Biología Pesquera 20: 21-35, 1991 ISSN N° 0067 - 8767

DAILY ANALYSIS OF ABUNDANCE AND SIZE VARIABILITY OF FISH LARVAE IN RELATION TO OCEANIC WATER INTRUSIONS IN COASTAL AREAS*

ANALISIS DIARIO DE LA VARIABILIDAD EN ABUNDANCIA Y TAMAÑO DE LARVAS DE PECES EN RELACION A INTRUSIONES DE AGUAS OCEANICAS EN AREAS COSTERAS*

Gonzalo Castillo [1], Hermann Muñoz [2], Humberto González [3] and Patricio Bernal [4]

ABSTRACT

The daily variability of the summer ichthyoplankton assemblage in the Gulf of Arauco (37°05'S, 73°20'W) was studied to characterize its composition, relative abundance, size distribution of larvae, and its response to environmental conditions. Three well defined environmental changes were observed during the 11 day study period: (1) sinking of isotherms and temperature increase of the surface layer, (2) a sharp decrease in chlorophyll concentration. Both (1) and (2) occurred on the 6th day of sampling, and (3) a storm on the 8th day. The first two events were due to onshore flow of oceanic water, which could have been enhanced by downwelling during the storm. The ichthyoplankton assemblage showed: (1) high concordance in the ranking of specific relative abundance among samples ($Wc = 0.87$, $P < 0.01$), (2) temporal concordance in the variations of relative abundance for larvae of the eight most dominant species ($Wc = 0.35$, $P < 0.01$), (3) presence of larger fish larvae after the storm for the four dominant species ($P < 0.03$), and (4) predominant ordination of samples into a pre-storm group and a post-storm group (Bray-Curtis index). Implications of transport processes in the dynamics and structure of coastal ichthyoplankton are discussed.

Key words: Ichthyoplankton assemblage, temporal variability, Chile-Perú Current.

RESUMEN

Se estudió la variabilidad diaria del conjunto ictioplanctónico de verano del Golfo de Arauco (37°05'S, 73°20'W) con el objeto de caracterizar su composición, abundancia relativa, distribución por tamaño de larvas y su respuesta frente a variaciones ambientales. Se observaron tres claros cambios ambientales durante los 11 dias de estudio: (1) hundimiento de isotermas y aumento de temperatura superficial, (2) una considerable disminución en concentración de clorofila. Ambos (1) y (2) ocurrieron durante el sexto día de muestreo, y (3) una tormenta durante el octavo día. Los dos primeros eventos indicaron una intrusión de aguas oceánicas, la cual pudo ser incrementada por una antisurgencia durante la tormenta. El conjunto ictioplanctónico mostró: (1) alta concordancia en el ranking de abundancias relativas específicas de todas las species ($Wc = 0.87$, $P < 0.01$), (2) concordancia en el patrón temporal de fluctuación en abundancia relativa para las ocho especies más abundantes ($Wc = 0.35$, $P < 0.01$), (3) mayor tamaño larval en las cuatro especies dominantes después de la tormenta ($P < 0.03$), y (4) ordenamiento general de muestras en un grupo previo a la tormenta y en un grupo posterior a la tormenta (índice de Bray-Curtis). Se discuten las implicancias de procesos de transporte en la dinámica y estructura del ictioplancton costero.

Palabras claves: Conjunto ictioplanctónico, variabilidad temporal, Corriente Chile-Perú.

**Research conducted at Departamento de Oceanografía. Universidad Católica de la SSMA. Concepción (formerly Pont. Universidad Católica de Chile, Sede Talcahuano). Casilla 127, Talcahuano, Chile.*

[1] *Department of Fisheries and Wildlife. Nash Hall 104, Oregon State University, Corvallis, Oregon 97331, U.S.A.*
[2] *Instituto de Fomento Pesquero. Sede Talcahuano, Casilla 347, Talcahuano, Chile.*
[3] *Alfred-Wegener-Institut für Polar und Meeresforschung, Columbusstrasse, W-2850. Bremerhaven, Germany.*
[4] *Instituto de Fomento Pesquero. José Domingo Cañas 2277. Casilla 1287, Santiago, Chile.*

INTRODUCTION

Increasing evidence suggests that environmental perturbations at early life stages of fishes influence their subsequent recruitment (e.g., Sharp, 1980; Lasker and Sherman, 1981). Yet, the details of the connection between spawning and oceanographic transport systems, and the consequences of deviations from normal transport mechanisms of eggs and larvae remain little understood (Norcross & Shaw, 1984; Bailey & Incze, 1985). It is now evident that the complex hydrodynamic phenomena affecting marine ecosystems (e.g., Robinson, 1983; Mooers & Robinson, 1984), and the different levels of aggregation of organisms (Haury *et al.*, 1978), require explicit consideration of spatial and temporal scales.

We examined the daily variability of a summer ichthyoplankton assemblage in the Southeast Pacific. Our aims were: (1) to characterize the species composition of the assemblage, the variability in relative abundance, and length composition of fish larvae, and (2) to infer possible hydrodynamic controls on ichthyoplankton by means of estimations of Ekman transport, water temperature, integrated chlorophyll concentrations and zooplankton displacement volumes.

The studied area is the Gulf of Arauco (37°05′ S, 73°20′ W). It is close to the southern limit of the southernmost Upwelling Maximum Region of the Peru-Chile Current System (Bakun & Parrish, 1982). In summer, the upwelling maximum region extends from Taltal (26°S) down to the Gulf of Arauco -the largest embayment off central Chile- in which waters from the Bio-Bio River and other smaller rivers are discharged (Alarcon, 1970). Although the Gulf of Arauco is a major spawning ground for several commercially valuable species of fish (Rojas *et al.*, 1983), the effects of short-term environmental influences on early life stages of fishes have not been studied.

MATERIALS AND METHODS

Samples of ichthyoplankton and oceanographic information were obtained as part of the Experiment Arauco-85 conducted in the Gulf of Arauco from January 15 to 27, 1985. The present study was based on 19 plankton samples taken from January 17 to 27 at Station 4 (Figure 1), this station was selected because of its longer and more regular temporal sequence of sampling. Water temperature at the same station was measured in-situ using a CTD system. Integrated chlorophyll concentrations were determined at stations 3 and 4 from vertical fluorescence profiles (Turner fluorometer model 10-000R).

Ichthyoplankton sampling was performed using oblique Bongo net hauls. Samples analyzed were extracted from a single net (335 μm mesh size, 0.282 m^2 mouth area) included in the Bongo net. The net was hauled from depths over 30 m to the surface (mean sampling depth: 45 m, bottom depth: c.a. 61 m). Mean towing speed was 1.4 (m/s).

Since the filtered volume of sea water measured with a flowmeter ranged from 59 to 170 m^3 (mean: 102.7 m^3), relative abundance of ichthyoplankton (herein after referred to as density) was standardized to 100 m^3. Samples were preserved in 4% buffered formalin, and fish eggs and larvae were sorted and counted without splitting the samples.

Larvae were classified to species level when possible. Larval length was measured at 0.5 mm intervals, from the anteriormost point of the head to the tip of the notochord (notochordal length: NL) or the base of the hypurals (standard length: SL), depending on which of the two gave the longest length at a given stage. Corrections for larval shrinkage due to capture and preservation were only applied to *Engraulis ringens* and *Sardinops sagax* assuming similar effects to those reported for *E. mordax* by Theilacker (1980). Unclassified species (c.a. 1.3% of total mean larval density) were not included in the analyses. Counting of eggs of *E. ringens* and *S. sagax* were performed separately from other species.

To determine the degree of aggregation of eggs and larvae, two non-dimensional indices proposed by Lloyd (1967) for spatial comparisons were used. These indices are:

i) Mean crowding (m^*), the mean density corrected by the amount that variance to mean ratio exceeds one:

$$m^* = m + [(s.d.^2 / m) - 1]$$

where m is the mean density, and $s.d.^2$ is the attendant variance of density.

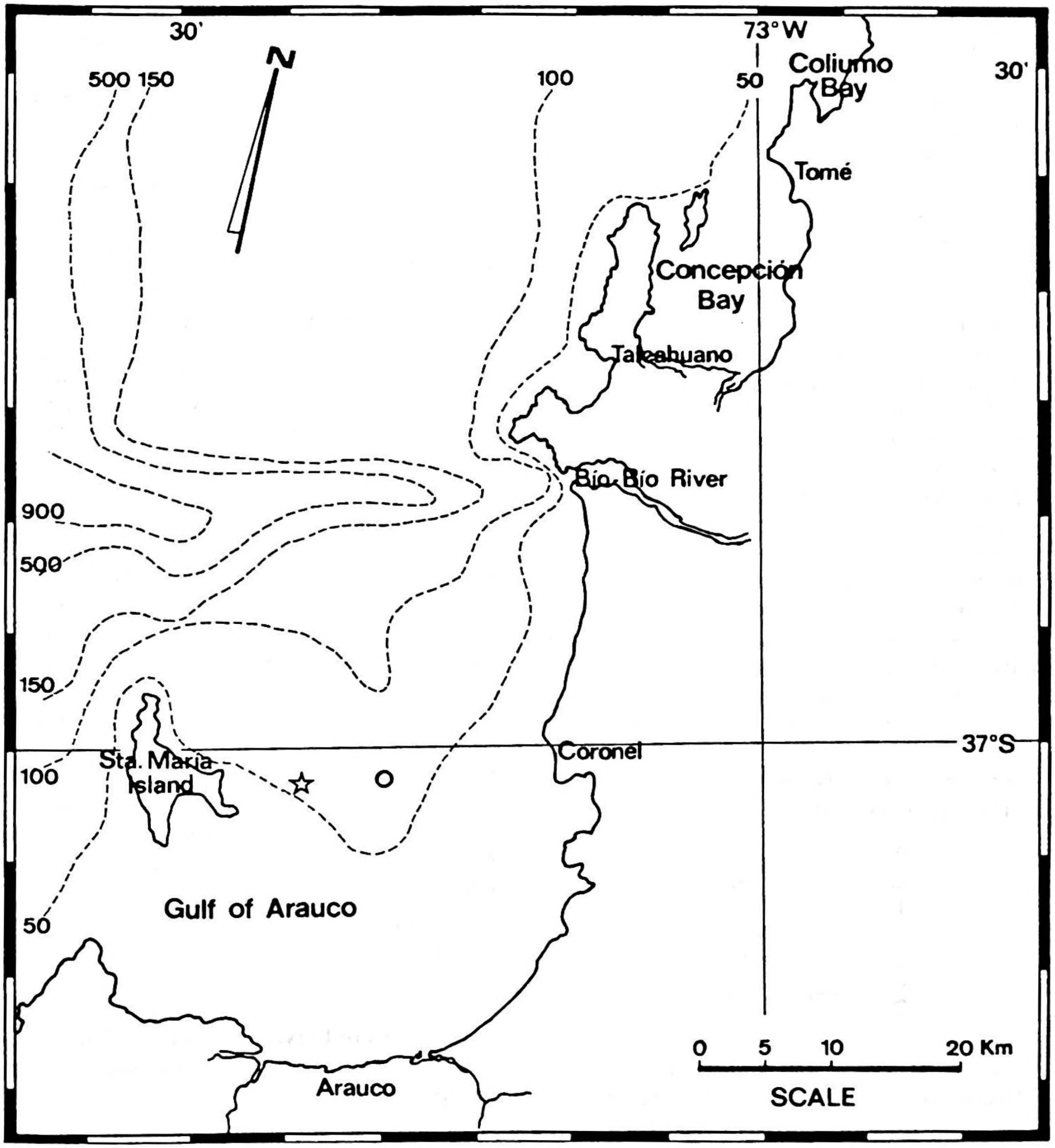

Figure 1. Sampling area showing the location of Station 4:☆ and Station 3: O. Bathymetry is shown in meters. (Modified from Mordojovich, 1983).

ii) Patchiness index (PI), that compares how many times more crowded an average individual is relative to an individual in a population of equal density but randomly dispersed:

$$PI = m^* / m$$

where m* is mean crowding and m is attendant mean density.

We investigated possible differences in larval density and size between tows taken at day and night. Statistical analyses were performed using non-parametric techniques (Tate & Clelland, 1957; Conover, 1971).

Kendall's coefficient of concordance was used to see whether there was a pattern in the ranking of specific larval densities, and to establish whether density fluctuations among species were coupled. Spearman correlations were used to determine possible relations among total larval density, zooplankton displacement volume, chlorophyll concentration and depth of the 12°C isotherm (a proxy for upwelling). We selected the depth of the 12°C isotherm because it is located near the bottom of the mixed layer, over which epipelagic fish larvae may be found (Gorbunova 1981). Ekman transport was estimated per 100 m of coastline (after Bakun, 1973). The median test was applied to compare changes in larval density among consecutive samples.

We used the Bray-Curtis dissimilarity coefficient (Clifford & Stephenson, 1975) to describe relations between species and samples. The equation used is:

$$Dab = \frac{\sum_{1}^{n} [Xaj - Xbj]}{\sum_{1}^{n} [Xaj + Xbj]}$$

Where *Dab* is a measure of dissimilarity between species (or periods) *a* and *b*, *Xaj* and *Xbj* are densities of species *a* and *b* in a given sample (or densities for the Jth species in *a* and *b* periods), and *n* is the number of species found (or times considered). Before classification was performed, data were log-transformed to reduce the effects of dominant species (Field *et al.*, 1982).

For ascertaining the degree of temporal variation in distribution of length frequencies of larvae, multiple pair-wise correlations between samples were computed for intervals ranging from c.a. 12 hr. to 11 days (i.e., correlations of each sample with all the subsequent samples in the series). Due to the problem resulting from these multiple comparisons, no inferential conclusions on single pair-wise comparisons were made. This procedure generates series of increasingly time-lagged correlations that depict the temporal coherence of larval length-frequencies.

RESULTS

Composition and Aggregation of Species

During the sampling period 18 taxa were found, 12 of them identified at the species level, other two as genera and four as morphotypes (Table 1). The four dominant species -*E. ringens*, *S. sagax*, *Normanichthys crockeri*, and *Stromateus stellatus*- contributed 84% of the total larval density and were found together with *Strangomera bentincki* and *Ethmidium maculatum* in all samples analyzed (Table 2). *E. ringens* alone accounted for 46.6% of the total larval density. With the exception of two species with standard deviations lower than one, mean crowding values were higher than mean density, and the patchiness index of larvae tended to be inversely related to mean larval density (Spearman's r = -0.65, P = 0.01).

Predictably, in this spawning ground the mean densities, mean crowding and degree of patchiness were higher for eggs of *E. ringens* and *S. sagax* than for larvae of the same species (Table 3).

Differences in Larval Density and Size Distribution Between Day and Night Samples

Due to low larval density for most of the species, potential differences in density between day and night catches were only examined for *E. ringens*, *S. sagax*, *N. crockeri* and *S. stellatus*.

The day/night ratio of mean counts in these four species were similar between day and night tows. Moreover, no significant differences were

Table 1. Fish larval density (and attendant standard deviation and variation coefficient), percentage of total larval density, frequency of occurrence, mean crowding and patchiness indices, size range of larvae (uncorrected for shrinkage), and egg type of species found in the Gulf of Arauco (Station 4, January 17 to 27, 1985. See foot-notes).

Species	Density [N°/100 m^3][1]	(s.d.)[2]	V.C.[3]	Total %[4]	Occurr.[5]	m*[6]	(m*/m)[7]	Size Range (mm)	Egg[8] Type
Engraulis ringens	132.5	87.6	66.1	46.6	100.0	189.4	1.4	1.5 - 22.5	P
Sardinops sagax	52.6	34.8	66.1	18.5	100.0	74.6	1.4	2.0 - 15.5	P
Normanichthys crockeri	30.7	26.5	86.3	10.8	100.0	52.6	1.7	2.0 - 16.0	?
Stromateus stellatus	24.3	16.0	65.8	8.5	100.0	33.8	1.4	2.0 - 8.0	?
Strangomera bentincki	7.2	5.6	77.7	2.5	100.0	10.5	1.5	2.0 - 18.0	P
Ethmidium maculatum	6.1	5.3	86.9	2.1	100.0	9.7	1.6	2.0 - 15.0	P
Tripterygion sp.[9]	5.0	5.7	114.0	1.8	88.8	10.5	2.1	3.0 - 16.0	?
Prolatilus jugularis	4.5	4.7	93.3	1.6	77.8	7.4	1.6	4.0 - 8.0	P
Hipoglossina macrops	3.6	4.0	111.1	1.3	83.3	7.0	2.0	3.0 - 5.5	P
Merluccius gayi	3.4	4.9	144.1	1.2	55.6	6.1	1.8	2.5 - 16.0	P
Sp. 1	2.6	2.3	88.5	0.9	83.3	3.6	1.4	2.0 - 9.0	?
Hypsoblennius sordidus	2.5	2.8	112.0	0.9	77.8	4.6	1.8	3.0 - 9.0	D
Hygophum bruuni	1.7	1.8	105.9	0.6	61.1	2.6	1.5	2.5 - 6.5	P
Paralichthys sp. [10]	1.6	2.1	131.2	0.6	66.7	3.4	2.1	2.5 - 8.0	P
Sp. 3	0.8	1.3	162.0	0.3	44.4	1.9	2.4	3.0 - 5.5	?
Austromenidia laticlavia	0.7	1.2	171.4	0.2	44.4	1.8	2.5	3.0 - 13.0	D
Sp. 2	0.4	0.5	125.0	0.1	44.4	c	c	2.0 - 3.5	?
Sp. 4	0.4	0.6	150.0	0.1	39.0	c	c	2.5 - 6.0	?
Other species	3.0	3.0	83.3	1.3	83.3	-	-	-	-

1: Number of larvae per 100 m^3 of filtered water.

2: Standard deviation of mean larval density.

3: Variation coefficient = 100 • (s.d./mean larval density)

4: Percentage of total fish larval density.

5: Percentage of samples in which the species is present.

6: Mean crowding index (Lloyd 1967).

7: Patchiness index (Lloyd 1967).

8: Egg type: P= pelagic, D= demersal, ?= unknown.

9: Could include *T. cunnighami* and *T. chilensis*.

10: Could include *P. adspersus* and *P. microps*

c: (s.d. < 1).

Table 2. Daily variation in larval and egg densities. Also shown are the original filtered sea water volumes. (Station 4, Gulf of Arauco, January 17-27, 1985. See foot-notes for identification of species and symbols).

Day-Hour	Filtered Volume (m³)	Larval Density (N° / 100m³) Species								Egg Density (N° / 100 m³) Species			
		1	2	3	4	5	6	Other Taxa	All Larvae	1	2	Other Taxa	All Eggs
17-02:12	88.9	49.5	32.6	7.9	7.9	9.0	24.6	26.8	158.3	1435	938	47	2420
17-13:18	152.8	308.9	41.2	6.5	3.9	9.1	7.1	12.8	389.5	169	55	71	295
18-03:50	132.1	297.6	51.5	3.8	3.8	9.9	4.6	34.3	405.5	88	29	38	155
19-06:35	63.1	223.4	65.0	1.6	9.5	12.6	12.6	42.8	367.5	81	32	167	280
19-17:08	58.9	73.0	17.0	1.7	1.7	3.4	5.1	49.3	151.2	1104	25	404	1533
20-06:28	83.6	232.1	149.5	21.5	8.4	44.4	38.4	40.7	535.0	245	2	205	452
20-23:11	102.9	102.9	32.0	14.6	6.8	95.1	20.4	27.3	299.1	73	11	140	224
21-11:30	81.5	43.0	4.9	6.1	6.1	-	-	-	-	503	145	147	795
22-02:56	157.4	68.6	45.7	2.5	5.1	31.4	16.0	28.3	197.6	1366	12	136	514
22-15:01	99.5	96.5	18.1	2.0	3.0	1.0	30.1	19.0	169.7	113	1	176	290
23-02:27	84.5	197.6	53.2	4.7	4.7	18.9	54.3	33.0	366.4	179	2	90	271
23-16:00*	89.3	34.7	14.5	2.2	2.2	4.5	7.8	22.4	88.3	10	7	54	71
24-05:51	78.0	88.5	41.0	6.4	2.6	20.5	24.3	14.3	197.6	19	1	99	119
25-14:15	63.2	144.0	75.9	17.4	25.3	80.6	52.1	49.1	444.4	104	375	491	970
25-21:56	81.1	167.6	55.5	6.2	6.2	50.4	12.3	25.8	324.0	9	0	33	42
26-07:22	124.4	75.5	28.9	5.6	6.4	40.2	19.3	49.6	225.5	168	8	134	310
26-17:55	127.5	138.0	119.2	10.2	3.9	43.1	48.6	36.8	399.8	0	56	165	221
27-02:55	113.7	62.4	67.7	5.3	4.4	32.5	23.7	18.6	214.6	19	9	46	74
27-20:35	170.0	23.5	38.2	8.8	3.5	45.9	36.4	26.3	182.6	21	34	159	214

1: *Engraulis ringens*
2: *Sardinops sagax*
3: *Strangomera bentincki*
4: *Ethmidium maculatum*
5: *Normanichthys crockeri*
6: *Stromateus stellatus*
-: Partially damaged sample
*: Sampling time (+/- 1 hr.)

Table 3. Parameters for eggs of *Engraulis ringens, Sardinops sagax*, and for all other species found in the Gulf of Arauco at Station 4. (January 17 to 27 of 1985. Terms correspond to those of Table 1).

Species	Density (N°/100 m³)	s.d.	V.C.	Total %	Occurrence	m*	m*/m
Engraulis ringens	282.6	477.4	168.9	55.0	94.4	1088.1	3.8
Sardinops sagax	88.5	228.8	258.0	17.2	94.4	679.0	7.7
Other species	142.4	124.8	87.6	27.6	100.0	250.8	1.8

detected between mean length frequencies of larvae caught during night and day (Kolmorogov-Smirnov test, $P > 0.05$).

Since lower larval densities were associated with smaller size ranges of larvae (Table 1), only the four dominant species were considered to estimate differences in larval size between day and night samples. The night/day ratios of larval density were greater than one for *E. ringens* and *S. sagax* over 9 mm SL (Figure 2). Due to the low densities of larger larvae in samples, unbiased estimates of night/day ratios by size intervals cannot be obtained for *S. sagax* over 11 mm SL and for *E. ringens* over 15 mm SL. Larvae of *S. stellatus* over 4 mm SL, and *N. crockeri* over 5 mm SL were more often collected at night, but not as clearly seen as in *E. ringens* or in *S. sagax*, which may be due to greater scarcity of larger larvae, differences in larval evasion, or a combination of both. On the other hand, no differences in larval sizes were detected when comparing tows taken from the upper 40 m of depth to the surface with tows taken from greater depths to the surface. Thus, differences in capture of large individuals between day and night tows were not ascribed to vertical migration of fish larvae.

Density Fluctuations of Larvae and Relations among Species and Samples

Large differences in larval densities among species suggested attendant variations in spawning and/or early survival in the summer ichthyoplankton assemblage. Significant

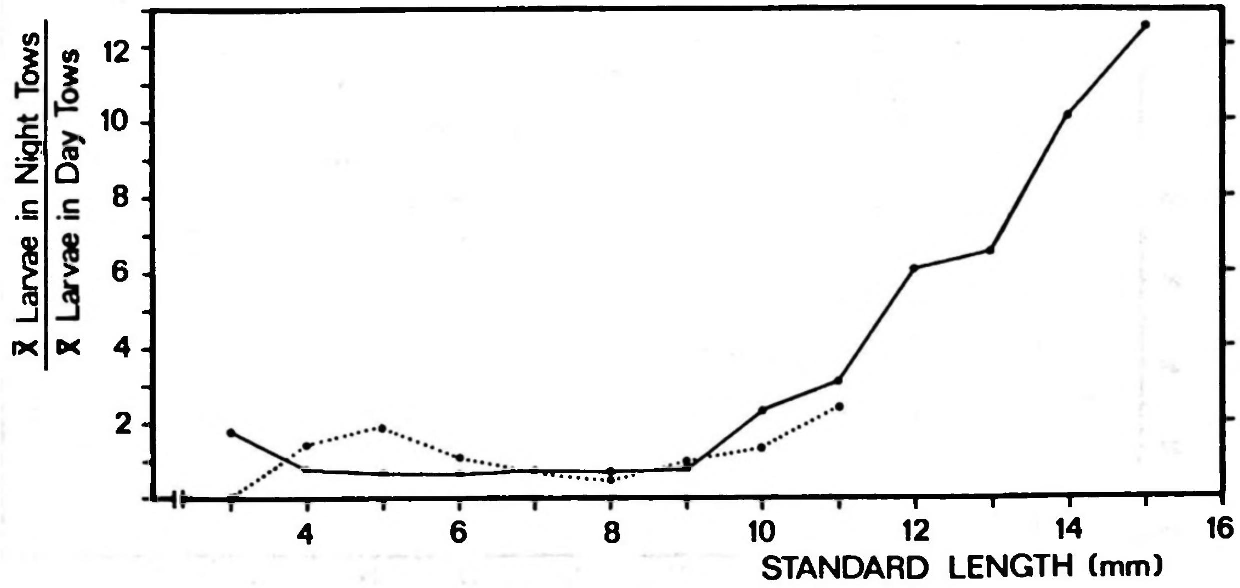

Figure 2. Night/day ratio of larval density by length intervals of 1 mm. Computed from the mean length composition of day and night tows. *Engraulis ringens:* (•———•). *Sardinops sagax:* (•··············•).

Table 2. Daily variation in larval and egg densities. Also shown are the original filtered sea water volumes. (Station 4, Gulf of Arauco, January 17-27, 1985. See foot-notes for identification of species and symbols).

Day-Hour	Filtered Volume (m^3)	Larval Density (N° / 100m^3) Species								Egg Density (N° / 100 m^3) Species			
		1	2	3	4	5	6	Other Taxa	All Larvae	1	2	Other Taxa	All Eggs
17-02:12	88.9	49.5	32.6	7.9	7.9	9.0	24.6	26.8	158.3	1435	938	47	2420
17-13:18	152.8	308.9	41.2	6.5	3.9	9.1	7.1	12.8	389.5	169	55	71	295
18-03:50	132.1	297.6	51.5	3.8	3.8	9.9	4.6	34.3	405.5	88	29	38	155
19-06:35	63.1	223.4	65.0	1.6	9.5	12.6	12.6	42.8	367.5	81	32	167	280
19-17:08	58.9	73.0	17.0	1.7	1.7	3.4	5.1	49.3	151.2	1104	25	404	1533
20-06:28	83.6	232.1	149.5	21.5	8.4	44.4	38.4	40.7	535.0	245	2	205	452
20-23:11	102.9	102.9	32.0	14.6	6.8	95.1	20.4	27.3	299.1	73	11	140	224
21-11:30	81.5	43.0	4.9	6.1	6.1	-	-	-	-	503	145	147	795
22-02:56	157.4	68.6	45.7	2.5	5.1	31.4	16.0	28.3	197.6	1366	12	136	514
22-15:01	99.5	96.5	18.1	2.0	3.0	1.0	30.1	19.0	169.7	113	1	176	290
23-02:27	84.5	197.6	53.2	4.7	4.7	18.9	54.3	33.0	366.4	179	2	90	271
23-16:00*	89.3	34.7	14.5	2.2	2.2	4.5	7.8	22.4	88.3	10	7	54	71
24-05:51	78.0	88.5	41.0	6.4	2.6	20.5	24.3	14.3	197.6	19	1	99	119
25-14:15	63.2	144.0	75.9	17.4	25.3	80.6	52.1	49.1	444.4	104	375	491	970
25-21:56	81.1	167.6	55.5	6.2	6.2	50.4	12.3	25.8	324.0	9	0	33	42
26-07:22	124.4	75.5	28.9	5.6	6.4	40.2	19.3	49.6	225.5	168	8	134	310
26-17:55	127.5	138.0	119.2	10.2	3.9	43.1	48.6	36.8	399.8	0	56	165	221
27-02:55	113.7	62.4	67.7	5.3	4.4	32.5	23.7	18.6	214.6	19	9	46	74
27-20:35	170.0	23.5	38.2	8.8	3.5	45.9	36.4	26.3	182.6	21	34	159	214

1: *Engraulis ringens*
2: *Sardinops sagax*
3: *Strangomera bentincki*
4: *Ethmidium maculatum*
5: *Normanichthys crockeri*
6: *Stromateus stellatus*
-: Partially damaged sample
*: Sampling time (+/- 1 hr.)

Table 3. Parameters for eggs of *Engraulis ringens, Sardinops sagax,* and for all other species found in the Gulf of Arauco at Station 4. (January 17 to 27 of 1985. Terms correspond to those of Table 1).

Species	Density (N°/100 m^3)	s.d.	V.C.	Total %	Occurrence	m*	m*/m
Engraulis ringens	282.6	477.4	168.9	55.0	94.4	1088.1	3.8
Sardinops sagax	88.5	228.8	258.0	17.2	94.4	679.0	7.7
Other species	142.4	124.8	87.6	27.6	100.0	250.8	1.8

detected between mean length frequencies of larvae caught during night and day (Kolmorogov-Smirnov test, $P > 0.05$).

Since lower larval densities were associated with smaller size ranges of larvae (Table 1), only the four dominant species were considered to estimate differences in larval size between day and night samples. The night/day ratios of larval density were greater than one for *E. ringens* and *S. sagax* over 9 mm SL (Figure 2). Due to the low densities of larger larvae in samples, unbiased estimates of night/day ratios by size intervals cannot be obtained for *S. sagax* over 11 mm SL and for *E. ringens* over 15 mm SL. Larvae of *S. stellatus* over 4 mm SL, and *N. crockeri* over 5 mm SL were more often collected at night, but not as clearly seen as in *E. ringens* or in *S. sagax*, which may be due to greater scarcity of larger larvae, differences in larval evasion, or a combination of both. On the other hand, no differences in larval sizes were detected when comparing tows taken from the upper 40 m of depth to the surface with tows taken from greater depths to the surface. Thus, differences in capture of large individuals between day and night tows were not ascribed to vertical migration of fish larvae.

Density Fluctuations of Larvae and Relations among Species and Samples

Large differences in larval densities among species suggested attendant variations in spawning and/or early survival in the summer ichthyoplankton assemblage. Significant

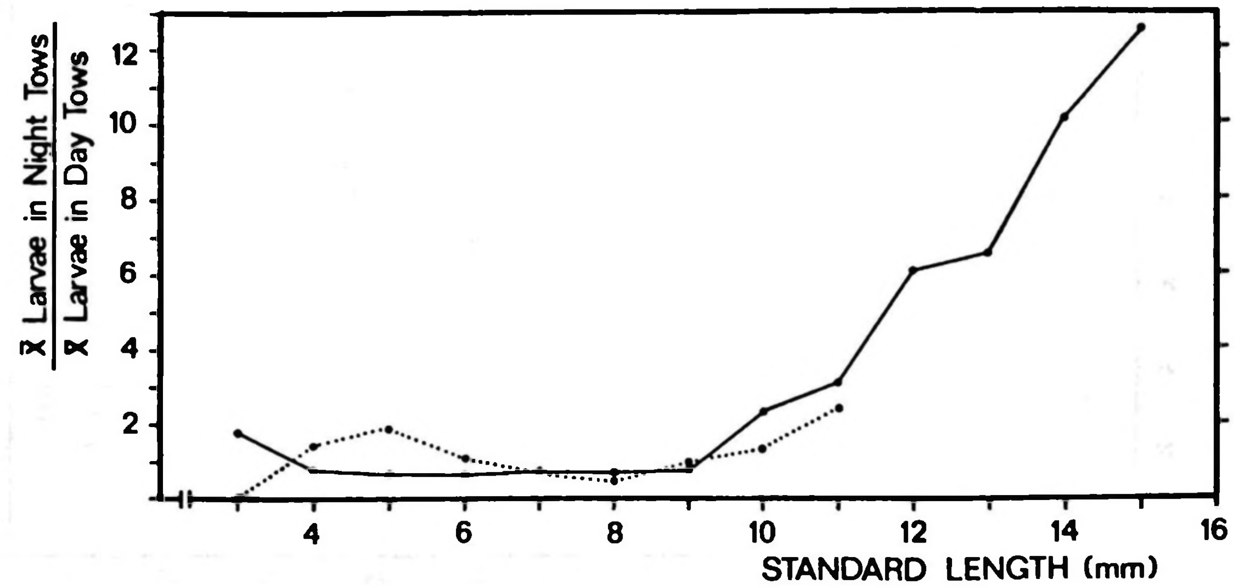

Figure 2. Night/day ratio of larval density by length intervals of 1 mm. Computed from the mean length composition of day and night tows. *Engraulis ringens:* (•———•). *Sardinops sagax:* (•··············•).

Kendall's coefficient of concordance (Wc) were obtained when comparing: (1) the ranking of density for each species among samples (Wc = 0.87, P = 0.005), and (2) the temporal changes in density among the eight most abundant species (Wc = 0.35, P = 0.005). Thus, the high consistency in the ranking of densities among species could be enhanced by the high temporal coincidence in density variations among species. A conceivable mechanism for such temporal pattern of larval densities is discussed later.

Total fish larval density was not clearly associated with environmental variables such as: (1) depth of the 12°C isotherm (Figure 3), (2) zooplankton displacement volume (Figure 4), and (3) chlorophyll concentration (Figure 5), (Spearman correlations, P > 0.10). Yet, two large differences in total larval density observed from paired sequential samples (median test, P = 0.10) were related to clear environmental changes. The first difference in total larval density coincided with a general sinking of isotherms and a sharp decrease in integrated chlorophyll concentration, both observed from January 22 to 23 (Figures 3 and 5). The second difference in total larval density, observed between January 24 and 25, coincided with a rainy storm characterized by strong southward winds. This atmospheric frontal system may have also mixed the water column and induced a downwelling event (Figure 6). Although favorable winds for upwelling alternated with winds favorable for downwelling, Ekman transport index and isotherm depths (Figure 3), only seemed related prior to January 22.

The Bray-Curtis dissimilarity measure among species (Figure 7a), grouped 66% of all species at a dissimilarity value of 0.56, which correspond to species with greater densities and higher percentages of occurrence. In general, species less likely to be found together showed higher dissimilarity values. In the temporal classification of samples through Bray-Curtis metric (Figure 7b), two major groups that included 83% of the samples were distinguished at a dissimilarity value of 0.28. The first group contained -with a single exception- samples taken before the storm. The second group was only formed by samples obtained after the storm.

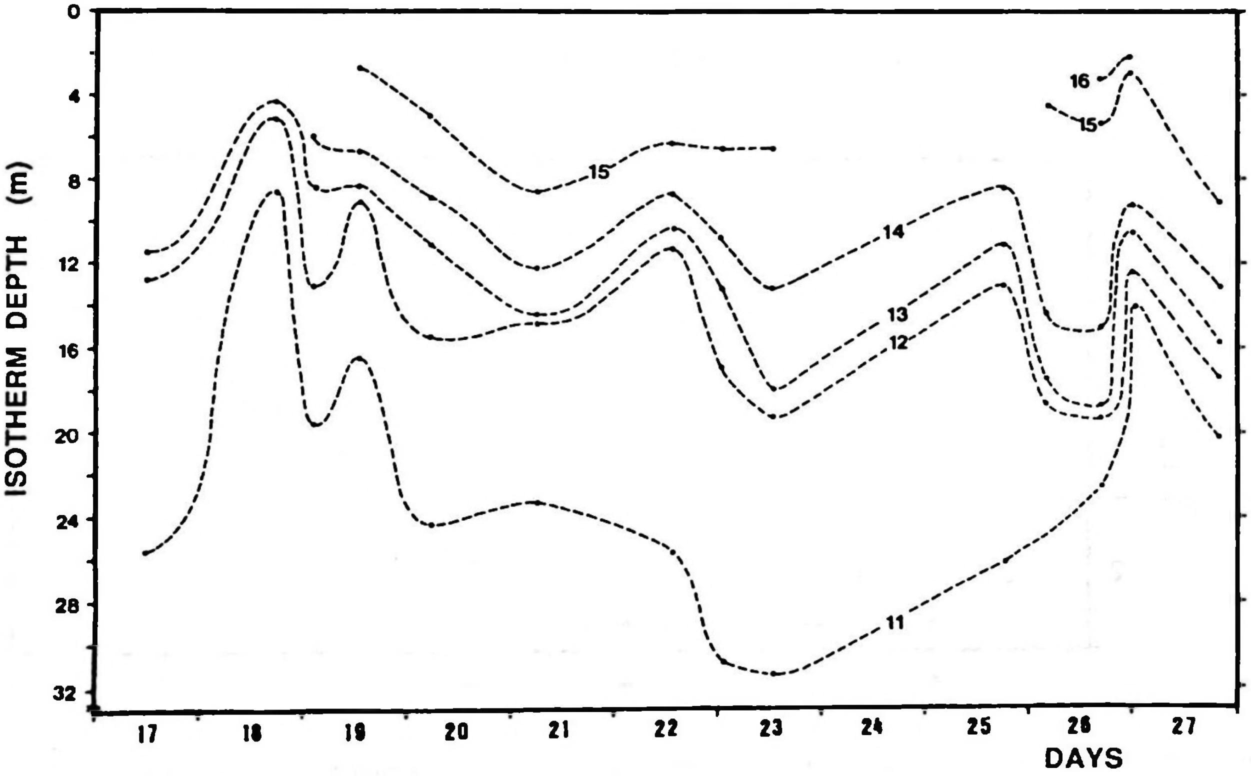

Figure 3. Temporal variability of isotherm depths in the upper 32 m of depth at Station 4 (temperature in °C).

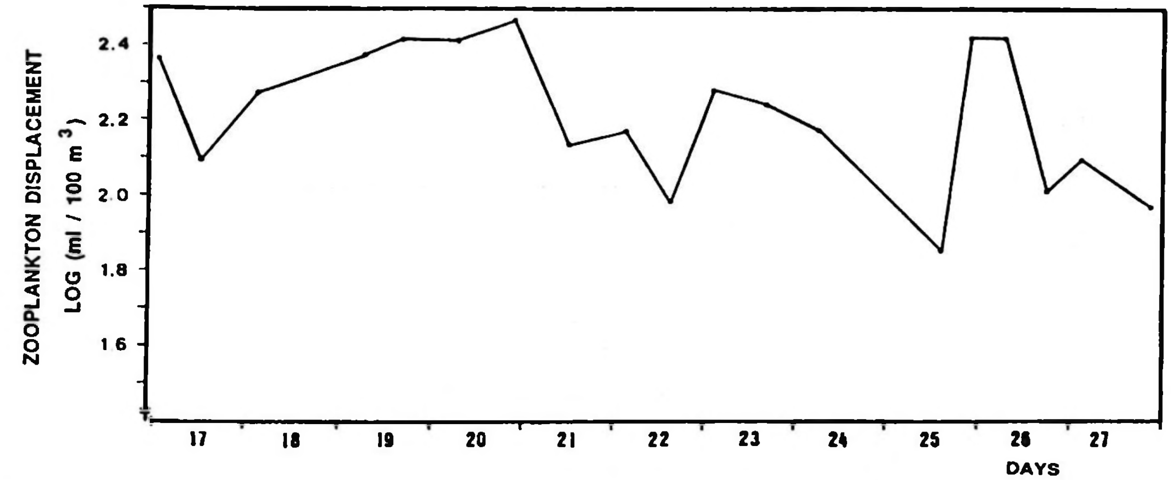

Figure 4. Temporal variation of log-transformed zooplankton displacement volume (ml/100 m^3) at Station 4.

Figure 5. Log-transformed integrated chlorophyll concentration (mg Chl-a/m^2) during the sampling period. Station 4: (•———•). Station 3: (•·········•).

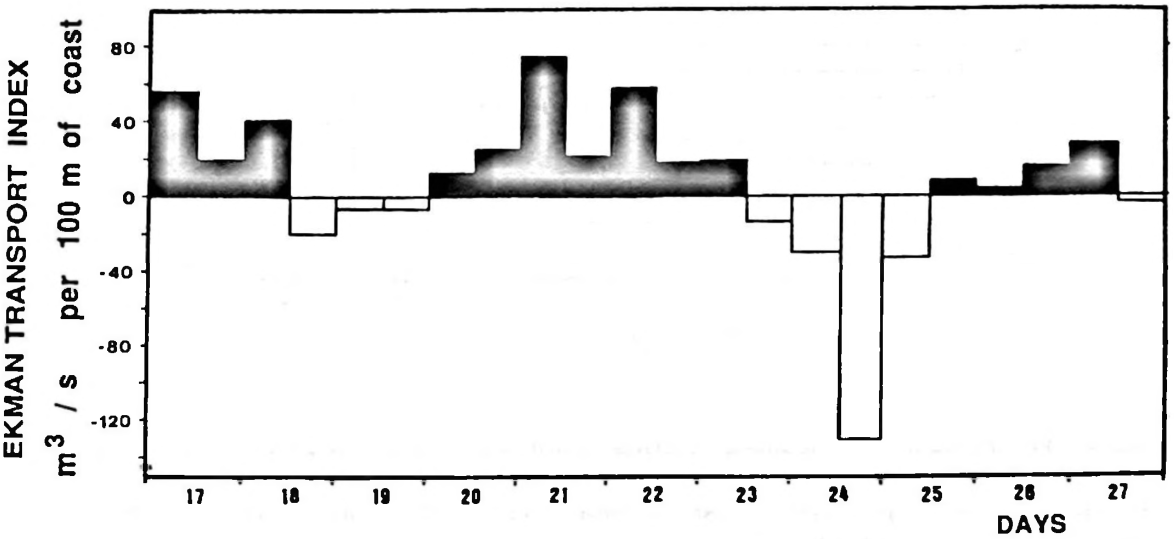

Figure 6. Index of mean Ekman transport (m^3/s per 100 m of coastline) calculated every 12 hr. Positive and negative values indicate potential upwelling and downwelling events respectively. (Wind records are from Carriel Sur Airport: 36°46'S - 73°04'W).

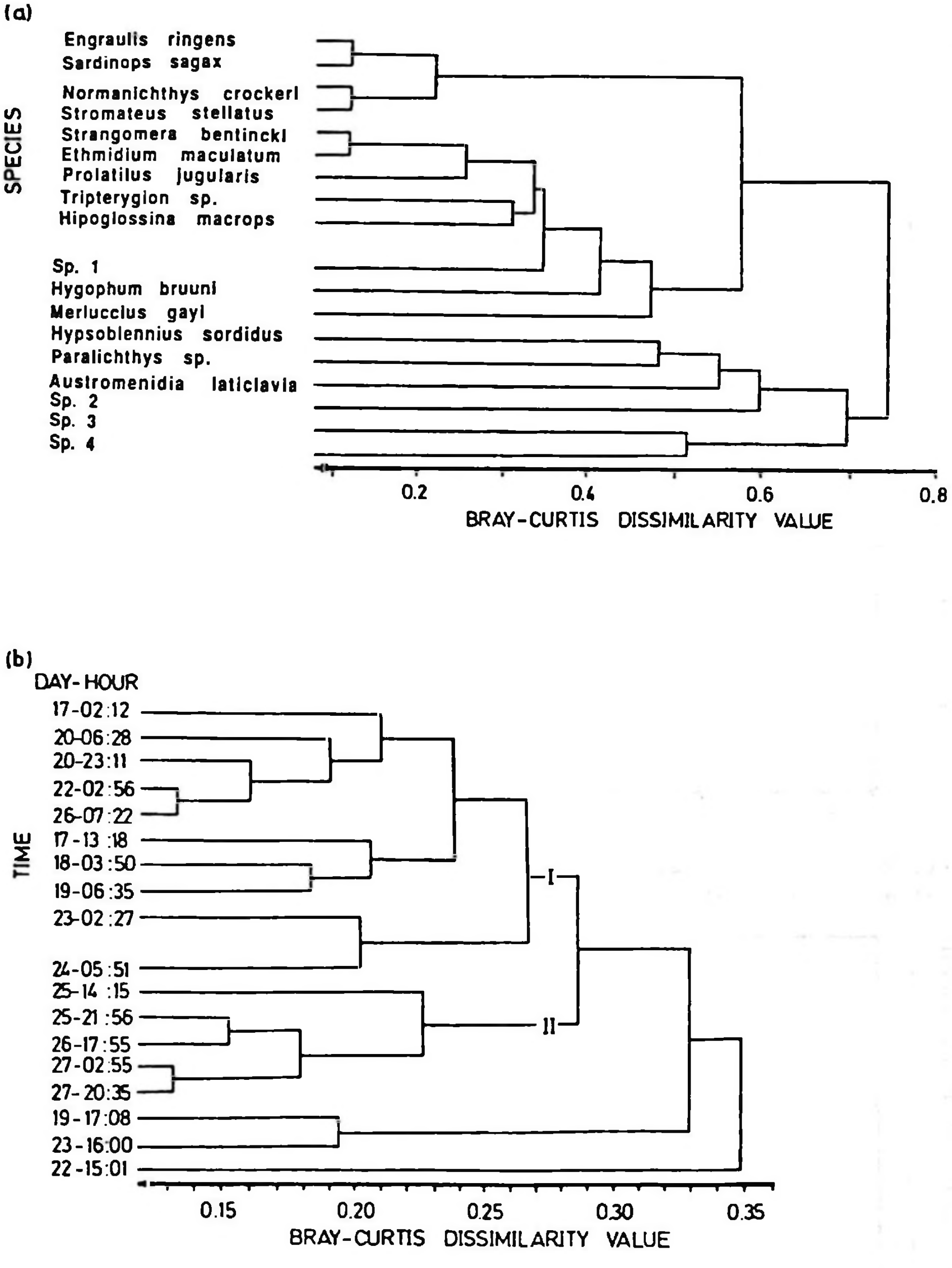

Figure 7. Bray-Curtis dendrogram alfer log(x+1) transformation of larval densities. (a): Clustering of species showing the lowest dissimilarities for the most frequent and abundant species. (b): Temporal comparison showing two major groups of samples: those collected mainly prior to the storm of January 24, 1985, and those only collected during or after the storm.

Analysis of Larval Length Frequencies

Only *E. ringens* and *S. sagax* were present in adequate numbers to be considered in this analysis. Length frequency comparisons were performed for larvae smaller than the approximate size of differential net evasion between day and night tows. For both species, two periods were identified in the whole series (Figure 8). The first period (January 17 to 23) showed relatively high positive length frequency correlations (LFC), and only one negative value for *S. sagax*: (*E. ringens*: mean LFC = 0.68, s.d. = 0.24; *S. sagax*: mean LFC = 0.59, s.d. = 0.32). The second period (January 24 to 27) also showed similar LFC among samples (*E. ringens*: mean LFC = 0.58, s.d. = 0.19; *S. sagax*: mean LFC = 0.67, s.d. = 0.17). Yet, low mean LFC were found when correlating samples from both periods (*E. ringens:* mean LFC = -0.12, s.d. = 0.39; *S. sagax:* mean LFC = -0.18, s.d. = 0.36).

Both *E. ringens* and *S. sagax*, showed significant differences in average larval length-frequencies before and after the storm of January 24. Such differences were also detected in *N. crockeri* and *S. stellatus* (Kolmorogov-Smirnov test, P < 0.03, Table 4).

Table 4. Distribution of mean length frequency (DMLF, in percentage) for the four dominant fish larvae sampled at Station 4 (Gulf of Arauco, 1985). DMLF only includes sizes under the approximate threshold of different larval evasion between day and night tows. I: (DMLF of larvae during the pre storm period, January 17-23). II: (DMLF of larvae during the storm and post-storm period, January 24-27). s.d. (standard deviation).

Larval Size	DMLF of Dominant Fish Larvae[1]															
	Engraulis ringens				*Sardinops sagax*				*Normanichthys crockeri*				*Stromateus stellatus*			
(mm)	I	s.d.	II	s.d.	I	s.d.	II	s.d.	I	s.d.	II	s.d.	I	s.d.	II	s.d.
2	-	-	-	-	-	-	-	-	10.9	10.7	6.2	7.2	36.4	29.1	20.3	13.6
3	11.7	10.3	0.4	0.8	4.9	8.8	-	-	36.0	9.6	16.8	13.3	34.0	19.3	41.9	13.1
4	43.9	18.1	8.7	5.4	11.4	10.7	0.1	0.4	31.8	14.9	30.4	9.0	29.5	26.4	37.7	14.4
5	15.7	6.0	14.7	7.9	43.0	20.8	8.2	5.9	21.2	12.8	46.4	20.1				
6	13.5	7.2	27.7	7.0	33.0	22.5	17.0	7.6								
7	9.4	9.8	17.4	6.9	4.5	6.1	24.6	6.8								
8	3.2	3.1	19.7	6.8	1.4	2.4	27.5	9.3								
9	2.4	3.6	11.2	8.0	1.7	3.2	22.5	11.9								

[1]: DMLF before and after the storm are significantly different (P < 0.03).

-: No larvae of these sizes were found after correcting for shrinkage.

DISCUSSION

This study investigated the high frequency variability of several factors relevant to ichthyoplankton ecology and survey planning which could not have been detected using weekly or monthly sampling. Our results indicate that coarse to mesoscale transport processes may cause significant short-term changes in the distribution, density and size composition of fish larvae, as well as marked changes in chlorophyll concentration in nearshore areas. Thus, in addition of appropriate design and statistical analysis in ichthyoplankton surveys (Colby, 1988), interpretation of ichthyoplankton data requires careful consideration of short-term environmental variation. This approach can be critical for understanding abundance and transport patterns, and for estimating survival of fish during early life stages.

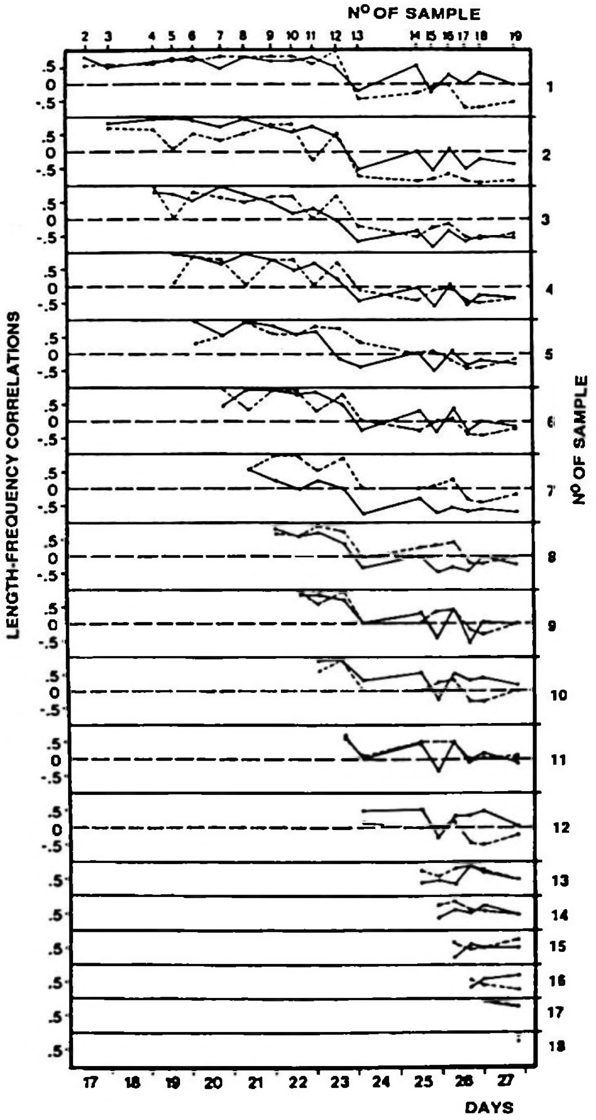

Figure 8. Temporal variation in length frequency correlations for larvae of *Engraulis ringens:* (•—•) and *Sardinops sagax:* (• ···· •). Length frequencies of fish larvae collected from January 17 to 23, 1985, tended to be negatively correlated with length frequencies of larvae collected after the storm of January 24 (Station 4, Gulf of Arauco).

In Concepcion Bay, (Figure 1), Aron (1980) found a total of 12 species from 1976 to 1977. All species reported in that work were also identified in the present study[1]. Muñoz (1983) found almost the same present species' list in Coliumo Bay (Figure 1). Thus, the species richness of ichthyoplankton in the Gulf of Arauco may not increase substantially during an annual period.

Aron (1980) found lower abundances for *E. ringens* and *S. sagax* than those reported here for the summer period, he also detected a clear dominance of *S. stellatus* and *N. crockeri* throughout the year. The average abundances of eggs and larvae of *E. ringens* found in the present study suggest a recovery of the local spawning stock after the fishery collapse of *E. ringens* and *Strangomera bentincki* in the 1970's. Our interpretation is also supported by ichthyoplankton surveys in Concepcion Bay (Guillermo Herrera, pers. comm.). It must be pointed out that no spawning of *S. sagax* was detected prior to El Niño 1972-73 at these latitudes (Bernal *et al.*, 1982). Thus, our finding of *S. sagax* larvae supports a southward extension of the geographical range of this species, and the establishment of a new local population (Bernal *et al.*, 1982).

After analyzing differences between day and night, depth of tows, standardized and non-standardized larval densities and filtered sea water volumes (Table 2), the near semi-daily (and in some cases daily) agreement in density fluctuations for the dominant species (Figure 9)

---

[1] Unfortunately, *Prolatilus jugularis* was mistakenly classified as *Trachurus murphyi* in Aron's (1980) study.

was not ascribed to an artifact of sampling. Considering the general decrease in offshore larval densities for dominant fishes found in the Gulf of Arauco (Rojas *et al.* 1983), it is possible that the observed density fluctuations of fish larvae had been forced by cross-shore advection.

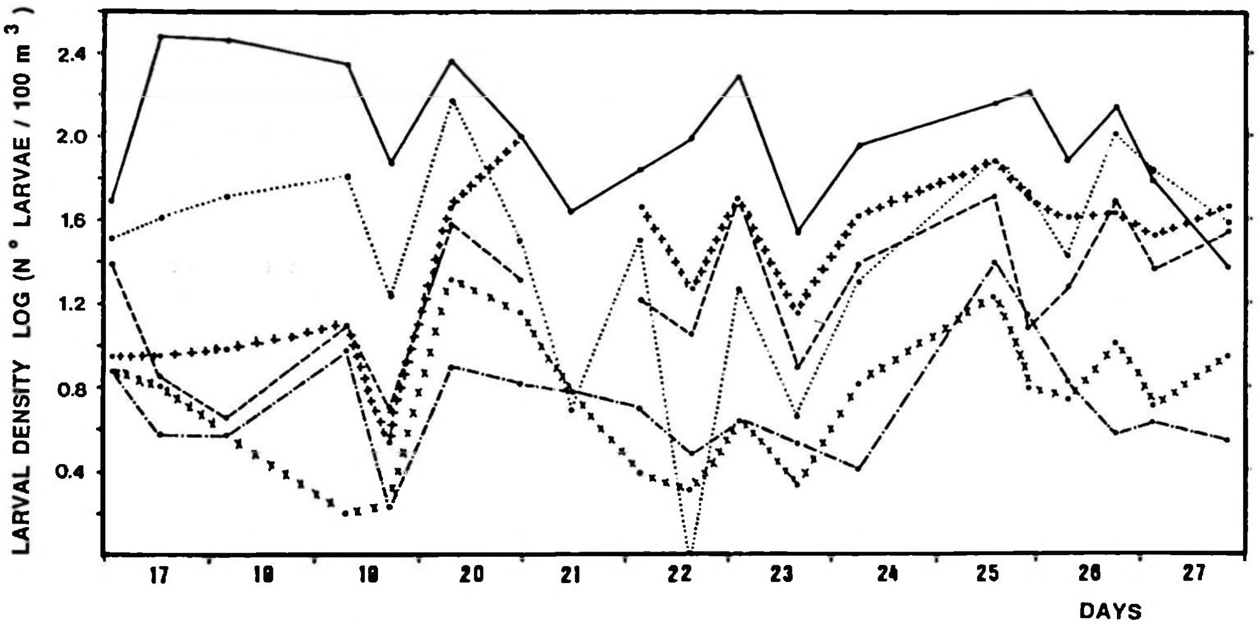

Figure 9. Temporal changes of log-transformed larval density (Nº larvae/100 m^3) for the six most abundant species at Station 4. *Engraulis ringens:*(———), *Sardinops sagax:*(—), *Normanichthys crockeri*[1]:(+ + + +), *Stromateus stellatus*[1]: (- - - - -), *Strangomera bentincki:* (x x x x), and *Ethmidium maculatum:* (- • - • - •). 1: Larval density not available for January 21.

Ichthyoplankton densities found in the Gulf of Arauco and in adjacent embayments (Figure 1) have been found to be higher than in more distant nearshore areas (Rojas *et al.*, 1983). In addition to wind-driven upwelling, other conceivable factors associated with the existence of this multispecies spawning ground include high concentrations of chlorophyll in the proximity of the Bio-Bio River outflow (Uribe and Neshyba, 1983), topographic upwelling and a shallow continental shelf (Bernal and Shaffer, 1987). Hence, these particular conditions could favor fish colonization and local adaptation to spawning in response to higher food supply for larvae and subsequent life stages.

Although interspecific associations of fish larvae could also be an adaptation to reduce predation on species with lower larval abundance (Frank & Leggett, 1983), a potentially lower predation on the less abundant species may only be a secondary benefit derived from spawning in highly productive habitats such as the Gulf of Arauco.

Despite the dominance of pelagic eggs in the studied fish assemblage (Table 1), the existence of temporal differences in the annual peaks of larval abundances for different species (e.g., Aron, 1980; Rojas *et al.* 1983), suggests different adaptations to environmental conditions for the optimal survival of early life stages.

Negative coastal temperature anomalies, and a narrow coastal strip with high chlorophyll concentrations, are typical of nearshore areas surrounding and including the Gulf of Arauco (Bakun & Parrish 1982; Uribe & Neshyba 1983; Espinoza *et al.* 1983; Arcos & Salamanca, 1984). Yet, the conditions observed since January 22 in the present study included: sinking of isotherms, a sharp decrease of integrated chlorophyll concentration (56.6% at Station 4 and 62.5% at Station 3), a reduction of the chlorophyll maximum layer concentration, and a change in the direction of water flow at Sation 4 (unpubl. data for the last two items). All these changes indicated that offshore warm waters, with low chlorophyll concentrations, entered the Gulf of

Arauco two days before the storm of January 24-25. A warming of sea surface waters in the Gulf of Arauco was further detected by satellites NOAA-C and NOAA-F from January 20 to 25, 1985 (Centro de Estudios Espaciales, Universidad de Chile). Moreover, inshore advection of waters with low chlorophyll content into the Gulf of Arauco seemed to have been enhanced by downwelling during the storm (Figure 6).

The environmental changes of January 22 were reflected in the ichtyoplankton by the: (1) greater difference in the median abundance of larvae between January 22 and 23 in relation to any other consecutive sample pair, (2) Bray-Curtis clustering for the majority of samples into two sets: one before and one after the storm. (3) temporal segregation of two groups of larvae defined through the length-frequency correlation analysis, and (4) a post-storm decrease in average egg densities for *E. ringens* (89%) and *S. sagax* (34%). Due to offshore dispersion of ichthyoplankton from coastal spawning areas, the large-scale distribution of larvae and eggs of *E. ringens* and *S. sagax*, shows an increase in larval size and a decrease in egg density towards offshore areas (Rojas *et al.*, 1983). Thus, the sudden change in larval length-frequency from January 23 to 24 indicated that older cohorts can be maintained further offshore and eventually transported back onshore, displacing the younger cohorts present there. Hence, short-term mesoscale processes and their interaction with other factors determining the observed larval length-frequencies (e.g., spawning frequency, survival, growth and behavior of larvae, advection, dispersion, sampling filter) can negate the intuitive interpretation that shorter time intervals between samples result in more similar larval sizes. Smith & Hewitt (1985) indicated that in general, structures in the ocean of 0.6, 2.8, 27 and 147 km can persist respectively for 6 hrs., a day, a week and a month. Therefore, the maintenance of large larval sizes of *E. ringens* and *S. sagax* from the beginning of the storm to the end of the sampling period (at least four days), implies the occurrence of a mesoscale coastal process that may have included the entire Gulf of Arauco. It must be pointed out that onshore intrusions of waters with reduced food supply (low concentration of particles) could increase the mortality of first-feeding fish larvae in nearshore regions. For example, insufficient food in the first 1.5 to 4.5 days of first-feeding larvae of *E. mordax* can reduce survival substantially (Lasker *et al.*, 1970).

Satellite images of sea surface chlorophyll and temperature distributions off Chile (CZCS: Coastal Zone Color Scanner) have revealed complex patterns of coastal intrusions of oceanic waters, upwelling fronts and plumes, meso- and large scale eddies (Espinoza *et al.*, 1983). Thus, similar changes in ichthyoplankton to those observed in the present study can occur in the absence of storms. On the other hand, Lobel and Robinson (1986) have shown that mesoscale eddies around islands can transport and retain coastal planktonic larvae for periods sufficient to complete their pelagic development phase. Thus, the potential role of eddies in generating entrapment structures for coastal ichthyoplankton deserves further consideration.

ACKNOWLEDGMENTS

We thank all members of the Arauco-85 research team who worked at sea. Guillermo Herrera contributed with identification of species and Aquiles Sepúlveda with data analyses. Two anonymous reviewers provided valuable suggestions to the manuscript. Study supported by FONDECYT-Chile Project N° 1190-84.

LITERATURE CITED

ALARCÓN, E. 1970. Descripción oceanográfica preliminar del Golfo de Arauco. Instituto de Fomento Pesquero, Chile, Boletín Científico N° 13, 35 pp.

ARCOS, D. F. & M. A. SALAMANCA. 1984. Distribución de clorofila y condiciones oceanográficas superficiales frente a Chile Central. Biología Pesquera 13:5-14.

ARON, A. P. 1980. Taxonomía, distribución y abundancia de las larvas de peces en Bahía Concepción (36°40'S; 73°02'W) Chile. Marine biologist thesis, Universidad de Concepción, Chile, 66 pp.

BAKUN, A. 1973. Coastal upwelling indices, West Coast of North America, 1946-71. NOAA Technical Report, National Marine Fisheries Service, U.S.A., SSRF-671, 103 pp.

BAKUN, A. & R. H. PARRISH. 1982. Turbulence, transport and pelagic fish in the California and Peru Current Systems. California Cooperative Fisheries Investigations Report 23:99-112.

BAILEY, K. M. & S. L. INCZE. 1985. El Niño and the early life history and recruitment of fishes in temperate marine waters. *In:* El Niño North. Niño effects in the Eastern Subartic Pacific Ocean. 143-165. W.S. Wooster & D.L. Fluharty (ed). Washington Sea Grant Program, University of Washington, U.S.A.

Bernal, P. A., F. L. Robles & O. Rojas. 1982. Variabilidad física y biológica en la región meridional del Sistema de Corrientes Chile-Perú. Monografías Biológicas 2:75-102.

Bernal, P. A., & G. Shaffer (coordinators). 1987. Arauco natural coordinate conservation experiment - 85. Data Report. Pontificia Universidad Católica de Chile. Sede Regional Talcahuano & Goteborgs Universitet Oceanografiska Institutionen. Sverige.

Clifford, H. T. & W. Stephenson. 1975. An introduction to numerical classification. Academic Press. New York, San Francisco, London, 229 pp.

Colby, D. R. 1988. Null hypotheses, models, and statistical designs in the study of larval transport. American Fisheries Symposium 3:149-162.

Conover W. J. 1971. Practical nonparametric statistics, John Wiley & Sons Inc. New York, London, Sydney, Toronto, 462 pp.

Espinoza, F. R., S. Neshyba & Z. Maoxiang. 1983. Surface water motion off Chile revealed in satellite images of surface chlorophyll and temperature. *In:* Marine Resources of the Pacific. 41-57. P.A. Arana (ed). Published jointly by the U.S. International Sea Grant Program and Escuela de Ciencias del Mar, Universidad Católica de Valparaíso, Chile.

Field, J. G., K. R. Clarke & R. M. Warwick. 1982. A practical strategy for analyzing multispecies distribution patterns. Marine Ecology Progress Series 8:37-52.

Gorbunova, N. N. 1981. Distribution of ichthyoplankton in the East Pacific upwelling region. Oceanology 21(6):759-762.

Haury, L. R., J. A. McGowan & P. H. Wiebe. 1978. Patterns and processes in the time space scale of plankton distributions. *In:* Spatial pattern in plankton communities. 3:277-327 J.H. Steele (ed). Plenum Press, New York.

Frank, K. T. & W. C. Leggett. 1983. Multispecies larval fish associations: Accident or Adaptation? Canadian Journal of Fisheries and Aquatic Sciences 40:754-762.

Lasker, R., H. M. Feder, G. H. Theilacker & R. C. May. 1970. Feeding, growth and survival of *Engraulis mordax* larvae reared in the laboratory. Marine Biology 5:345-353.

Lasker, R. & K. Sherman. (ed). 1981. The early life history of fish: recent studies. Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer 178 (3-6), 607 pp.

Lloyd, M. 1967. Mean crowding. Journal of Animal Ecology 36:1-30.

Lobel, P. S. & A. R. Robinson. 1986. Transport and entrapment of fish larvae by ocean mesoscale eddies and currents in Hawaiian waters. Deep-Sea Research 33(4):483-500.

Mooers, N. K. & A. R. Robinson. 1984. Turbulent jets and eddies in the California Current and inferred cross-shore transports. Science 223 (4631):51-53.

Mordojovich, C. 1983. Plataforma continental de Chile y sus posibilidades petrolíferas. *In:* Marine Resources of the Pacific. 131-154. P.A. Arana (ed). Published jointly by the U.S. International Sea Grant Program and Escuela de Ciencias del Mar, Universidad Católica de Valparaíso, Chile.

Muñoz, H. 1983. Catálogo ilustrado de las larvas de peces presentes en el zooplancton de Bahía Coliumo (36°32'S; 72°57'W). VIII Región, Chile. Marine Biologist Thesis. Universidad de Concepción, Chile, 73 pp.

Norcross, B. L. & R. F. Shaw. 1984. Oceanic and estuarine transport of fish eggs and lavae: a review. Transactions of the American Fisheries Society 113:153-165.

Robinson, A. R. (ed). 1983. Eddies in marine sciences. Springer-Verlag, Berlin, 609 pp.

Rojas, O. J., A. R. Mujica, M. C. Labra, G. H. Lederman & H. U. Miles. 1983. Estimación de la abundancia relativa de huevos y larvas de peces. Instituto de Fomento Pesquero, Chile, AP 83-31, 98 pp.

Sharp, G. D. (Raporteur). 1980. Report and supporting documentation of the workshop on the effects on environmental variations on the survival of larval pelagic fishes. IOC Workshop Report 28, 323 pp.

Smith, P. E. & R. P. Hewitt. 1985. Anchovy egg dispersal and mortality as inferred from close-interval observations. California Cooperative Fisheries investigations Report 26:97-110.

Tate, M. W. & R. C. Clelland. 1957. Nonparametric and shortcut statistics in the social, biological and medical sciences. Interstate Printers and Publishers Inc. Illinois, 171 pp.

Theilacker, G. H. 1980. Changes in body measurement of larval northern anchovy, *Engraulis mordax* and other fishes due to handling and preservation. Fishery Bulletin, U.S. 78 (3):685-692.

Uribe, E. & S. Neshyba. 1983. Phytoplankton pigments from the NIMBUS-7 Coastal zone color scanner: Coastal waters of Chile from 18° to 40° S. *In:* Marine resources of the Pacific. 33-40. P.A. Arana (ed). Published by the U.S. International Sea Grant Program and Escuela de Ciencias del Mar, Universidad Católica de Valparaíso, Chile.