

Study of *Sardinella aurita* mortality in Las Piedras Bay

Estudio de la mortandad de *Sardinella aurita* en la bahía de Las Piedras

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Abstract

*Las Piedras is a coastal town on the Paraguaná Peninsula in Falcón State, where a high mortality rate of *Sardinella aurita* occurred in its bay during October 2009. This event triggered a series of environmental problems that prompted an investigation into the causes of the species' deaths. The research design was non-experimental, field-based, and explanatory. The study examined the physicochemical, environmental, and biological variables of Las Piedras Bay during the period of the phenomenon. The results were analyzed using a one-way analysis of variance with Tukey and Duncan's post-hoc tests. The findings determined that the fish died due to a synergistic effect of oxygen deficiency at night, feeding failure, and thermal stress, resulting from possible stratification of water masses caused by altered environmental conditions in the area due to the El Niño phenomenon.*

Keywords: Bahía de las Piedras, fish mortality, *Sardinella aurita*.

Resumen

*Las Piedras es un pueblo costero de la Península de Paraguaná del Estado Falcón, en el que durante el mes de Octubre de año 2009 se presentó una elevada mortandad de *Sardinella aurita* en su Bahía, desencadenando una serie de problemas ambientales que despertaron el interés por determinar las causas de la muerte de esta especie en la bahía de Las Piedras. El diseño de la investigación es no experimental, tipo de campo y nivel explicativo. En esta se estudiaron las variables físicoquímicas, ambientales y biológicas de la Bahía de Las Piedras durante los días del fenómeno. Los resultados obtenidos se analizaron mediante un análisis de varianza de un solo factor con pruebas a posteriori de HDS Tukey y Duncan, determinándose que las especies murieron por un efecto sinérgico entre déficit de oxígeno durante la noche, fallas de alimentación y estrés térmico, a consecuencia de una posible estratificación de las masas de agua debido alteración en las condiciones ambientales de la zona, causadas por la presencia del fenómeno El Niño.*

Palabras claves: Bahía de las Piedras, mortandad de peces, *Sardinella aurita*.

1. Introduction

Venezuela is an important fishing country in the Caribbean. Across its vast territory, the country possesses fishery resources in both its marine and riverine environments, characterized by their high diversity and growing potential (FAO, 2025). The *Sardinella aurita* stands out as Venezuela's most important hydrobiological resource, being the

most accessible source of animal protein for the population (Gómez, 2022).

The Venezuelan coastline stretches for 2,830 km and has a continental shelf of 90,000 km². With the creation of the new Maritime Legal Regime, national jurisdiction was extended to 200 nautical miles (Organic Law of Aquatic Spaces, 2014), establishing an extensive exclusive economic zone of approximately 640,000 km². This represents a

significant opportunity to expand and develop fishing activity through the comprehensive utilization of marine resources.

Las Piedras is a coastal town on the Paraguaná Peninsula, located in the North Parish of the Carirubana Municipality in Falcón State, Venezuela. Its economy is based primarily on artisanal fishing and shrimp farming, making it a town of great importance to the fishing industry (García, 2023).

The inhabitants of this community reported that at the end of the second week of October 2009, a high mortality rate of *Sardinella aurita* began to occur in the bay. This worsened in the third week of October with an increase in the biomass of dead fish, triggering a series of environmental problems. This prompted their interest in understanding the causes of this situation.

Given this problem, and in order to find answers to this question, document the facts, and lay the groundwork for future studies on this or similar events, the present investigation was undertaken. Its objective was to determine the causes of the *Sardinella aurita* mortality in Las Piedras Bay, Carirubana Municipality, Falcón State.

The study was carried out as part of an extension project developed in the community of the Las Piedras sector of the North parish, Carirubana municipality of the Falcón state by an interdisciplinary team from UNEFM and ULA, during 9 months, in the period between the end of October 2009 and July 2010, time during which the project was developed and the actions undertaken by the community were monitored.

2. Theoretical Framework

2.1 Background on Aquatic Species

The Pan American Health Organization (PAHO, 2009) reported the most significant and recent mortality event of aquatic species in the Caribbean Sea, occurring between July and September 1999, due to the number of countries affected almost simultaneously. This phenomenon affected numerous waters of the countries of the Caribbean Community and Common Market (CARICOM), including Grenada, Saint Vincent and the Grenadines, Barbados, and Tobago. Other affected countries were Guyana in July and Venezuela in August; no other CARICOM country reported fish mortality. The study did not provide definitive evidence to link the fish deaths to a single factor; these incidents were more likely due to the action and interaction of several physicochemical and biological environmental factors (PAHO, 2009).

Pomares (2004), in his study on the mass mortality of bivalve mollusks in Amuay Bay, Venezuela, concluded that the mollusk mortality was due to the deposition of contaminated and previously suspended sediments from the southern part of the bay (with historical pollution patterns) onto the mollusk beds to the north (with little or no pollution),

which suffocated and impregnated the species. Globally, many causes have led to the mortality of aquatic species, both marine and freshwater. In 2009 alone, the following events occurred: On February 17, Herrera (2009) published an article on fish mortality in Santa Marta Bay, Colombia. The results of the investigations, provided by the José Benito Vives de Andrés Institute of Marine and Coastal Research (INVEMAR, 2009), revealed that the convergence of several factors, including the influx of wastewater, limited water circulation in the area, and a massive presence of fish, caused the oxygen levels to drop to anoxic levels, resulting in the mass death of the fish by asphyxiation.

According to information published by Bionero (2009), in May of that year, approximately nine tons of dead fish of various species appeared in the Laguna del Carpintero in the city of Tampico, Mexico. These included snook, tilapia, carp, shad, silver catfish, catfish, mullet, and crab, some weighing up to 3 kilograms. The investigation concluded that the cause of death was oxygen deficiency in the water.

The environmental magazine Catorce 6 (2009) from Cartagena, Colombia, published an article entitled: "Temperature change would be responsible for another fish kill in Cartagena," this event occurred in August in the Chambacú lagoon, where the conclusion was that the death of species occurred due to an increase in the temperature of the lagoon water.

2.2 The Sardine (*Sardinella aurita*)

This is a coastal pelagic species that forms very compact schools. It is distributed from the United States to Brazil and has also been reported in the Mediterranean Sea and the western Pacific. In Venezuela, it is found mainly in the eastern part of the country and is associated with the highly productive coastal zone due to upwelling (Castillo et al., 2012; Mendoza et al., 2021; González et al., 2021).

The continental shelf off northeastern Venezuela represents the most important fishing area in the Caribbean Sea. This is largely attributed to the upwelling event produced by local winds, which establishes high biological productivity reflected primarily in the increase in the biomass of planktonic organisms, which, through filter feeding, constitute the main food source for sardines (Castillo et al., 2012; Gómez, 2022; González et al., 2021; Mendoza et al., 2021).

In Venezuela, sardines are considered a strategic resource because they represent a low-cost protein source and support the country's most socio-economically important artisanal fishery, due to the large catch volumes and the numerous jobs generated by their extraction. However, since 2005, the sardine fishery has suffered a significant collapse, possibly due to a combination of environmental factors and overfishing (Castillo et al., 2012; Gómez, 2022).

2.3 Self-purification in water

Zaror (2000) explains that living activity gives a body of water a certain capacity for self-purification, since the organic compounds that are discharged into it are consumed by heterotrophic microorganisms. As a result of metabolic activity, the dissolved organic compounds are transformed into cellular biomass, CO₂ and other simple inorganic compounds.

The same author states that the capacity for self-purification is highly dependent on the availability of dissolved oxygen in the water. This element is the essential reactant in aerobic systems. When aerobic organisms metabolize, organic nutrients simultaneously consume dissolved oxygen. The high metabolic requirements of the gas are offset by its low solubility in water (in the range of 7-10 g/m³). If the rate of oxygen transfer from the air into the water is less than the rate of its metabolic consumption, its concentration in the water will gradually decrease, eventually becoming a limiting reactant in intracellular oxidation reactions.

The reduction in oxygen availability will primarily affect the higher organisms in the food chain. This will cause an imbalance in the population equilibrium, leading to a rapid increase in the number of microorganisms in the water body. As a consequence, oxygen consumption increases, eventually creating an anoxic aquatic environment (Zaror, 2000).

2.4 Biological Parameters of Water Quality

Water is a medium where thousands of biological species live and carry out their life cycle. According to Arellano (2002), the range of aquatic species in size and diversity extends from unicellular organisms to the largest fish, and these are, in a sense, parameters of water quality, since their presence or absence can indicate the condition of a body of water. If it contains a wide variety of species in a balanced proportion, it can be considered a healthy system.

2.5 Physicochemical Parameters of Seawater

These are variables that allow us to understand the behavior of aquatic ecosystems over a specific period of time. They can be useful for identifying the possible causes of abnormal events in these ecosystems. Some of the most important parameters are:

2.5.1 Sea Surface Temperature (SST)

SST is one of the most widely used oceanographic variables as an environmental indicator because it is related to physical aspects such as ocean currents, surface wind intensity, mixed layer dynamics, precipitation, solar radiation intensity, upwelling, and sea level changes. Furthermore, it is related to life cycles, metabolism, population factors, organism stress, and, in general, all biological variability (Bernal et al., 2006).

In the oceans, temperature limits are between 2 and 30

°C. Increased temperature intensifies respiration; in some zooplankton, respiratory activity doubles when the water temperature rises from 10 to 20 °C. An increase in this parameter implies an increase in metabolism and greater gill permeability. Fish are poikilothermic, meaning they cannot regulate their body temperature. There is a direct relationship between water temperature and their metabolic rate; increases in temperature cause hyperventilation, loss of appetite, lethargy, and even death. According to Seoanez (2000), temperature can influence the mortality rate of various species and is crucial for the survival of juvenile sardines. It also affects the amount of dissolved oxygen. Water at 15°C can contain 10 mg/L of oxygen, while at 30°C it can only contain 1 mg/L.

2.5.2 Oxygen

Oxygen is a non-conservative gas and, like other gases, is dissolved in seawater. The solubility of oxygen in water depends on the partial pressure of the gas, the temperature, and the salinity of the water; it increases with the first and decreases with the latter two. According to SHOA (2007), dissolved oxygen in seawater comes from the atmosphere and is a product of photosynthesis.

Dissolved oxygen unsaturation is often observed in waters where its consumption through the decomposition of organic matter is high and its renewal through water circulation is low. Extreme situations of unsaturation have also been observed in very isolated areas with very low circulation and large inputs of organic matter, whether natural or deposited by humans, where dissolved oxygen becomes depleted, producing an anoxic condition that prevents the development of aerobic organisms. Fish need high oxygen levels of at least 5 mg/l, invertebrates need lower levels, and bacteria need the lowest levels (SHOA, 2007; Seoanez, 2000).

2.5.3 Phosphates, Nitrates, and Silicates

These are important nutrient salts whose depletion in water limits organic production. The amounts of these elements in a location indicate its potential fertility and the biological processes that have occurred or are occurring there. Nutrient pollution, especially from nitrogen and phosphorus, has consistently been identified as a major cause of degradation in some U.S. waters for over a decade. Excess nitrogen and phosphorus lead to significant water quality problems, including harmful algal blooms, hypoxia, and the decline of wildlife and wildlife habitat (Ager et al., 1974).

2.5.4 Salinity

This is the most commonly used measure of seawater salinity and is defined as the total number of grams of inorganic salts dissolved in 1 kg of seawater (S‰). The average salinity of seawater is 35‰, which is equivalent to 35 g of salts in 1 kg of seawater. According to SHOA (2007), salinity changes are important in pollution phenomena, since

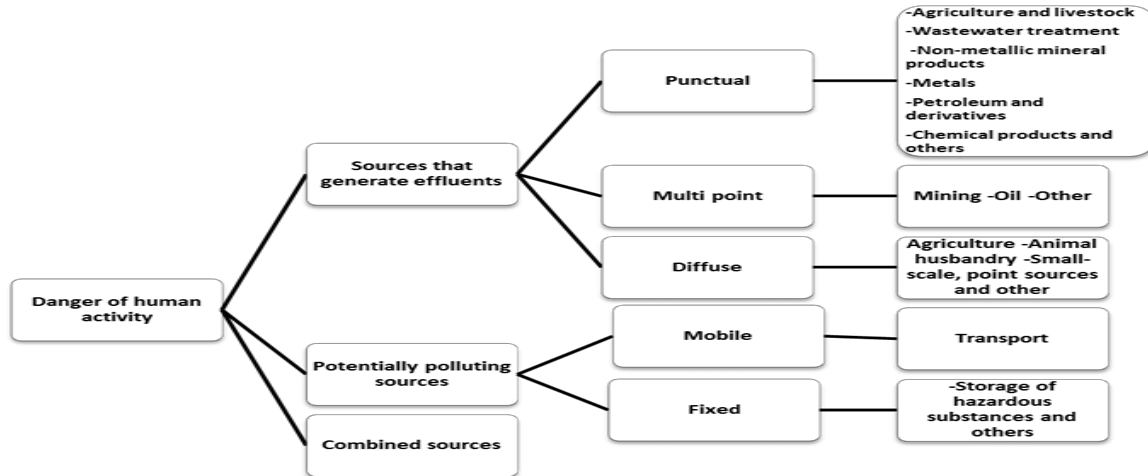


Figure 1. Types of water pollution sources according to the method of effluent production. Source: (INVEMAR, 2009).

lower salinity increases the toxicity of certain heavy metals such as mercury, copper, and cadmium, among others. Seoanez (2000) states that salinity variations far from the coast are relatively small, but are considerable in coastal areas due to changes in runoff, which influence the osmotic balance of fish and the buoyancy of pelagic eggs.

2.5.5 Hydronium Ion Potential (pH)

In a body of water, pH is a parameter to consider when determining the solubility of various organic and inorganic substances in water. It is an abiotic factor that regulates enzyme-mediated biological processes (photosynthesis, respiration), as well as the availability of essential nutrients that limit microbial growth in many ecosystems (NH_4^+ , PO_4^{3-} , and Mg^{+2}), the mobility of heavy metals such as copper, which is toxic to many microorganisms, and also affects or regulates the structure and function of macromolecules and organelles such as nucleic acids, structural proteins, and cell wall and membrane systems. Variations in pH can therefore have marked effects on each level of organization of living matter, from the cellular level to the ecosystem level (Seoanez, 2000).

2.5.6 Heavy Metals

Heavy metal pollution is one of the major pollution problems in the coastal marine environment. The main problem with these elements in the marine environment is that they are not degraded by microbial activity; on the contrary, they can be enriched by organisms that sometimes form organometallic complexes; others, when present in concentrations that exceed natural levels, cause serious ecological problems as a result of bioaccumulation and biomagnification processes through the food chain (Ansari, et al., 2004).

2.5.7 Thermocline

This is defined as the “layer of marine or lacustrine

water whose temperature decreases rapidly with depth.” It is the zone of the ocean's surface layer where the seawater temperature decreases rapidly vertically, with little increase in depth. It constitutes a thin layer of water located between the warmer surface and the colder bottom (Trujillo and Thurman, 2016; Wetzel, 2001; Garrison and Ellis, 2016).

2.5.8 Terrestrial Sources of Pollution

The risk and hazard of pollution sources are related to the environment's capacity to assimilate, process, disperse, dilute, or filter the waste or effluents that enter the physical environment, transporting them to locations where the impacts are of low or moderate severity, keeping them below the levels permitted by current legislation or acceptable standards (Fernández, 2006).

The external factors that give rise to a risk situation represent the hazard; therefore, they can be called the “source of risk,” whether natural or induced by human activity, with the potential to cause damage.

Water pollution sources can be natural, usually very dispersed and not causing high concentrations of pollution, except in some very specific locations, or anthropogenic (human activities), which present some type of hazard to the quality of the water resource, as shown in Figure 1.

2.6. National and international standards

2.6.1 Main laws

The Constitution of the Bolivarian Republic of Venezuela (1999), in Articles 127, 128, and 129, establishes environmental rights and the State's obligation to protect water resources. Within this framework, the fundamental pillar is the Water Law (2007), which establishes provisions for the integrated management of water as an essential element for life and sustainable development. Likewise, the Environmental Criminal Law (2012) criminalizes actions that degrade, pollute, or poison water sources.

2.6.2 Technical Standards (Official Gazettes)

Decree 883 (Extraordinary Official Gazette No. 5,021, 1995), which establishes the "Standards for the Classification and Quality Control of Water Bodies and Liquid Discharges." Article 12 of this decree establishes the maximum permissible concentration levels of metals in discharges into the marine environment. The criteria established by the international EPA standard (2002), which has allowed for the evaluation of the environmental quality of coastal and estuarine ecosystems, were also used as a reference for the assessment.

3. Experimental Procedure

This study used a non-experimental, field-based, and explanatory research design. To carry out the research, the mortality of the species was characterized in situ using an adaptation of the instrument "Monitoring and Advisory Program for Cases of Fish Mortality in Aquatic Environments of the Province of Buenos Aires" (MAA, 2007).

Water samples were collected randomly in five (5) stations of the bay at the surface, in accordance with the General Plan for Global Research on Marine Pollution and Guidelines for Basic Studies (UNESCO, 1976). In the lab, dissolved oxygen, nitrogen, phosphorus, and the heavy metals lead, copper, cadmium, and zinc, were determined according to Standard Methods (APHA, 1995).

Species sampling consisted of collecting 15 specimens of (*Sardinella aurita*). Necropsies of collected species were performed according to the necropsy protocol for aquatic specimens at the "laboratorio de Ciencias Biológicas del Programa de Ingeniería Pesquera de la UNEFM". Temperature and salinity were measured at surface in each station using a YSI multiparameter probe (Yellow Springs Instruments), and pH with a digital pH meter.

Sea Surface Temperature (SST) and Chlorophylla concentrations in the area were evaluated using information from the Cariaco Project of the "Instituto de Tecnología y



Figure 2. Bahía de Las Piedras, October 30, 2009 (during the *Sardinella aurita* mortality)

Ciencias Marinas" (2009) at Simón Bolívar University. Information regarding wind speed and direction was also requested from the National Institute of Civil Aeronautics (2009), located in the control tower of the Josefa Camejo

Airport in Punto Fijo. Statistical analyses include one-way analysis of variance (ANOVA) and Tukey and Duncan post-hoc tests.

4. Results and Discussion

4.1 In situ characterization of species mortality

On October 30, 2009, the Las Piedras Bay pier was visited to gather details about the species mortality reported by affected residents. It was observed that there was indeed a large number of dead fish on the bay shores and floating on the water's surface, primarily the *Sardinella aurita* species. An iridescent surface film with a diesel odor was also observed. Therefore, information was collected from community members, yielding the following results:

4.1.1 General Data on the Phenomenon

Community members reported that the phenomenon began on October 16, 2009, between approximately 2:00 am and 3:00 am, when they observed fish rising to the surface and exhibiting erratic swimming. This situation lasted only a few minutes; afterward, the fish would die, floating to the surface and piling up along the shore. Despite this, the community members stated they hadn't paid much attention to the situation, assuming they were simply fish caught in the fishing nets (seines) set in the area, which were released when the catch was hauled in.

However, by Thursday, October 29, 2009, the situation had gradually worsened with the continued accumulation of dead marine life on the beach, causing foul odors, a proliferation of flies, and the potential outbreak of disease. They also stated that this situation had never before occurred on the shores of the bay.

4.1.2 Data Regarding the Fish.

Regarding the species involved, it was determined through information from local residents (mostly fishermen), as well as through direct observation and subsequent taxonomic classification, that the most affected species was the Sardine (*Sardinella aurita*), followed in much smaller quantities by the Corocoro (*Haemulon plumieri*). The size was relatively uniform, with most fish being small, and the approximate quantity exceeded 1000 kg. Most of the fish found on the banks were in a state of decomposition, while those observed in the water were either dying or dead. No external abnormalities were observed in the dead specimens in the water, and those on the banks exhibited characteristics consistent with decomposition (swelling of the ventral area and a putrid odor). The fish kill was progressive. It was also observed that dead fish were present on nearby beaches such as Villa Marina, Punta Cardón, Amuay, and Los Taques, carried to the shore by the surface currents of the bay

4.1.3 Data Regarding the Body of Water

The environment where the fish kill occurred is a bay with open access to both the Caribbean Sea and the Atlantic Ocean. Its location is at 11° 42' 23.99" N latitude and 070° 12' 55.65" W longitude. The surface area is approximately 225 hectares, the bottom is sandy, and the predominant vegetation is floating.

4.1.4 Observations Regarding the Last Week

The community reported that the most noticeable change was the formation of a shiny, iridescent film on the water's surface, with a strong, characteristic diesel odor and abnormal behavior in the area's birds, which were not feeding as they normally did on the species found in the bay. They also reported the gradual appearance of dead fish, mainly sardines.

4.1.5 Climatic Data from the Days Prior to the Phenomenon

The residents of Las Piedras reported that in the days prior, there was an almost total absence of wind in the area, with completely clear skies and no rain, as well as abnormally high water and air temperatures.

Table 1. Average concentration in ppm of heavy metals in the water of Las Piedras Bay.

Date (ppm)	Date			
	CCM	30/10/2009	05/11/2009	24/11/2009
Cadmium	40	0,2667±0,0033 ^a	0,2629±0,0052 ^a	0,5677±0,0044 ^b
Copper	4,8	0,1100±0,0000 ^a	0,0943±0,0037 ^a	0,1485±0,0036 ^b
Lead	210	1,1167±0,0088 ^a	1,0571±0,0187 ^a	1,9362±0,0760 ^b
Zinc	90	0,1067±0,0328 ^a	0,0671±0,0061 ^a	0,0969±0,0072 ^b
Nickel	74	0,7067±0,0240 ^a	0,7129±0,0151 ^a	1,5577±0,0151 ^b

^{a,b} The mean metal concentrations for each sample with different superscripts are significantly different.

CCM, maximum permissible concentration for saline surface waters in ppm, according to EPA regulations (2002).

4.1.6 Human Activity Surrounding the Body of Water

At the time of the event, the Las Piedras sector had a population of 1,504 people. In some cases, due to sewage pipe collapses, waste ends up in the bay's waters. There are various industries that can affect the beach's water quality, including PDVSA, the military pier of the Naval Base, the fishing pier for the local artisanal boats, and the Las Piedras pier, where industrial trawlers have been anchored since March 2009, awaiting conversion or scrapping. There are also restaurants, inns, fish markets, and other businesses that, according to information provided by the community, occasionally discharge their waste directly into the sea. In

addition, there is constant jet skiing activity, as well as artisanal and industrial boats. The predominant construction materials are fiberglass, naval steel, and wood. There is no direct presence of agricultural, forestry, or aquaculture activity in the area.

4.2 Physicochemical Variables of the Water in Las Piedras Bay

4.2.1 Metals

Table 1 shows that the concentrations of cadmium, copper, lead, zinc, and nickel (in ppm) in the bay water sampled on days within the mortality period were below the levels specified in national (Decree 883) and international EPA (2002) standards. Specifically, the EPA values were lower than the maximum concentration limits at which the marine ecosystem is affected. However, an increase in the presence of these contaminants was observed on November 24th, although the recorded values did not exceed the levels considered hazardous.

The one-way analysis of variance shown in Table 1 demonstrates that in 2009, the metal concentrations for October 30 and November 5 differed significantly ($p < 0.05$) from the sample taken on November 24 of the same year. This could indicate that the concentrations obtained in the water on that day reflect the effects of specific events that can change over short periods. This phenomenon may be influenced by changes caused by water discharges and variations in the suspended solids load, which are ultimately deposited in the sediments through various physicochemical processes.

4.2.2 Temperature.

Table 2 shows the monthly variation in sea surface temperature (SST) from 2004 to 2009. The observed pattern coincides with that described by Arteaga (2009) for the years 1995 to 2005, characterized by low SSTs at the beginning of the year, between January and March, and the highest temperatures during September and October.

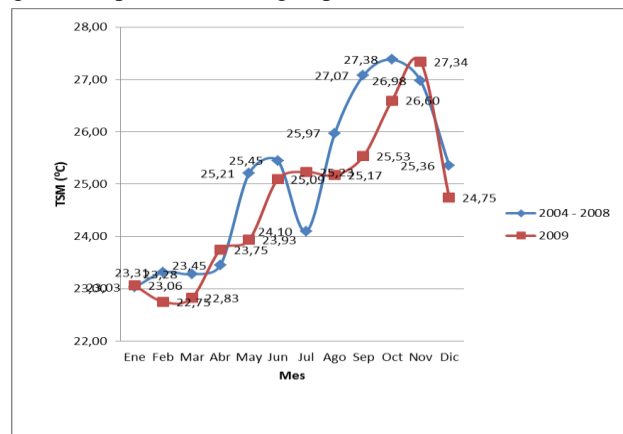


Figure 3. Variación de las medias de TSM para el promedio del periodo 2004 al 2008 comparado con el año 2009.

Table 2. Average Monthly Sea Surface Temperature (SST) in °C, per Year

Year	2004	2005	2006	2007	2008	2009
Month						
January	22,47±1,18	23,65±1,43 ^a	23,55±0,76	22,52±1,25 ^b	22,94±0,99	23,06±1,05
February	24,37±0,77 ^a	24,73±1,14 ^a	22,86±1,23 ^b	22,25±1,12 ^b	22,36±0,80 ^b	22,75±0,63 ^b
March	23,09±0,86 ^{a,c}	25,06±1,06 ^b	23,36±1,17 ^a	22,61±0,54 ^a	22,27±0,90 ^c	22,83±0,62 ^a
April	23,74±2,13	23,74±1,19	23,48±1,99	23,86±1,64 ^a	22,45±1,10 ^b	23,75±1,05 ^a
May	24,21±1,97 ^{a,c}	25,62±2,49 ^a	25,59±0,85	26,24±1,41 ^b	24,38±1,33	23,93±1,47 ^c
June	23,70±1,27	26,37±1,74	26,07±0,93	25,68±1,95	25,43±0,88	25,09±1,15
July	23,23±1,25 ^a	25,32±1,56 ^b	24,37±1,40	23,47±1,64 ^a	24,11±1,06 ^a	25,23±1,00 ^b
August	25,36±2,43 ^a	25,45±2,17 ^a	24,97±1,01 ^a	28,02±1,32 ^b	26,05±1,88 ^a	25,17±0,78 ^a
September	27,02±2,00 ^{a,b,c}	26,35±1,60 ^a	26,87±1,15 ^a	27,76±1,19 ^b	29,39±1,27 ^d	26,00±1,19 ^c
October	27,55±1,79	28,55±0,77 ^a	27,83±1,00 ^a	28,53±1,05 ^a	28,27±1,46 ^a	26,60±1,20 ^b
November	26,05±1,38 ^a	26,87±1,74	27,23±1,12	27,56±1,21 ^b	27,18±1,21	27,34±1,20 ^b
December	24,80±1,16 ^a	25,17±1,56	25,72±1,17	25,16±1,64	25,94±0,75 ^b	24,75±1,08 ^a

^{a,b,c} The average monthly temperatures for each year with different superscripts are significantly different ($p < 0.05$).

Figure 3 shows an increasing trend in SST averages from 2004 to 2008, from January to October. This contrasts with the monthly averages for 2009, where the increasing trend begins in February and ends in November. This observation is corroborated in Table 2 by the analysis of variance, which demonstrated significant differences in monthly sea surface temperatures (SSTs) for the years 2004 to 2008 compared to 2009. The analysis showed that 2009 differed from the other years primarily in the month of October, while the other months did not show significant differences. This suggests that the increase in temperature is one of the possible variables involved in the mortality of *Sardinella aurita*.

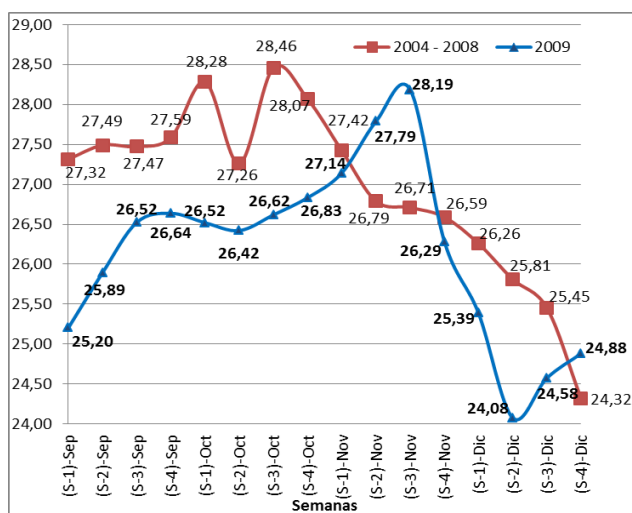


Figure 4. Average weekly variation of the SST during the months of September to December in the years 2004 – 2008 and 2009.

In order to observe the behavior of the SST in detail, Figure 4 shows the average weekly variation of the temperature, during the months of September to November for the years 2004 to 2008 in contrast to 2009. It can be seen that in the latter, there is a completely different behavior to the average of the years 2004 to 2008, showing a tendency to increase the temperature from the fourth week of October, when according to the behavior of the years 2004 to 2008 the temperature should have decreased.

During the last weeks of October 2009, significant daily temperature variations were observed, as shown in Figure 5, with differences of up to 3°C on some days. This abnormal temperature behavior coincided with the beginning of the die-off of species in Las Piedras Bay, as reported by local residents.

The prolonged period of high temperatures in 2009 is

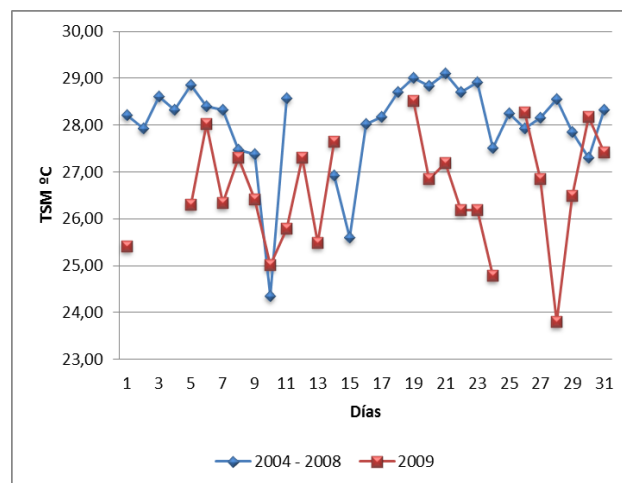


Figure 5. Daily variation of the SST during the month of October of the years 2004 – 2008 and 2009.

Table 3. ANOVA of Average Fortnightly Temperatures in °C for the Month of October from the Years 2004 to 2009.

Year Fortnight	2004	2005	2006	2007	2008	2009
1st	27,02±2,35	28,73±0,51	27,59±0,66	28,51±1,31	28,19±2,38	26,46±1,05
2nd	28,09±0,94 ^a	28,09±0,94 ^a	28,49±0,61 ^a	28,01±1,18 ^a	28,55±0,59 ^a	26,73±0,40 ^b

The average fortnightly temperatures for each year with different superscripts (a,b,c) are significantly different .

related to the El Niño phenomenon detected by NOAA (2009), which reported abnormal temperature increases in the tropical Atlantic Ocean starting in October of that year, along with a decrease in winds and convection currents. These conditions hindered the mixing processes that promote primary productivity and, consequently, the production and dissolution of oxygen in the water, which could be fatal for the species found there.

On the other hand, Gonzales et al. (2007) report a negative correlation between sea surface temperature (SST) and the distribution of *Sardinella aurita*, implying that this species is severely affected by increased temperatures. Similarly, Hernández (2009) states that sardines are organisms that are stressed by temperature changes; specifically, the

average temperatures for the years 2004 to 2009. The results showed significant differences ($p < 0.05$) in sea surface temperatures (SSTs) for the last two weeks of October from 2004 to 2009. Duncan's post-hoc test and Tukey's HSD test for the bi-weekly averages showed that 2009 differed from the other years only in the last weeks of the month, while the other weeks showed no significant discrepancies. This supports the hypothesis that temperature variation may have contributed to the mortality.

However, in Figure 5 we can also observe that for the average of the years 2004 to 2008, temperatures were higher than those reported in 2009, without any species mortality occurring, which is indicative that although the variation of the SST affected the species, it could not by itself generate the phenomenon, so it is inferred that other factors could also have influenced as possible causes of the mortality.

4.3 Meteorological Variables

4.3.1 Wind Direction and Speed

Table 4 shows the analysis of variance for wind speed from 2004 to 2009. This analysis demonstrated significant differences ($p < 0.05$) in wind speed between these years.

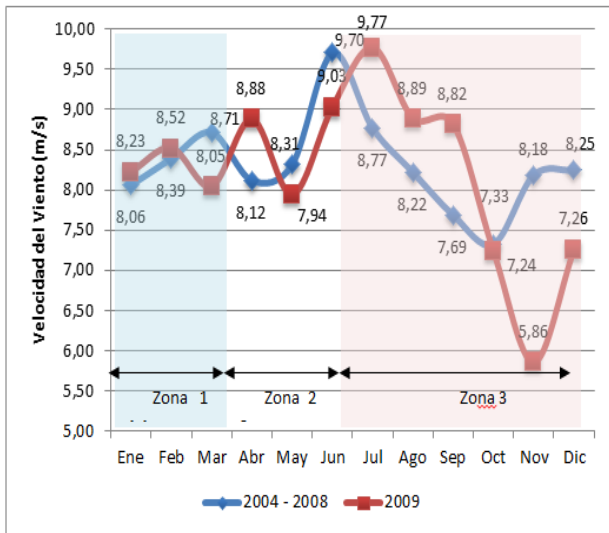


Figure 6. Monthly variation of wind speed for the years 2004–2008 and 2009.

species *Sardinops sagax* exhibits a thermal preference in the range of 17°C to 20°C with a maximum critical temperature of 26°C to 32°C. The same author obtained mortality rates of 40% for temperature increases from 18°C to 23°C, and also noted that at a constant temperature between 15°C and 27°C, mortality exceeded 70% at the highest temperature.

Table 3 below presents the results of the one-way analysis of variance (ANOVA) applied to the bi-weekly av-

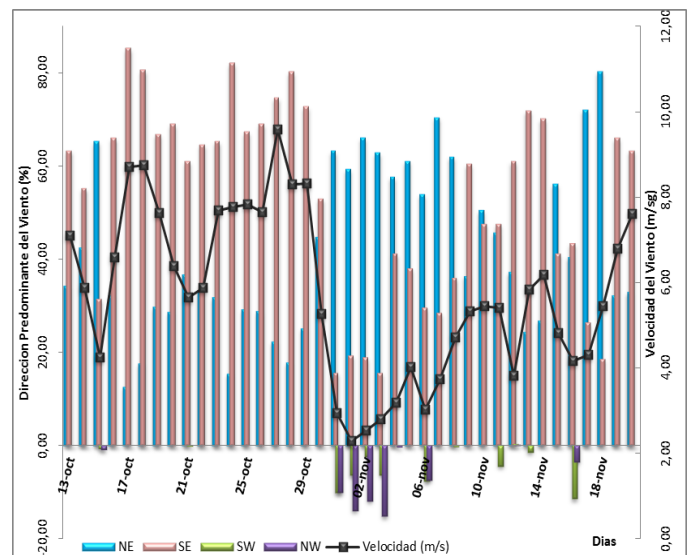


Figure 7. Wind speed and direction from the second half of October to the first half of November

Duncan's post-hoc test and Tukey's HSD test for monthly averages showed that wind speed in 2009 differed significantly from the other years in November, while the other months showed no significant differences.

and October (7.69 m/s and 7.33 m/s respectively). In the figure, three zones are also distinguished in which the average speed of the years 2004-2008 increases to a maximum point and then decreases.

Table 4. Monthly Average Wind Speed in m/s for the Years 2004 to 2009.

Month	Year	2004	2005	2006	2007	2008	2009
January		8,12±1,55	7,88±2,00	7,62±1,79	8,53±1,40	8,19±1,71	8,10±1,82
February		8,64±1,44	8,49±1,40	8,39±1,06	8,00±2,17	8,45±2,11	8,52±1,89
March		8,94±1,99	9,00±1,89	8,65±1,26	8,64±1,43	8,23±1,37	8,04±1,40
April		8,26±2,46	8,44±2,81	7,60±2,42	8,04±1,91	8,27±2,18	8,88±1,68
May		8,52±2,33	7,77±2,38	8,17±2,14	8,13±1,78	9,00±1,60	7,94±2,24
June		10,54±1,27 ^a	8,37±2,47 ^b	9,55±1,85	10,44±1,83 ^{a,c}	9,63±1,14	9,03±1,82 ^{b,c}
July		8,71±1,69	8,41±2,35	9,46±2,41	8,58±2,04	8,64±1,80	9,76±1,37
August		9,49±2,09 ^a	7,88±2,01	8,41±1,78 ^a	8,62±2,24 ^a	6,53±2,62 ^b	8,89±1,80 ^a
September		6,56±2,26	8,01±2,30	8,18±2,14	8,21±2,66	7,48±2,78	8,62±1,50
October		7,31±1,81	6,59±2,58	8,49±3,24	6,43±2,29	7,91±3,00	7,24±1,58
November		8,18±2,41 ^a	7,90±2,57 ^a	8,31±1,17 ^a	8,91±2,02 ^a	7,65±1,51 ^a	5,86±2,21 ^b
December		7,33±1,65 ^a	8,83±1,93 ^{b,c}	9,28±1,53 ^b	7,90±1,74 ^{a,c}	7,90±1,28 ^{a,c}	7,26±1,37 ^a

The average wind speeds for each year with different superscripts (a,b,c) are significantly different.

Figure 6 illustrates the average wind speed behavior from 2004 to 2008. For most of the year, wind speeds were above 8 m/s, while the lowest speeds occurred in September

In 2009, a delay in the wind speed curve was observed, with peak wind speeds occurring in months later than the historical average for 2004-2008. Specifically, in November, the wind should have reached higher speeds, but instead, it continued to decrease. This abnormal wind speed behavior coincided with the days of highest mortality among species in Las Piedras Bay, as reported by local residents. Regarding wind direction in the area, it is noteworthy that, for most of the year, winds predominantly come from the southeast and northeast, according to historical data provided by the "Dirección de Hidrografía y Navegación, Estación Meteorológica Punto Fijo".

Figure 7 shows the wind speed and direction patterns during October and November 2009. A key observation is that wind speed coincides with the prevailing southeasterly wind direction, and it is noted that when the frequency of this direction decreases, so does the wind speed. This figure also illustrates the sharp decrease in wind speed on October 13-15, October 18-21, and October 27-November 1. During these periods, the frequency of northwesterly winds increased relative to the frequency of southeasterly winds, and there was an atypical presence of winds from the northwest and southwest.

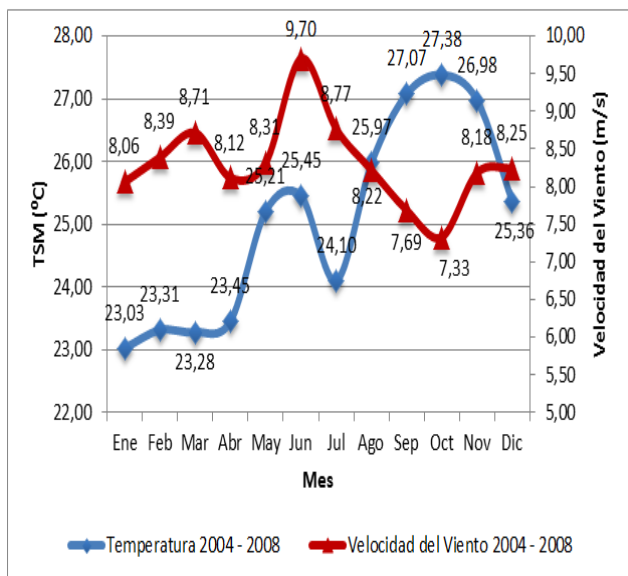


Figure 8. Average monthly variation of SST and wind speed between the years 2004 – 2008.

This behavior again coincides with the period during which species mortality was observed in the bay. According to Pomares et al. (2004), these decreases in wind speed and changes in wind direction bring about changes in the dynamics of water currents, since these are a function of the tangential stress of the wind and the action of the tides, leading to negative consequences for the organisms that inhabit them.

Figure 8 shows the average monthly variation of sea surface temperature (SST) and wind speed between 2004 and 2008, in which it can be observed that these variables have an inversely proportional relationship: while the wind speed tends to decrease until reaching a minimum in October, the SST increases to a maximum in the same month.

Figure 9 shows the average monthly variation of sea surface temperature (SST) and wind speed for 2009. This figure shows a similar pattern to that of 2004-2008, but unlike those years, November saw the lowest wind speed and the highest SST.

According to Quintero and Terejova (2008), these changes tend to decrease the amount of water flowing out of the bay, even leading to calm conditions. This, combined

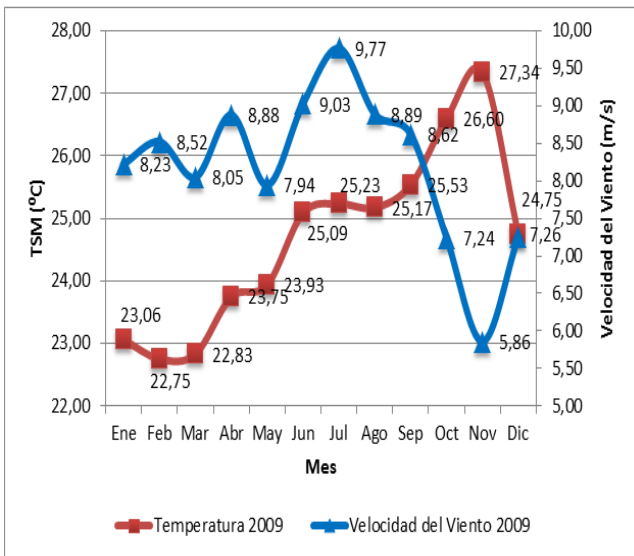



Figure 9. Average monthly variation of SST and wind speed for the year 2009.

with high SST, results in stratification of the water column, with a corresponding impact on the primary productivity of ecosystems and a decrease in oxygen levels. This is similar to what was reported by NOAA (2009) for the Central Pacific Ocean, where temperature anomalies of +1 to +5 °C were observed at the end of October 2009, as well as changes in wind direction, indicating a strengthening of the El Niño phenomenon.

The conditions observed from October 15, 2009, through the first week of November suggest increased thermal stratification (thermocline depression) in the water masses of Las Piedras Bay. This was caused by atmospheric

disturbances, possibly due to the El Niño phenomenon in the Pacific, which led to lower wind speeds and changes in wind direction. The thermocline separates the water body into two distinct layers based on their physical properties: an upper layer with low density due to high temperatures resulting from solar radiation on the water's surface, and a

Universidad Nacional Experimental
Francisco de Miranda
Area de Tecnología
Departamento de Ciencias Pesqueras



Fecha: 30/10/09	Procedencia: Sector Las Piedras, Municipio Carrubana
Especies: Se evaluaron 15 peces pertenecientes a la familia Clupeidae (Sardinias) y familia Haemulidae (Coro coro)	
Edad:	Sexo:
Largo: 12-16 cm	Peso: -
Hallazgos de Necropsia:	
Sistema Sensorial: Piel, aletas, ojos sin lesiones aparentes, ausencia de olor anormal	
Sistema Respiratorio: Branquias y apérculos sin lesiones aparentes	
Sistema Digestivo: Vacío, sin lesiones aparentes	
Sistema Musculo Esquelético: especímenes con flacidez y sin rigidez o curvaturas anormales del sistema esquelético	
Sistema Nervioso: Cerebro intacto y sin lesiones aparentes	


Protocolo de Necropsia en especímenes acuáticos

Nota: Considerando la ausencia de aspectos macroscópicos o hallazgos significativos que pudieran indicar sospechas de patologías, se sugiere evaluar otros factores que sean indicativos de efectos ambientales (Agua, pH, Concentraciones de oxígeno, disponibilidad de alimentos, xenobioticos o metales, entre otros)

Atte.

Responsables de la evaluación macroscópica

Ing. Jorge Jurado



M.V. Carmen Medina

Figure 10. Necropsy of species belonging to the Clupeidae family

deeper layer with greater density due to lower temperatures. This condition prevents the upper and lower layers from mixing, negatively impacting the species inhabiting these ecosystems.

When the depth of the thermocline increases, there is a decrease in the transfer of heat and oxygen from surface to deep waters. Similarly, the transport of nutrients from deep to surface waters is impeded, affecting primary productivity. Consequently, organisms at higher trophic levels (phytoplankton and zooplankton) are affected in their survival, reproduction, and distribution, causing marine organisms to die or fail to reproduce due to lack of food (Snet, 2010; Trasviña et al., 2009).

According to Freón and Mendoza (1998), the species *Sardinella aurita*, with its omnivorous diet preferring zooplankton, filter-feeding habits, low selectivity, and predominantly opportunistic nature, is affected by a decrease in zooplankton volume. This is corroborated by the results of the necropsy of the *Sardinella aurita* species collected in the bay of Las Piedras at the time of mortality (figure 10), which showed no stomach contents, this being an indication of a feeding deficit.

4.4 Physicochemical Parameters Measured in the Waters of Las Piedras Bay.

Table 5 shows the average values obtained from the surface physicochemical variables measured in Las Piedras Bay. These values were taken on November 5, 2009, in the afternoon (between 2:00 pm and 3:00 pm) and at midnight (between 11:00 pm and 12:00 am) when marine life was still observed in the bay. It is important to note the decrease in oxygen levels that occurred that day, dropping from 6.04 mg/L in the afternoon to 2.87 mg/L at night. According to Freon and Mendoza (2003), the vertical distribution of temperature and dissolved oxygen shows greater stratification and critical decreases in oxygen in the deep layers of water

(%), and Freon and Mendoza (2003) (37 %).

It is important to note that although the temperature values found during the sampling on November 5th coincide with those reported by other authors, they are slightly above the maximum temperature values to which the *Sardinella aurita* is acclimatized, as reported by Freon and Mendoza (2003) (28°C), who studied the physicochemical characteristics of the *Sardinella aurita* habitat in eastern Venezuela, indicating that the temperature to which they are acclimatized has a minimum during the first quarter of the year, varying between 25°C and 26°C, and a maximum between September and October of 27°C and 28°C, a period during which they begin to migrate to western Venezuela.

The average total nitrogen concentration was 120.96 ± 32.77 µg/L (see Table 7), exceeding the values considered safe by the EPA (2002). High nitrogen concentrations in the water result in critically low oxygen levels due to the decomposition of organic matter by bacteria (EPA, 1997). Regarding total hydrocarbons and oils and greases measured on November 5, 2009, the values obtained were 8.4 and 8.3 ppm, respectively. These values are below the permissible levels established by Venezuelan regulations (Decree 883) and are not indicative of species mortality. The analysis of

Table 5. Physicochemical Parameter Values in Water Samples Taken from Las Piedras Bay

Variable	05/11/2009		24/11/2009	
	Afternoon	Night	Afternoon	Night
Temperature (°C)	28,94 ± 0,46	27,58 ± 0,46	27,44 ± 0,25	-
Salinity (‰)	39,42 ± 0,46	39,40 ± 0,05	39,56 ± 0,07	-
Oxygen (mg/L)	6,04 ± 0,27	2,87 ± 0,09	4,00 ± 0,32	-
pH	8,30 ± 0,05	8,31 ± 0,03	8,33 ± 0,00	-
Total Nitrogen (µg/L)	120,96 ± 32,77	-	-	-
Oils and Fats	8,3	-	-	-
Total Hydrocarbons	8,4	-	-	-

in the month of October, with concentrations lower than 3mg/l from 50 meters, which is an indication that the month of October can become critical for the sardine if the environmental conditions alter the critical limits.

A subsequent sampling was carried out on November 24, 2009, when conditions had apparently returned to normal, as no dead or dying species were observed. The temperature, pH, and oxygen values taken on the afternoons of November 5 and 24, 2009, were found to coincide with those reported by Chirinos (2002) and Pomares et al. (2004). Average salinity values of 39.42 ± 0.46 ‰ and 39.56 ± 0.07 ‰ were observed, higher than those reported by Chirinos (2002) (31.82 ‰), Pomares et al. (2004) (34.39

variance showed significant differences ($p < 0.05$) in oxygen concentration and temperature between the day and night of the November 5 sampling. Salinity and pH did not show significant differences.

The distribution of dissolved oxygen in the water column is characterized by a saturated surface layer in equilibrium with the atmosphere. Oxygen production by photosynthetic organisms during the day causes supersaturation above the thermocline. The greatest oxygen unsaturations are found below the thermocline. The reasons for this are strong density stratification, which inhibits vertical mixing between the surface and subsurface layers, isolating the latter from atmospheric oxygen and even from the oxygen

produced in the surface layers during the day (SHOA, 2007). Conversely, the amount of particulate organic matter in the thermocline zone is greater than in the deeper zone, so the demand for dissolved oxygen for its decomposition is greater. This becomes critical at night, when photosynthesis ceases and plant respiration begins, which can dramatically lower oxygen levels to hypoxic or anoxic concentrations.

Table 6. Average annual chlorophyll concentrations from 2004 to 2009.

Year	Chlorophyll mg/m ³
2004	0,65±0,41a
2005	0,48±0,27a
2006	0,72±0,52a
2007	1,62±1,88b
2008	0,68±0,62a
2009	0,68±0,50a

a,b,c The average chlorophyll values for each year with different superscripts are significantly different.

The conditions described above, along with high SSTs, increase the likelihood of stress in most aquatic species, which are unable to regulate their temperature to tolerate changes in the water (poikilotherms). This, in turn, leads to an increase in metabolism and, consequently, a greater demand for oxygen. If this demand is not met by the environmental conditions, it can trigger mortality, especially in species that move in schools, such as *Sardinella aurita* (Wheaton, 1982). This coincides with what was described

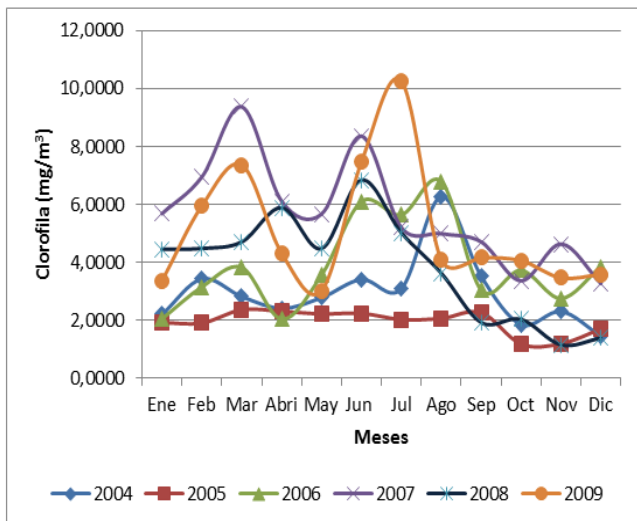


Figure 11. Variation in chlorophyll concentration during the years 2004 to 2009.

by the inhabitants of the community, who stated that the species began to die from approximately 3 a.m. onwards,

and then throughout the rest of the morning they gradually accumulated on the shores of the bay.

4.5 Biological Variables

4.5.1 Chlorophyll

Analysis of variance using one-way ANOVA showed significant differences ($p < 0.05$) in chlorophyll levels between 2004 and 2009, as shown in Table 6. Duncan's post-hoc test and Tukey's HSD test for the annual averages showed that 2009 belongs to the homogeneous group containing all years except 2007. 2009 showed no relevant differences compared to 2004-2006 and 2008.

Figure 11 shows the variation in chlorophyll concentration from 2004 to 2009. It can be observed that the months with the highest chlorophyll concentrations are March, June, and August, while the months with the lowest concentrations correspond to the last quarter of the year, with a marked downward trend after the month of highest concentration. This suggests that, due to the relationship between chlorophyll levels and oxygen levels, there is a tendency for oxygen levels to decrease after June. This, combined with the previously described temperature increase, would result in lower amounts of oxygen available to the species during the last quarter of the year.

5 Conclusions

The most probable cause of death of *S. aurita* was the oxygen deficits during the night, as a consequence of a possible stratification of water masses due to the decrease in wind speed and changes in its direction. That could have been caused by the presence of the "El Niño" phenomenon; ruling out the influence of mortality due to heavy metals, hydrocarbons or their derivatives.

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