Chilean Jack Mackerel Workshop

Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2008)

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Abstract

Jack Mackerel (JM: *Trachurus murphyi*) is being acoustically assessed since 1983 by the Instituto del Mar del Perú (IMARPE). That monitoring supported the management of the fishery of JM off Peru which was initiated by foreign fleets. By the mid 1990's an offshore Peruvian purse seine fleet was developed though its activities were early affected by changes in distribution and a reduction of JM abundance after the strong El Niño event of 1997-98. Since this event, cold coastal waters extend far from the coast, the oxycline is shallow, anchovy dominate the system, and the population of squat lobster (*Pleuroncodes monodon*) and jumbo squid (*Dosidicus gigas*) exploded. On the opposite the abundance and availability of JM, sardine and mackerel reduced dramatically. Using a GAM approach we show the changes of JM distribution and related (abiotic) parameters along the period in which IMARPE conducted acoustics surveys, and describe the negative correlations among the abundance of mentioned species. Using acoustic data from commercial fishing we also show interactions between JM and its preys, mainly euphausiids. These results support the hypothesis according to which the main drivers of JM distribution along the South American coast are the prey distribution and the location of the Oxygen Minimum Zone (both effect can be related). Finally we emphasize on the use of acoustic techniques to collect simultaneous in situ data from fishing vessels about a variety of species, preys and predators, to support the necessary ecosystem approach adapted to the fishery of JM.

Keywords: distribution, abundance, variability, acoustics, fishing, oxygen, thermocline, preys.

Introduction

JM fishery has become an important item for human feeding in Peru. The fish is caught by a fleet equipped with RSW cooling systems and used by the canning and frozen industries which also export fish to a few countries. The

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activity of this fleet is relatively recent, first vessels of this kind (500 to 800 tons of capacity) were build up by mid the 1990's. The JM fishery was founded by foreign fleets by early the 1980's which operated mid-water trawlers along the Peruvian coast, particularly the northern area.

Figure 1 shows the acoustic distribution of JM off Peru since 1983. We hypothesize that observed changes and the increase of the variability of its abundance is a similar process like the one described for the anchovy-sardine alternance since that a regime shift occurred in 1992 (Gutierrez et al 2007). Chavez et al (2003) described decadal cycles favorable to sardine ('El Viejo' conditions) when warm conditions prevail; on the opposite cold conditions are favorable to anchovy ('La Vieja'). A new regime shift occurred during the strong El Niño event in 1997-98 triggering the colder conditions that prevail up to date (Gutierrez et al 2007; F. Chavez, pers. comm.). Our hypothesis is also related to the water masses composition changes regarding their physical and chemical (oxygen) characteristics which driven a variation of the local productivity and diversity of zooplankton communities.

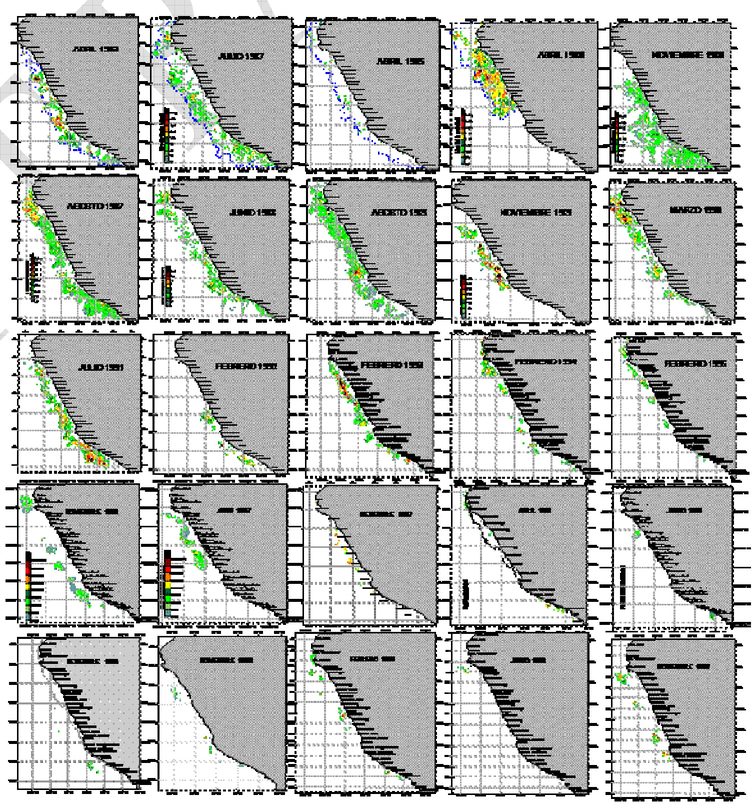


Figure 1. JM acoustic distribution off Peru from 1983 to 1999

Swartzman et al (2008, in press) describe no clear relationship in the association of sardine to any particular water type off Peru but to a latitudinal range of distribution, while anchovy is strongly related to coastal cold waters. Figure 2 (from Swartman et al, 2008, in press) roughly shows that physical changes in water masses occurred during studied period. Accordingly we support the hypothesys of changes in vertical chemical conditions to explain the reduction of JM abundance and others off Peru, specifically the vertical dissolved oxygen as a proxy of JM, sardine and mackerel availability. Stramma et al (2008) demonstrated that depth of upper and lower limits of the Oxygen Minimun Zone (OMZ) are expanding hence reducing the habitat for pelagic fish. This has an apparent direct relationship with JM abundance reduction then we strongly support the need for collecting data on OMZ as a measure of habitat suitability.

Following the conclusions of Bertrand et al (2004) we propose to consider the habitat range as a direct measure of JM and others species abundance.

Furthermore, from the scrutiny of acoustic data collected both aboard research and commercial vessels we found a 'biological proxy' of habitat suitability. We refer to euphausiids which are often detected 'by eye' from 120 kHz echograms. Using data collected by fishing vessels from the summer 2008 we found a certain positive correlation between location of clusters and euphausiids spatial proximity later confirmed through trophic ecology studies (Espinoza & Alegre, 2008, in prep.).

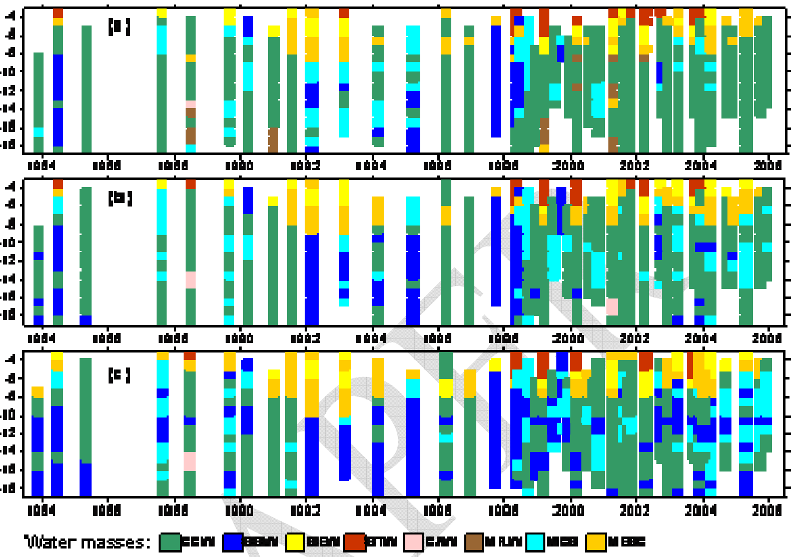


Fig. 2. Dominant water mass by degree of latitude along the Peruvian coast for each survey (a) between 0 and 10 n.mi. from the coast; (b) between 10 and 25 n.mi. from the coast; (c) between 25 and 50 n.mi. from the coast. Year markers refer to January 1. During some years survey results overlap due to intensive temporal coverage.

Nevertheless the results presented in this informative paper are preliminary and subject to revision though we can foresee the conclusion that is a need to establish a set of ecosystem indexes and a multidisciplinary focus on all aspects regarding JM habits and interactions.

Material and Methods

Acoustic survey data

45 acoustic surveys were performed from 1983 to 2006 by the Instituto del Mar del Peru (IMARPE) on a variety of vessels, most commonly the R/V Humboldt (76-m long), the R/V Olaya (41-m long), the R/V SNP-1 (36-m long) and R/V SNP-2 (21-m long). At least two acoustic surveys were run each year. Survey design was composed of parallel transects averaging 100 nautical miles (182 km) long with a cross-transect distance varying between 14 and 16 nautical miles (26–30 km) depending on the survey. Extensive midwater trawl sampling accompanied the acoustic surveys for species identification. The acoustic surveys deployed Simrad (Kongsberg Simrad AS, Kongsberg, Norway) scientific echosounders EK, EKS, EK400, EY500, EK500 and EK60 (2001–2006 in one vessel). A review of calibration methods in Peru (Ken Foote; Woods Hole Oceanographic Institute, Woods Hole,

MA, USA, unpubl. data) suggested that there is no bias in s_A (acoustic biomass) values because of differences in used calibration methods. Acoustic back-scattered energy by surface unit (s_A) was recorded in each geo-referenced elementary sampling distance unit (ESDU) of 1 n.mi. (1994–2003) or 2 n.mi. (1983–1993). Acoustic echo identification was performed by using fishing trawl results and echotrace characteristics. Biomass estimation based on the acoustic backscatter for each species was carried out by IMARPE for each survey. A noise threshold of -65 dB was used.

Temperature anomaly as a proxy of environmental conditions

Temperature data have been collected at Chicama (7°40’S) by a moored temperature recorder since 1927 and serves as a surrogate for temperature anomaly (tA) calculations for the entire Peruvian HCS (Direccion de Hidrografia y Navegacion, Peru). The tA was calculated on a monthly basis by differencing the current temperature and the average for that month over the 1966–2006 time period. The choice of Chicama as a time series rather than an index of temperature is based on (1) the desire to have a univariate data series for the temperature covariate; (2) the high correlation of Chicama data with temperature records from 1976 to 2006 at Callao (south-central Peru; r^2=0.930) and Ilo (southern Peru; r^2= 0.791); and (3) the fact that Chicama is the most complete time series available.

GAM models

In this paper we do not seek to assess the abundance change at every survey but the location of every ESDU where JM was detected. We sought potential relationships between location and abiotic variables (temperature, salinity, distance to the coast, latutude) for each ESDU. As the relationships are likely to be nonlinear and multivariate, a generalized additive modelling (GAM) approach was used (Hastie and Tibshirani 1990) using S-Plus (Insightful Corporation, Seattle, WA, USA). Cubic spline smoothers were used to estimate these nonparametric functions.

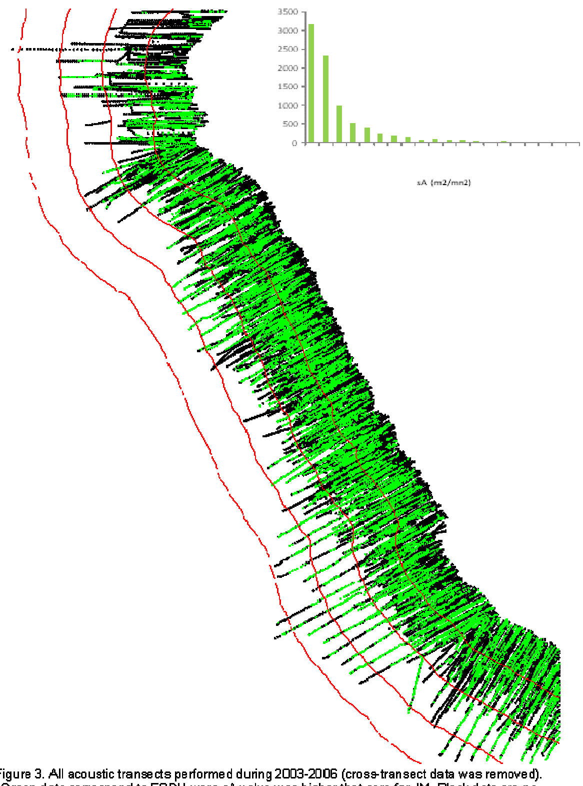


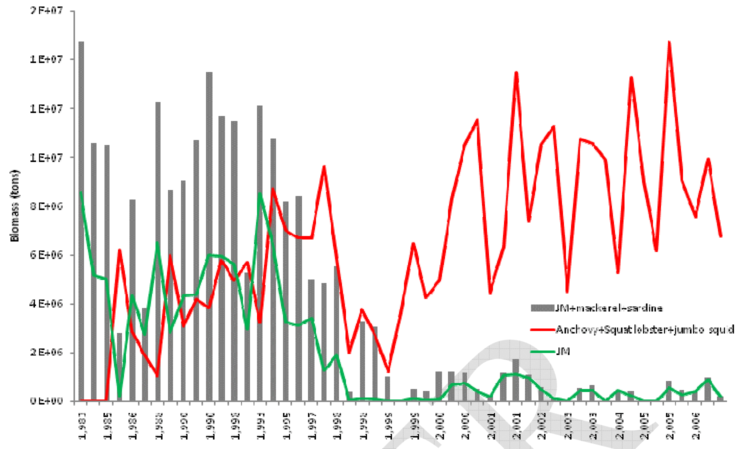
Figure 3. All acoustic transects performed during 2003-2006 (cross-transect data was removed). Green dots correspond to ESDU were sA value was higher that cero for JM. Black dots are no JM at that point. Histogram shows PDF of sA values (echointegration).

Collection of Acoustic data from Fishing Vessels

We applied the protocols of the ICES[5] Cooperative Research Report 287 (Karp et al, 2006) on the Collection of Acoustic *Data from Fishing Vessels.*

Tecnologica de Alimentos (TASA), a Peruvian fishing company, owns 13 fishing vessels equipped with digital echosounders Simrad ES60 (120 kHz) and split beam transducers. These vessels have freezing facilities and used in the fishery of JM.

Fig. 4 Acoustic biomass of most abundant species off Peru (1983-2006)



Echograms were randomly selected from transits and during fishing operations in order to get information on prey-predators relationships and to compare patterns of thermoclyne depth against vertical distribution of backscatterers. For analyzing and extracting information we used Echolog and Echoview software (Myriax, Tasmania).

CTD profiles

For collecting oceanic vertical profiles we used a SeaBird CTD SBE19 during fishing operations aboard TASA fishing vessels. Casts were performed randomly or according to what it was observed at the sounder's display. CTD profiles, temperature and salinity were empirically related to echograms thresholded at -90 dB. Depth, temperature and salinity at lower limit of thermocline were recorded. Linear regressions were performed to relate upper limit of OMZ to thermocline limits. We included results of a review of oxygen data obtained using Niskin bottles and CTDO by IMARPE since 1960, the purpose being to trace the depth of the oxycline.

Trophic ecology

JM stomachs were collected during research surveys at different times and locations to analyze fullness and foraging activities according to time of day. Samples were collected at sea and preserved for further analysis. Our hypothesis is related to the degree of preference of euphausiids as main dietary item for JM. The abudance of euphausiids is seasonal in Peru at least inside the observational window covered by acoustic surveys (1 to 100 n.mi. off shore as a mean).

[5] International Council for the Exploration of the Sea

Euphausiids are relatively easy to be detected by eye when observing a high frequency sounder's display. Furthermore virtual algorithms of acoustic software can be used to automatically detect and quantify communities of the zooplankton (e.g. Holliday 1990; Hewitt et al, 2004; Higgimbottom & Pauly, 2000).

Results

Statistics

The distribution of the number of ESDU of 45 surveys containing JM is shown in figure 3. The wide range of distribution of JM indicates how ubiquitous it can be. The function of probability of density roughly indicates the higher frequency for values lower than 6.00 m^2/mn^2 (lower 25% quartile). The 75% quartile is placed in 60.00 m^2/mn^2 within a range from 1.00 to 53,150.00 m^2/mn^2. Mean values is 107.32 and standard deviation 607.83 m^2/mn^2. Coefficient of variation is 5.66 and skewness 42.35.

Biomass time series

Acoustic surveys revealed a regime shift by mid the 1990's (Gutierrez et al, 2007). The cooling of the Humboldt Current Ecosystem after the strong El Niño 1997-98 would not be the climatic pulse that characterized the reduction of abundance of certain species (JM, mackerel, sardine) while others increased (anchovy, squat lobster, jumbo squid). A reduction on the JM availability had been already observed since 1993 as it is shown in figure 4. JM had been by far the most abundant pelagic fish during the 1980 decade (fig. 4).

GAM results

The GAM analysis were made on the basis of 'presence' considering the ESDUs where JM was detected without taken into account the acoustic biomass (s_A) at every point or the number of positive ESDUs for every survey. The black dotted lines show the 95% confidence limits of GAM models for different abiotic parameters. Left y-axis

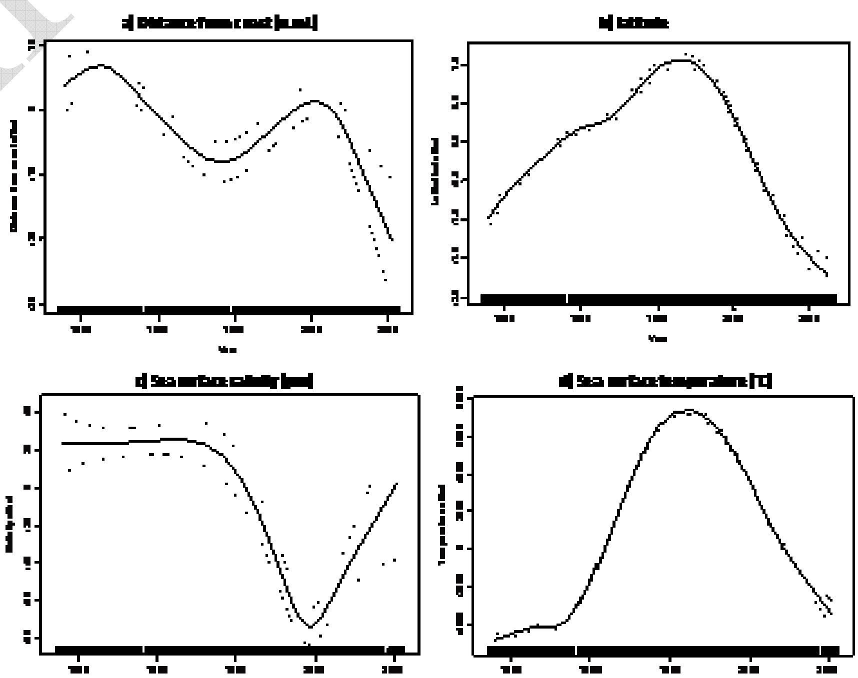


Figure 5. GAM models on the effect of abiotic parameters regarding the distribution of JM off Peru between 1983 and 2005. It is the location of ESDUs what is assessed instead acoustic biomass in order to show how it changes the distribution pattern of JM along the studied period.

shows a relative scale, they corresponds to the spline smoother that was fitted on the data, so that a y-value of zero is the mean effect of the environmental variable on the response. Positive and negative y-values indicate respectively positive and negative effect on the response. Tick marks on the x-axis show the location of data points. Results show rather drastic changes in JM distribution.

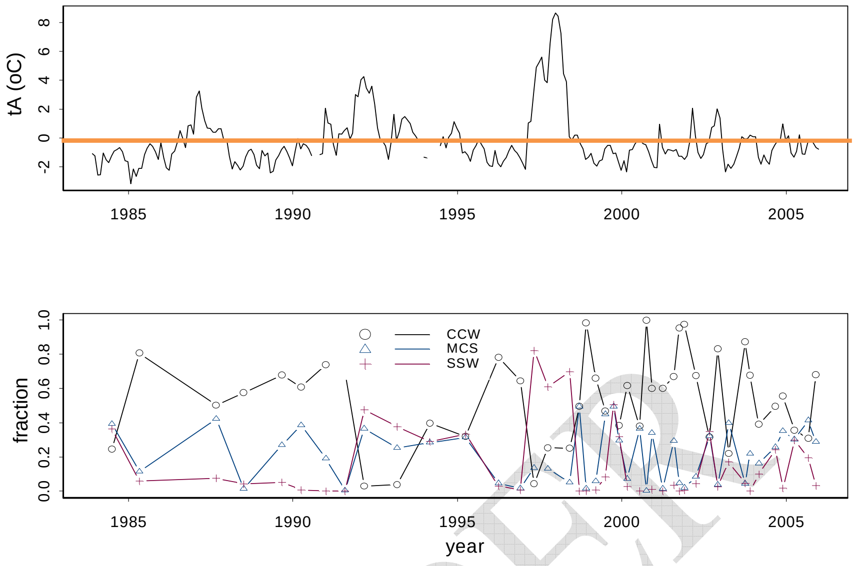


Fig. 6. (a) Temperature anomaly (tA) for surface temperature off the Peruvian coast near Chicama (8ºS), Peru (b). Percentage of the survey area covered by CCW, SSW, and MCS from 1983-2005. El Niño periods are shown by salmon coloured bands with intensity proportional to opacity.

Figure 5a describe the change in distance from coast (DC) along the studied period. A constant decrease of DC is observed between 1985-1995 until the onset of La Niña 1999-2000. After 2000 continued the decrease of the mean distance from coast.

Figure 5b shows the mean change of latitude of JM distribution regarding the year. A northern distribution was in progress until 1997 when it started the distribution to change southward. Figure 5c presents the effect of surface salinity on the JM distribution. Salinity is constant until 1995 when a sudden trend reduced salinity to a lower limit during 2000 (the effect of dominance of coastal waters). After that year there is a trend of the salinity to increase in places were JM distributes. Figure 5d is a plot of the way (probability) how surface temperature (SST) changed along the studied period.

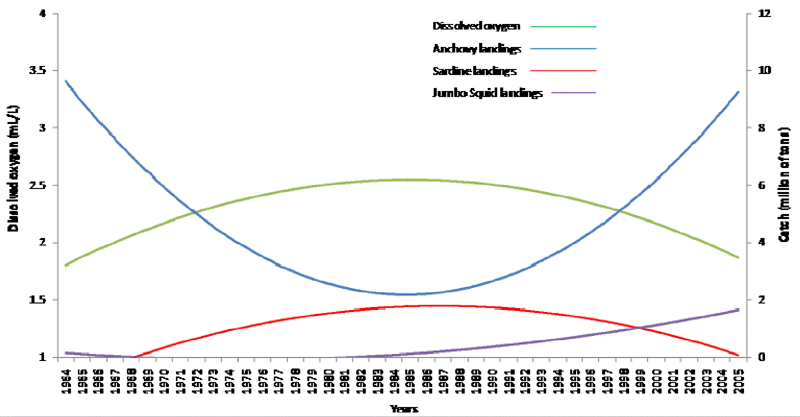
SST increased until 1997 to later on decrease steadily. This result is very similar to the one from latitude which is consistent with the latitudinal patterns (the southernmost the ESDU the colder the temperature). After 1998 the thermal anomalies in Chicama (7°40’S) are mostly under cero.

Indeed before 1998 anomalies had similar trend (zero anomaly) although the occurrence of El Niño events was more noticeable or frequent before that year (fig. 6, top panel). Also the composition of water masses inside the study area shows that no significant variation has occurred in surface along the studied period. Nevertheless the biomass of some species reduced, and other increased. Answers might be under surface.

Effects of oxygen

No noticeable effect is observed from water masses composition and surface temperature. So the vertical extent of habitat might provide a consistent explanation to the reduction of JM abundance. Papers by Bertrand et al (2005, 2006) show the plasticity and foraging effects of JM aggregations though describe limitations of JM to access to regions with certain vertical temperature and dissolved oxygen values.

Fig. 8. Catches of anchovy , sardine and jumbo squid regarding mean dissolved oxygen (0-100 m)



Then we strongly support the hypothesis of being the dissolved oxygen the main forcing which model the JM distribution and abundance patterns (another important topic is the prey availability). Figure 7 shows the time series of dissolved oxygen until 100 m depth and the way the oxycline varied in the coastal region off Peru. The location (depth) of oxycline increased the habitat suitability for certain pelagic fish and roughly matches the abundance patterns of JM, sardine and mackerel (1975-1995).

The possible dependence of JM regarding the vertical range of habitat suitability is presented in figure 8. Because the lack of a fishery of JM in Peru before the 1980's we show the catches of sardine as an indication of habitat range, which are in phase with mean dissolved oxygen (DO) at least in the right slope of the DO curve. At the same time the catches of anchovy are out of phase as well as those of *D. gigas* regarding DO. Anchovy might indeed be affected by DO vertical reduction though it has shown its ability to inhabit epipelagic zones where DO is always high.

Furthermore anchovy would be affected by coastal waters horizontal reductions (Bertrand et al, 2004) instead the vertical extent of its habitat.

Detection of thermocline and MOZ

Regarding thermocline we found a constant relationship between its lower limit and the lower limit of vertical distribution of biological backscatterers. This might be related to the upper limit of the MOZ. That relationship has been appointed to exist (M.Ballon, pers. comm..) though we contribute with a way to empirically measure it using echosounder data.

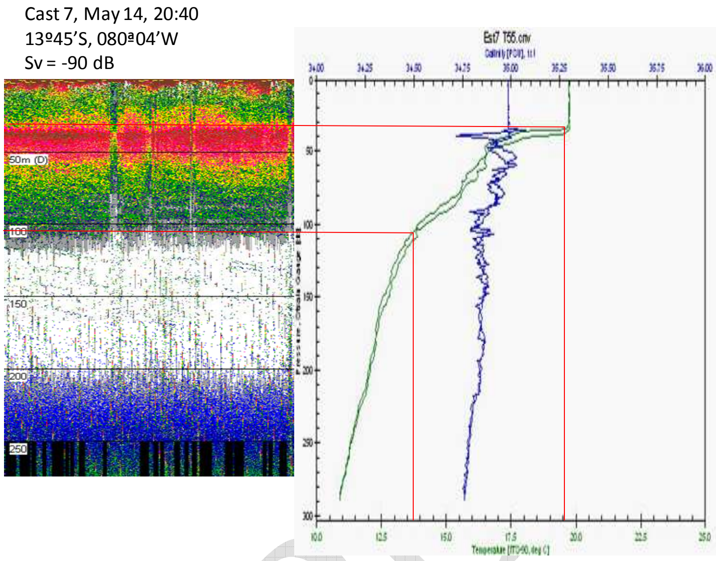


Figure 9 show an echogram collected at 120 kHz aboard a fishing vessel during a sampling cast where we deployed a CTD. The echogram adjusted to a wide threshold revealed several scattering layers. In all cases we analyzed the second and last relevant lines which matched the upper and lower limits of thermocline, hence allowing us to use commercial echosounders for collecting scientific information. This should be used for building datasets for modeling the thermocline and MOZ depth distributions.

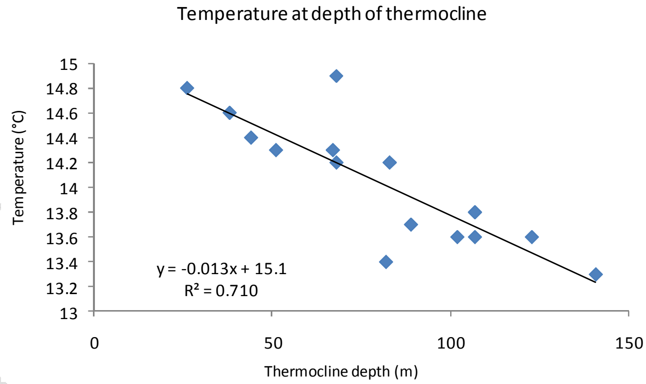


Fig. 9. Thermocline as observed in a CTD (upper right graphic, green line is temperature, blue one is salinity). An echogram appeared adjusted at same depth with a threshold of -90 dB (upper left picture). Red lines indicate limits of the thermocline. Red lines relate graphics between them. Bottom panel show a relationship between depth and lower limit of thermocline.

The bottom panel of figure 9 is a sample of 15 casts in which the temperature at depth of thermocline were plotted against each other. The result (R^2=0.71) is consistent though other sets of measurements are necessary to validate this method.

Preys

Acoustic equipment aboard fishing vessels can also be used for collecting scientific data on prey distribution. Often it is possible to detect and identify biological scatterers with particular reflective features and typologies. It is the case of euphausiids, which can be observed at high frequency sounders displays according to its local density in order to study feeding aspects and interactions with other species.

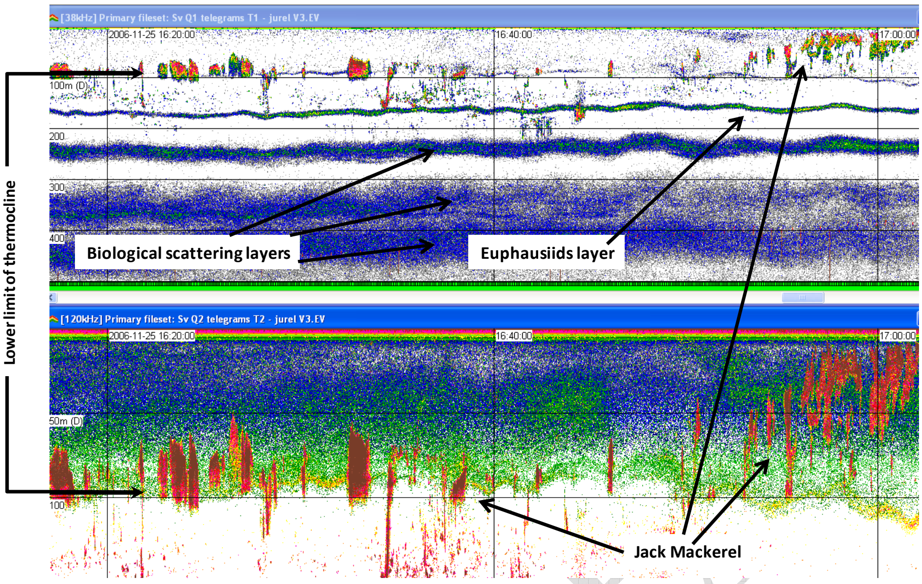


Fig.10. Synchronized echograms of 38 (top, 500 m depth) and 120 (bottom, 150 m depth) kHz showing different kind of biological scatterering layers and Jack Mackerel (JM) recordings. During day JM rests at the bottom of the thermocline. According to its feeding behaviour JM moves up at dusk to surface as well as all the biological organisms. Depending on its local density eupausiids can be observed at an sounder's display.

The data can be retained if digital sounders are used. In figure 10 they are described several characteristics over digital echograms, including thermocline depth (echograms presented at thresholds of -75 dB (top) and -90 dB (bottom). At a wider range JM can be plotted predating on eupahusids as it is seem in the figure 11, were the spatial proximity between both preys and predators is highlighted.

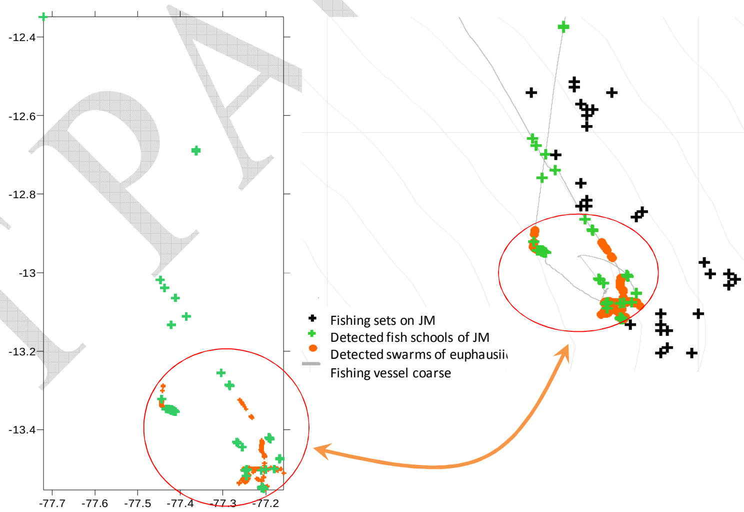


Fig. 11. Spatial proximity of Jack Mackerel to eupahusiids' swarms as visually identified at the sounder display during one trip of a fishing vessel (Tasa 54).

Dietary items

JM is certainly a carnivore in whose diet there is a number of available items. However, according to our results this fish have a remarkable preference for euphausiids at least during October to April, the season when the fish is relatively abundant in Peru. Other species or groups are squat lobster, anchovy, vinciguerria sp etc. Using data from fishery it would be possible to acoustically record most of these communities in time, allowing the creation of databases over wider areas than usually surveyed during scientific research.

Discussion

The aim of this document is informative in first place. The results that have been shown are part of the set of research topics currently performed by The Peruvian Marine Research Institute (IMARPE) with support of The French Institute of Research for Development (IRD) and Tecnologica de Alimentos (TASA). Secondly we wish to point out the need for ecological monitoring to support decision-making processes regarding fisheries management.

Fisheries management might consider an approach in which the habitat range for every target species is known, not only its biomass or the population structure. This requires a frequent monitoring and data collection effort but the possibility of using fishing vessels as continuous samplers (e.g. using acoustics) opens a good opportunity to obtain a information on habitat characteristics.

Habitat range hypothesis describe the welfare of a population as a function of the size of the ecological niche with suitable characteristics (Paloheimo and Dickie 1964, MacCall 1990; Bertrand et al. 2004). In the Peruvian case the variation of mean oxygen concentration in the water column is linked to –at least- to a decadal variation of fishery productivity and abundance changes. One way we propose to keep records on habitat range indicators (e.g. oxycline, thermocline distributions and Ekman’s transport) is to use the regular acoustic equipment (e.g. echosounders) aboard fishing and scientific vessels as tracers of parcels of water with different vertical features.

Furthermore the use of that kind of data will permit to obtain overall indexes of distribution of both preys and predators. Some experiments and observations conducted in Peru have shown the persistence of anchovy and jack mackerel to inhabit areas where certain zooplankton populations spreads. It is particularly interesting to notice the possible relationship between euphausiids and jack mackerel, which is being observed at least during summers along the southern coasts off Peru.

However, the Stramma et al paper (2008) warns about an increasing upwelling of the hypoxic layer in the eastern boundary of upwelling ecosystems which might have very serious consequences on pelagic habitats. The combined use of Satelital altimetry regarding oxycline variations might be a promising technique to understand distribution changes and/or to allocate sampling effort during the usually expensive scientific surveys during fish stock assessment.

There are concerns about the increase of squids and jelly fish populations. The evidence we collected suggest a competition for space and food resources in the subtropical surface waters (zooplankton) between pelagic fish (*T. murphyi, S. sagax* and *S. japonicas* mainly) and giant flying squid (*D. gigas*). They are observed indeed out of phase cycles of abundance between the squid and the group of species. This phenomenon should be further investigated in several time and space scales due to its ecological implies. *D. gigas* is a voracious predator, widely distributed, short lived, high growth rate and characterized by its cannibalism, then feeding ecology studies are necessary to establish at what extent it contributed to the biomass reduction of the pelagic species off Peru.

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