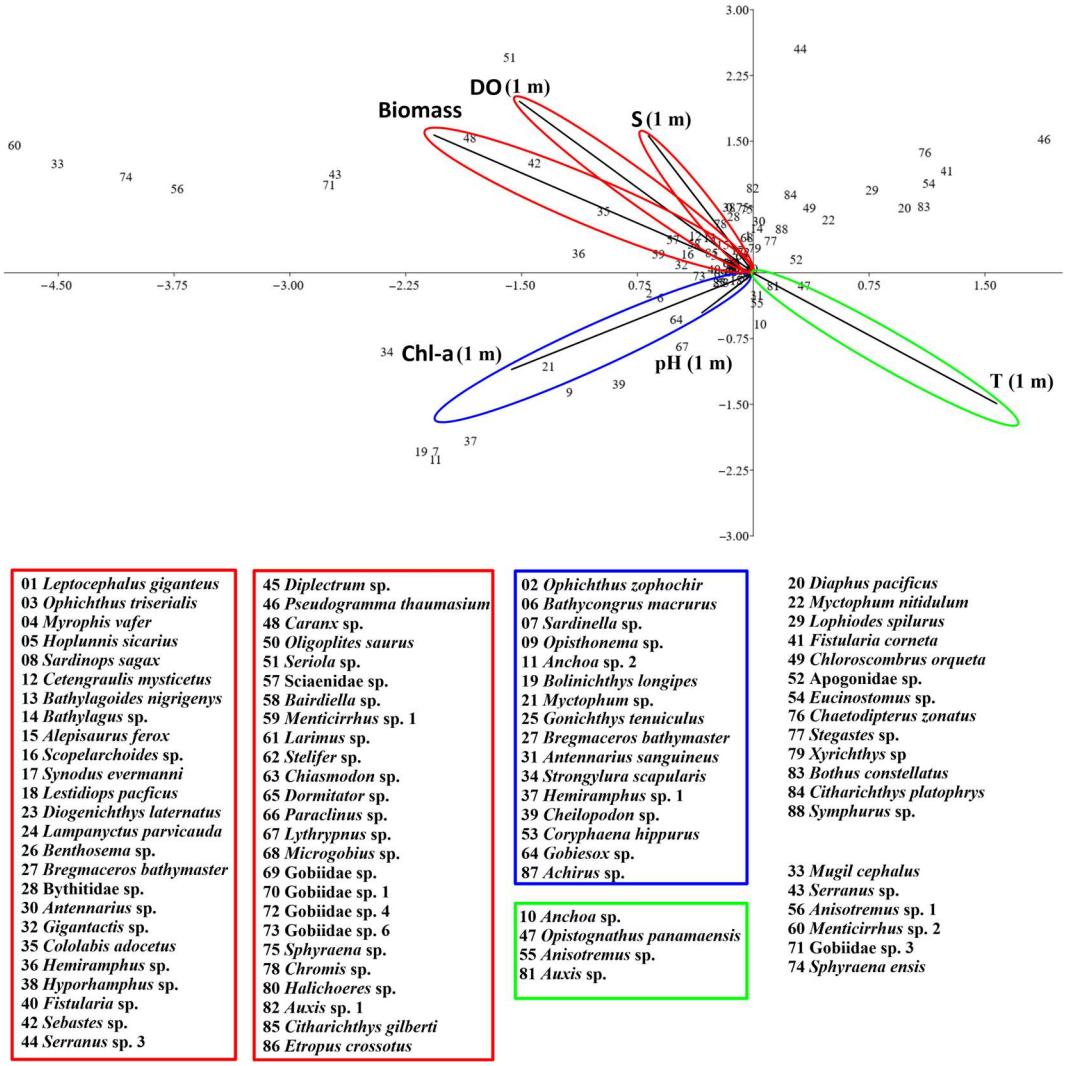


Figure 5. Canonical correspondence analysis using the abundance of species found with frequency >5%. The first two canonical axes explain 67% of the total variance. DO: dissolved oxygen, S: salinity, T: temperature, Chl-a: chlorophyll-a.

4. Discussion

In the water column of the La Azufrada coral reef, there were abundant larvae of fish species that are typical of different marine environments. This characteristic is frequently reported in the scientific literature, where species have been recorded from oceanic areas, sandy bottoms, and even mangrove environments in rocky or coral reef areas [8,55,56]. Planktonic organisms, such as fish larvae, are modulated by physical processes of transport

(such as advection) and behavioral (vertical migrations) and life history characteristics, and they tend to exhibit a high dispersal capacity [57,58]. This means that they can be present in environments that are atypical for adults. Furthermore, on the reef, coral structures can function as originators of accumulation areas by mechanically disrupting currents, waves, and tidal flows [59,60].

The species richness distribution during the sampling periods was variable and did not show a clear temporal or annual trend. However, there were significant differences in larval density between the periods (March and September 2018), which coincided with a temporal order consistent with the climatic and oceanographic periods of the area (cold and warm seasons). Similarly, it was observed that there was a higher total larval density in the months of March in all the years evaluated; this may be because, in general, there was a greater availability of zooplankton biomass in the months of March. We found significant differences between March and September of the years 2017 and 2018, thus favoring the hypothesis that adults fish species synchronize their spawning periods for these dates. Furthermore, although the cluster analysis suggested that each period evaluated was a separate group from the others, in a general way, a tendency was observed for the groups to be ordered concordantly with the cold and warm seasons. Similarly, in the analysis of similarity (ANOSIM), the overall *R* determined that all groups (periods evaluated) were different, but there was a tendency for the fish larval assemblages from September to be more like each other.

Over the last few decades, marine fish larval assemblages have been described to present high spatial and temporal dynamics, where variations in composition and abundance occur on time scales ranging from hours to annual seasons [61]. In general terms, this temporal variability would modulate the simultaneous effect of multiple hydrographic and environmental factors that may come to determine larval survival [14,62–64], so it could come to determine the distribution, abundance, and, in general, the composition of fish larval assemblages [65–69].

Another determining factor in the distribution, abundance, and composition of fish larval assemblages is food availability, which is largely responsible for their survival and growth in the early stages of fish development [70]. Generally, fish larval density is closely related to zooplankton biomass and correlates with an increase in local food availability [71–73]. This coincides with the results obtained in this study, in which most fish larval species found on the coral reef were directly correlated with zooplankton biomass. Moreover, it has been documented that marine surface circulation patterns have a strong effect on the spatial distribution of fish larvae [74–76], giving rise to retention or advective processes that can decrease or increase the abundance of fish larvae in a locality [77,78]. During September, on the eastern side of Gorgona Island, the instantaneous surface circulation pattern is towards the sea, favoring the drifting movement of fish larvae, while during February, the trend is towards the coast, which increases the retention of larvae above the La Azufrada coral reef [38]. In our study, a trend towards a higher larval density in March compared to September was evident in all years evaluated. This result could be associated with the formation during the first months of the year of a cyclonic gyre in the vicinity of the la Azufrada coral reef [38], which may favor the retention of fish larvae and directly increase the larval density in the cold period of the year.

The structural complexity of coral reefs is considered one of the most important factors in the organization of fish assemblages [79]. These habitats provide refuge areas against predators for many fish species and generate a food source consisting mainly of benthic invertebrates and macroalgae [8,80–82]. They also constitute natural sites where fish larvae can find the protection and food necessary for their rapid growth [83]. However, although the La Azufrada coral reef may serve a function as a nursery area for different fish species,

most of these species probably exhibit life history strategies that reduce their dependence on coral environments, and are likely to exploit different habitat types during vulnerable life stages [14]; this is reflected in the few species of fish larvae found in this study that, in their adult stage, are related to coral reefs (*Antennarius sanguineus*, *Pseudogramma thaumasium*, *Oligoplites saurus,* and *Chaetodipterus zonatus*), in addition to the fact that all were found exclusively in the month of March, with the exception of *Oligoplites saurus*.

Another aspect to consider is the seasonal fluctuations in larval production, which are strongly associated with the reproductive events of the species and seem to be synchronized with the requirements of the larvae to increase recruitment success, defining the spatiotemporal pattern of distribution [59,84–86]. Thus, species such as *C. mysticetus*, *B. bathymaster*, *Caranx* sp., and *Anisotremus* sp. reproduce several times a year. Species collected only during a local oceanographic period could be larvae of species that present only one reproductive event per year, such as *Dormitator* sp. and *Menticirrhus* sp., which were recorded in the month of March, and *Microgobius* sp., and *Stelifer* sp., which were present in September.

5. Conclusions

The composition of the fish larval assemblage varied across all evaluated periods, with each period showing distinct characteristics. However, a tendency was observed for the assemblages to group together or be more similar during the climatic and oceanographic periods described for the study area (cold and warm seasons). This suggests that intra-annual variations in oceanographic parameters have a greater effect on fish larval assemblages than interannual variations. It is evident that the cold period (March) presents better conditions for fish species to carry out their spawning season, resulting in a higher larval density in the La Azufrada coral reef compared to the warm period (September).

The results of this study enhance the available knowledge on the fish larval assemblage associated with the ETP coral reef and its variation throughout the year and between years. The findings indicate that intra-annual variation, particularly during the cold season (characterized by higher salinity and lower dissolved oxygen), has a greater effect on the composition of the fish larval assemblage associated with the La Azufrada coral reef. Specifically, *Cetengraulis mysticetus*, *Diaphus pacificus*, *Anchoa* sp., *Anisotremus* sp., *Bremaceros bathymaster*, *Oligoplites saurus*, *Caranx* sp., *Seriola* sp., *Gobiidae* sp., *Microgobius* sp., and *Synodus evermanni* were the species that most contributed to the intra-annual variability of the fish larval assemblage.

We recommend implementing complementary sampling strategies to assess the effect of adult fish spawning strategies on the temporal variability of fish larval assemblages in coral environments. Light traps would likely provide relevant information on fish larvae in more developed stages, which would increase species diversity records. This would improve our understanding of the assemblage composition and its temporal variability in the coral reef formations of the Eastern Tropical Pacific.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d17010023/s1.

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References

1. Amador, J.A.; Alfaro, E.J.; Lizano, O.G.; Magaña, V.O. Atmospheric forcing of the eastern tropical Pacific: A review. *Prog. Oceanogr.* **2006**, *69*, 101–142. [CrossRef]
2. Fiedler, P.C.; Talley, L.D. Hydrography of the eastern tropical Pacific: A review. *Progress. Oceanogr.* **2006**, *69*, 143–160. [CrossRef]
3. Fiedler, P.C.; Lavín, M.F. Oceanographic Conditions of the Eastern Tropical Pacific. In *Coral Reefs of the Eastern Tropical Pacific. Coral Reefs of the World*; Glynn, P., Manzello, D., Enochs, I., Eds.; Springer: Dordrecht, The Netherlands, 2017; Volume 8, pp. 59–83.
4. Eslava, J.A. Climatología. In *Colombia Pacífico*; Leyva, P., Ed.; Fondo para la protección del Medio Ambiente: Bogotá, Colombia, 1993; Volume 1, pp. 136–147.
5. Velandia, M.C.; Scheel, M.; Puentes, C.; Durán, D.; Osorio, P.; Delgado, P.; Obando, N.; Prieto, A.; Díaz, J.M. *Atlas Marino-Costero del Bajo Baudó, Colombia*; Fundación MarViva: Bogotá, Colombia, 2019; p. 180.
6. Sale, P.F. Connectivity, recruitment variation, and the composition of reef fish communities. *Integr. Comp. Biol.* **2004**, *44*, 390–399. [CrossRef] [PubMed]
7. Cortés, J.; Enochs, I.C.; Sibaja-Cordero, J.; Hernández, L.; Alvarado, J.J.; Breedy, O.; Cruz-Barraza, J.A.; Esquivel-Garrote, O.; Fernández-García, C.; Hermosillo, A.; et al. Marine biodiversity of Eastern Tropical Pacific coral reefs. In *Coral Reefs of the Eastern Tropical Pacific*; Glynn, P., Manzello, D., Enochs, I.., Eds.; Springer: Dordrecht, The Netherlands, 2017; pp. 203–250.
8. Bellwood, D.R.; Wainright, P.C. The history and biogeography of fishes on coral reefs. In *Coral Reef Fishes*; Sale, P., Ed.; Academic Press: Cambridge, MA, USA, 2002; pp. 5–32.
9. Parravicini, V.; Kulbicki, M.; Bellwood, D.R.; Friedlander, A.M.; Arias-Gonzalez, J.E.; Chabanet, P.; Floeter, R.S.; Myers, R.; Vigliola, L.; D'Agata, S.; et al. Global patterns and predictors of tropical reef fish species richness. *Ecography* **2013**, *36*, 1254–1262. [CrossRef]
10. Hamner, W.M.; Largier, J.L. Oceanography of the planktonic stages of aggregation spawning reef fishes. In *Reef Fish Spawning Aggregations: Biology, Research and Management*; Sadovy de Mitcheson, Y., Colin, P.L., Eds.; Springer: Dordrecht, The Netherlands, 2012; pp. 159–190.
11. Cowen, R.K.; Paris, C.B.; Srinivasan, A. Scaling of connectivity in marine populations. *Science* **2006**, *311*, 522–527. [CrossRef] [PubMed]
12. Lefevre, C.D.; Bellwood, D.R. Disturbance and recolonisation by small reef fishes: The role of local movement versus recruitment. *Mar. Ecol. Prog. Ser.* **2015**, *537*, 205–215. [CrossRef]
13. Kingsford, M.J. Diel patterns of abundance of presettlement reef fishes and pelagic larvae on a coral reef. *Mar. Biol.* **2001**, *138*, 853–867. [CrossRef]
14. Leis, J.M.; McCormick, M.I. The biology, behavior and ecology of the pelagic, larval stage of coral-reef fishes. In *Coral Reef Fishes: New Insights into Their Ecology*; Sale, P.F., Ed.; Academic Press: San Diego, CA, USA, 2022; pp. 171–199.
15. Flores-Coto, C.; Gutiérrez, R.M.; González-Félix, M.; Sanvicente-Añorve, L.; García, F.Z. Annual Variation of Ichthyoplancton Assemblages in Neritic Waters of the Southern Gulf of Mexico. *Caribb. J. Sci.* **2000**, *36*, 233–243.
16. Jiménez-Rosenberg, S.P.A.; Saldierna-Martínez, R.J.; Aceves-Medina, G.; Cota–Gómez, V.M. Fish larvae in Bahía Sebastián Vizcaíno and the adjacent oceanic region, Baja California, México. *Check. List.* **2007**, *3*, 204–223. [CrossRef]
17. León-Chávez, C.A.; Beier, E.; Sánchez-Velasco, L.; Barton, E.D.; Godínez, V.M. Role of circulation scales and water mass distributions on larval fish habitats in the Eastern Tropical Pacific off Mexico. *J. Geophys. Res. Oceans* **2015**, *120*, 3987–4002. [CrossRef]
18. Ribeiro, F.; Hale, E.; Hilton, E.J.; Clardy, T.R.; Deary, A.L.; Targett, T.E.; Olney, J.E. Composition and temporal patterns of larval fish communities in Chesapeake and Delaware Bays, USA. *Mar. Ecol. Progr. Ser.* **2015**, *527*, 167–180. [CrossRef]

19. Gallego-Zerrato, J.J.; Córdoba-Rojas, D.F.; Giraldo, A. Composición taxonómica de las larvas de peces en el arrecife coralino de La Azufrada, Pacífico colombiano, entre 2017 a 2019. *Bol. Cient. Mus. Hist.* **2023**, *27*, 245–261. [CrossRef]
20. Blaxter, J.H.S. The effect of temperature on larval fishes. *Neth. J. Zool.* **1991**, *42*, 336–357. [CrossRef]
21. Lambert, Y.; Yaragina, N.; Kraus, G.; Marteinssdottir, G.; Wright, P.J. Using environmental and biological indices as proxies for egg and larval production of marine fish. *J. Northwest Atl. Fish. Sci.* **2003**, *33*, 115–159. [CrossRef]
22. Perry, R.I.; Cury, P.; Brander, K.; Jennings, S.; Möllmann, C.; Planque, B. Sensitivity of marine systems to climate and fishing: Concepts, issues and management responses. *J. Mar. Syst.* **2010**, *79*, 427–435. [CrossRef]
23. Villamizar, N.; Blanco-Vives, B.; Migaud, H.; Davie, A.; Carboni, S.; Sanchez-Vazquez, F.J. Effects of light during early larval development of some aquacultured teleosts: A review. *Aquaculture* **2011**, *315*, 86–94. [CrossRef]
24. Leis, J.M. Larval fish assemblages near Indo-Pacific coral reefs. *Bull. Mar. Sci.* **1993**, *53*, 362–392.
25. Victor, B.C.; Wellington, G.M. Endemism and the pelagic larval duration of reef fishes in the eastern Pacific Ocean. *Mar. Ecol. Prog.* **2000**, *205*, 241–248. [CrossRef]
26. Leis, J.M. Pacific coral-reef fishes: The implications of behaviour and ecology of larvae for biodiversity and conservation, and a reassessment of the open population paradigm. *Environ. Biol. Fish.* **2002**, *65*, 199–208. [CrossRef]
27. Edgar, G.J.; Banks, S.A.; Bessudo, S.; Cortés, J.; Guzmán, H.M.; Henderson, S.; Martinez, C.; Rivera, F.; Soler, G.; Ruiz, D.; et al. Variation in reef fish and invertebrate communities with level of protection from fishing across the Eastern Tropical Pacific seascape. *Glob. Ecol. Biogeogr.* **2011**, *20*, 730–743. [CrossRef]
28. Dubuc, A.; Quimbayo, J.P.; Alvarado, J.J.; Araya-Arce, T.; Arriaga, A.; Ayala-Bocos, A.; Julio Casas-Maldonado, J.; Chasqui, L.; Cortés, J.; Cupul-Magaña, A.; et al. Patterns of reef fish taxonomic and functional diversity in the Eastern Tropical Pacific. *Ecography* **2023**, *2023*, e06536. [CrossRef]
29. Eisele, M.H.; Madrigal-Mora, S.; Espinoza, M. Drivers of reef fish assemblages in an upwelling region from the Eastern Tropical Pacific Ocean. *J. Fish Biol.* **2021**, *98*, 1074–1090. [CrossRef]
30. Rubio, E.A.; Gutiérrez, B.; Franke, R. *Peces de la Isla de Gorgona*; Universidad del Valle: Cali, Colombia, 1987; p. 323.
31. Mora, C.; Ospina, A. Experimental effect of cold, la nina temperatures on the survival of reef fishes from Gorgona island (eastern Pacific Ocean). *Mar. Biol.* **2002**, *141*, 789–793.
32. Ospina, A.F.; Mora, C. Effect of body size on reef fish tolerance to extreme low and high temperatures. *Environ. Biol. Fish.* **2004**, *70*, 339–343. [CrossRef]
33. Palacios, M.M.; Zapata, F.A. Fish community composition on coral habitats with contrasting architecture in the Tropical Eastern Pacific. *Rev. Biol. Trop.* **2014**, *62*, 343–357. [CrossRef]
34. Palacios, M.M.; Muñoz, C.G.; Zapata, F.A. Fish corallivory on a pocilloporid reef and experimental coral responses to predation. *Coral Reefs* **2014**, *33*, 625–636. [CrossRef]
35. Alzate, A.; Zapata, F.A.; Giraldo, A. A comparison of visual and collection-based methods for assessing community structure of coral reef fishes in the Tropical Eastern Pacific. *Rev. Biol. Trop.* **2014**, *62*, 359–371. [CrossRef]
36. Quimbayo, J.P.; Zapata, F.A. Cleaning interactions by gobies on a tropical eastern Pacific coral reef. *J. Fish. Biol.* **2018**, *92*, 1110–1125. [CrossRef]
37. Calle-Bonilla, I.C.; Giraldo, A.; Cuéllar-Chacón, A. Spaciotemporal variation in the coral fish larvae assembly of Gorgona Island, Colombian Pacific. *Bol. Investig. Mar. Cost.* **2017**, *46*, 55–72.
38. Ramírez-Martínez, G.A.; Giraldo, A.; Rivera-Gómez, M.; Aceves-Medina, G. Daily and monthly ichthyoplankton assemblages of La Azufrada coral reef, Gorgona Island, Eastern Tropical Pacific. *Reg. Stud. Mar. Sci.* **2022**, *52*, 102378. [CrossRef]
39. Blanco, J.F. The hydroclimatology of Gorgona Island: Seasonal and ENSO–related patterns. *Act. Biol.* **2009**, *91*, 111–121. [CrossRef]
40. Giraldo, A.; Rodríguez-Rubio, E.; Zapata, F. Condiciones oceanográficas en isla Gorgona, Pacífico oriental tropical de Colombia. *Lat. Am. J. Aquat.* **2008**, *36*, 121–128. [CrossRef]
41. Giraldo, A.; Díaz-Granados, M.C.; Gutiérrez-Landázuri, C.F. Isla Gorgona, enclave estratégico para los esfuerzos de conservación en el Pacífico Oriental Tropical. *Rev. Biol. Trop.* **2014**, *62*, 1–12. [CrossRef]
42. Zapata, F.A.; Morales, Y.A. Spatial and temporal patterns of fish diversity in a coral reef at Gorgona Island, Colombia. In Proceedings of the 8th International Coral Reef Symposium, Ciudad de, Panama, Panama; 1996; Volume 1, pp. 1029–1034.
43. Zapata, F.A.; Vargas-Ángel, B. *Corals and Coral Reefs of the Pacific Coast of Colombia. En: Coral Reefs of Latin America*; Cortes, J., Ed.; Elsevier: Amsterdam, The Netherlands, 2003; pp. 419–447.
44. Glynn, P.W.; Von Prahl, H.; Guhl, F. Coral reefs of Gorgona Island, Colombia, with special reference to corallivores and their influence on community structure and reef development. *An. Inst. Investig. Mar. Punta Betín.* **1982**, *12*, 185–214. [CrossRef]
45. Valencia, B.; Lavaniegos, B.; Giraldo, A.; Rodríguez-Rubio, E. Temporal and spatial variation of hyperiid amphipod assemblages in response to hydrographic processes in the Panama Bight, eastern tropical Pacific. *Deep-Sea Res. I Oceanogr. Res.* **2013**, *73*, 46–61. [CrossRef]
46. Rivera-Gómez, M.; Giraldo, A.; Lavaniegos, B. Structure of euphausiid assemblages in the Eastern Tropical Pacific off Colombia during El Niño, La Niña and neutral conditions. *J. Exp. Mar. Biol. Ecol.* **2019**, *516*, 1–15. [CrossRef]

47. Valencia, B.; Giraldo, A. Structure of hyperiid amphipod assemblages on Isla Gorgona, eastern tropical Pacific off Colombia. *J. Mar. Biol. Assoc.* **2012**, *92*, 1489–1499. [CrossRef]
48. Giraldo, A.; Valencia, B.; Acevedo, J.D.; Rivera, M. Fitoplancton y zooplancton en el área marina protegida de Isla Gorgona, Colombia, y su relación con variables oceanográficas en estaciones lluviosa y seca. *Rev. Biol. Trop.* **2014**, *62*, 117–132. [CrossRef]
49. Moser, H.G. *The Early Stages of Fishes in the California Current Region. California Cooperative Oceanic Fisheries Investigations, Atlas No. 33*; Allen Press: La Jolla, CA, USA, 1996; p. 181.
50. Beltrán-León, B.S.; Ríos, R. *Estadios Tempranos de Peces del Pacífico Colombiano*; Instituto Nacional de Pesca y Acuicultura INPA: Buenaventura, Colombia, 2000; p. 727.
51. Boeing, W.J.; Duffy-Anderson, J.T. Ichthyoplankton dynamics and biodiversity in the Gulf of Alaska: Responses to environmental change. *Ecol. Indic.* **2008**, *8*, 292–302. [CrossRef]
52. Soberón, M.J.; Llorente, B.J. The use of species accumulation functions for the prediction of species richness. *Conserv. Biol.* **1993**, *7*, 480–488. [CrossRef]
53. Clarke, K.R.; Warwick, R.M. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 2nd ed.; Warwick, R.M., Ed.; Plymouth Marine Laboratory: Plymouth, UK, 2001; p. 172.
54. Escarria, E.; Beltrán, B.; Giraldo, A.; Zapata, F. Ichthyoplankton in the National Natural Park Isla Gorgona (Pacific Ocean of Colombia) during September 2005. *Bol. Investig. Mar.* **2007**, *35*, 127–133.
55. Leis, J.M.; Goldman, B. A preliminary distributional study of fish larvae near a ribbon coral reef in the Great Barrier Reef. *Coral Reefs* **1984**, *2*, 197–203. [CrossRef]
56. Sponaugle, S.; Fortuna, J.; Grorud, K.; Lee, T. Dynamics of larval fish assemblages over a shallow coral reef in the Florida Keys. *Mar. Biol.* **2003**, *143*, 175–189. [CrossRef]
57. Leis, J.M. Are larvae of demersal fishes plankton or nekton? *Adv. Mar. Biol.* **2006**, *51*, 57–141. [PubMed]
58. Hamner, W.M.; Wolanski, E. Hydrodynamic forcing functions and biological processes on coral reefs: A status review. In Proceedings of the 6th International Coral Reef Symposium, Townsville, Australia; 1988; pp. 103–113.
59. Irisson, J.O.; LeVan, A.; De Lara, M.; Planes, S. Strategies and trajectories of coral reef fish larvae optimizing self-recruitment. *J. Theor. Biol.* **2004**, *227*, 205–218. [CrossRef]
60. Leahy, S.M.; Russ, G.R.; Abesamis, R.A. Pelagic larval duration and settlement size of a reef fish are spatially consistent, but post-settlement growth varies at the reef scale. *Coral Reefs* **2015**, *34*, 1283–1296. [CrossRef]
61. Leis, J.M. The pelagic stage of reef fishes: The larval biology of coral reef fishes. In *The Ecology of Fishes on Coral Reefs*; Sale, P.F., Ed.; University of Hawaii: Honolulu, HI, USA, 1991; pp. 183–230.
62. Robertson, D.R. *The Role of Adult Biology in the Timing of Spawning of Tropical Reef Fishes. En: The Ecology of Fishes on Coral Reefs*; Sale, P.F., Ed.; Academic Press: San Diego, CA, USA, 1991; pp. 356–386.
63. Lo, W.T.; Hsieh, H.Y.; Wu, L.J.; Jian, H.B.; Liu, D.C.; Su, W.C. Comparison of larval fish assemblages between during and after northeasterly monsoon in the waters around Taiwan, western North Pacific. *J. Plankton Res.* **2010**, *32*, 1079–1095. [CrossRef]
64. Sánchez-Velasco, L.; Beier, E.; Godínez, V.M.; Barton, E.D.; Santamaría-del-Angel, E.; Jiménez-Rosemberg, S.P.A.; Marinone, S.G. Hydrographic and fish larvae distribution during the "Godzilla El Niño 2015–2016" in the northern end of the shallow oxygen minimum zone of the Eastern Tropical Pacific Ocean. *J. Geophys. Res. Oceans* **2017**, *122*, 2156–2170. [CrossRef]
65. Franco-Gordo, C.; Godínez-Domínguez, E.; Suárez-Morales, E. Larval fish assemblages in waters off the central Pacific coast of Mexico. *J. Plankton Res.* **2002**, *24*, 775–784. [CrossRef]
66. Funes-Rodríguez, R.; Flores-Coto, C.; Esquivel-Herrera, A.; Fernández-Alamo, M.A.; Gracia-Gásca, A. Larval fish community structure along the west coast of Baja California during and after the El Niño event (1983). *Bull. Mar. Sci.* **2002**, *70*, 41–54.
67. Aceves-Medina, G.; Jiménez-Rosenberg, S.P.A.; Hinojosa-Medina, A.; Funes-Rodríguez, R.; Saldierna, R.J.; Lluch-Belda, D.; Smith, P.E.; Watson, W. Fish larvae from the Gulf of California. *Sci. Mar.* **2003**, *67*, 1–11. [CrossRef]
68. Aceves-Medina, G.; Saldierna-Martínez, R.J.; Hinojosa-Medina, A.; Jiménez-Rosenberg, S.P.; Hernández-Rivas, M.E.; Morales-Ávila, R. Vertical structure of larval fish assemblages during diel cycles in summer and winter in the southern part of Bahía de La Paz, México. *Estuar. Coast. Shelf Sci.* **2008**, *76*, 889–901. [CrossRef]
69. Hsieh, H.Y.; Lo, W.T.; Chen, H.H.; Meng, P.J. Larval fish assemblages and hydrographic characteristics in the coastal waters of southwestern Taiwan during non-and post-typhoon summers. *Zool. Stud.* **2016**, *55*, 1–18.
70. Somarakis, S.; Drakopoulos, P.; Filippou, V. Distribution and abundance of larval fish in the northern Aegean Sea—Eastern Mediterranean—In relation to early summer oceanographic conditions. *J. Plankton Res.* **2002**, *24*, 339–358. [CrossRef]
71. Kaunda-Arara, B.; Mwaluma, J.M.; Locham, G.A.; Øresland, V.; Osore, M.K. Temporal variability in fish larval supply to Malindi Marine Park, coastal Kenya. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2009**, *19*, S10–S18. [CrossRef]
72. Sponaugle, S.; Llopiz, J.K.; Havel, L.N.; Rankin, T.L. Spatial variation in larval growth and gut fullness in a coral reef fish. *Mar. Ecol. Prog. Ser.* **2009**, *383*, 239–249. [CrossRef]
73. Leis, J.M. Ontogeny of behaviour in larvae of marine demersal fishes. *Ichthyol. Res.* **2010**, *7*, 325–342. [CrossRef]

74. Cowen, R.K.; Castro, L.R. Relation of coral reef fish larval distributions to island scale circulation around Barbados, West Indies. *Bull. Mar. Sci.* **1994**, *54*, 228–244.
75. Reiss, C.S.; Panteleev, G.; Taggart, C.T.; Sheng, J.; DeYoung, B. Observations on larval fish transport and retention on the Scotian Shelf in relation to geostrophic circulation. *Fish. Oceanogr.* **2000**, *9*, 195–213. [CrossRef]
76. Feng, M.; Slawinski, D.; Beckley, L.E.; Keesing, J.K. Retention and dispersal of shelf waters influenced by interactions of ocean boundary current and coastal geography. *Mar. Freshw. Res.* **2010**, *61*, 1260–1267. [CrossRef]
77. Sánchez-Velasco, L.; Beier, E.; Avalos-García, C.; Lavín, M.F. Larval fish assemblages and geostrophic circulation in Bahía de La Paz and the surrounding southwestern region of the Gulf of California. *J. Plankton Res.* **2006**, *28*, 1081–1098. [CrossRef]
78. Olivar, M.P.; Emelianov, M.; Villate, F.; Uriarte, I.; Maynou, F.; Alvarez, I.; Morote, E. The role of oceanographic conditions and plankton availability in larval fish assemblages off the Catalan coast (NW Mediterranean). *Fish. Oceanogr.* **2010**, *19*, 209–229. [CrossRef]
79. Sale, P.F. Habitat structure and recruitment in coral reef fishes. In *Habitat Structure: The Physical Arrangement of Objects in Space*; Springer: Dordrecht, The Netherlands, 1981; pp. 197–210.
80. Moberg, F.; Folke, C. Ecological goods and services of coral reef ecosystems. *Ecol. Econ.* **1999**, *29*, 215–233. [CrossRef]
81. Nagelkerken, I.; Dorenbosch, M.; Verberk, W.C.E.P.; De La Morinière, E.C.; van Der Velde, G. Importance of shallow-water biotopes of a Caribbean Bay for juvenile coral reef fishes: Patterns in biotope association, community structure and spatial distribution. *Mar. Ecol. Prog. Ser.* **2000**, *202*, 175–192. [CrossRef]
82. Mumby, P.J.; Broad, K.; Brumbaugh, D.R.; Dahlgren, C.P.; Harborne, A.R.; Hastings, A.; Holmes, K.E.; Kapple, C.V.; Micheli, F.; Sanchirico, J.N. Coral reef habitats as surrogates of species, ecological functions, and ecosystem services. *Conserv. Biol.* **2008**, *22*, 941–951. [CrossRef] [PubMed]
83. McConnell, R.; Lowe-McConnell, R.H. *Ecological Studies in Tropical Fish Communities*; Cambridge University Press: Cambridge, UK, 1987; p. 382.
84. Johannes, R.E. Traditional marine conservation methods in Oceania and their demise. *Annu. Rev. Ecol. Evol. Syst.* **1978**, *9*, 349–364. [CrossRef]
85. Pineda, J.; Porri, F.; Starczak, V.; Blythe, J. Causes of decoupling between larval supply and settlement and consequences for understanding recruitment and population connectivity. *J. Exp. Mar. Biol. Ecol.* **2010**, *392*, 9–21. [CrossRef]
86. China, V.; Holzman, R. Hydrodynamic starvation in first-feeding larval fishes. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 8083–8088. [CrossRef] [PubMed]

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