Pergamon

0967–0637(95)00096–8

Deep-Sea Research I, Vol. 43, No. 1, pp. 49–57, 1996

0967–0637/96 $15.00 + 0.00

Influence of temperature and ENSO events on the growth of the deep demersal fish, alfonsino, *Beryx splendens*, off New Caledonia in the western tropical South Pacific Ocean

PATRICK LEHODEY* and RENÉ GRANDPERRIN*

(*Received* 27 *February* 1995; *in revised form* 15 *August* 1995; *accepted* 21 *August* 1995)

Abstract—This paper deals with the influence of temperature on the growth of alfonsino, *Beryx splendens*, caught in New Caledonia at 23–25°S and 165–171°E. The mean temperature of the 0–500 m water layer was cross-correlated with the Southern Oscillation Index after the seasonal cycles were removed. It is shown that the interannual fluctuations of temperature are influenced by ENSO (El Niño-Southern Oscillations) events with a time-lag of several months. The growth study is based on the reading of annuli on sagittal otoliths. In order to show fluctuations in otolith growth, an index of increase variation I_{va} was defined. Superposition of the I_{va} series on temperature series suggests the growth of alfonsino to be strongly related to temperature fluctuations in intermediate-depth water masses and consequently by ENSO events which appear further north at low latitudes in the equatorial Pacific. "El Niño" events would increase growth rate whilst "La Niña" events would reduce it.

INTRODUCTION

Temperature fluctuations are often considered responsible for the formation of seasonal and annual marks (annuli) on fish otoliths, which are interpreted as fluctuations in growth rate (Panella, 1980). These otolith rings are particularly conspicuous in temperate shallow-water species, but it has also been reported frequently that some tropical or deep-water fishes show similar markings, even though temperature fluctuations in their environment are much weaker (Panella, 1980; Wilson, 1982; Samuel *et al.*, 1987; Matsui *et al.*, 1990). This applies to alfonsino, *Beryx splendens*, a deep demersal fish caught by longliners over seamounts off New Caledonia at depths ranging from 500 to 900 m (Lehodey *et al.*, 1994). This species shows clear annuli on sagittal otoliths (Lehodey, 1994; Lehodey and Grandperrin, in press). The present paper shows that variations in annulus width in alfonsino seems strongly related to temperature fluctuations in intermediate-depth water masses. Furthermore, although the alfonsino fishing grounds in New Caledonia are located 23–25° south of the equatorial zone where the ENSO (El Niño-Southern Oscillation) phenomena arises, the temperature fluctuations appear to be influenced by the occurrence of "El Niño" warm and "La Niña" cold events.

*ORSTOM, BP A 5 Nouméa, New Caledonia.

MATERIALS AND METHODS

Temperature data

The temperature data recorded by depth, date and position concern the zone delimited by 23–25°S and 165–171°E where the New Caledonia seamounts commercially fished are located (Fig. 1). They were extracted from the two data bases of the TOGA programme (Tropical Ocean and Global Atmosphere) and of the physical oceanography laboratory of the Noumea ORSTOM Centre. These have been collected through a merchant ships expendable bathythermograph (XBT) network and from temperature profiles recorded during scientific cruises. A total of 358 XBT casts and 351 temperature profiles are available in this zone for the period 1975 to 1992. Both the irregularity in sampling (Fig. 2(a)) and the decrease in temperature data frequency with depth (Fig. 2(b)) led us to select only the years 1981–1992 and the 0–500 m water layer. This selection is justified by the fact that although alfonsino were caught on the bottom at depths ranging from 500 to 900 m, these fish are known to migrate vertically during the night (Galaktionov, 1984) through the 0–500 m water layer for the purpose of feeding, where they are subject to the temperature fluctuations prevailing there.

The temperature data were averaged quarterly, and the seasonal cycle was removed in order to separate the interannual fluctuations from the seasonal fluctuations. The decomposition was made according to the X 11 procedure (Shiskin and Eisenpress, 1957; Cleveland, 1983; SAS, 1991).

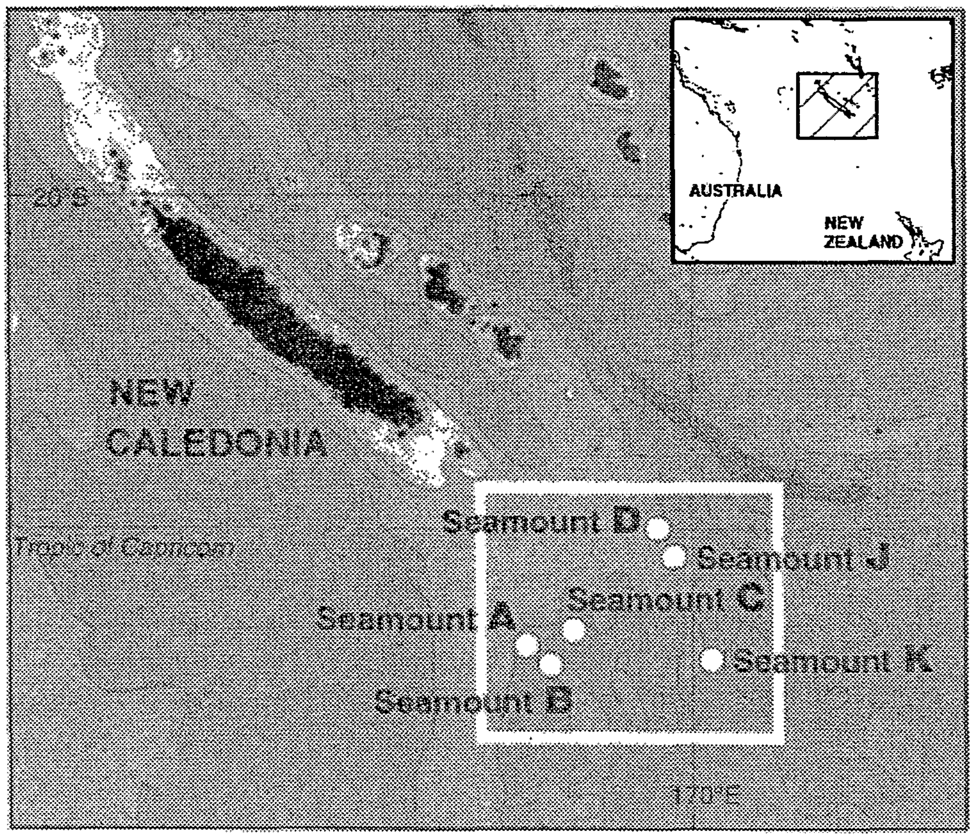

Fig. 1. Location of the seamounts exploited for alfonsino, *Beryx splendens*, south-east of New Caledonia. The temperature data were collected in the 23–25°S, 165–171°E zone.

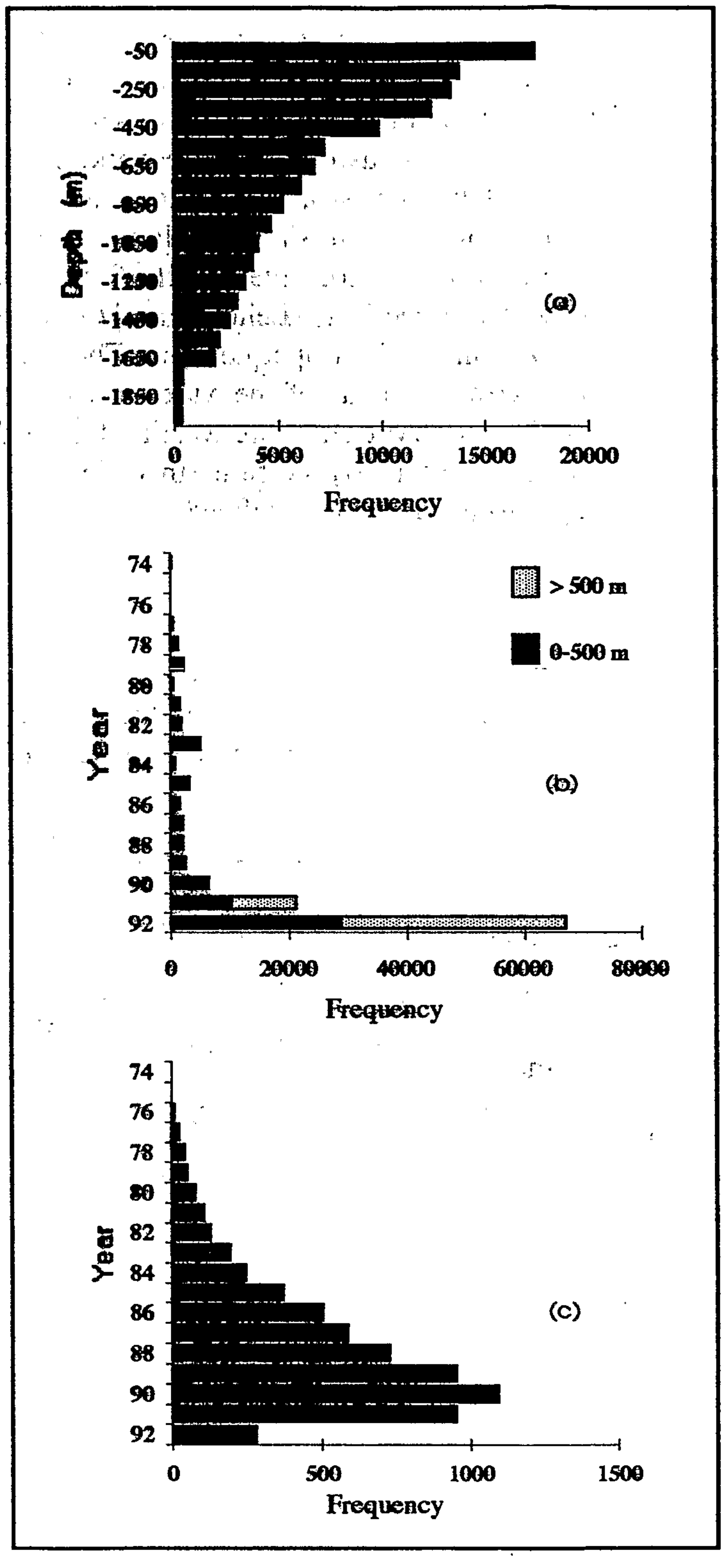

Fig. 2. Frequencies of data. Temperature data collected according to year (a), depth (b) and frequencies of measurements (after weighting) of the annuli widths according to their year of formation (c).

Otolith data

In order to study the growth of alfonsino, sagittal otoliths were collected during several commercial (Laboute, 1989; Lehodey, 1991) and scientific cruises (Grandperrin *et al.*, 1990; Grandperrin and Lehodey, 1993) carried out over the seamounts fished by the longliners. A total of 610 samples of pairs of otoliths were available, corresponding to fish ranging from 13 to 52 cm in fork length. At least five pairs of otoliths for each 1-cm size class were collected for both sexes. The otoliths of alfonsino show an alternation of clear and opaque zones conspicuous on the anterior part of their concave side, the formation periods of which correspond to warm and cool seasons, respectively (Lehodey and Grandperrin, in press), so that a full annulus includes a clear zone and an opaque zone. The nucleus is large and is counted as the first opaque zone. Measurements of the width of each annulus were made with an ocular micrometer (Fig. 3). Observations were weighted according to confidence rating (from 0 to 4) applied to readings interpretation. In order to emphasize growth fluctuations, an index of increase variation, I_{va}, was defined

$$I_{va} = \frac{Wi - \overline{Wi}}{\overline{Wi}}$$

where Wi is the width of a given annulus in microns and $\overline{Wi}$ the mean width of the ith annulus. This index reflects the growth anomaly of each annulus by comparing its width to the mean width of all the annuli which have the same age. It was calculated for all the annuli

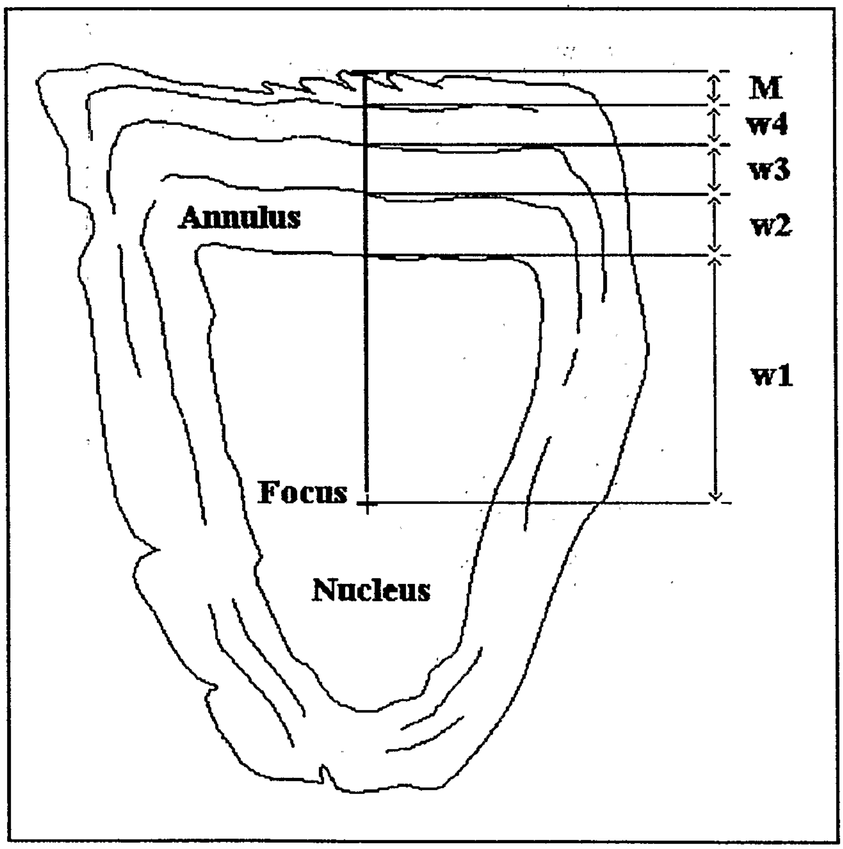

Fig. 3. Diagram of a sagittal otolith of alfonsino, *Beryx splendens*, showing the method used to measure widths (W) of annuli. M is the width of the margin.

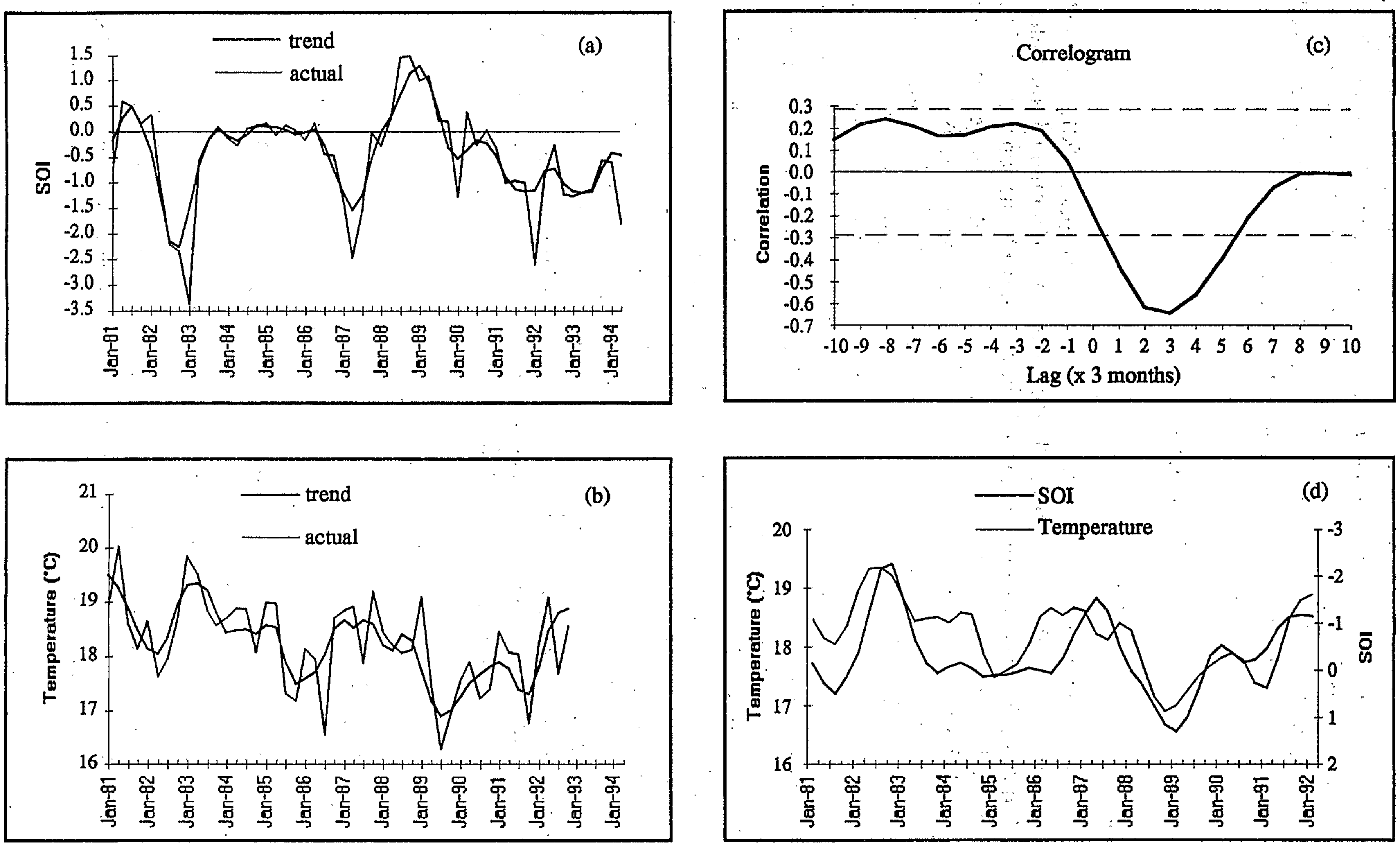

Fig. 4. Comparison between SOI and temperature time series. The cross-correlation between the Southern Oscillation Index (a) and the averaged temperature of the 0–500 m water layer for the zone 23–25°S, 165–171°E (b) indicates a significant correlation with a shift of between 6 and 9 months (c). This correlation express itself by a good superimposition of the temperature series shifted by 7.5 months on the reversed SOI series (d). Dashed lines delimit the confidence interval at the 95% level.

after the age of each of them was back-calculated. As back-calculations start from sampling years 1991–1992, and as the number of otolith samples is constant whatever the size class, the number of observations decreases progressively going back in time (Fig. 2(c)). In order to allow comparison between I_{va} and temperature series, the I_{va} values were averaged quarterly to obtain a time series consistent with that of the temperature series.

RESULTS

Interannual fluctuations of temperature

The evolution of the temperature of the 0–500 m water layer since 1981, averaged quarterly (Fig. 4(a)), shows, after removal of the seasonal cycle, interannual anomalies which seem to follow ENSO events expressed through the Southern Oscillation Index (SOI). This commonly used index (Fig. 4(b)) gives the normalized sea-level pressure difference between Tahiti and Darwin (Chen, 1982), negative values corresponding to El Niño (1982–1983, 1986–1987 and 1991–1993) and positive values to La Niña (1988–1989). Bradley *et al.* (1987) used this index to examine the time-dependent relationship between ENSO events and continental surface air temperatures between 0 and 25° N. Here we use a cross-correlation (Legendre and Legendre, 1984; SAS, 1991) to compare the two time series of SOI and water temperature. After the SOI was averaged quarterly, the seasonal cycle was removed, as it was for the temperature series, to allow comparison between the interannual fluctuations of temperature and SOI. A preliminary test of stationarity (Dickey *et al.*, 1986; SAS, 1991) was applied to the quarterly-averaged temperatures series in order to make sure that this series was stationary ($\tau_\tau = -4.63 < -3.60$ at a 5% significance level, df = 43). The cross-correlation of the temperature on the SOI is highly significant (Fig. 4(c)), with a maximum negative value between 2 and 3 lags (i.e. 7.5 months). This correlation is shown by the good superimposition of the temperature series shifted by 7.5 months on the SOI series (Fig. 4(d)). In other words, ENSO events have repercussions at latitudes 23–25°S, with a shift of at least six months, inducing temperature anomalies within the 0–500 m water layer. These anomalies would be positive during "El Niño" warm events and negative during "La Niña" cold events.

Influence of temperature on growth

The graph of the I_{va} index does not show a conspicuous trend, which is confirmed by a test of stationarity ($\tau_\tau = -5.23 < -3.60$, df = 45). Superimposition of I_{va} series and temperature series (Fig. 5) shows that they are directly correlated for the last 4 years (1989–1992), while they are not for years prior to 1989, for which both temperature data and I_{va} observations were scarce (Fig. 2). Thus, the influence of temperature fluctuations within the 0–500 m water layer on the growth of the annuli of alfonsino for the years 1989–1992 appears clearly. For earlier years this influence might be obscured by the lack of data. In addition, otolith reading becomes increasingly difficult as fish get older, because the widths of the annuli decrease as their number increases. This may induce uncertainty in age determination and consequent unpredictable shifts between I_{va} and temperature series as we look further back in time. Also, as the increments become more narrow with age, precision of measurement decreases, and slight differences among years may not be detected.

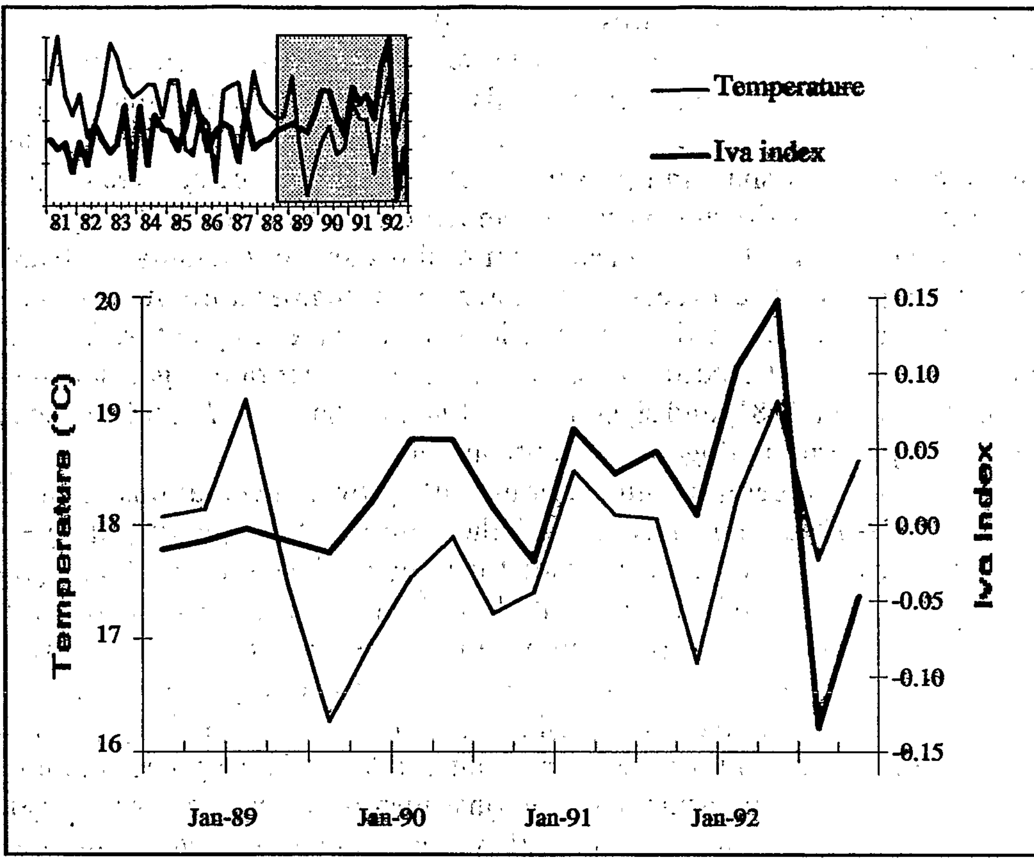

Fig. 5. Superimposition of the I_{va} index and temperature trend of the 0–500 m water layer after removal of the seasonal cycle for the zone 23–25°S, 165–171°E and for 1981–1992.

DISCUSSION

Oceanographers and meteorologists who study ENSO events focus their effort on the equatorial and tropical Pacific Ocean, where the signal originates. Thus, the area studied by the international TOGA (Tropical Ocean and Global Atmosphere) and COARE (Couple Ocean Atmosphere Response Experiment) programmes is limited to 20°N–20°S. Therefore the oceanic consequences of this phenomenon at higher latitudes are poorly known. However Delcroix and Henin (1989) have studied the influence of ENSO events on the south-east Pacific water masses during the 1982–1983 "El Niño" event between 10°S and 24°S for the 0–400 m layer. They show that interannual temperature fluctuations were stronger below 100 m than in the 0–100 m layer, this latter being more affected by seasonal fluctuations. Delcroix and Henin (1989) also shown that between latitudes 18 and 24°S the temperature anomaly due to the El Niño event seems to reverse, which means that the heat content of the 0–400 m layer increases. This is in agreement with the results of our study. However the signal seems to appear with a shift of at least six months. The causes of the appearance of such a signal and the reasons for the time-lag remain so far unknown (possibilities being low-frequency wave propagation, advection induced by the displacement of the Warm Pool, wind stress fluctuations and local Ekman pumping). More generally, the mechanisms of the repercussions of ENSO events in mid-latitudes are poorly known and probably complex. Recent studies even suggest that the consequences of the strong 1982–1983 El Niño could have lasted 11 years and spread over the northern

Pacific Ocean (McPhaden, 1994; Jacobs *et al.*, 1994).

Temperature is by far the factor that is most often studied with regard to its influence on the growth of otoliths and consequently of fish. Numerous authors have showed the importance of temperature on the growth of fish, the otoliths of which grow faster when temperature increases. Marshall and Parker (1982) showed that the otoliths of the salmon *Onchorhynchus nerka* stop growing when the temperature drops below 5°C whilst the body carries on growing very slowly. This means that otoliths are very sensitive to temperature and are consequently good recorders of the interannual temperature fluctuations. In the same way several studies were carried out in order to deduce the temperature fluctuations of past oceans using the fossil records of certain marine invertebrate organisms like corals (Dunbar and Wellington, 1981) and shells (Jones, 1981; Williams *et al.*, 1982), which present carbonate growth patterns analogous to otolith annuli.

The correlation of temperature fluctuations with growth fluctuations is particularly conspicuous for 1989–1992, years during which the quality and the quantity of observations of the I_{va} index are greater. As a matter of fact, for studying the influence of temperature on growth over a longer period of time, it would have been better to increase the number of otolith samples from large fish. This would have increased the number of observations of back-calculated annuli and consequently decreased the uncertainty induced in age reading going backwards into the lifespan of the fish. Furthermore, the bulk of temperature data was collected during the scientific cruises carried out in 1991–1992 over the seamounts where fish were sampled. These temperature data are consequently also particularly representative of the environment of alfonsino at the time they were caught. Therefore only the results obtained for the last 4 years should be considered as wholly reliable. They indicate that the growth of alfonsino seems directly influenced by temperature fluctuations occurring in the water layer they inhabit. As these temperature fluctuations appear to be themselves influenced by ENSO events with a lag of several months, it may be concluded that the growth of alfonsino is influenced by ENSO events even though this fish lives in deep waters far away from the equator where ENSO events arise. El Niño events would increase growth rate whilst La Niña events would reduce it. Confirmation of such unsuspected phenomena would require the long-term collection of additional temperature data and alfonsino otolith samples. The growth of other deep-bottom fish like armorhead (*Pseudopentaceros richardsoni*), bluenose (*Hyperoglyphe antarctica)* and macrourids should also be considered provided their otoliths show clear annuli.

Acknowledgements—The authors wish to thank their colleagues, oceanographers of the Noumea ORSTOM Centre SURTROPAC programme, and particularly F. Masia, for the temperature data sorting and T. Delcroix, C. Henin and J. Picault for their advice and editorial comments.

REFERENCES

Bradley R. S., H. F. Diaz, G. N. Kiladis and J. K. Eischeid (1987) ENSO signal in continental temperature and precipitation records. *Nature*, **327,** 497–501.

Chen W. Y. (1982) Assessment of Southern Oscillation sea level pressure indices. *Monthly Weather Review*, **110,** 800–807.

Cleveland W. S. (1983) Seasonal and calendar adjustment. In: *Handbook of statistics 3. Time series in the frequency domain*, D. R. Brillinger and P. R. Krishnaiah, editors, Elsevier Science Publishers B. V., pp. 39–72.

Delcroix T. and C. Henin (1989) Mechanisms of subsurface thermal structure and sea surface thermohaline variabilities in the southwestern tropical Pacific during 1975–85. *Journal of Marine Research*, **47,** 777–812.

Dickey D. A., W. R. Bell and R. B. Miller (1986) Unit roots in time series models: tests and implications. *American Statistician*, **40**, 12–26.

Dunbar R. B. and G. M. Wellington (1981) Stable isotopes in a branching coral monitor seasonal temperature variation. *Nature*, **293**, 453–455.

Galaktionov G. Z. (1984) Features of the schooling behaviour of the alfonsina *Beryx splendens* (Berycidae) in the thalassobathyl depths of the Atlantic Ocean. *Journal of Ichthyology*, **24**, 148–151.

Grandperrin R., P. Laboute, R. Pianet and L. Wantiez (1990) Campagne "AZTEQUE" de chalutage de fond au sud-est de la Nouvelle-Calédonie (N.O. "Alis", du 12 au 16 février 1990.) ORSTOM, Nouméa: *Rapports de Missions, Sciences de la Mer, Biologie marine*, **7**, 21 pp.

Grandperrin R. and P. Lehodey (1993) Etude de la pecherie de poissons profonds dans la zone économique de Nouvelle-Calédonie. Rapport final. Contrat de recherche ORSTOM/Territoire de Nouvelle-Calédonie. ORSTOM, Nouméa: *Conventions Sciences de la Mer, Biologie marine*, **9**, 325 pp.

Jacobs G. A., H. E. Hurlburt, J. C. Kindle, E. J. Metzger, J. L. Mitchell, W. J. Teague and A. J. Wallcraft (1994) Decade-scale trans-Pacific propagation and warming effects of an El Niño anomaly. *Nature*, **370** (6488), 360–363.

Jones D. S. (1981) Annual growth increments in shells of *Spissula solidissima* record marine temperature variability. *Science*, **211**, 165–167.

Laboute P. (1989) Mission d'observation halieutique sur le palangrier japonais "Fukuju Maru" du 21 nov. au 12 déc. 1988. ORSTOM, Nouméa: *Rapports de Missions, Sciences de la Mer, Biologie marine*, **2**, 15 pp.

Legendre L. and P. Legendre (1984) *Ecologie numérique, Tome 2: La structure des données écologiques*, (2ème éd.) MASSON, Paris, 335 pp.

Lehodey P. (1991) Mission d'observations halieutiques sur le palangrier "Humboldt". Campagne de peche du 30 mai au 12 juillet 1991. ORSTOM, Nouméa: *Rapports de Missions, Sciences de la Mer, Biologie marine*, **8**, 44 pp.

Lehodey P. (1994) Les monts sous-marins de Nouvelle-Calédonie et leurs ressources halieutiques. ORSTOM Edition Paris, *Trav. Doc. micr.*, **122**, 401 pp.

Lehodey P. and R. Grandperrin (in press) Age and growth of alfonsino, *Beryx splendens*, over the seamounts off New Caledonia. *Marine Biology.*

Lehodey P., P. Marchal and R. Grandperrin (1994) Modelling the distribution of alfonsino, *Beryx splendens*, over the seamounts of New Caledonia. *Fishery Bulletin US*, **92**, 748–759.

Marshall S. L. and S. S. Parker (1982) Pattern identification in the microstructure of sockeye salmon (*Oncorhynchus nerka*) otoliths. *Canadian Journal of Fisheries and Aquatic Sciences*, **39**, 542–547.

Matsui T., S. Kato and S. E. Smith (1990) Biology and potential use of pacific grenadier, *Coryphaenoides acrolepis*, off California. *Marine Fisheries Review*, **52**, 1–17.

McPhaden M. J. (1994) The eleven-year El Niño? *Nature*, **370** (6488), 326–327.

Panella G. (1980) Growth patterns in fish saggitae. In: *Skeletal growth of aquatic organisms: biological records of environmental change*, D.C. Rhoads and R.A. Lutz, editors, (Topics in Geobiology series vol 1), Plenum, New York, pp. 519–556.

Samuel M., C. P. Mathews and A. S Bawazeer (1987) Age and validation of age from otoliths for warm water fishes from the Arabian Gulf. In: *Age and growth of fish*, R. C. Summerfelt and G. E. Hall, editors, Iowa State University Press, pp. 253–265.

SAS (Statistical Analysis System) (1991) *Applications guide 1, version 6, first edition: time series modelling and forecasting, financial reporting and loan analysis.* Cary, NC: SAS Institute Inc., 380 pp.

Shiskin J. and H. Eisenpress (1957) Seasonal adjustments by electronic computer methods. *Journal of the American Statistical Association*, **52**, 415–449.

Williams D. F., M. A. Arthur, D. S. Jones and N. Healy-Williams (1982) Seasonality and mean annual sea surface temperatures from isotopic and sclerochronological records. *Nature*, **296**, 432–434.

Wilson R. R. Jr (1982) A comparison of ages estimated by the polarized light method with ages estimated by vertebrae in females of *Coryphaenoides acrolepis* (Pisces: Macrouridae). *Deep-Sea Research*, **29**, 1373–1379.