

Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2006)

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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 abundance and related (abiotic) parameters of JM 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.

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Introduction

fishery JM has become 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 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.

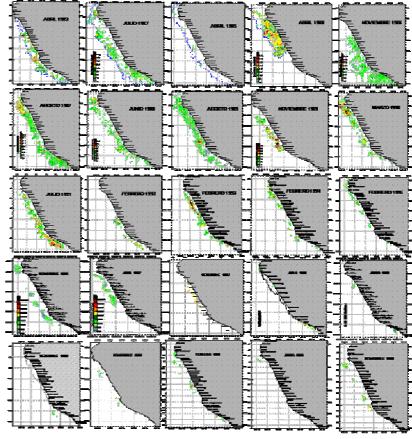


Figure 1 shows the acoustic distribution of JM off Peru since

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

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 alternancy since that a regime shift occurred in 1992 (Gutierrez et al 2007). Our hipothesys 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.

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 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 biomass.

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.

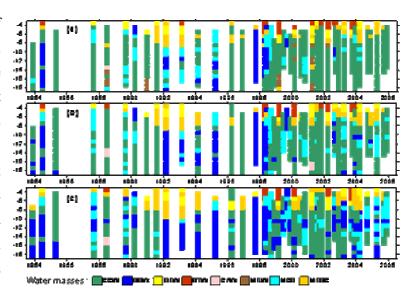


Fig. 2. Dominant water mass by degree of latitude along the Perunian coact for exchange; (a) between 0 and 25 numi. From the coact; (b) between 10 and 25 numi. From the coact; (c) between 25 and 50 numi. From the coact. Year markers refer to laneary 1. During some years survey results overlap due to intersive tempural coverage.

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) and the R/V SNP-1 (36-m long). At least two acoustic surveys were run each year. Survey design was composed of parallel transects averaging 90 nautical miles (167 km) long with an inter-transect distance varying between 14 and 16 nautical miles (26–30 km) depending on the cruise. Extensive midwater trawl sampling accompanied the acoustic surveys for species identification.

Temperature anomaly as a proxy of environmental conditions

Temperature data have been collected at Chicama by a moored temperature recorder since 1927 and serves as a surrogate for temperature anomaly (tA) calculations for the entire Peruvian HCS (Direccion de Hidrografía 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.

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) 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. When necessary the response variable (acoustic abundance of JM was log-transformed in order to reduce skew.

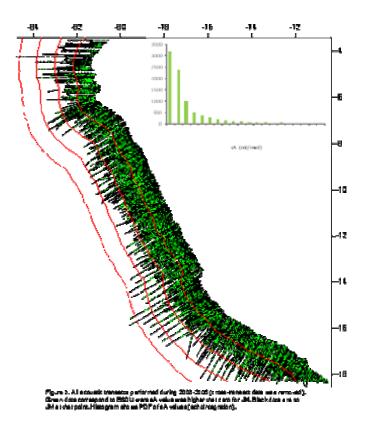
Collection of Acoustic data from Fishing Vessels

We applied the protocols of the ICES⁵ Cooperative Research Report 287 (Karp et al, 2006) on the Collection of Acoustic Data from Fishing Vessels. Tecnologica de Alimentos S.A. (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.

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 ships. Casts were performed randomly or according to what it was observed at the sounder's display. CTD profiles, temperature and salinity were empirically related

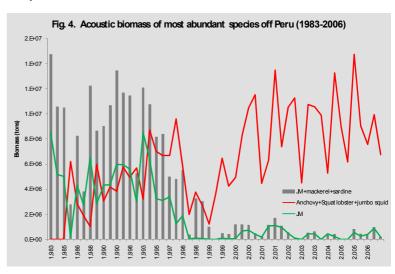


⁵ International Council for the Exploration of the Sea

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 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). Euphausiids are often visible and relatively easy to be detected by eye when observing a sounder's display. Furthermore virtual algorithms of acoustic software can be used to automatically detect and quantify communities of the zooplankton (e.g. Holliday 1992; Hewitt et al, 2004; Higgimbottom & Pauly, 2000).

Results

Statistics

The distribution of the number of ESDU of 45 surveys containing JM is shown if figure 3. The wide range of distribution of JM indicates how ubiquitous it is. The function of probability of density roughly indicates the higher frequency for values lower than 6.00 m²/mn² (lower 25% quartile). The 75% quartile is placed in 60.00 m²/mn² within a range from 1.00 to 53,150.00 m²/mn². Mean values is 107.32

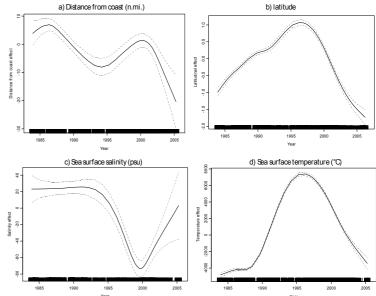


Figure 5. GAM models on Tiffe effect of abiotic parameters regarding the distribution of JMToff Peru between 1983 and 2006. It is the location of ESDUs what is assessed instead acoustic biomass in order to show how it changes the distribution pattern of JM along the studied period.

and standard deviation 607.83 m²/mn². Coefficient of variation is 5.66 and skewness 42.35.

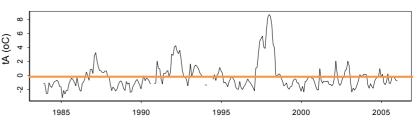
Biomass time series

Acoustic surveys revealed a regime shift by mid the 1990's. The cooling of the Humboldt Current Ecosystem after the strong El Niño 1997-98 would not be the climatic pulse that determined 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 was by far the most abundant pelagic fish during the 1980 decade.

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 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. 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 is in progress until 1997 when it started 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



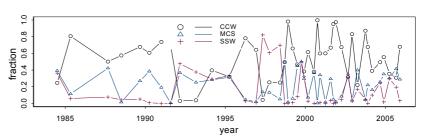


Fig. 6. (a) Temperature anomaly (tA) for surface temperature off the Peruvian coast near Chicama (8°S), Peru (b). Percentage of the survey area covered by COW, SSW, and MCSfrom 1983-2005. B Niño periods are shown by salmon coloured bands with intensity proportional to opacity.

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

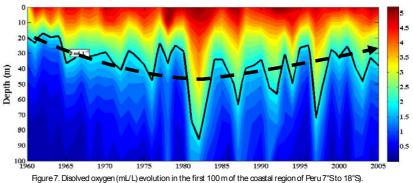


Figure 7. Disolved oxygen (mL/L) evolution in the first 100 m of the coastal region of Peru 7°S to 18°S). Data obtained using Niskin bottles and CTDO.

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 that year anomalies had similar trend though the occurrence of El Niño events or warmer summers was more noticeable or frequent before 1998. Figure 6 shows this basic observation and the composition of water masses inside the area covered by every one of the 45 surveys used for this analysis, so no significant variation has occurred along the studied period. Nevertheless the biomass of some species reduced, and other increased. Answers are under surface.

Effects of oxygen

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.

We strongly support the idea of being the oxygen one of the main forcings which model the JM distribution and abundance patterns (another 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

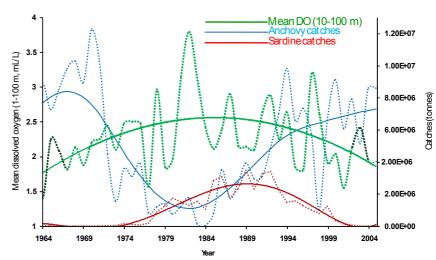


Fig. 8. Time series of catches of anchovy and sardine regarding mean dissolved oxygen (DO).

increased the habitat suitability for oceanic pelagic fish and roughly matches the abundance patterns of JM, sardine and mackerel (1975-1995).

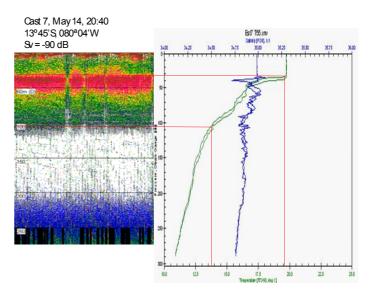
The possible dependence of JM regarding the vertical range of habitat suitability is presented in figure 8. Because the lack of a fishery of JM in Peru before the 1980's we show the catches of sardine as an indication of habitat range, which are in phase with mean dissolved oxygen (DO) at least in the righ

slope of the DO curve. At the same time the catches of anchovy are asymmetric with DO probably because that fish is not affected by an increase of DO but by a reduction of its habitat range, the coastal cold waters (CCW).

Detection of thermocline and MOZ

Regarding thermocline we found a constant relationship between its lower limit and the lower limit of biological backscattering. This might be related to the upper limit of the MOZ. That relationship has been appointed to exist though what we want to contribute is 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



Temperature at depth of thermodine

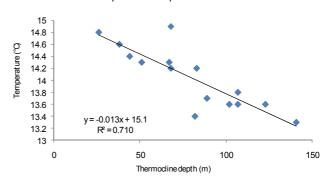


Fig. 9. Thermodine as observed in a CTD (upper right graphic, green line is temperature, blue one is salinity). An echogram appeared adjusted at same depth with a threshold of -90 dB (upper left picture). Red lines indicate limits of the thermodine. Red lines relate graphics between them. Bottom panel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

commercial echosounders for collecting scientific information. This should be used for building datasets for modeling the thermocline and MOZ depth distributions.

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 detect and identify biological scatterers with particular reflective features and typologies. It is the case of euphausiids, which can be observed sounders at displays according to its local density in order to study feeding aspects and interactions with other species.

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).

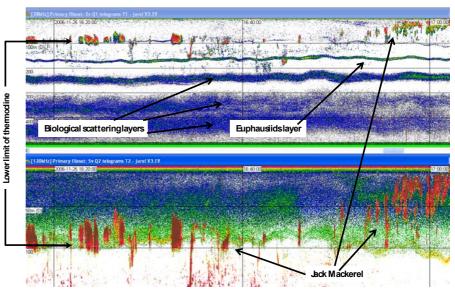


Fig. 10. Synchronized echograms of 38 (top, 500 m depth) and 120 (bottom, 150 m depth) kHz showing different kind of biological scatterering layers and Jack Mackerel (JM) recordings. During day JM rests at the bottom of the thermodine. According to its feeding behaviour JM moves up at dusk to surface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

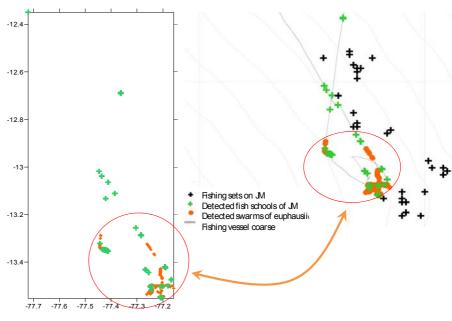


Fig. 11. Spatial proximity of Jack Mackerel to eupahusids' swarms as visually identified at the sounder display during one trip of a fishing vessel (Tasa 54).

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.

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. Figure 12 contain a description of food items of JM diet in three places along the Peruvian coast (Callao, Pisco and Ilo) and different distances off shore.

Euphusiids (red color) is one of the main items from 12 identified. Other species or

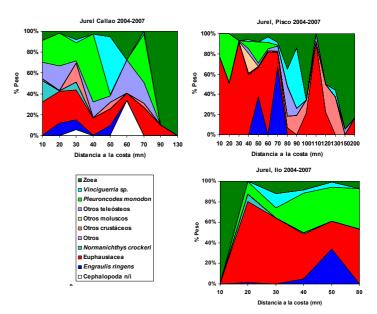


Fig. 12. Diet of jack mackerel off Peruvian coast in percentage of weigth

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.

Discusion

Note: this is an incomplete and preliminar version of a paper intended to be presented at the Chilean Jack Mackerel Workshop (Santiago, June 30 to July 4). The submission of this paper has been done to fulfill the outlined program of the meeting. We apologize for any mistmatch and numerous mistakes surely we have not been able to clean up. A complete discussion will be included in the final version of the document.

References

Bertrand A., M. A. Barbieri, F. Gerlotto, F. Leiva, J. Córdova. 2006. Determinism and plasticity of fish schooling behaviour as exemplified by the South Pacific jack mackerel Trachurus murphyi. Mar Ecol Prog Ser Vol. 311: 145–156.

Bertrand A., M. A. Barbieri, J. Cordova, C. Hernandez, F. Gomez, and F. Leiva. 2004. Diel vertical behaviour, predatoreprey relationships, and occupation of space by jack mackerel (Trachurus murphyi) off Chile. ICES Journal of Marine Science, 61: 1105e1112 (2004)

Bertrand, A., Segura, M., Gutie'rrez, M. and Va'squez, L. (2004) From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish Fish. 5:296–316.

Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen, M. (2003) From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science 299:217–221.

Foote, K.G., Knudsen, H., Vestnes, G., MacLennan, D., and Simmonds, E.J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. Cooperative Research Report, Internacional Council for the Exploration of the Sea, 144, 57 pp.

Gutierrez M. G. Swartzman, A. Bertrand and S. Bertrand. 2007. Anchovy (Engraulis ringens) and sardine (Sardinops sagax) spatial dynamics and aggregation patterns in the Humboldt Current ecosystem, Peru, from 1983–2003. Fish. Oceanogr. 16:2, 155–168, 2007

Hastie, T. and Tibshirani, R. (1990) Generalized Additive Models. Chapman and Hall, London, UK.

Hewitt R, S. Kim, M. Naganobu, M. Gutierrez, D. Kang, Y. Takao, J. Quiñones, Y.H. Lee, H.C. Shin, S. Kawaguchi, J.H. Emery, D.A. Demer, and V.J. Loeb. 2003. Variation in biomass density and demography of Antarctic krill in the vicinity of the South Shetland Islands during the 1999/2000 austral summer. Deep-Sea Research II 51 (2004) 1411–1419.

Higginbottom, I.R., Pauly, T.J. and Heatley D.C. (2000). Virtual echograms for visualization and post-processing of multiple-frequency echosounder data. Proceedings of the Fifth European Conference on Underwater Acoustics, ECUA 2000 (Ed. M.E. Zakharia), 1497-1502.

Karp W., J. Dalen, R. Kloser, G. Macaulay, G. Melvin, R. Mitson, R. O'Driscoll, H. Peña, T. Ryan. 2007. ICES Cooperative Research Report n° 287. Collection of Acoustic Data from Fishing Vessels.

Swartzman G., A. Bertrand, M. Gutiérrez, L. Vasquez and S. Bertrand (2008). The relationship of anchovy and sardine to water masses in the Peruvian Humboldt Current Ecosystem from 1983-2005. In press: Progress in Oceanography.