

PRODUCTIVITY INDICATORS

SUMMARY

Currently, the scientific debate, public and academic world is facing climate change and human activities, their impacts on the natural resources of the planet and their trend for the coming decades. Despite existing controversies on the subject, it is clear that these impacts are manifesting in different regions but with different intensities. Oceans and biotic and environmental components do not escape the influence of this global phenomenon, especially those regions of high biological production.

The Large Marine Ecosystem Humboldt Current (HCLME) extends along the coast of Peru and Chile (4° - 40° S), and comprises a complex system of streams that support some of the world's most productive fisheries whose relatively constant winds along the coast that blow Ecuador produce strong coastal upwelling zones characterized by high productivity and food chains relatively short, allowing massive energy transfer to higher trophic levels.

In recent years, the LME of the Humboldt Current (HCLME) and particularly the northern component against Peru, has been a natural setting for several studies and of great interest to many scientists from various countries of the world due to its unique and their paradigms: 1) one of the highest productivity, 2) one of the most shallow, acidic intense OMZ, 3) one of the areas of intense loss of nitrogen and 4) with stronger interannual variability associated with the Equatorial remote forcing (Graco et al. 2010).

In normal HCLME environmental variability is manifested by multiple scales of time and space, which alternates positive or negative impacts on the marine ecosystem and economic activities. Additionally, in this large ecosystem develop a series of activities that have impacts on it, eg, agriculture, oil exploitation, industry and mining, industrial fishing, fishing, tourism and sports, shipping, coastal development and domestic effluents.

In this sense, the project "Towards an Ecosystem Approach to Management of Large Marine Ecosystem of the Humboldt Current (2011-2016)" as an activity of the United Nations Program for Development (UNDP) and funding from the Global Environmental Facility (GEF), aims to ensure the sustainability of resources, species that goods and services produced in harmony with the interest groups and economic activities that depend on those. For this, the national focal points of this project straddling, multisectoral and multidisciplinary are the Instituto del Mar del Peru (IMARPE) and Instituto de Fomento

Pesquero in Chile, that will increase the monitoring and training of stakeholders developed decisions participatory mechanisms in marine and coastal management, management of artisanal fisheries, tourism, shipping, effluent control, etc..

As for the priority problems related to productivity indicators, and based on the various research and publications have:

- In regional climate change, uncertainty reflects the limited knowledge of the local and regional physical processes that can amplify or dampen the effects of global warming.
- Both scenarios, cold in the south and warmer in the north, can displace coastal upwelling system off the 'optimal environmental window' that holds the huge population of anchovy, due to compression of natural habitat or the decrease in recruitment success
- Critical to the future evolution of the system is if the oxygen minimum layer will approach the surface, associated with the intensification of thermal stratification, or, on the contrary, will deepen, because of increased ventilation subsurface and reduction of breathing in the water column.
- In either of the above cases, adaptation measures are necessary for fisheries and local communities in order to reduce the vulnerability of the ecosystem and fisheries resources and coastal human populations
- There is little knowledge about benthic-pelagic coupling and the role of meroplankton, especially in the area near the coast.
- The taxonomy of zooplankton off Peru is in its infancy and there is a strong need to combine morphological and genetic studies.
- Little is known about the ecology of many species, so it requires a greater understanding of the life cycles of zooplankton.
- Difficulties in sampling euphausiids (much of zooplankton biomass) and gelatinous species.
- Requires macrozooplankton implement monitoring assessments gelatinous commercial pelagic resources.
- Little is known of the role of microzooplankton (<200 μm) and microbial chain.
- Only biovolúmenes data are not sufficient to understand regime change and its consequences for higher trophic levels.
- It requires greater application of models for zooplankton

Furthermore, photosynthetic activity and productivity primary limitation associated with seasonal variability light and chlorophyll, are influenced substantially by the insolation and its variability. In this regard it should be noted that the insolation shows significant seasonal variation over the area of Perú. On average, the solar flux climatological COADS (Comprehensive Ocean-Atmosphere Data Set) near the coast is highest in the austral summer (between 240 and 280 W/m²) and lowest in the southern winter (between 120 and 160 W/m²). Cycle amplitude is maximum near insolation at 15° S.

Also on the coast of Peru, there have been reductions in photosynthetic pigment concentration of about 50% during El Niño events, such as 1982-83 (Feldman et al. 1984) thus decreasing fertility of the marine ecosystem, mainly by the weakening of upwelling systems and the deepening of the thermocline, situations that reduce the supply of nutrients to the euphotic zone, causing a decrease in the biological productivity of the ocean (Barber et al. 1985). Thus, in Peru the decrease in 1997 was almost 60%, with similar numbers in 1998 (Duffy and Bryant 1998). Hence in normal periods plankton biomass near the coast is high average volumes presenting > 3.0 mL/m³, with a predominance of phytoplankton by more than 80% of all the assessment area, concentrations that decrease with increasing distance coast, seasonally the highest peaks of plankton biomass concentration with the predominance of phytoplankton recorded in spring and autumn part of the concentration of chlorophyll "a", reaches its peak in mid-summer and early autumn, decreasing in Winter, its distribution is related to local circulation processes, with concentrations ranging from 0.02 to 12.69 ug.L⁻¹.

Echevin et al. (2008) studied the seasonal variability of surface chlorophyll concentration in the Peruvian upwelling system whose results show a strong seasonality, with low values in the austral winter and high values in the austral spring and summer, in phase opposition to the upwelling intensity.

Recent research based on the analysis of the seasonal series of chlorophyll-a, indicating an upward trend throughout the series: +1 mg/m³/década, an increase in the productivity of the system in the past 40 years, with an intensification in this trend from the year 2000 (+3 mg/m³/década) (Fig. 1), pattern matching with the findings of paleoceanographic studies in the area (Gutiérrez et al. 2009) and recent satellite data also indicate a positive trend in productivity primary (Demarq, 2009; Heliman et al. 2009).

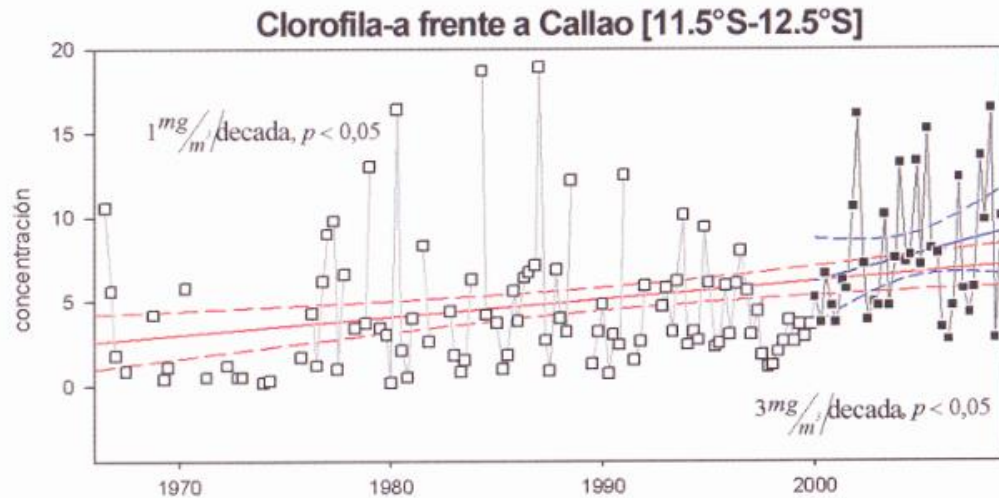


Figure 1. Trend of the seasonal averages of chlorophyll-a concentration off Callao, from 1960-2009 (red) and 2000-2008 (blue). Taken from Purca et al. (2010).

Harmful algal blooms (HABs) and designated to denote the occurrences of a heterogeneous group of organisms harmful to human health, development of aquaculture, coastal tourist areas and wild populations of marine organisms in the last two decades have shown an apparent increase in the South American coast in intensity, duration and geographical distribution (Reguera, 2002; Delgado, 2003). These events are very common in spring and summer, but in the last five years they have had longer duration and / or stay along the Peruvian coast. The strong penetration Subtropical Surface Water (SSW) to the coast associated with abrupt changes in the speed and intensity of the winds from the southeast and the formation of fronts along the coast, would favor the generation and survival of these organisms. Between 1980 and 2001 there have been 269 cases of red tide along the Peruvian coast, from Tumbes and Ilo. 82% of these episodes were observed in the northern and central Peruvian coast, and 18% in the southern region.

Pseudonitzschia spp. is a diatom, producer of the biotoxin called domoic acid, that has shown an alarming increase in its occurrence along the California coast during the mid-90s, after a regime change in temperature of water in the North Pacific Ocean (Bejarano et al. 2008). Elsewhere has caused the death of fish, birds and marine mammals in 1997 in Chile and 2000 in Argentina was reported unusual mortality of seabirds and content analysis petrel stomachs and intestines, Magellanic penguins and cormorants and anchovy same region recorded the presence of domoic acid at low levels, but were higher in the viscera of anchovies.

The HCLME is characterized by a high climatic variability mainly due to the influence of ENSO events and La Niña, which largely determine oceanographic dynamics, changes in the spatial distribution of water masses and biogeochemical processes turn key to the ecosystem, such as primary production. However, which is currently being discussed are the likely impacts of global climate change will have on the oceans and their resources.

The current system of Humboldt (SCH) against Peru is characterized by based on the salinity and temperature, four bodies of surface water and subsurface water mass between the coast and varying distances from it (Morón, 2000): Surface Tropical Waters (STW), Surface Equatorial Water (SEW), Cold Coastal Waters (CCW), Subtropical Surface Water (SSW), the Sub-Antarctic Temperate Waters (SATW).

The marine environment off the coast of Peru is affected considerably by the presence of El Niño and La Niña lesser extent, yet notable addition to temperature changes, salinity and other parameters which show very significant changes in the area affected (Morón, 2011).

Morón (2011) to analyze the time series latitudinal (3° - 19° S) of the monthly averages of sea surface salinity for the coastal (0-60 nm) during the period 1960 to 2008 shows that there is variability spatiotemporal different water masses off Peru: STW (<34.0 psu), SEW (34.0 - 34.8 psu), SSW (<35.1 psu) and CCW (34.8 - 35.0 psu), noting that in the 60 decadalmente there was a predominance of relatively low salinities (about 35 psu), in the 70's trend with mid-80s a predominance of the ASS, in the mid-80s and even before the 1997-98 El Niño, one SSM values intermediate values between CCW and SSW. After El Niño 1997-98 and until 2008, associated with moderate salinities show a predominance CCW on SSW on the coastal side.

The Peruvian marine circulation is very complex as it is composed of surface and subsurface currents, whose knowledge is based largely on geostrophic calculations based on hydrographic data collected over many years. The surface current system to the Ecuador is composed of the Peruvian Coastal Current (PCC) and the Peru Oceanic Current (COP), which carry sub-Antarctic waters of origin, both streams are the Peruvian Current. Among the currents flowing past a counter, the Peruvian Current Subsurface (PCSS) or Peru-Chile Subsurface current with speeds greater than 20 cm/s off Punta Falsa, weakening in their advance southward.

On the other hand, the equatorial current system whose streams have flows poleward under the surface layers in Peru and northern Chile and up to 100 nautical miles off the coast of Peru, is constituted by the Equatorial Undercurrent (CSE) or Cromwell Current which is fractionated in the Galapagos Islands. A branch heads north to 3° - 6° N and southward SSC divides into two branches: one coastal and one offshore near 84° W, both branches are weakened south. The coastal branch has a maximum surface at 4° S and subsurface maximum at 6° S, being called South Extension Cromwell Current (ESCC). Guevara and Wosnitza-Mendo (2009), based on the depth of the 15 ° C isotherm ESCC indicator indicates the existence of three periods between 1970 and 2005. Thus, in the 80's would have been more encouraging deeper background oxygenation, from the late 80s and early 90s would have become shallower (Fig. 2).

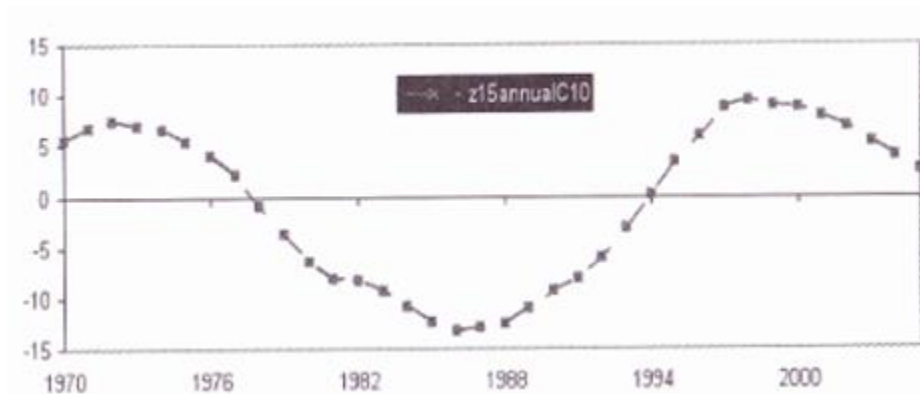


Figure 2. Isotherm depth of 15° C. Years 1970 - 2000 (From Guevara and Wosnitza-Mendo, 2009).

Regarding the Equatorial Current System (SCE) recently Montes et al. (2010) indicates that of the three equatorial subsurface currents eastward (Equatorial counter current EUC or Cromwell; Southern Subsurface Countercurrent primary or primary jet Tsuchiya, pSSCC; Southern Subsurface Countercurrent secondary or secondary jet Tsuchiya, sSSCC) water most contributes to the EUC flows westward, including the CSE and deeper flows under it, and surprisingly only a very small fraction fed to the Peruvian Countercurrent - Chilean (PCUC), while a significant part of both SSCs contribute substantially. Additionally, about 30% of the PCUC is fed by three streams equatorial subsurface (EUC, pSSCC, sSSCC). The remaining part comes from a

recirculation PCUC along the coast associated with flows below it, forming the southern part of the domain (south of $\sim 9^\circ$ S).

The northern component HCLME, against Peru, is characterized by cold-water upwelling rich in nutrients that promote high primary production, with intense upwelling cells which are located along the coast. However, the average level of primary productivity is estimated as moderate ($150\text{-}300 \text{ gCm}^{-2}\text{y}^{-1}$) Class II.

Upwelling zones in Peru, are those in which upwelled waters may come from depths less than 120 m range between 14 and 17° C, and 34.85 to 35.00 psu; dissolved oxygen between 2.0 - 4.0 mL/L, phosphate from 1.0 to 2.5 ug-at/L and silicates <2.0 to >30 ug-at/L (Morón, 2000).

The principal and permanent upwelling zone, and with greater intensity is between $14\text{-}15^\circ$ S (Independence Bay - San Juan), other important areas are located between $5\text{-}6^\circ$ S (Paita - Punta Falsa), $7\text{-}8^\circ$ S (Pimentel - Chicama) and $11\text{-}12^\circ$ S (Huacho-Callao) (Fig. 14). Upwelling can feed on different bodies of water: relatively oxygenated waters emerge ESCC north of 6° S; oxygen-deficient waters of the Peruvian Current Subsurface going outcrop poleward north of 12° S and sometimes a little further south, and the Sub-Antarctic Temperate Water mixture and feed Subsurface Equatorial Waters outcrops south of 14° S (Zuta and Guillén, 1970) (Fig. 3).

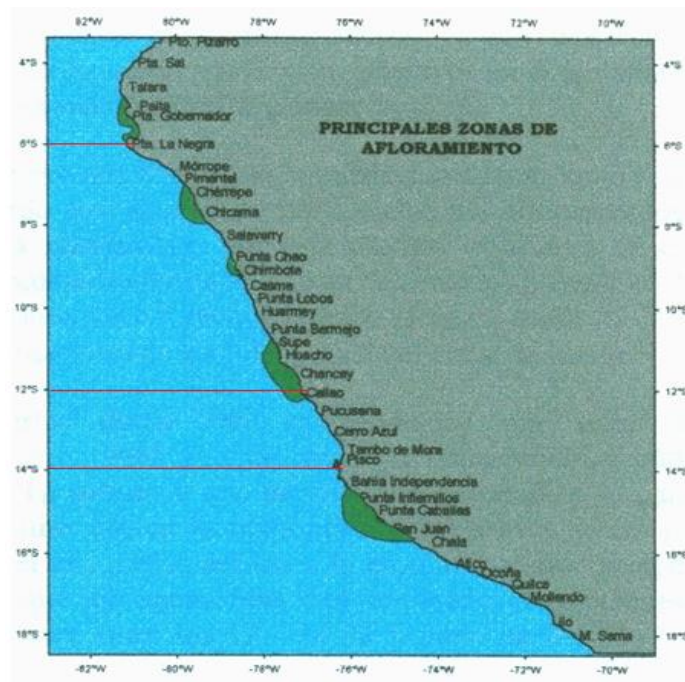


Figure 3. Main areas of upwelling in the current system of Peru Humboldt (Modified from Morón, 2000).

According to Hileman et al. (2009), the most important front in the Peruvian sea is caused by coastal upwelling induced by wind. The Peruvian upwelling front (PUF) extends along the shelf break from 5° S to 19° S. Beyond the south, the coastline abruptly changes its orientation and is not very favorable for upwelling in the wind. A new front in summer time has been described from satellite data, called the Nazca Front (NF) due to its proximity to the Cordillera de Nazca (Belkin et al. 2009; Belkin & Cornillon, 2003), which developed in March is becoming a tuna fishing area, especially yellowfin.

The high primary production off Peru is due to the wide availability of nutrients and forcing factors remain favorable throughout the year (Pocklington, 1981).

The highest concentrations of nutrients compared to Peru are located near the coast, and are the result of the contribution of water from upwelling currents transport and biogeochemical processes occurring regeneration and / or consumption of nutrients in the euphotic layer or sediment. The average surface nutrient ranges for the Peruvian coast are: 0.2 - 4.0 mM PO_4^{2-} , 0.0 - 35.0 mM NO_3^- , 0.0 - 30.0 mM SiO_2^{4+} (Zuta and Guillen, 1970, Calienes et al. 1985).

In relation to the latitudinal distribution, various authors suggest that nutrients decrease from north to south (Codispoti, 1981), and north of 15° S are recorded higher nitrate concentrations (up to 35.0 mM) and silicates (up to 30.0 mM) versus south (Guillén & Izaguirre de Rondán, 1973). This distribution is associated with different types of water body involved with the movement of the area. Phosphates and silicates with higher values (> 2.5 mM and > 20.0 mM, respectively) associated with active upwelling and lower ASS AES and northern features. Regarding the latitudinal differences in nitrate concentration, these are due to the existence of nitrate reduction processes in oxygen deficient conditions, which intensifies the south of 10° S (Ward et al. 1989).

The vertical distribution of nutrients occurs through four layers: a surface (50 m), a transition (above 100 m), one intermediate and deep. The surface layer exhibits low values and almost uniform with respect to the deeper layers, where phosphorus is always in excess. The transition layer recorded a rapid increase phosphates, whereas in the intermediate layer reaches the maximum phosphate concentration (2.5 mM) to 3.5 mM and between 500 and 1000 m. Bottom layer, the phosphate values are generally reduced,

while the silicates reach values greater than 50 μM to 110 μM ; nitrates μM reach values of 40.0 - 55.0 mM.

In relation to the temporal variability of nutrients, phosphates have high (2.0 μM) in winter and in summer lower (0.25 mM), whereas the silicate and nitrate show similar variability, the highest concentrations of silicate (25.0 μM) observed in winter and spring and lower in summer (1.0 μM) but with maximum concentrations in the south (ca. 15° S). The maximum values of nitrate (20 mM) occur in winter and the values are close to 0.0 in summer.

In general, the seasonal variability of nutrients is associated with variability in the intensity of upwelling events, maximum in winter and spring, and weaker in summer and autumn (Calienes et al. 1985). Also the El Niño/La Niña influence the distribution of nutrients, and during 1997-1998 the concentrations of nitrates, silicates and phosphates decreased significantly, particularly between the months of spring and summer with respect to the values observed during years who did not have the condition El Niño (Purca, 2005, Flores et al. 2006; Graco et al. 2006). Decadal changes are expected to also affect the distribution and concentration of nutrients, however has not yet explored this type of variability, being necessary to the retrospective analysis of the historical information in the region (Graco et al. 2010).

You should consider the thermal history of the GEM is structured in the ENSO, where the northern part of the GEM is strongly impacted by El Niño and La Niña, while the south is not directly impacted by these events (Heileman et al. 2009). This panorama is associated with environmental changes that reflect the high variability to which it is subjected Humboldt System, one of the most productive environments. Among the highlights environmental change short-term or seasonal (summer - winter), medium-term or interannual (El Niño - La Niña), long-term or decadal (warm periods - cold periods) and very long-term or secular (heating - cooling globe), however, it is evident that there is a physical variable associated with atmospheric or oceanic forcing large scale (ie multidecadal).

In this context, Chavez et al. (2003) have pointed out that in the Pacific Ocean, the temperatures of the air and ocean, atmospheric CO_2 , landings of anchovies and sardines, and the productivity of coastal and open ocean have changed over periods of about 50 years , called "biological changes in regime", where fluctuations of sardine and anchovy

are associated with large-scale changes in ocean temperatures, for 25 years, the Pacific is warmer than average (the warm, the regime of the sardine) and then changes to colder than average for the next 25 years (the cold, anchovy regime). Instrumental data provide evidence for two complete cycles: cool phases from 1900-1925 and 1950-1975 and warm phases from 1925-1950 and 1975 to the mid-90s.

In reference to climate change for the oceanic domain, Sherman and Mc Govern (2011) and Heliman et al. (2009) indicate that for the period 1982 to 2006 the SST in 61 of the 64 GEMs increase followed a warming trend, indicating that despite global warming, the surface temperature in the HCLME experienced a cooling 1°C between 1957 - 1973 followed by a long heating decade culminating in 1983. Mostly, the linear trend over 1982-2006 produces a slight cooling of -0.10°C . with variations in primary and secondary productivity is moderate to high (Fig. 4).

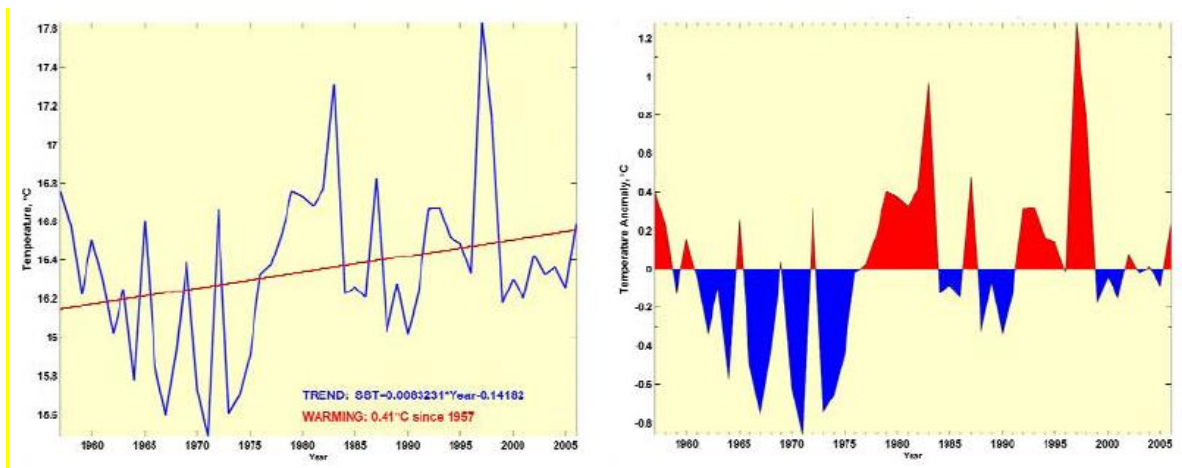


Figure 4. Average annual SST (left) of HCLME and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

This cooling over the past 25 years, probably due to an increase in the intensity of upwelling caused by force or persistent upwelling favorable winds that lead to high chlorophyll and primary productivity, although Pennington et al. (2006) found significant variations in the monthly values of chlorophyll and primary production of the sub-systems of the Humboldt Current.

In parallel, the SST time series available suggest a decrease in sea surface temperature from the central coast of Peru to northern Chile, and a positive trend in primary productivity near the coast (Gutierrez et al. 2011) (Fig. 5).

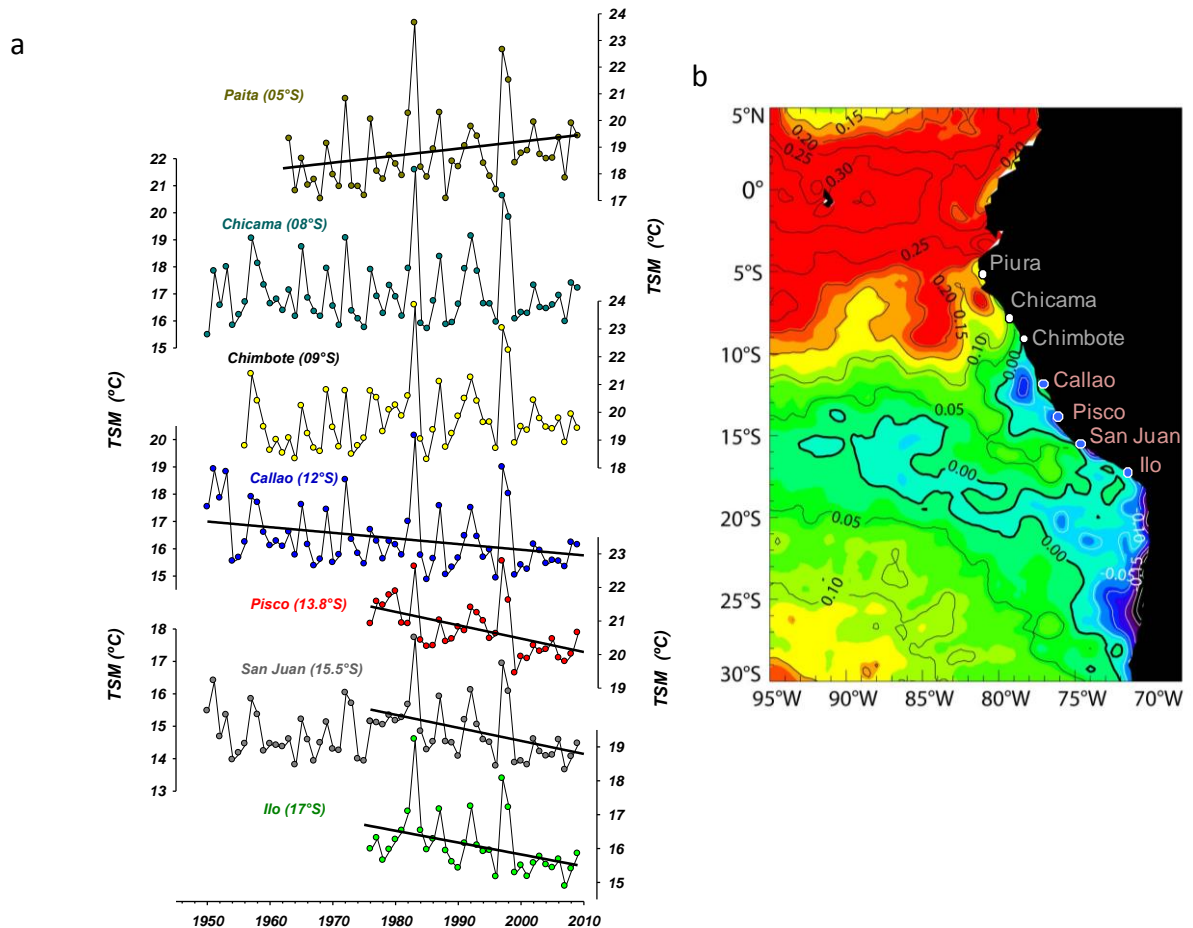


Figure 5. a) Time series of annual mean SST (1950 - 2009) for coastal stations (springs) along the coast: Piura, Chicama, Chimbote, Callao, Pisco, Ilo (source: IMARPE) and San Juan (source: DHN). b) SST anomalies during the period 1/01/1984- 31/05/2010 for the region (Gutierrez et al. 2011).

In this context, the Peruvian coastal domain, there are two possible scenarios in debate: the first posits an intensification of coastal upwelling due to interactions Earth/atmosphere/ocean, while the second displays a weakening of coastal upwelling associated with the weakening of the trade winds and the Walker Circulation. However, considering the interdecadal variability and / or the inertia of current trends, the first scenario (coastal cooling) seems to be more likely in the next decade, while the warming scenario most likely will take longer. Both scenarios can displace coastal upwelling system off the

'optimal environmental window' that holds the huge population of anchovy, due to compression of the wild or the decrease in recruitment success. In fact, in the Peruvian upwelling area, Ekman transport (TE) decreased during the period 1976 to 1999, but expanded during the period from 2000 to 2008, especially during the period of greatest concentration of chlorophyll-a (October - November-December) (Purca et al. 2010).

While cooling the SCH has been observed during recent decades, there is still debate about potential impacts of elevated atmospheric CO₂ concentrations on the dynamics of upwelling and productivity. Recent studies suggest that under increased atmospheric CO₂ scenarios oceanic stratification may increase sharply and the winds favorable for upwelling may remain almost constant against Peru and increased off Chile (Brochier et al. 2013). Numerical experiments (ROMS models, PISCES, IBM) based on small-scale hydrodynamics the HCS from forced simulations for three scenarios: pre-industrial (PI), 2 x CO₂ and 4 x CO₂, the three scenarios used in this study reproduced the main features of the circulation of the HCS commonly observed. Coastal upwelling was observed in all three scenarios as shown by the favorable wind forcing upwelling and relatively cool SSTs along the coast of Peru and Chile, while in the SCHS, temperatures were cooler, with median values 13° C, 15° C and 17.5° C for P1, 2 x 4 x CO₂ and CO₂.

The oxygen minimum zone (OMZ) is an area of the ocean that is distributed at intermediate depths, mostly between 50 and 800 m and is characterized by conditions of very low oxygen or even anoxic. One of the reasons for explaining handle sustained increase seas hypoxia relates to climate change, more directly with global warming, an increase in temperature in the ocean causes a decrease in oxygen solubility so warmer waters hold less oxygen than cold seas.

Against Peru, the OMZ is identified by present dissolved oxygen concentrations (DO), between 0.0 and 0.5 ml.L⁻¹ in the water column (Graco et al. 2007), exhibiting significant fluctuations at different scales, both seasonal and annual cycle associated with El Niño and La Niña, whose signal is one of the strongest on the planet. Compared with other systems, the OMZ off Peru is well developed, much more intense and brief (Helly & Levin, 2004), showing that the oxygen-deficient layer (<0.5 ml/L) known as OMZ, is found from of 30-50 m deep intersecting the euphotic layer (Zuta and Guillén, 1970).

Variations in the OMZ thickness and depth of its upper limit in the coastal marine strip off Callao (12° S) and 20 nm, between 1999 and 2008, during the cold periods had an

influence on the upper limit of the OMZ (50 m), the summer-autumn period influence a shallow upper limit (25 m) while warm events OMZ deepen below 100 m. They say that in this season, at least, the OMZ is influenced by warm events that deepen its upper limit in any season. During the summer, a cooler in normal times, the OMZ exhibits a greater expansion, shallower recording of the upper limit of the OMZ to 25 m (Fig. 6).

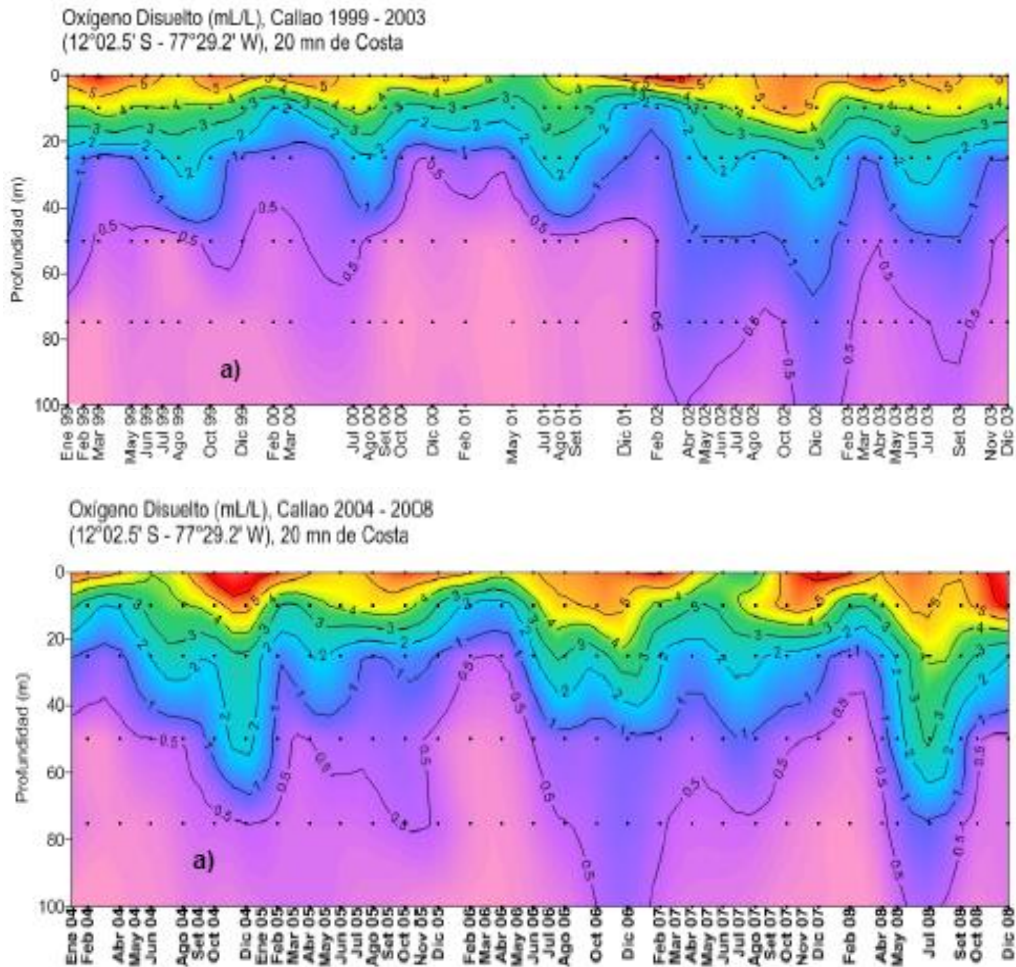


Figure 6. Diagram Hovmöller depth - time of dissolved oxygen to 20 nm offshore off Callao: 1999-2003 and 2004-2008.

On the other hand, under Puerto Pizarro (03° 35 'S) the depth of the upper boundary of the OMZ is located around 200 m, in contrast to the coastal zone (ca. 15 nm) of Punta Falsa (05° 59.99 'S) and Pisco (13° 59.91' S), where this boundary was located at 33 and 45 m, respectively. The thickness to 15 nm offshore facing Puerto Pizarro was ca. 402 m, while in Punta Falsa and Pisco were thicker ca 637 m and 555 m, respectively. An

important conclusion is that in the area close to the central coast and enclosed by the platform, the OMZ reach 700 m in thickness.

In this context, it should be noted that as the upwelling ecosystems HCLME where biological and geochemical cycles plays an important role, are very sensitive to acidification processes due to low natural pH levels associated with OMZ and having its correspondence with CO₂ Maximum Zone (ZMC) (Paulmier et al. 2011). In the SCH against Peru recently León et al. (2011) after analyzing 2007-2009 data on pH, partially dissolved CO₂, chlorophyll a, oxygen, salinity and temperature found an inverse relationship between the Cold Coastal Waters (CCW) rich in nutrients with pH, with values of 7.6 to 8.0 associated with upwelling events, while La Niña cold conditions as 2007 the predominant pH was below 8.0. ASS in case the pH values around 8.3. A spatial level, the data show great variability, as the pH was lower in the coastal zone, especially on the coast of Callao (12° S) and Pisco (14° S) with values of 7.6 to 7.9 , coincident with the nuclei of upwelling and the presence of ACF, whereas in Paita (5° S) values ranged between 7.8 and 8.2 within 50 min.

They also found a strong interannual variability, as the 2007 was characterized by La Niña conditions and intense upwelling (hence higher CO₂ content of total) with pH values up to 7.52 for the autumn, while in winter 2008, the conditions were slightly warmer than restricted the influence of coastal upwelling areas inside the 35 nm offshore.

The partially dissolved carbon dioxide (mg/L), as the CO₂ involved in the process of photosynthesis to elevated rates drops below atmospheric values (380 mg/L), as a result of CO₂ sinks areas.

It is known that primary productivity patterns in the global ocean patterns roughly follow the topography of the thermocline and nutricline, with the passage of coastal Kelvin waves trapped one of the main forces that can cause variability in these patterns. Oceanic equatorial Kelvin waves are mostly forced into the central equatorial Pacific wind shift and spread to 1-3 ms⁻¹. According to the type of wind anomalies (east or west), one can raise equatorial Kelvin wave (Upwell) or deeper (downwell) the thermocline (often tens of meters) and the height of the sea surface (cm). Bertrand et al. (2008), through bivariate correlations amplitude data analyzed oceanic Kelvin waves, SST, extension of upwelled coastal waters, spatial distribution and statistical anchovy fishing fleet from 1983 to 2006 showing that the effects of the forcing of Kelvin waves ocean are significant in all

components of the coastal ecosystem, from oceanography to the behavior of fish predators stop. This result shows evidence that from a standpoint predictivo, the amplitudes of Kelvin waves observed in the central Pacific can be used to predict the state of the system that will dominate the HCS over the next 2-6 months and so integrate adaptive management in the Peruvian fishery.

Also, Purca et al. (2010) analyzes the warm period (1976-1999) and cold (1960-1975 and 2000-2008) and observe the depth of the isotherm of 15° C and decreased chlorophyll-a during the warm period and otherwise in the cold periods. He points out that the differences between cold periods are related to decreased activity of intraseasonal equatorial Kelvin waves. In general, in the equatorial Pacific studies have shown that various time scales, the variability is dominated by oceanic Kelvin waves, while intraseasonal variability also appears modulated in the Pacific from the intraseasonal Kelvin waves, whose activity is increased from 2000.

There are processes such as mesoscale eddies or vortices exert impacts on the marine ecosystem (Chaigneau et al., 2008). These eddies are currents flowing in circular motion around the center of the vortex, which transport heat and biogeochemical properties from forming region to remote areas, have diameters of 50-100 km and persist for periods of days to months.

For the south Pacific Ocean mesoscale propagation can extend the area of high primary productivity (Chavez, 1995) through advection of phytoplankton biomass and nutrient-rich coastal waters, while in the vertical pumping swirl may be an important mechanism for subsurface water carry nutrients into the euphotic zone. It is also considered that the variability of the subsurface OMZ highly pronounced and observed in the current system of Peru - Chile could be modulated by the westward movement of mesoscale eddies. Off Peru, anticyclonic vortices tend to spread to the northwest, while the cyclonic migrate to the southwest, with slightly more intense in autumn, reaching a higher activity during El Niño 1997-98 and in 2004, probably due the passage of a coastal trapped Kelvin wave (Chaigneau et al. 2008).

In general, paleoceanography and paleoproductivity of the continental shelf off South America has received little attention and climate over the past thousand years remains little studied. In this context, SIFEDDINE et al. (2008) using the mineral content and organic and inorganic markers in cores of sediment accumulated in the OMZ rolled off

Callao ($\sim 12^\circ \text{ S}$) and Pisco ($\sim 14^\circ \text{ S}$) examined different time scales, past changes in the productivity, redox conditions and revenue clastic sediments during the last 500 years, in this case the TOC was used to infer productivity.

The results indicate that for several centuries before 1820, corresponding to the Little Ice Age (LIA), the northern Humboldt current was less productive and experienced high terrigenous input related to wetter conditions on the continent. These conditions were probably caused by a southward shift of the ITCZ and the subtropical high pressure cell during the LIA. Since 1870, increases in TOC and terrigenous mineral fluxes suggest an increased wind directed upwelling and high productivity. These conditions continued to intensify during the 20th century, according to instrumental records of wind forcing, an intensification of this trend is observed since the mid 20th century, which is probably caused by an upwelling improved.

In northern Peruvian sea ($4^\circ \text{ S} - 7.6^\circ \text{ S}$) are observed up to 12 submarine canyons that originate between 300 and 1000 m depth and having varying lengths, highlighting the five present from Punta Aguja (Sechura) until Lobos de Afuera islands.

So far it is unknown the influence and relationship they might have with the productivity of the area in the context of a bento-pelagic coupling. However, it has been postulated that a phenomenon caused by the weather and is occurring at a decadal time scale, is the formation of dense water on the shelf and subsequent cascade downslope (Company et al. 2008). In this sense, applying the findings to overall fishing scenario, waterfall sites platform identified in various parts of the world could be considered favorable regions for deep sea demersal fisheries, similarly as are areas upwelling, considered favorable regions for pelagic fisheries.

With regard to the distribution of ichthyoplankton in the Peruvian coast, particularly under normal environmental conditions it shows a well-defined distribution pattern, in which shows three main groups: the first with anchovy distributed between 06° and 18° S to 60 miles the coast, the second with high species richness and dominance without any present between $03^\circ 30'$ to $06^\circ 00' \text{ S}$, and the last located 60 miles from the coast, with mesopelagic species dominant as bioluminescent fish and some fish flashlight (Ayon and Aronés, 2002). The invasion of warm waters caused by El Niño changes the community structure of ichthyoplankton along the coast (and Aronés Ayon, 2002). Regarding the diversity of ichthyoplankton in the summer of 2001 found 104 species of fish belonging to

48 families, which highlighted Myctophidae, Engraulidae Bathylagidae, Paralichthyidae, Oneirodidae, Hemirhamphidae, Scianidae, Scomberesocidae and Serranidae. The family with the highest number of species was Myctophidae. The species that showed higher frequency and abundance was *Engraulis ringens*, followed by *Vinciguerria lucetia* (Aronés, 2004), however during the austral spring of 2001, the entire Peruvian coast found 76 species of fish belonging to 38 families, which highlighted Bathylagidae, Phosichthyidae, Myctophidae, Scomberesocidae, Engraulidae where the most frequent species was followed by *Vinciguerria lucetia* *Engraulis ringens*.

Also the SNCH, like all other major upwelling systems of the world, has huge quantities of fish that feed on plankton, suggesting that the dynamics of these populations can "drive" or "control" the dynamics of the ecosystem. However, global changes associated with interdecadal regime shift, the dominant small pelagic fish in the Pacific Basin form the general framework in which we try to understand the trends of zooplankton volumes. The spatial distribution of zooplankton volumes show high values from the coast up to 60 nautical miles (111 km) and between 4° - 6° S and between 14° - 16° S, coincident with the major upwelling areas identified by Zúñiga and Guillén in 1970 (Ayon et al. 2004)

The zooplankton bio-volume was very high until the 1970s, and then declined sharply, remaining low until the late 1980s, and then rose, but without reaching the levels seen during the 1960s.

The long-term trend of the average annual volume of zooplankton between 1964-2001, shows three different periods: the first maximum value between 1964-1973, a collapse after 1973, the second low values from 1974-1989 (although the recovery seems to start in 1985), and a third intermediate levels of biovolúmenes from 1990 to 2002 (Ayon et al. 2004).

The results suggest a strong local reduction of the volume of zooplankton (abundance), predation by anchovy in areas where anchovy abundance is high (Ayon et al. 2008). In general, knowledge of the taxonomy of the fauna (biodiversity) of zooplankton is poor if you consider the amount of research and the ecological and economic importance of the HCLME (Ayon et al. 2008). Santander cataloged three siphonophores, 31 copepods, 35 amphipods, 66 species of euphausiids and chaetognaths; Abanto (2011) presented a list of 152 copepod species from 54 genera. However, it is known that ENSO alters not only the diversity but also the abundance and distribution of mesozooplankton. An increase in

diversity is caused by the intrusion of tropical species in the central and southern Peruvian coast, the ENSO 1982/83 caused an increase in the biomass of zooplankton, particularly gelatinous species and diversity. In contrast, there was a sharp decline in meroplanktonic larvae and ichthyoplankton in coastal waters during EN.

The gelatinous macrozooplankton, generally composed of species of Cnidaria and Scyphozoa particularly, has shown in recent decades an increase in distribution and abundance in most of the world's oceans. In Peru, it is indicated that the catch of the species *Chrysaora plocamia* affects the anchovy fishery, as occurred in southern Peru during the summer of 2008 - 2009 (Quiñones et al. 2012). It has been determined that this species showed abundance peaks in summer and during El Niño and during the regime / warm-phase El Viejo.

Recently, Condon et al. (2013) has shown that the current trend indicates that populations mostly of "jellyfish" experience large global oscillations (approximately every 20 years), for the case of Peru from 1985 has not seen any change in the abundance of these species (Fig. 7).

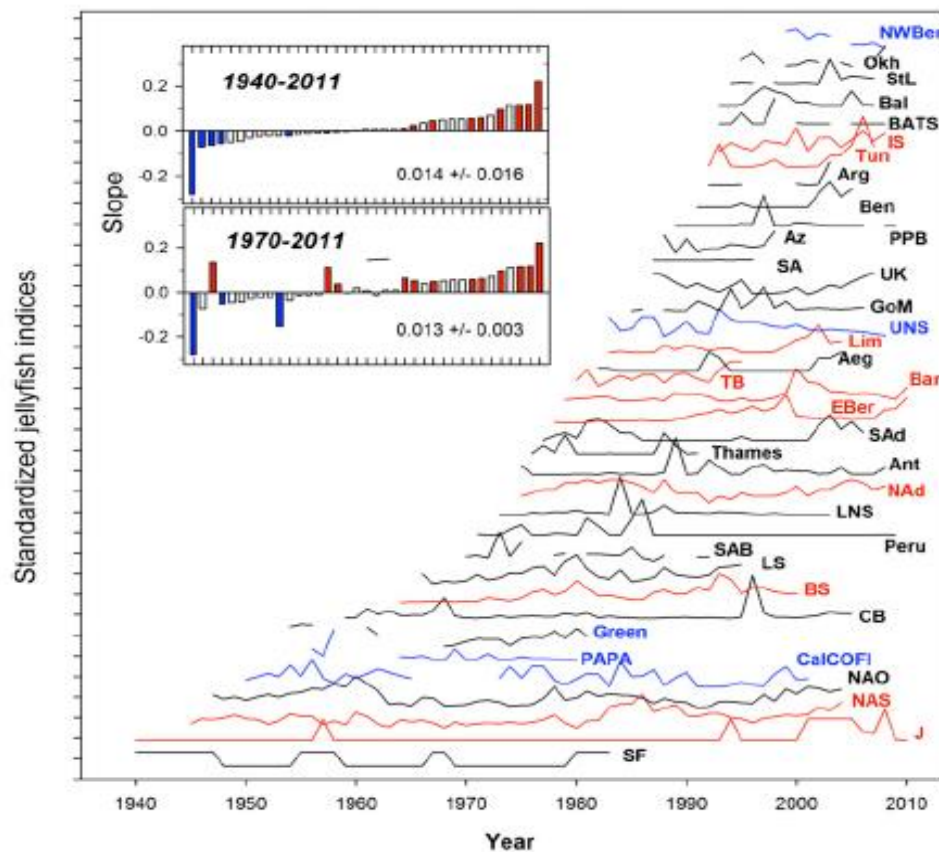


Figure 7. Individual time series abundance of "jellyfish" from 1940 to 2011. (Taken from Condon et al. 2013)

In recent years Sechura Bay contributed to 50-70% of the national production of scallop *Argopecten purpuratus*, constituting one of the most productive bays Peruvian coast in scallop cultivation. As one of the objectives of the management of aquaculture is to have tools available to predict and measure the ability of an area to support the cultivation of a species, is that the Instituto del Mar del Peru (IMARPE) conducted a study bio-oceanographic in summer (February-March) and winter (July) of 2012 in the Bay of Sechura to determine load capacity. The results obtained for three environmental scenarios (neutral years, La Niña and El Niño weak or moderate) indicate that for the neutral scenario load capacity phytoplankton ranged from 17902 (February) and 42811 (May) million individuals, while oxygen capacity ranged from 6201 (April) and 29212 (August) million individuals. However, aquaculture in the Bay of Sechura develops in the form of areas of repopulation in the sea floor, so that the capacity of adult scallops in these areas under the different scenarios was 1637 million individuals (La Niña), 6.09 billion individuals (neutral year) and 9157 million individuals (El Niño).

According to the publications, jobs and existing monitoring raises some initiatives to integrate and compare information on indicators of productivity of both ecosystems: coastal upwelling indices (Paita, Piura and Santa Rosa - Lambayeque) chlorophyll-a concentration (images satellite and cruise/sea operations, etc); carrying capacity of Sechura Bay and Coquimbo, the OMZ and its influence on the productivity of the Peruvian sea; harmful algal blooms (HAB); species of phytoplankton and zooplankton mass indicator water, such as early warning signal of El Niño or La Niña; expanding South Pacific anticyclone and changes in the wind field.

Regarding priority common problems shared by both countries with productivity indicators can point to: expansion of oxygen minimum zone (OMZ); increased acidification in areas of upwelling; high primary productivity variability; presence gelatinous macrozooplankton; increase in harmful algal blooms frequencies; likely to expand south Pacific anticyclone (APS) Ekman transport variability and optimal environmental window.

Based on the results obtained by various authors, especially Purca et al. (2010), the expected hypothetical scenario about the temporal relationships between environmental variables and biotic components of the ecosystem of the Humboldt Current off Peru There

is a positive global trend of SST, except for California and Humboldt GEM, because both have negative trend after 1982 (Sherman et al.2008). On the other hand, the trend of chlorophyll-a off Callao is positive especially after 2000, confirming the inverse response Peruvian upwelling ecosystem compared to other GEM.

Furthermore, during 1975 - 1990 the 15°C isotherm and 0.5 ml.L⁻¹isooxygen deepened, after 1990 shows the increased efficiency of upwelling, expansion of the Cold Coastal Water (CCW), the area expansion OMZ, increased the activity of intraseasonal Equatorial Kelvin waves as well as the increase in zooplankton biomass and anchovy (Fig. 8).

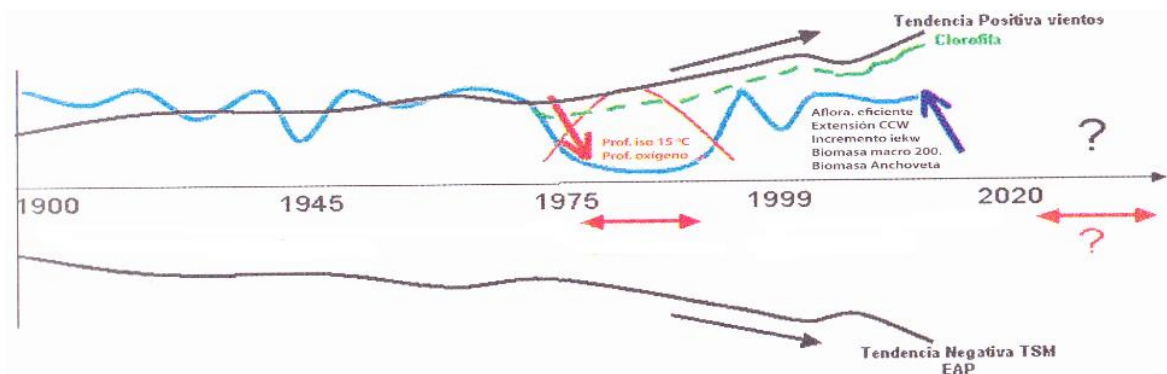


Figure 8. Scheme hypothetical scenario environmental decadal variability in the Peruvian upwelling ecosystem (EAP) (Modified from Purca et al. 2010).

However, in relation to climate change, the simulation models show a large uncertainty of their climate projections, particularly in the Peruvian upwelling area (Wang et al. 2009).