Multi-decadal to centennial-scale changes in fish scale deposition from marine laminated sediments off pisco, Peru

Renato Salvatteci, Dimitri Gutiérrez, David Field, Abdelfettah Sifeddine, Mohammed Boussafir, Luc Ortlieb

45 mm

MULTI-DECADAL TO CENTENNIAL-SCALE CHANGES IN FISH SCALE DEPOSITION FROM MARINE LAMINATED SEDIMENTS OFF PISCO, PERU

Salvatteci, R.[1,2]; Gutierrez, D.[2], Field, D.[3], Sifeddine, A.[1,4], Boussafir, M.[5], Ortlieb, L.[1]

renato.salvatteci@ird.fr

[1]- LOCEAN, UMR 7159 (IRD, CNRS, UPMC, MNHN), Institut Pierre Simon Laplace. Centre IRD France Nord; [2]- Instituto del Mar del Perú; [3]- Hawaii Pacific University, College of Natural Sciences; [4]- Departamento de Geoquimica-Universidade Federal Fluminense; [5]- ISTO- Université d'Orléans.

Postal address of first author
Centre de recherche d'Ile-de-France
32, avenue Henri Varagnat
93143 Bondy Cedex
France

ABSTRACT
The highly productive upwelling environment off Peru sustains one of the world's largest fisheries, the Peruvian anchoveta (Engraulis ringens), but biomass variability on interannual to decadal timescales results in dramatic catch variations. In order to infer decadal- to centennial-scale variability in pelagic fish populations, we quantified variations in fish scale abundance preserved in laminated sediments collected in the Oxygen Minimum Zone off Pisco, Peru. Sediment redox conditions were reconstructed using Molybdenum while productivity was inferred from total organic carbon. Given the complex sedimentation patterns, we reconstructed a composite record from four box-cores, which was dated using ^{210}Pb*,* ^{241}Am *and* ^{14}C*. The composite record allows the identification of three marked periods. From ~1550 to ~1820, low abundance and higher degradation of fish scales, in combination with lower productivity and oxidizing conditions characterized the record. A multi-decadal period, from ~1820 to ~1890, is characterized by the presence of oceanic waters species and strong variability in redox conditions and productivity. Finally, from ~1890 to the present, a centennial-scale increase of anchovy scales is supported by high productivity and reducing conditions. Various modes of variability with regards to the relative abundances of anchovy and sardine can be observed in the Humboldt Current Ecosystem.*

Keywords: *Anchovy, Sardine, multi-decadal variability, Humboldt Current Ecosystem, chrono-stratigraphy*

45 mm

1. *INTRODUCTION*

The highly productive upwelling environment off the coast of Peru sustains one of the world's largest fisheries, the Peruvian anchoveta (*Engraulis ringens*), but biomass variability on interannual to decadal timescales results in dramatic variations in catch. As observed in other upwelling ecosystems of the world, a decline in anchovy landings in the Humboldt Upwelling Ecosystem from 1975 to the middle to late 1990s coincided with an increase in sardine (*Sardinops sagax sagax*). The decadal scale variability is largely attributed to physical and biological mechanisms, although several explanations have been proposed (Checkley et al. 2009). Testing these hypotheses of mechanisms driving decadal variability in fish abundances require long records of fish population variability prior to the development of industrial fishing, which is best achieved through the development of fish scale records from marine sediments.

Over time fish scales and bones as well as debris of many organisms fall to the ocean floor, get buried and accumulate. Under favorable conditions they may be preserved providing a record of pelagic communities which inhabited the area. However, natural events such as strong bottom currents (erosion), bioturbation (sediment mixing) and slumps (lateral deposition of sediments and/or sediment losses) may cause discontinuities in the sedimentary record. Therefore, a critical step in order to reconstruct any proxy at high resolution is to develop an accurate chronology, which is usually obtained from decaying isotopes such as ^{241}Am, ^{210}Pb, and ^{14}C. Yet, the verification of the stratigraphic continuity is often neglected.

Despite the complex sedimentation patterns off Peru, it was possible to reconstruct a continuous record combining several sets of undisturbed and complete stratigraphic sequences from 4 box-cores. We reconstructed fish population variability, productivity and sediment redox conditions during the last ~500 years, using a high resolution composite record derived from cross-stratigraphy that provided a well constrained temporal framework and allowed avoiding misleading interpretations derived from one record (Baumgartner et al. 1991).

2. *METHODOLOGY*

From a set of more than 30 gravity and box cores retrieved off Pisco, Peru, 4 box-cores were chosen to construct a composite record based on the preservation of the laminae. X-ray and SCOPIX images were obtained from each core in order to study in detail the stratigraphy. The laminae correlations were done by visual inspections. The 4 box-cores were sampled at a high resolution and dated measuring ^{210}Pb, ^{241}Am and ^{14}C. In order to construct a composite record, spliced sequences of different cores were assembled considering the sequences that contained more and better preserved laminae in comparison to equivalent segments in the other cores. The homogeneous sections that were identified as slumps were removed in order to assemble the composite record.

45 mm

In order to reconstruct past redox conditions, the Enrichment factor for Molybdenum (Mo) was used. Mo concentrations were analyzed by ICP-MS. Organic matter characterization and quantification was done using Rock-Eval 6 programmed pyrolysis. Total organic carbon (TOC %) reflects the quantity of organic matter present in the sediment. In order to infer decadal- to centennial-scale pelagic fish population variability prior to the development of the fishery, we quantified variations in fish scale abundance from 4 box-cores. The degree of degradation was inferred using the integrity index of anchovy scales (Salvatteci et al., *in press*).

3. *RESULTS*

There is an evident shift in density in all cores, previously dated as ~1820 in core B6 (Gutierrez et al. 2009; Sifeddine et al. 2008), which served as an anchor in order to make the laminae correlations. Prior to the shift, laminated sequences and homogeneous or slumped sections can be observed in all cores and usually the first group of laminae above the homogeneous deposits can be cross-correlated among the cores. An overlap of images of different cores containing these marker layers makes evident that some cores contain more laminae in comparison with the others. The lack of some laminae in some cores can be explained by erosion caused by a slump. The cross-correlation indicates differences in thickness of the homogeneous sections among cores, which stands in clear contrast to the relatively similar thickness of the laminated sequences. The different thickness of equivalent homogeneous deposits reveals that they are instantaneous deposits from upslope (Field et al. 2009). Although the laminae after the shift are not so well defined, the ^{210}Pb and ^{241}Am profiles were used to validate the few cross-correlations. After the sedimentary shift, the cores B13 and B14 contain more laminated sequences than B6 and B9. Moreover the ^{210}Pb profiles goes deeper in B13 and B14 in comparison to B6 and B9, which can be explained by loss of sediment sequences rather than changes in sedimentation rates. Cores B9 and B13 (retrieved at 200 meters depth) show visual evidence of sediment mixing, which is further confirmed by the constant ^{210}Pb values in some parts of the records. It is very likely that these mixing events were caused by bottom water oxygenation during strong El Niño events.

The proxies developed in the composite record show three marked periods of temporal changes (Fig. 1). The interval from ~1550 to ~1820 is characterized by low abundance of fish scales of all species and higher fish scale degradation in association with lower productivity and oxidizing sediment conditions. By contrast, the multi-decadal period, from ~1820 to ~1890, features strong variability in redox conditions and productivity, associated with low anchovy abundances and the presence of oceanic waters species like sardine (*Sardinops sagax sagax*), jack mackerel (*Trachurus picturatus murphyi)* and mackerel (*Scomber japonicus*). Finally, a centennial-scale increase of anchovy scales, supported by an even greater increase in productivity occurs from ~1890 to the present.

45 mm

4. CONCLUSIONS

The sediment records off Pisco are not continuous in time; therefore, a composition of several cores must be analyzed in order to appropriately infer high resolution variability. Multiple cores retrieved off Pisco show evidence of erosion and discontinuities and the addition of homogeneous deposits from upslope arising from slumps/ sediment gravity flows.

Various modes of variability can be observed in the Humboldt Current Ecosystem regarding the relative abundances of anchovy and sardine instead of alternations of populations as observed in the fish landings. A relative long period with oceanographic conditions favorable to oceanic species persisted for several decades (~1820-1890), another period of low anchovy abundance persisted without a respective increase in sardine (~1550-1820).

5. REFERENCES

Baumgartner, T. R., Ferreira-Bartrina, V., Cowen, J. and Soutar, A., 1991. Reconstruction of a 20th century varve chronology from the central Gulf of California. *The Gulf and Peninsular Province of the Californias*.

Checkley, D., J. Alheit, Y. Oozeki, and C. Roy. 2009. Climate Change and Small Pelagic Fish. Cambridge University Press, Cambridge.

Field, D., Baumgartner, T. R., Ferreira, V., Gutierrez, D., Lozano-Montes, H., Salvatteci, R. and Soutar, A., 2009. Variability from scales in marine sediments and other historical records. pp. 45-63. In D. M. Checkley, C. Roy, J. Alheit, and Y. Oozeki, eds. *Climate Change and Small Pelagic Fish*. Cambridge University Press.

Gutierrez, D., Sifeddine, A., Field, D., Ortlieb, L., Vargas, G., Chavez, F., Velazco, F., Ferreira, V., Tapia, P., Salvatteci, R., Boucher, H., Morales, M. C., Valdes, J., Reyss, J. L., Campusano, A., Boussafir, M., Mandeng-Yogo, M., Garcia, M. and Baumgartner, T., 2009. Rapid reorganization in ocean biogeochemistry off Peru towards the end of the Little Ice Age. *Biogeosciences* 6:835-848.

Salvatteci, R., Field, D., Baumgartner, T., Ferreira, V., Gutierrez, D., *in press*. Evaluating fish scale preservation in sediment records from the oxygen minimum zone off Peru. *Paleobiology*.

Sifeddine, A., Gutierrez, D., Ortlieb, L., Boucher, H., Velazco, F., Field, D., Vargas, G., Boussafir, M., Salvatteci, R., Ferreira, V., García, M., Valdes, J., Caquineau, S., Mandeng-Yogo, M., Cetin, F., Solis, J., Soler, P. and Baumgartner, T., 2008. Laminated sediments from the central Peruvian continental slope: A 500 year record of upwelling system productivity, terrestrial runoff and redox conditions. *Progress in Oceanography* 79:190–197.

6. *ACKNOWLEDGEMENTS*

The AMS radiocarbon measurements were obtained by the Laboratoire de mesures de C-14 LMC14 (UMS 2572, CEA-CNRS-IRD-IRSN-Ministère de la Culture), Gif-sur Yvette, France, through the IRD financial and technical support to this laboratory.

45 mm

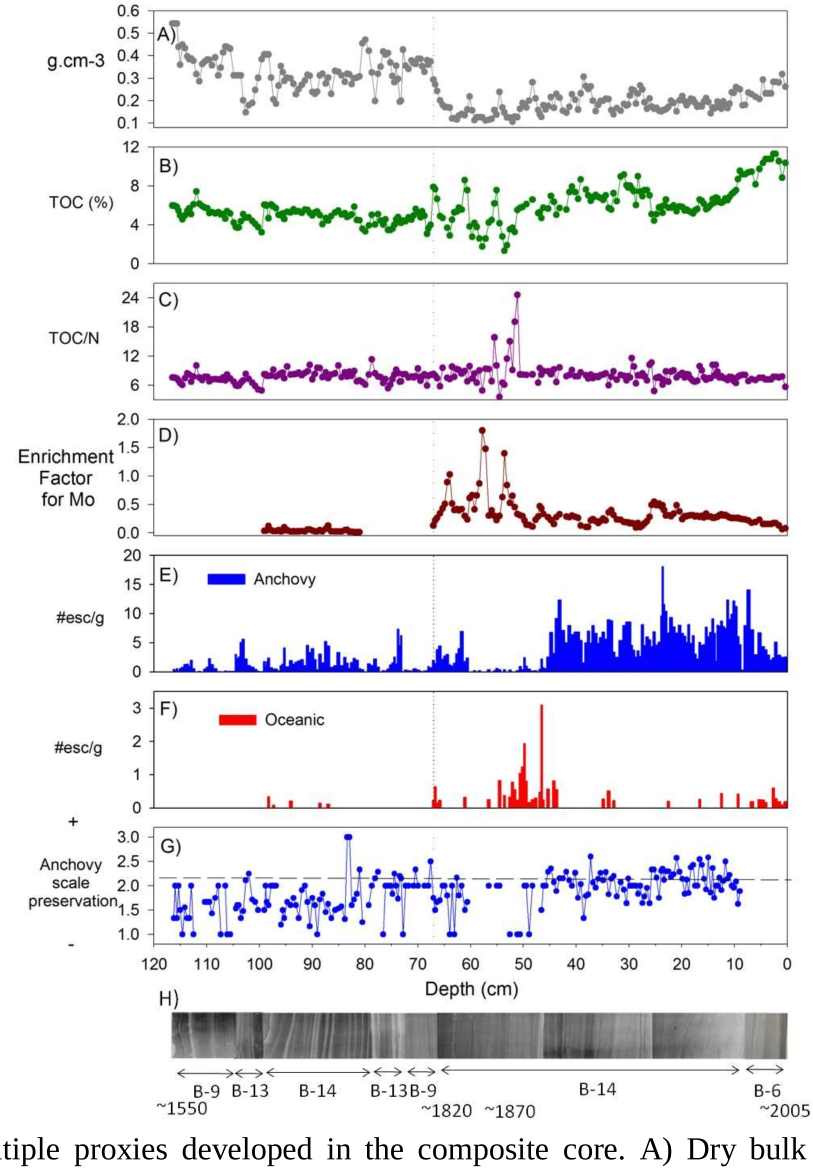

Figure 1. Multiple proxies developed in the composite core. A) Dry bulk Density (DBD) g.cm^{-3}. B) Total Organic Carbon (TOC). C) Ratio TOC/N. D) Enrichment factor for Molybdenum, E) Anchovy scales abundances. F) Combined abundances of scales of oceanic species: sardine (*Sardinops sagax sagax*), mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus picturatus murphyi*). G) Integrity index of anchovy scales (estimate of scale wholeness relative to fragmentation), taken from Salvatteci et al. (*in press)*. H) Composite core from Figure 1B including some references dates (AD). The vertical dotted lines indicate the shift from a less productive period to a higher productive period (Gutierrez et al. 2009; Sifeddine et al. 2008). Fish scale data of cores B6, B-13 and B-14 from Gutierrez et al. (2009) and Salvatteci et al. (accepted).