Latin American Journal of Aquatic Research, 49(5): 702-716, 2021
DOI: 10.3856/vol49-issue5-fulltext-2669

Research Article

Migration behavior of anchoveta (*Engraulis ringens*) in the Northern Humboldt Current System between September 2019 and September 2020

Pedro Ramiro Castillo[1], Miguel Ñiquen[1], Luis La Cruz[1]
Renato Guevara-Carrasco[1] & Gustavo Cuadros[1]
[1]Instituto del Mar del Perú (IMARPE), Callao, Perú
Corresponding author: Pedro Ramiro Castillo (prcastillo@imarpe.gob.pe)

ABSTRACT. Migrational behavior of anchoveta (*Engraulis ringens*) in the Northern Humboldt Current System between September 2019 and September 2020 is analyzed. Acoustic, biological, and oceanographic data and information from the several research cruises carried out by the Instituto del Mar del Perú (IMARPE) during this period were considered. The results showed the presence of transitory warm oceanographic events that induced the anchoveta population to make horizontal and vertical migrations in their search for cold conditions, the adult specimens (bigger than 12 cm of total length) retracted near the bottom of the platform being inaccessible to the fishing fleet; after the normalization of environmental conditions, their abundance was accessible to the fishing fleet. Therefore, the fishing activity in the second season of anchoveta fishing in 2019 had a negative impact due to the joint action of environmental events and events of a biological nature (entry of strong recruitment and migration). The anchoveta was preferably found in cold coastal waters that varied in the seasons. In the spring of 2019, it was found in temperatures lower than 22.1°C, in the summer of 2020 at temperatures lower than 23.1°C, and in the winter of 2020 at temperatures lower than 17.2°C; as for, salinity was always found in values lower than 35.2. The strategy of the migratory behavior of the anchoveta concerning its habitat in this period has allowed it to remain in its abundance in the Humboldt Current System, which added to adequate fishing management will allow it to maintain its sustainability.

Keywords: *Engraulis ringens*; anchoveta; habitat; climate variability; behavior; cold coastal waters; Humboldt Current System

INTRODUCTION

Several ecologists have investigated the relationship between the presence of a species and its environment (Silva et al. 2018), the niche or habitat of a species in an area or hypervolume of n-dimensions where the environmental conditions (factors) in which the species can survive (Hutchinson 1957). Habitat is generally defined as "the resources and conditions present in a given area that allow an organism to survive and reproduce" (Rowston et al. 2002, Finlayson et al. 2008). In the marine environment, these environmental factors indicate that, if an individual lives and interacts in a certain place, it is because that place fulfills the requirements that the individual or group of individuals need.

The anchoveta (*Engraulis ringens*) is a small pelagic neritic species that live in the Humboldt Current System of the southeastern Pacific (Perú and Chile) (Thiel et al. 2007), and preferentially inhabit the Cold Coastal Waters (CCW) (Jordán & Chirinos de Vildoso 1965, Guillén et al. 1969, Zuta & Guillén 1970, Jordán 1971, Mathisen 1989, Muck et al. 1989, Bertrand et al. 2004, Bertrand et al. 2008, Swartzman et al. 2008, Santivañez 2017), and its distribution is associated with the variability of these waters determined by the oceanographic variables of temperature, salinity, and oxygen (Bertrand et al. 2004, Chavez et al. 2008, Purca et al. 2010, Bertrand et al. 2011, Grados et al. 2016, Castillo et al. 2018), which is sensitive to environmental changes by moving or migrating according to the variability of these waters in search of appropriate habitats as a survival instinct.

Corresponding editor: Patricio M. Arana

Normally, oceanographic variability in the northern Humboldt Current System is differentiated by season (Morón 2000). In the summer the cold waters that flow from north to south are withdrawn towards the coast by the approach of the Surface Subtropical Waters (SSW), which also generates a greater concentration of the anchoveta towards the coastal zone; whereas, in the winter these CCW extend towards the west generating a greater amplitude of the cold waters and as such a greater dispersion of the anchoveta (Castillo et al. 2015). In these seasons (summer and winter) there is a certain stability in a short period; while, in autumn and spring they are considered as transition seasons in which high dynamics of the marine currents are generated (Morón 2000).

The anomalous conditions as a consequence of the alterations to the normal patterns of the ocean-atmosphere interrelation in the tropical Pacific generate important repercussions on the meteorological conditions, mainly in the Humboldt Current System (Takahashi et al. 2019); these anomalous conditions are generated by recurrent events El Niño (El Niño Southern Oscillation or ENSO) (Bertrand et al. 2020) and La Niña (Pabón-Caicedo et al. 2017), as well as hot or cold equatorial oceanic Kelvin waves, which are gravity waves modified by the earth's rotation (Mosquera 2014). These events or waves increase the oceanographic variability and affect the biological processes (growth, mortality, reproduction, and size), abundance, and behavior (movements and aggregative level) of the anchoveta (Bertrand et al. 2008, Arias-Schreiber et al. 2011, Moron et al. 2019). By adapting their behavior, they perform temporary horizontal and/or vertical migrations which, on many occasions, make schools inaccessible to the purse seines of the fishing fleet.

In this study, the anchoveta was analyzed considering its distribution strategies related to oceanographic conditions between September 2019 and September 2020, considering the Pelagic Resources Hydroacoustic Assessment Surveys Cr 1909-11 and Cr 2002-03 (for example, in Cr 1909-11, Cr is referred to the cruise, the first two-digit of number (19) represent the year (2019), the second pair of digits (09) and the last number (11) refer to the months during which the survey was carried out), anchoveta fishing seasons (2nd season of 2019 (F2019-II) and 1st season of 2020 (F2020-I)), biological-fishing prospection (Pr) of the anchoveta 2020 (Pr 2001-01) and Cr 2009-09 anchoveta spawning biomass assessment survey. The health standards established in the protocol "Surveillance, prevention and control onboard scientific vessels of IMARPE during the health emergency Covid-19" were established on the surveys 2020 (IMARPE 2020a).

MATERIALS AND METHODS

Sequential analysis of the investigations carried out

a) Hydroacoustic evaluation survey of pelagic resources carried out in the spring of 2019 (Cr 1909-11), by the Instituto del Mar del Perú (IMARPE).

The 1909-11 survey was conducted between September 29 and November 15, 2019, along the entire Peruvian coast from 0.5-1.5 nm (nautical miles) up to a maximum distance of 116 nm, to estimate the biomass, determine the distribution and biological aspects of the main pelagic resources, with emphasis on the anchoveta (IMARPE 2019a).

b) Second fishing season of 2019 (F2019-II)

Satellite information of the georeferenced data of the fishing fleet in the second fishing season of 2019 (F2019-II) initiated on November 16, 2019 (Produce 2019) and culminated on January 15, 2020 (Produce 2020), corresponding to the north-central zone (03°30'-16°00'S). On November 5, an exploratory fishery was authorized to begin on November 6, to update information on the distribution, size structure, and incidence of other species, for 10 days. This volume was considered as part of the Maximum Total Allowable Catch Limit for this 2019 fishing season.

c) Biological-fishery prospection of the anchoveta carried out in the summer of 2020 (Pr 2001-01)

The biological-fishery prospection of the anchoveta was carried out between the 4th and 12th of January 2020 (Pr 2001-01), in the coastal zone of 30 mn of distance to the coast between the island Lobos de Tierra (06°26´S, 080°51´W) and Ilo, to estimate the percentage of juvenile anchovies in this zone (IMARPE 2020b).

d) Hydroacoustic evaluation survey of pelagic resources carried out in the summer of 2020 (Cr 2002-03)

The Cr 2002-03 survey was conducted between February 15 and March 29, 2020, along the entire Peruvian coast from 0.5-1.5 nm up to a maximum distance of 110 nm, to study mainly the anchoveta with the same purpose as for survey Cr 1909-11 (IMARPE 2020c).

e) First fishing season of 2020 (F2020-I)

Satellite information of the georeferenced data of the fishing fleet in the first fishing season of 2020 (F2020-I) started on May 13, 2020 (Produce 2020b) and culminated on August 15, 2020 (Produce 2020c),

corresponding to the north-central zone (03°30'-16°00'S).

f) Anchoveta spawning biomass evaluation survey carried out in the winter of 2020 (Cr 2009-09)

The Cr 2009-09 survey was conducted between September 2 and 19, 2020 inside of the 50 nm of the coast between Callao and Punta La Negra, to estimate the spawning biomass of the anchoveta through the method of egg production (IMARPE 2020d).

Acoustic data

The *NASC* (Nautical Area Scattering Coefficient) values obtained from the scientific echo sounders of the IMARPE vessels participating in the research cruises and the fisheries-biological prospecting were used. The *NASC* value is a measurement of energy emitted by a target, fish, or schools expressed in m^2 nm^{-2} (MacLennan et al. 2002, Simmonds & MacLennan 2005). The procedure to obtain the *NASC* value of anchoveta for each acoustic sample of 1 nm (nautical mile) is described in Castillo et al. (2009).

In the horizontal distribution graphs, inertia was added, which is a measure of population dispersion (*NASC*) around its center of gravity; that is, the mean square distance between the individual fish (*NASC*) and the center of gravity of the distribution (Bez & Rivoirard 2001, Woillez et al. 2007). The formulation is:

$$Inercia = \frac{\sum_{i=1}^{N} z_i \ . \ (x_i - CG)^2}{\sum_{i=1}^{N} z_i}$$

$$CG = \frac{\int x \ \mathrm{z(x)} dx}{\int z(x) \ dx}$$

where: z_i is the *NASC* value of the anchoveta, x_i is the point in space (latitude or longitude) of the sample and CG is the center of gravity. Inertia is made up of an ellipse with a larger diameter (latitudinal) and a smaller diameter (longitudinal).

In the case of fishing seasons, inertia was calculated from the spatial distribution of the fishing fleet. The Satellite Tracking System (SISESAT of the IMARPE) of the fishing vessels was obtained by the TeraScan system and by the Defense Meteorological Satellite Program (DMSP), which broadcast geographic information every 10 minutes. The location of the fishing operations of the purse-seine vessels was carried out by the selection of speed ranges between 0.2 and 1.6 knots ($nm\ h^{-1}$) and by time. In a fishing operation, the speed of the vessel decreases and stays longer in one area.

The mean location was measured using the center of mass (CM), the average of all depths sampled weighted by their s_v values. The formulation described by Urmy et al. (2012):

$$CM = \frac{\int z \ s_v(z) dz}{\int s_v \ (z) dz}$$

where: z is the depth, $s_v(z)$ is the volume backscattering coefficient at depth z. s_v is the sum of the dispersion measures (backscattering cross-section) of all discrete targets in a volume, expressed in m^{-1} (Maclennan et al. 2002).

The S_v is the mean volume-backscattering strength that allows knowing the density, it is expressed in decibels to 1 m^{-1} (Maclennan et al. 2002). This value was used in the energetic characteristics of the anchoveta schools. The s_v and S_v values were generated by the calibrated scientific echo sounder and obtained from the acoustic data post-processing program Echoview.

Oceanographic data

Oceanographic data were collected on the variables of temperature, salinity, and dissolved oxygen on the surface of the sea from research cruises and biological-fishery prospection. Equipment (oceanographic rosettes, CTD, Niskin bottles, salinometers) and methodologies (oxygen by Winkler method) are described in IMARPE (2019a, 2020b,c). The characteristics of the water masses: Cold Coastal Waters (CCW), Subtropical Surface Waters (SSW), Equatorial Surface Waters (ESW), and Tropical Surface Waters (TSW) in the Humboldt Current System are described in Zuta & Guillén (1970) and Morón & Sarmiento (2001).

Biological data

The biological information on the size structure of the anchoveta was obtained from the fishing hauls made by the research vessels with a pelagic trawl that participated in the analyzed research activities. The sizes (total length, TL) were weighted with the *NASC* values of anchoveta (three values before and after, of each fishing set with anchoveta capture), described in IMARPE (2019a, 2020b,c).

Data processing for resource-environment relationship

Generalized additive models (GAM) are applied to an acoustic and physical-oceanographic dataset to examine the effects of environmental variables (e.g. oceanographic conditions) on the anchoveta distributions. The GAM uses the backfitting algorithm to combine different smoothing with the restricted maximum likelihood method (REML), Gaussian family because the response variable has a symmetric

distribution (Murase et al. 2009, Hastie & Tibshirani 2017). The dependent variable was the *NASC* value of anchoveta for each nautical mile and the independent variables were the temperature, salinity, and dissolved oxygen at the sea surface. The analyzes were carried out for each research activity. The *NASC* values of anchoveta were logarithmically transformed due to their wide range.

This GAM-based analysis used the "*mgcv*" package (version 1.8-34) of the R program (R Development Core Team, 2020). "Deviance explained" (analogous to variance in linear regression), adjusted r^2, and GCV scores were calculated (Wood 2017).

RESULTS

Inertia of the horizontal distribution of the anchoveta

The anchoveta distribution was variable, in the spring survey Cr 1909-11 (Fig. 1). It was wide between Talara-Supe, where it was found until 115 nm of the coast. From the south of Supe to Sama it was registered mainly in the coastal strip of the 30 nm with important nuclei of high concentration in diverse zones of the coast. The inertia was centered in the north zone between the Island Lobos de Tierra-Pucusana with a wide area of dispersion. The distribution of the fishing fleet in the F2019-II was precisely in the region of inertia of the survey recorded mainly between Chicama-Huacho (area in which the anchoveta approached the coast) with a reduced latitudinal and longitudinal diameter, and slightly away from the coast, indicating that between November 2019-January 2020 the anchoveta performed a horizontal migration towards the coast and towards the south. In Pr 2001-01 carried out in January 2020, the inertia was registered between Punta Bermejo-San Juan de Marcona with the inertia of longitudinal diameter similar to the second season, which indicated a migration towards the southern zone (due to the location of the latitudinal diameter of the inertia) with high concentrations between Chancay-San Juan de Marcona and remaining in the coastal zone. In the summer survey Cr 2002-03 the anchoveta was distributed mainly in the 40 nm coastal strip between Punta La Negra-Sama with the highest abundances between Punta La Negra-Pisco and in front of Bahía Independencia and Quilca; the inertia was registered between Pimentel-Chancay with a narrow longitudinal diameter that indicated a migration towards the north and towards the coast, habitual behavior in the summer.

The F2019-II was initiated at the end of the survey, which showed similar inertia with diameters similar to those obtained in the Cr 2002-03, which indicates full exploitation in the captures of the high concentrations of anchoveta. Finally, in the Cr 2009-09 spawning biomass survey, the anchoveta distribution was in a large part of the investigated area with important abundances between Pimentel-Casma, the inertia with latitudinal diameter was between Pimentel-Huarmey and a slightly larger longitudinal diameter, which indicated a horizontal migration to the north and west.

If we visualize the anchoveta fishing seasons, we observe that at the beginning of the F2019-II the industrial fishing fleet was located mainly between Chicama-Chimbote precisely in an area of high abundance of anchoveta found in the survey Cr 1909-11 (detected in October 2019), in the following weeks the captures were made towards the south of this area, located between Huarmey-Chancay, which indicated the migration of the anchoveta coastward and southward in areas that were not recorded as "dense" in the survey Cr 1909-11, in the last weeks the boats decreased and were located in the coastal area between Pimentel-Chicama with reports of a high incidence of juveniles (Fig. 2). While, in F2020-I the fishing fleet between the months of May-June was between Mórrope-Bahía Independencia precisely in the dense or high abundance areas found in the Cr 2002-03, in July 2020 the fishing boats decreased and were located in the coastal area between Punta La Negra-Pacasmayo, which indicated a northward migration.

Vertical distribution of the anchoveta

Under normal oceanographic conditions, the anchoveta was recorded mainly in the surface layer of the 60 m depth. During the Cr 1909-11 the fluctuation of the school located in the water column was variable in this range, in the surface layer of the 25 m between Punta La Negra-Chicama, Callao-Bahía Independencia, and between Quilca-Sama. In the biological-fishing prospection, the superficial schools of anchoveta (<25 m) were located in Chicama and between Chancay-Pisco. In the Cr 2002-03, surface schools located at depths of less than 20 m were located in Pimentel, Casma-Punta Bermejo, and Chancay-Cerro Azul; while the deepest (between 50-80 m) were recorded between Punta La Negra-Pimentel and San Juan de Marcona-Ático. Finally, in the Cr 2009-09, the schools recorded at depths of less than 30 m were located in Punta La Negra, between Chicama-Salaverry, and in the Huacho area. In general, the vertical mass center of the acoustic backscattering volume of the anchoveta schools on these cruises indicated that the greatest abundances were located in the surface layer at 18 m depth. The Cr 2002-03 being the most abundant along almost the entire Peruvian coast with a CM of 9.53 m, and as for the greatest abundance at greater depth, it was recorded

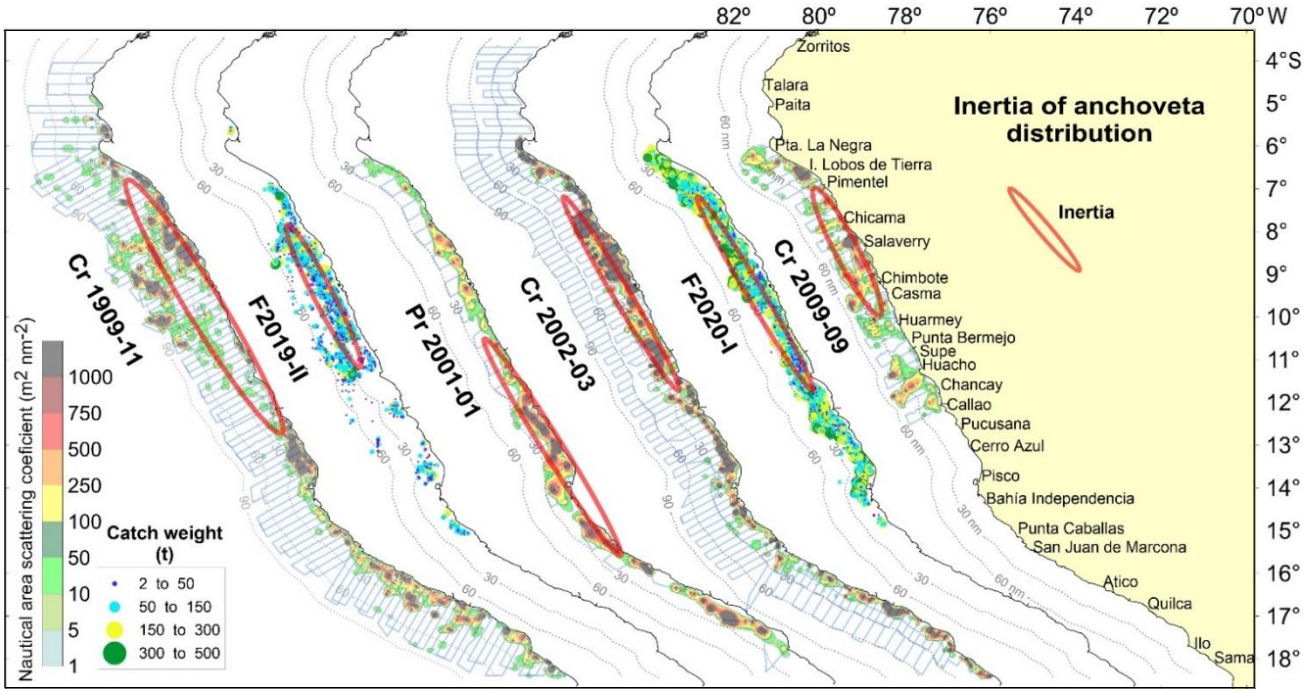

Figure 1. Inertia of the anchoveta (*Engraulis ringens*) distribution in the research surveys carried out by Instituto del Mar del Perú and the fishing seasons of the fishing fleet between September 2019 and September 2020.

on the Cr 2009-09 with a CM of 13.94 m (Table 1, Fig. 3).

When comparing the morphometric (depth, height, and length), volumetric (area), and energetic (*NASC* and S_v, ref MacLennan et al. 2002) characteristics of the anchoveta schools, we noticed that in the Cr 2002-03 the highest values were recorded from 46833 schools as: i) morphological characteristics: maximum school depth (86.30 m) and maximum height (37.08 m), ii) volumetric characteristics: area (101428.79 m^2), and iii) energetic characteristics: *NASC* (909667.18 m^2 nm^{-2}) and S_v (-14.70 dB); which indicated a higher concentration and size of the schools. In the Cr 2009-09, schools of smaller morphometric and volumetric characteristics were recorded, with a higher coefficient of variation (CV) value; which indicates, a greater dispersion of schools (variability) constituted in smaller sizes.

Anchoveta's size structure

In the analyzed period, high variability was recorded in the structure by the anchoveta's size in the north-central region (Table 2, Fig. 4). The Cr 1909-11 presented a polymodal structure, which was formed by individuals whose sizes fluctuated between 2.0 and 17.5 cm TL, with the main mode in 9.5 cm and secondary mode in 2.5, 11.5 and 14.5 cm. The percentage of juvenile individuals was 67% in number (IC95% = 47-77%) and 33% in weight (IC95% = 16-43%). It was interesting to note the presence of new cohorts, which meant that the stock continued to be renewed. The mode identified in 2.5 cm corresponded to individuals of 0 years of age born in the 2019 winter reproductive process, those of 9.5 cm corresponded to individuals of 0.5 years of age born in the 2019 summer reproductive process, those of 11.5 cm corresponded to individuals of 1 year of age born in the 2018 winter reproductive process and those of 14.5 cm corresponded to individuals of 1.5 years of age born in the 2018 summer reproductive process.

At the beginning of the F2019-II (November to December 2019), the fishery clearly showed a dominance of adult specimens, with the main mode in 14.5 cm TL. This situation changed in January 2020 when the dominance of juvenile specimens was observed in the coastal zone of the 30 mn with the main mode in 10 cm TL, which were found in the biological-fishing Pr 2001-01.

In the Cr 2002-03, the anchoveta in the north-central region was formed by individuals whose sizes fluctuated between 2.0 and 16.5 cm TL, with the main mode in 9.0 cm and secondary mode in 3.5, 8.0, 11.0, and 15.0 cm. The percentage of juvenile individuals was 89% in number (IC95% = 85-91%) and 75% in weight (IC95% = 68-77%). It is important to point out that the contingent of juvenile individuals was made up of up to four different groups, maintaining the domi-

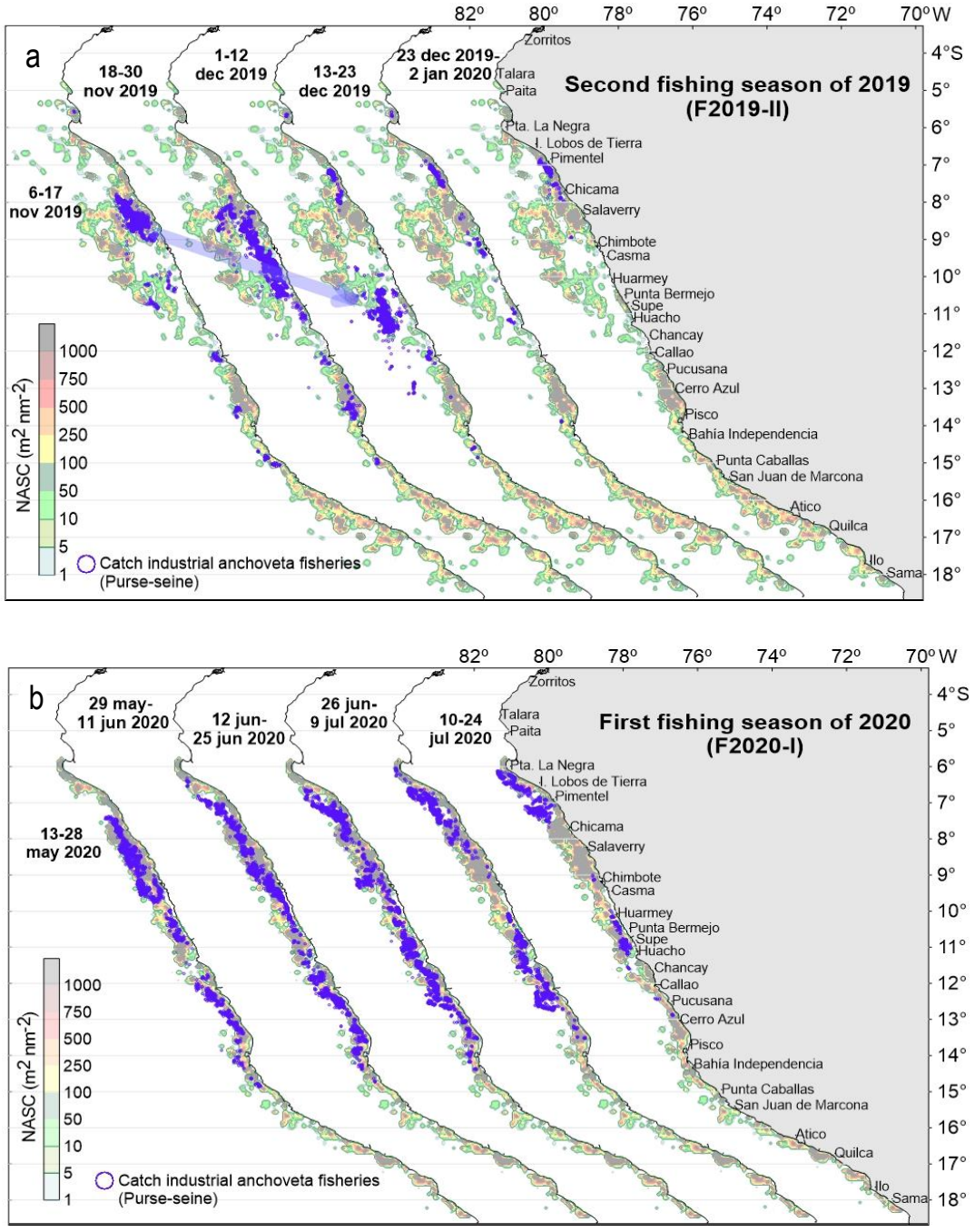

Figure 2. Location of the industrial anchoveta (*Engraulis ringens*) fishing fleet by periods (small blue circles) during the fishing seasons: a) second fishing season 2019 (F2019-II) and b) first fishing season 2020 (F2020-I). Distribution of anchoveta Nautical Area Scattering Coefficient (NASC) values are from survey Cr 1909-11 in Figure 2a and from survey Cr 2002-03 in Figure 2b.

nance of juveniles observed in January 2020 in the fishery (during F2019-II). The most numerous groups corresponded to individuals with a modal length of 11.0 cm (close to the commercial size of 12.0 cm), which in the Cr 2002-03 were located mainly north of 9°S and which had their origin in the late reproductive process of the summer of 2019. The next group was made up of individuals with a modal size of 9.0 cm, which originated in the winter-spring reproductive process in 2019. The third group was made up of individuals with a modal size of 8.0 cm TL, which also had their origin in the winter-spring reproductive process of 2019, but

Table 1. Statistical descriptors of the anchoveta (*Engraulis ringens*) schools obtained in the research surveys and biological-fishery prospection carried out by Instituto del Mar del Perú between September 2019 and September 2020. NASC: Nautical Area Scattering Coefficient.

Survey and prospection	Number of schools	Center of mass (m)	Statistic	Depth (m)	Height (m)	Length (m)	Area (m^2)	NASC ($m^2\,nm^{-2}$)	S_v (dB)
			Xmin	1.19	0.20	0.50	0.01	0.94	-71.90
			Xmax	57.33	20.13	4853.61	26694.48	2198730.36	-15.71
Cr 1909-11	41138	10.52	$\bar{x}$	9.54	1.05	22.76	31.30	2409.40	-52.21
			sd	5.98	0.97	77.05	300.34	24097.72	7.13
			CV(x)	0.63	0.92	3.39	9.60	10.00	-0.14
			Xmin	0.90	0.19	0.50	0.13	2.39	-67.35
			Xmax	59.00	31.71	6257.41	25080.33	211943.13	-23.98
Pr 2001-01	26698	9.83	$\bar{x}$	10.50	1.14	21.43	38.50	1331.88	-50.71
			sd	6.86	1.12	80.11	343.26	5818.98	5.68
			CV(x)	0.65	0.98	3.74	8.92	4.37	-0.11
			Xmin	1.21	0.14	0.50	0.04	1.58	-67.95
			Xmax	86.30	37.08	5860.91	101428.79	909667.18	-14.70
Cr 2002-03	46833	9.53	$\bar{x}$	9.36	1.18	31.52	87.95	3660.73	-49.24
			sd	7.29	1.53	126.24	917.78	21049.12	6.55
			CV(x)	0.78	1.30	4.01	10.44	5.75	-0.13
			Xmin	1.24	0.17	0.50	0.11	2.10	-67.99
			Xmax	61.96	15.96	1717.94	13244.20	466830.55	-19.25
Cr 2009-09	22519	13.94	$\bar{x}$	12.73	1.18	14.65	26.00	1856.31	-52.89
			sd	7.73	1.01	40.78	212.96	9896.42	6.94
			CV(x)	0.61	0.86	2.78	8.19	5.33	-0.13

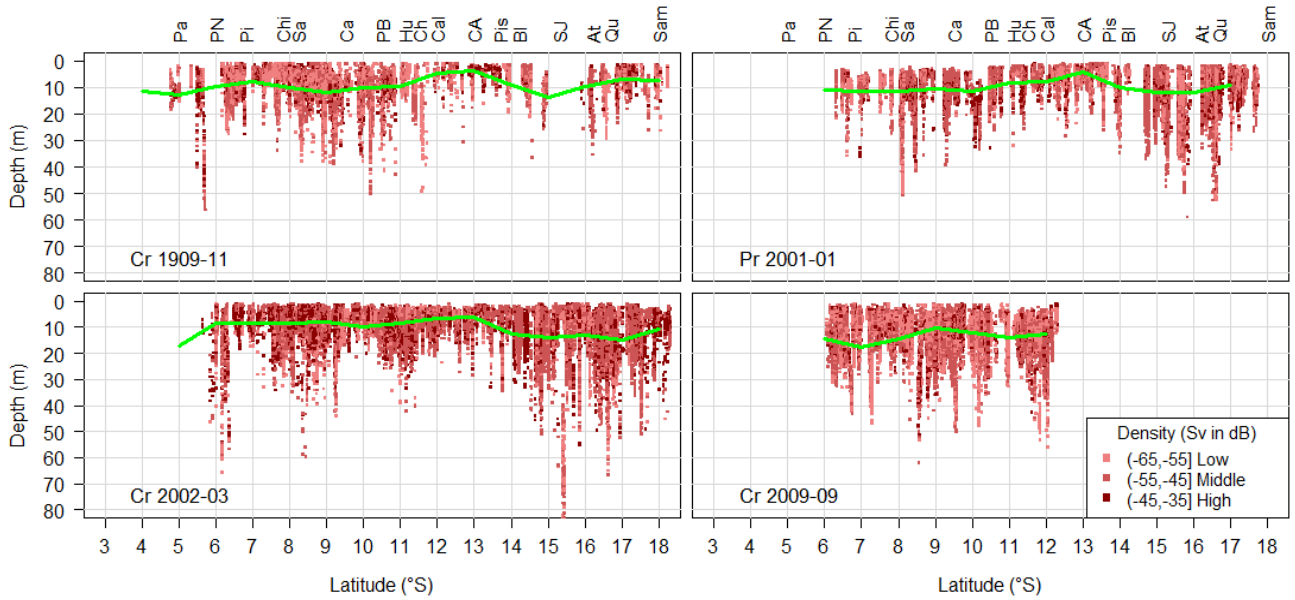

Figure 3. Vertical distribution of anchoveta (*Engraulis ringens*) schools by latitudinal grade and the trend of the vertical mass center of the acoustic backscattering volume in the research cruises carried out by the Instituto del Mar del Perú between September 2019 and September 2020. The schools are recorded according to their density by the volume of acoustic backscattering given in decibels (dB). Pa: Paita, PN: Punta La Negra, Pi: Pimentel, Chi: Chicama, Sa: Salaverry, Ca: Casma, PB: Punta Bermejo, Hu: Huacho, Ch: Chancay, Cal: Callao, CA: Cerro Azul, Pis: Pisco, BI: Bahía Independencia, SJ: San Juan de Marcona, At: Atico, Qu: Quilca, Sam: Sama.

in its late phase. The fourth group of juveniles was made up of individuals with a modal length of 3.5 cm TL, distributed mainly south of 13°S and which originated in the summer 2020 reproductive process.

Table 2. Characteristics of structure by size of the anchoveta (*Engraulis ringens*) in the central-northern region during the period from September 2019 to September 2020, according to observations from research surveys and biological-fishery prospection. TL: total length, IC: confidence interval.

Activity		Cr 1909-11	F2019-II	Pr 2001-01	Cr 2002-03	F2020-I	Cr 2009-09
Range of size (cm TL)			2.0 - 17.0		2.0 - 16.5		5.5 - 16.0
Type of structure by size			Polymodal	Adult	Juvenile	Adult	Polymodal
Mode (cm TL)	Main	9.5	14.5	10.0	9.0	13.0	14.5; 11.5
	Secondary	2.5; 11.5; 14.5	-	-	3.5; 8.0; 11.0; 15.0	-	7.5
Juveniles (number)	Percentage (%)	67			89		34
	IC (95%)	47 - 77			85 - 91		18 - 35
Juveniles (weigth)	Percentage	33			75		15
	IC (95%)	16 - 43			68 - 77		14 - 29

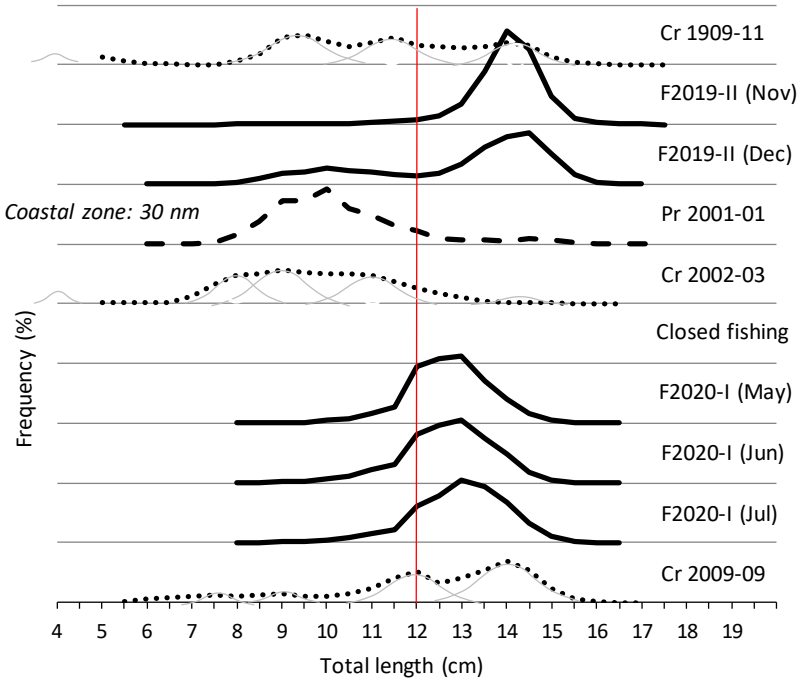

Figure 4. Structure by size of the anchoveta (*Engraulis ringens*) in the central-northern region during the period from September 2019 to September 2020, according to observations from research cruises and biological-fishery prospection. Vertical dotted line indicates the minimum length of catchable fish.

Additionally, there was a group of adult individuals with a mode size of 15.0 cm that formed part of the adult contingent observed in the Cr 1909-11 (mode size of 14.0 cm TL and that supported the captures made in November-December 2019).

In the F2020-I, the fishery during May to July 2020, clearly presented a dominance of adult specimens, with the main mode in 13.0 cm TL. Finally, in the Cr 2009-11, the anchoveta presented a size range of 5.5 to 16.0 cm TL with the main mode in 14.0 cm TL located between Punta La Negra-Casma; while, the juvenile specimens were registered in all the investigated area.

Relationship of the presence of anchoveta with surface oceanographic variables

In the development of the Cr 1909-11, the oceanographic conditions were neutral or normal, typical of this season, the cold waters were wide between Talara-Punta La Negra, Cerro Azul-San Juan de Marcona; and folded towards the coast between Chicama-Huarmey and Quilca-Sama, precisely in the areas where the anchoveta was at temperatures between 18.5-22.1°C, salinity between 34.85-35.20 and oxygen between 3.8-7.6 mL L^{-1}. In the F2019-II, the fishing fleet was concentrated in areas with temperatures between 15.0-

Table 3. Surface oceanographic conditions in the distribution of the anchoveta (*Engraulis ringens*) in the different activities carried out between September 2019 and September 2020.

Activity	General condition	Presence of anchoveta with superficial oceanographic variables		
		Temperature (°C)	Salinity	Oxygen (mL L^{-1})
Cr 1909-11	Normal	18.5 - 22.1	34.85 - 35.20	3.8 - 7.6
F2019-II		15.0 - 20.0	34.94 - 35.10	
Pr 2001-01	Warm Kelvin wave in the north	18.2 - 23.2	34.93 - 35.10	
Cr 2002-03	Neutral	17.3 - 23.1	34.93 - 35.20	3.5 - 7.3
F2020-I		14.9 - 21.8	34.65 - 35.10	
Cr 2009-09	Cold	14.8 - 17.2	34.95 - 35.21	3.4 - 5.3

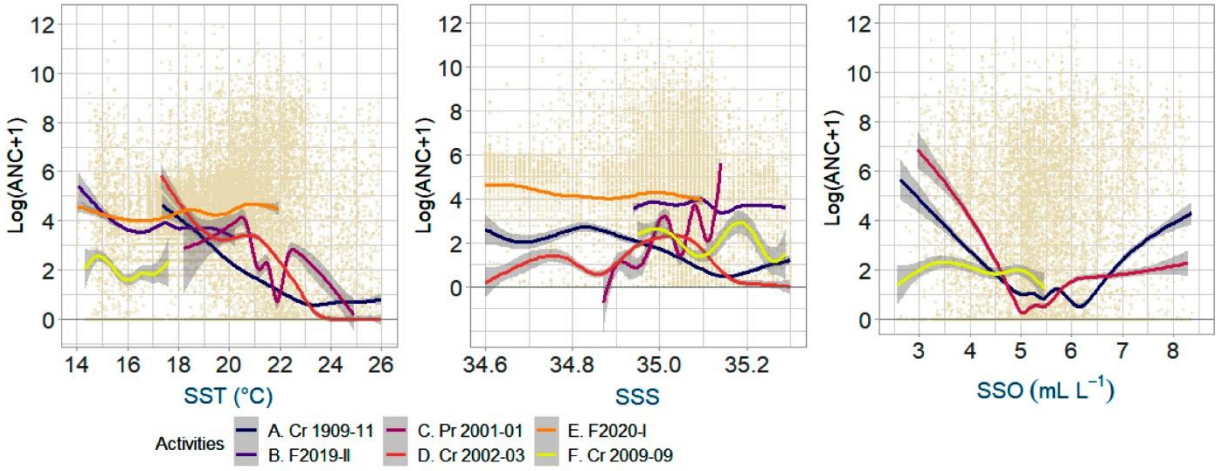

Figure 5. Generalized additive model of anchoveta (*Engraulis ringens*) Nautical Area Scattering Coefficient values with the oceanographic surface variables of temperature, salinity and oxygen, for the cruises carried out between September 2019 and September 2020. Only in the Cr 1909-11 and Cr 2002-03 were oceanographic samples taken from the entire Peruvian coast. SST: sea surface temperature, SSS: sea surface salinity, SSO: sea surface oxygen.

20.0°C and salinities between 34.94-35.10. In the biological-fishing Pr 2001-01 carried out only in the coastal strip of the 30 mn of the coast, the anchoveta was found between temperatures of 18.2-23.2°C and salinities between 34.93-35.10. In the Cr 2002-03 the oceanographic conditions changed to neutral-slightly cold, being the area between Salaverry-Chimbote with the greatest extension of the CCW. The intromission of the ESW from the north and the approach of the SSW from the west towards the coast, kept the CCW concentrated mainly in the first 40 nm of distance to the coast, a zone that was occupied by the anchoveta with temperatures between 17.3-23.1°C, salinities between 34.93-35.20 and oxygen between 3.5-7.3 mL L^{-1}. In the F2020-I, the fishing fleet was in an area with temperatures between 14.9-21.8°C and salinity between 34.65-35.10. Finally, on the Cr 2009-09 it was located in waters with temperatures between 14.8-17.2°C, salinities between 34.95-35.21, and oxygen between 3.4-5.3 mL L^{-1} (Table 3, Fig. 5).

In general, the distribution of anchoveta was preferentially in the CCW that varied in the seasons of the year, in the spring of 2019 it was found in temperatures lower than 22.1°C, in the summer of 2020 at temperatures lower than 23.1°C and in the winter of 2020 at temperatures lower than 17.2°C; as for, the salinity was always found in salinities lower than 35.2.

DISCUSSION

The high oceanographic variability in the Peruvian marine ecosystem registered in this study period generated, in early 2020, horizontal and vertical migration behaviors in anchoveta (*Engraulis ringens*) adult specimens, generating inaccessibility to purse seine nets in the surface layer of the sea.

A detailed description by activity is as follows:

a) In the Cr 1909-11, the oceanographic conditions were neutral with a wide distribution of anchoveta, the

IMARPE (2019a,b) report indicated total biomass of 8.37 million tons, a wide size range from 2.0 to 17.5 cm LT with several modes along the coast and with an important modal group of pre-recruits mainly between Punta La Negra-Chimbote associated with the presence of saline fronts (mixing areas between CCW and SSW). The anchoveta distribution was normal.

b) In the F2019-II, the fishing fleet was distributed south of Chicama with the main area between Salaverry-Chimbote within 40 nm of the coast with landings of modal sizes in 13.5 and 14.5 cm; however, the season was suspended due to the high presence of juvenile anchovies, capturing 35.98% of the assigned quota (1.00 million tons).

What happened? One week after the start of the F2019-II, changes in oceanographic conditions were observed, such as a) negative wind anomalies on the Peruvian coast (weak winds) in part of the central and southern coast, b) an upward trend in sea surface temperature anomalies, which led to a tendency for the waters of the Peruvian coast to warm up in the face of weakening winds, c) the approach of warm waters from the west (Ocean Waters or SSW) generated a process of warming and increase of salinity, in an important part of the Peruvian coast, d) the arrival of a warm Kelvin wave to the coasts of South America that caused in the Peruvian coast, favorable conditions for the warming of the waters, increase of the sea level and sinking of the thermocline, described in DHN (2019a,b) and IMARPE (2019c). These climatic conditions generated a spatial rearrangement of the anchoveta in a search for appropriate conditions for its distribution, consisting of i) a horizontal migration towards the coast (from west to east) and towards the south, and ii) a vertical migration towards areas close to the bottom of the continental platform. This vertical migration is carried out by the adult specimens, while the juvenile specimens (less than 12 cm in size) always remain in the surface layer, due to their low biological resistance.

The evidence of this behavior of the anchoveta was observed in a survey carried out in the fishing vessel "Dorado" of the Pesquera Exalmar S.A.A. in December 2019 in northern Peru. In some echograms, mainly in the southwest of the island Lobos de Tierra (06°26´S and 80°51´W) (Fig. 6), compact echo traces of greater intensity were recorded near the bottom that corresponded to schools of adult specimens; while, more tenuous echo traces of less intensity were found in the superficial layer of 30 m, which corresponded to juvenile specimens. Similar vertical behavior was observed for Castillo & Gutiérrez (1998) in the survey 9711 (recorded up to 150 m depth) carried out in November 1997 due to the presence of warm waters in the surface layer of the sea. This fact led the fishing fleet to capture mainly juvenile specimens due to their vulnerability to the purse seine net (accessibility), and that the 2019 winter spawning recruitment was added to this surface layer.

c) The Pr 2001-01 carried out in the coastal strip of 30 nm from the coast showed the high incidence of juveniles in this area, and that they were accessible to the artisanal anchoveta fleet.

In summary, between November-December 2019, a sequence of events occurred that had a strong impact on the anchoveta population in the following way: i) impact of the variation of environmental oceanographic conditions, such as weakening of the winds, intromission of the ESW in the north and SSW towards the coast, and the presence of a warm Kelvin wave, ii) impact on the distribution (biological), which caused horizontal and vertical migrations, iii) impact on the size structure (biological), the adult specimens migrated near the bottom and the juvenile specimens remained in the surface layer of the sea added to the new entrance of juveniles (recruitment) from the second half of December 2019, iv) impact on the fishery, by the variations of the sizes in the daily landings of anchoveta in the north-central region. This temporary situation, which had a similar negative history in the second seasons of 2010 and 2017, also presented a rapid recovery of the population during the first seasons of 2011 and 2018 (Fig. 7).

d) In February 2020, when the climatic conditions were normalized, the Cr 2002-03 was carried out with the usual approach towards the coast of the anchoveta (horizontal migration from west to east) and the ascent of the schools towards the surface layer (vertical migration from bottom to top). The IMARPE (2020c) report describes that the anchoveta biomass in the survey was 11.05 million tons, distributed mainly in the 40 nm of the coast with sizes that fluctuated between 2.0 and 16.5 cm of LT, the anchoveta distribution was normal.

e) In F2020-I, the anchoveta catch was 98% of the quota assigned in the north-central region (2.41 million tons), with only 278 fishing vessels from the steel fleet and 316 from the wooden fleet, due to the health standards for the current situation of the Covid-19. The biomass of juveniles of the anchoveta resource extracted during the season was of the order of 7.94%, a value below the established limit.

f) Subsequently, due to seasonal changes, climatic conditions throughout the northern zone up to Chimbote were cold, producing negative SST anomalies (La Niña coastal) associated with the remnant of the cold Kelvin wave in July, which was prolonged in August and with less intensity in September 2020, which were reported

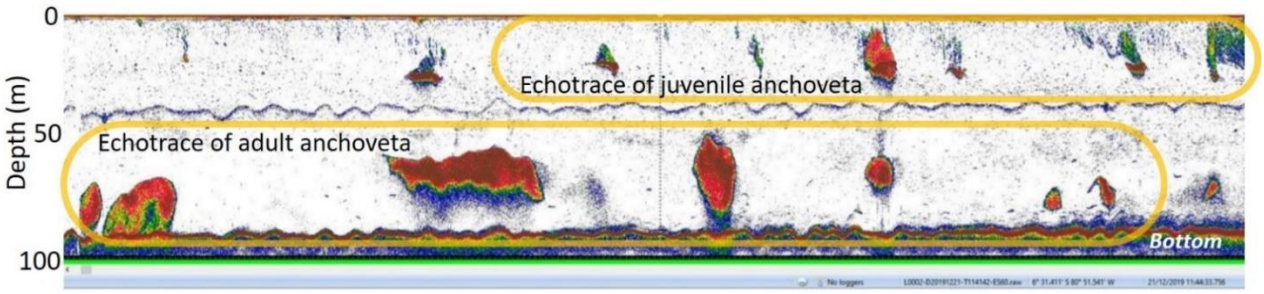

Figure 6. Echogram of the ES60 120 kHz Simrad echo sounder of the fishing vessel "Dorado". Echotraces of adult and juvenile anchoveta (*Engraulis ringens*), recorded southwest of Lobos de Tierra Island (06°26´S and 080°51´W) on December 21, 2019, can be observed. Source: Pesquera Exalmar S.A.A.

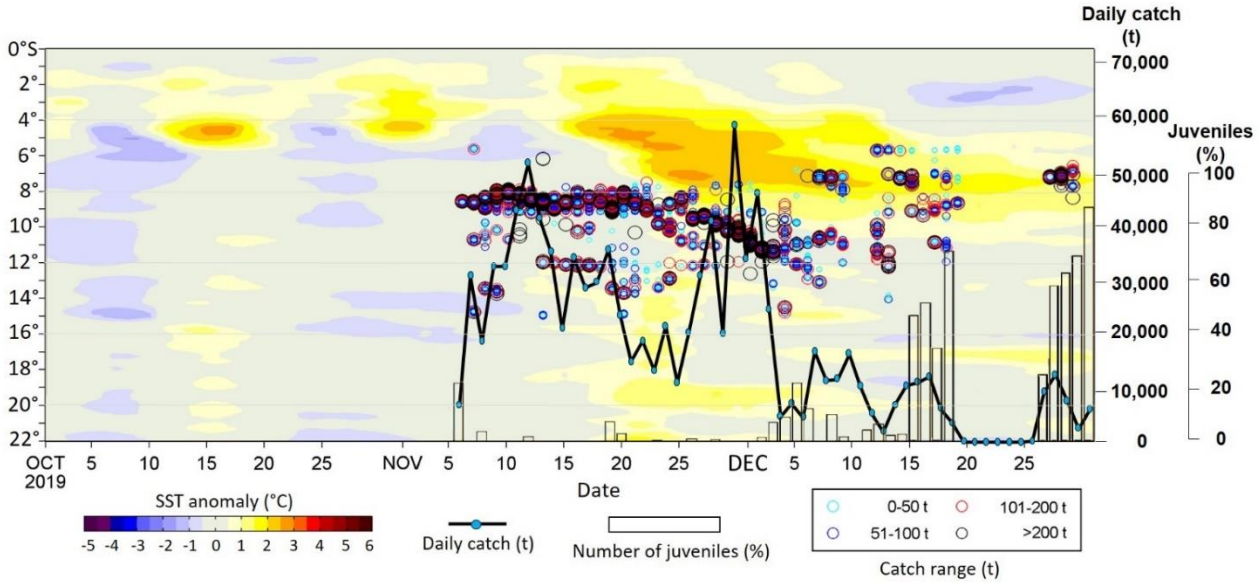

Figure 7. Daily latitudinal catch of anchoveta (*Engraulis ringens*) in relation to sea surface temperature (SST) anomalies and the incidence of juveniles (October-December 2019). An increase in SST anomalies is observed between November 15 and December 30, 2019.

in DHN (2020) and later by Salvá-Pando (2020). These oceanographic conditions generated that the anchoveta distribution is wider and more dispersed in a greater area of extension by the amplitude of the CCW, being reported as incidental capture in the fishing of mackerel in the zone of influence of the Gulf of Guayaquil until Salinas (Ecuador), which was reported in DHN (2020); evidencing the horizontal migration towards the north, a situation that occurs when cold conditions are generated and that are preferential of this species. The Cr 2009-09 anchoveta spawning biomass cruise showed the wide anchoveta distribution, although only a part of the distribution is presented (50 nm coastal strip between Callao-Punta Falsa).

The anchoveta is a species sensitive to oceanographic changes, like all species in adverse conditions, it migrates in search of appropriate environments for its normal development or, on the contrary, when conditions are favorable, it has a larger dispersion area. Results obtained during this study period showed anchoveta had migrational behavior because of environmental variability. Figure 8 shows a time series of satellite images of temperature and salinity anomalies made by the IMARPE Remote Sensing Area, it is visualized that between November 2019 and March 2020, positive anomalies of the SST between latitudes 06-09°S due to the arrival towards the coast of a warm Kelvin wave and between March and May 2020 the approach towards the coast of the SSW (salinities >35.2) between latitudes 09-13°S.

Finally, we conclude the coherence and scientific evidence of the research carried out by IMARPE concerning the abundance of anchoveta obtained in the Cr 1909-11 (described in Castillo et al. (2020) with

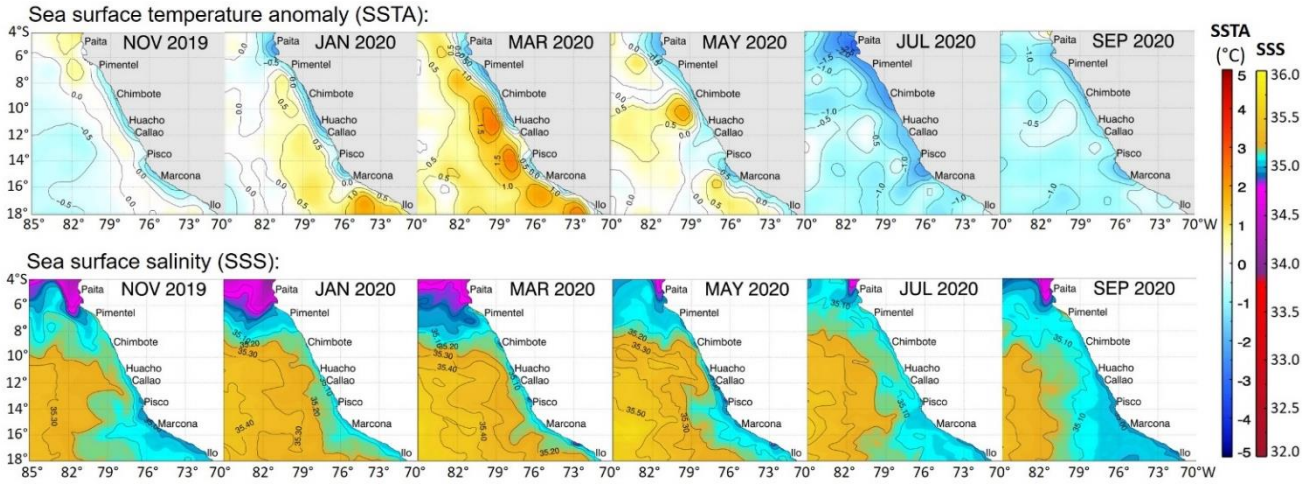

Figure 8. Series every two months of satellite images of monthly average of anomalies in the temperature and surface salinity of the sea in the analyzed period 2019-2020, obtained by the Instituto del Mar del Perú remote sensing area.

diverse hydroacoustic methodologies in the estimation of anchoveta biomass) and in the summer survey of 2020, which are consistent with the catches obtained in the quota of the F2020-I. What happened in the second fishing season of 2019, one week after the end of the cruise, due to atypical conditions in which the anchoveta had a strategy in its vertical distribution, making it inaccessible to the nets used by the fishing fleet described above.

CONCLUSIONS

The strategy of the migratory behavior of the anchoveta concerning its habitat (CCW) has allowed staying in the marine ecosystem of the Humboldt Current System that added to suitable fishing management will allow greater sustainability of the species, generating food, employment and economic, and social well-being.

The presence of positive oceanographic anomalies (equatorial Kelvin wave) generated transitory heating in the marine ecosystem of the Peruvian current, which induced the anchoveta to make horizontal and vertical migrations in its search for appropriate conditions.

The fishing activity in the F2019-II had a negative impact due to the joint action of environmental events (warm Kelvin wave) and biological events (entry of strong recruitment and vertical migration of adult specimens).

The anchoveta distribution was preferentially in the CCW that varied in the seasons of the year. In the spring of 2019, it was found in temperatures lower than 22.1°C, in the summer of 2020 at temperatures lower than 23.1°C and in the winter of 2020 at temperatures lower than 17.2°C; as for, the salinity was always found in salinities lower than 35.2.

Given the continuous environmental variability in the marine system of the Humboldt Current System, IMARPE must continue conducting research cruises to learn about the impacts on the anchoveta's habitat to adopt measures for its conservation and management.

ACKNOWLEDGEMENTS

We are grateful to the fishing company Exalmar S.A.A. for providing us with part of the acoustic data obtained in its prospection carried out in December 2019; likewise, to Jaime Atiquipa of the DGIHSA's Remote Sensing Functional Area for providing satellite tracking data of the anchoveta fishing seasons in the period analyzed. Special recognition to almost all the researchers of the Hydroacoustics Functional Area who, despite the difficulties that arose in January 2020, were strengthened by demonstrating their spirit of research and responsibility.

REFERENCES

Arias-Schreiber, M., Ñiquen, M. & Bouchon, M. 2011. Coping strategies to deal with environmental variability and extreme climatic events in the Peruvian anchovy fishery. Sustainability, 3: 823-846. doi: 10.3390/su3060823

Bertrand, A., Segura, M., Gutiérrez, M. & Vásquez, L. 2004. From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish and

Fisheries, 5: 296-316. doi: 10.1111/j.1467-2679. 2004. 00165.x

Bertrand, A., Gerlotto, F., Bertrand, S., Gutiérrez, M., Alza, L., Chipollini, A., et al. 2008. Schooling behaviour and environmental forcing in relation to anchoveta distribution: an analysis across multiple spatial scales. Progress in Oceanography, 79: 264-277. doi: 10.1016/j.pocean.2008.10.018

Bertrand, A., Chaigneau, A., Peraltilla, S., Ledesma, J., Graco, M., Monetti, F. & Chavez, F.P. 2011. Oxygen: a fundamental property regulating pelagic ecosystem structure in the coastal southeastern Tropical Pacific. Plos One, 6: e29558. doi: 10.1371/journal.pone. 0029558

Bertrand, A., Lengaigne, M., Takahashi, K., Avadí, A., Poulain, F. & Harrod, C. 2020. El Niño Southern Oscillation (ENSO) effects on fisheries and aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 660. FAO, Rome.

Bez, N. & Rivoirard, J. 2001. Transitive geostatistics to characterise spatial aggregations with diffuse limits: an application on mackerel ichtyoplankton. Fisheries Research, 50: 41-58. doi: 10.1016/s0165-7836(00) 00241-1

Castillo, R. & Gutiérrez, M. 1998. Distribución geográfica de la anchoveta (*Engraulis ringens*) entre Huacho y Pacasmayo a diferentes estratos de profundidad. Crucero BIC Humboldt 9711. Instituto del Mar del Perú, 133: 49-55.

Castillo, P.R., Madureira, L., Marangoni, J., Gerlotto, F. & Guevara-Carrasco, R. 2015. Variability in distribution and aggregation behavior of the Peruvian anchovy (*Engraulis ringens*) analyzed using a fifteen years-long series of acoustic surveys (2000-2014). 2015 IEEE/OES Acoustics in Underwater Geosciences Symposium (RIO Acoustics). doi: 10.1109/bioacoustics.2015.7473636

Castillo, P.R., La Cruz, L., Grados, D., Cornejo, R., Guevara-Carrasco, R. & Csirke, J. 2020. Anchoveta (*Engraulis ringens*) biomass in the Peruvian marine ecosystem estimated by various hydroacoustic methodologies during spring of 2019. Journal of Marine Biology & Oceanography, 9: 2.

Castillo, P.R., Dalla-Rosa, L., García-Diaz, W., Madureira, L., Gutiérrez, M., Vásquez, L. & Koppelmann, R. 2018. Anchovy distribution off Peru in relation to abiotic parameters: a 32-year time series from 1985 to 2017. Fisheries Oceanography, 28: 389-401. doi: 10.1111/fog.12419

Castillo, P.R., Peraltilla, S., Aliaga, A., Flores, M., Ballón, M., Calderón, J. & Gutiérrez, M. 2009. Protocolo técnico para la evaluación acústica de las áreas de distribución y abundancia de recursos pelágicos en el mar peruano. Instituto del Mar del Perú, 36: 7-28.

Chavez, F., Bertrand, A., Guevara-Carrasco, R., Soler, P. & Csirke, J. 2008. The northern Humboldt Current System: brief history, present status and a view towards the future. Progress in Oceanography, 79: 95-105. doi: 10.1016/j.pocean.2008.10.012

Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú (DHN). 2019a. Comunicado oficial ENFEN Nro.13-2019. Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú. Callao 14 de octubre del 2019, 5 pp. [https://www.dhn.mil.pe/Archivos/oceanografia/enfen/comunicado-oficial/13-2019.pdf]. Reviewed: October 24, 2020.

Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú (DHN). 2019b. Comunicado oficial ENFEN Nro.14-2019. Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú. Callao 14 de noviembre del 2019, 5 pp. [https://www.dhn.mil.pe/Archivos/oceanografia/enfen/comunicado-oficial/14-2019.pdf]. Reviewed: October 24, 2020.

Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú (DHN). 2020. Comunicado oficial ENFEN Nro. 10-2020. Dirección de Hidrografía y Navegación de la Marina de Guerra del Perú. Callao 04 de setiembre del 2020, 6 pp. [https://www.dhn.mil.pe/Archivos/oceanografia/enfen/comunicado-oficial/10-2020.pdf]. Reviewed: October 24, 2020.

Finlayson, G.R., Vieira, E.M., Priddel, D., Wheeler, R., Bentley, J. & Dickman, C.R. 2008. Multi-scale patterns of habitat use by re-introduced mammals: a case study using medium-sized marsupials. Biological Conservation, 141: 320-331. doi: 10.1016/j.biocon. 2007.10.008

Grados, D., Bertrand, A., Colas, F., Echevin, V., Chaigneau, A., Gutiérrez, D., et al. 2016. Spatial and seasonal patterns of fine-scale to mesoscale upper ocean dynamics in an Eastern Boundary Current System. Progress in Oceanography, 142: 105-116. doi: 10.1016/j.pocean.2016.02.002

Guillén, O., Rojas de Mendiola, B. & Izaguirre de Rondán, R. 1969. Producción primaria y fitoplancton en las aguas costeras peruanas Informe Especial Instituto del Mar del Perú, 56: 47-82.

Hastie, T.J., & Tibshirani, R.J. 2017. Generalized additive models. Routledge, London.

Hutchinson, G.E. 1957. Concluding remarks. Cold Spring Harbour Symposium on Quantitative Biology, 22: 415-427. doi: 10.1101/SQB.1957.022.01.039

Instituto del Mar del Perú (IMARPE). 2019a. Informe Ejecutivo del "Crucero de evaluación hidroacústica de recursos pelágicos 1909-11". Informe Instituto del Mar del Perú, 66 pp.

Instituto del Mar del Perú (IMARPE). 2019b. Informe sobre la "Situación del stock norte-centro de la anchoveta peruana (*Engraulis ringens*) al 05 de noviembre de 2019 y perspectivas de explotación para la segunda temporada de pesca 2019". Informe Instituto del Mar del Perú, 25 pp.

Instituto del Mar del Perú (IMARPE). 2019c. Informe de las condiciones oceanográficas y biológico-pesqueras noviembre 2019. Actividad 4: Generación de información y monitoreo del Fenómeno El Niño. Programa presupuestal por resultados N°068. Informe Instituto del Mar del Perú, 52 pp.

Instituto del Mar del Perú (IMARPE). 2020a. Protocolo N°003-2020-IMARPE/PE Vigilancia, prevención y control a bordo de embarcaciones científicas del IMARPE durante la emergencia sanitaria COVID-19. Informe Instituto del Mar del Perú, 14 pp.

Instituto del Mar del Perú (IMARPE). 2020b. Informe de la prospección biológica-pesquera de la anchoveta. Isla Lobos de Tierra (latitud 06°25´S, longitud 080°51´W) - Ilo (latitud 17°38´S, longitud 071°20´W). 4-12 de enero del 2020. Informe Instituto del Mar del Perú, 26 pp.

Instituto del Mar del Perú (IMARPE). 2020c. Informe del crucero de evaluación hidroacústica de anchoveta, jurel, caballa y otros pelágicos 2002-03. Informe Instituto del Mar del Perú, 58 pp.

Instituto del Mar del Perú (IMARPE). 2020d. Informe interno del crucero de evaluación de biomasa desovante de la anchoveta en el invierno del 2020. Informe Instituto del Mar del Perú, 26 pp.

Jordán, R. 1971. Distribution of anchoveta (*Engraulis ringens* J.) in relation to the environment. Revista Investigación Pesquera, 35: 113-126.

Jordán, R. & Chirinos de Vildoso, A. 1965. La anchoveta (*Engraulis ringens* J.): conocimiento actual sobre su biología ecología y pesquería. Informe Instituto del Mar del Perú, 6: 3-52.

MacLennan, D.N., Fernandes, P.G. & Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science, 59: 365-369.

Mathisen, O.A. 1989. Adaptation of the anchoveta (*Engraulis ringens*) to the Peruvian upwelling system. In: Pauly, D., Muck, P., Mendo, J. & Tsukayama, I. (Eds.). The Peruvian upwelling ecosystem: dynamics and interactions. ICLARM Studies and Reviews, Manila, 18: 220-234.

Ministerio de la Producción (Produce). 2019. Resolución Ministerial Nro. 483-2019-PRODUCE. Lima, 11 de noviembre de 2019. [https://busquedas.elperuano.pe/normaslegales/autorizan-el-inicio-de-la-segunda-temporada-de-pesca-del-rec-resolucion-ministerial-n-483-2019-produce-1825767-1/]. Reviewed: November 24, 2020.

Ministerio de la Producción (Produce). 2020. Resolución Ministerial Nro. 015-2020- PRODUCE. Lima, 14 de enero de 2020. [https://www.gob.pe/institucion/produce/normas-legales/395566-015-2020-produce]. Reviewed: November 24, 2020.

Ministerio de la Producción (Produce). 2020b. Resolución Ministerial Nro. 147-2020-PRODUCE. Lima, 7 de mayo de 2020. [https://busquedas.elperuano.pe/normaslegales/autorizan-el-inicio-de-la-primera-temporada-de-pesca-2020-de-resolucion-ministerial-n-147-2020-produce-1866150-1/]. Reviewed: October 24, 2020.

Ministerio de la Producción (Produce). 2020c. Resolución Ministerial Nro. 263-2020-PRODUCE. Lima, 6 de agosto de 2020. [https://www.gob.pe/institucion/produce/normas-legales/1079679-263-2020-produce]. Reviewed: October 24, 2020.

Morón, O. 2000. Características del ambiente marino frente a la costa peruana. Boletín Instituto del Mar del Perú, 19: 179-204.

Morón, O. & Sarmiento, M. 2001. Aspectos océanográficos de El Niño 1997-98 y su relación con los recursos pelágicos. In: Tarazona, J., Arntz, W.E. & Castillo de Maruenda, E. (Eds.), El Niño en América Latina: impactos biológicos y sociales. Consejo Nacional de Ciencia y Tecnología. Lima, pp. 5-27.

Moron, G., Galloso, P., Gutierrez, D. & Torrejon-Magallanes, J. 2019. Temporal changes in mesoscale aggregations and spatial distribution scenarios of the Peruvian anchovy (*Engraulis ringens*). Deep Sea Research Part II: Topical Studies in Oceanography, 159: 75-83. doi: 10.1016/j.dsr2.2018.11.009

Mosquera, K. 2014. Ondas Kelvin oceánicas y un modelo oceánico simple para su diagnóstico y pronóstico. Boletín técnico "Generación de modelos climáticos para el pronóstico de la ocurrencia del Fenómeno El Niño". Instituto Geofísico del Perú, 1: 4-7. [http://www.met.igp.gob.pe/publicaciones/2014/Boletin_El_Nino_ 201401.pdf]. Reviewed: October 24, 2020.

Muck, P., De Moreno, A.Z. & Aranda, C. 1989. The seasonal dynamics of sea surface temperature and its impact on anchoveta distribution off Peru. In: Pauly, D., Muck, P., Mendo, J. & Tsukayama, I. (Eds.). The Peruvian upwelling ecosystem: dynamics and interactions, ICLARM Studies and Reviews, Manila, 18: 33-44.

Murase, H., Nagashima, H., Yonezaki, S., Matsukura, R. & Kitakado, T. 2009. Application of a generalized additive model (GAM) to reveal relationships between environmental factors and distributions of pelagic fish and krill: a case study in Sendai Bay, Japan. ICES

Journal of Marine Science, 66: 1417-1424. doi: 10.1093/icesjms/fsp105

Pabón-Caicedo, J.D. & Montealegre-Bocanegra, J.E. 2017. Los fenómenos de El Niño y de La Niña, su efecto climático e impactos socioeconómicos. Academia Colombiana de Ciencias Exactas, Físicas y Naturales, Bogotá, 34: 168 pp. [http://accefyn-dspace.metabiblioteca.org/jspui/handle/001/113]. Reviewed: October 24, 2020.

Pesquera Exalmar S.A.A. 2019. Reporte de la prospección en la E/P Dorado: características de la pesca y condiciones ambientales. Pesquera Exalmar S.A.A., Lima.

Purca, S., Graco, M., Gutiérrez, D., Dewitte, B., Tam, J., Bertrand, A., et al. 2010. Relationships between anchoveta and environment at different temporal scales. Boletín Instituto del Mar del Perú, 25: 13-21.

Rowston, C., Catterall, C. & Hurst, C. 2002. Habitat preferences of squirrel gliders *Petaurus noforcelncis* in the fragmented landscape of southeast Queensland. Forest Ecology and Management, 164: 197-209.

Salvá-Pando, A.J. 2020. Presencia de la Niña. Boletín ASP, 61: 17 pp.

Santivañez, M.A. 2017. Caracterización y comparación de patrones espaciotemporales y nichos ecológicos de la múnida (*Pleuroncodes monodon*) y la anchoveta (*Engraulis ringens*) en el mar peruano desde 1998 hasta 2013. Tesis de Pregrado, Universidad Nacional Mayor de San Marcos, Lima.

Silva, C., Leiva, F. & Lastra, J. 2018. Predicting the current and future suitable habitat distributions of the anchoveta (*Engraulis ringens*) using the Maxent model in the coastal areas off central-northern Chile. Fisheries Oceanography, 28: 171-182. doi: 10.1111/fog.12400.

Received: November 24, 2020; Accepted: June 16, 2021

Simmonds, J. & MacLennan, D. 2005. Fisheries acoustics. Theory and practice. Blackwell Science, New Jersey.

Swartzman, G., Bertrand, A., Gutiérrez, M., Bertrand, S. & Vasquez, L. 2008. The relationship of anchoveta and sardine to water masses in the Peruvian Humboldt Current System from 1983 to 2005. Progress in Oceanography, 79: 228-237. doi: 10.1016/j.pocean.2008.10.021

Takahashi, K., Karamperidou, C. & Dewitte, B. 2019. A theoretical model of strong and moderate El Niño regimes. Climate Dynamics, 52: 7477-7493. doi: 10.1007/s00382-018-4100-z)

Thiel, M., Macaya, E., Acuna, E., Arntz, W., Bastias, H., Brokordt, K., et al. 2007. The Humboldt Current System of northern and central Chile. Oceanography and Marine Biology, 45, 195-345. doi: 10.1201/9781420050943.ch6.

Urmy, S.S., Horne, J.K. & Barbee, D.H. 2012. Measuring the vertical distributional variability of pelagic fauna in Monterey Bay. ICES Journal of Marine Science, 69: 184-196. doi: 10.1093/icesjms/fsr205

Woillez, M., Poulard, J.-C., Rivoirard, J., Petitgas, P. & Bez, N. 2007. Indices for capturing spatial patterns and their evolution in time, with application to European hake (*Merluccius merluccius*) in the Bay of Biscay. ICES Journal of Marine Science, 64: 537-550. doi: 10.1093/icesjms/fsm025.

Wood, S.N. 2017. Generalized additive models: an introduction with R. CRC Press, Boca Raton.

Zuta, S. & Guillén, O. 1970. Oceanografía de las aguas costeras del Perú. Boletín Instituto del Mar del Perú, 2: 157-324.