

Long-term changes in the mean trophic level of Central Chile fishery landings*

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SUMMARY: We explore long-term changes in the mean trophic level (*T_{Lm}*) of Central Chile fishery landings, using a 21 years data series (1979-1999) of official landings (Chilean Fisheries Service) of 16 species that comprise about 95% of total landing, and their corresponding trophic level estimated using gut content analysis and a trophic model of the Central Chile marine ecosystem. Because total landings off Central Chile have been strongly influenced by landings of horse mackerel (*Trachurus symmetricus*), which is a trans-zonal fishery resource (*sensu* FAO), and the periodic occurrence of El Niño Southern Oscillation (ENSO) events in the study area, we explore changes in *T_{Lm}* both excluding landings of horse mackerel and excluding landings in ENSO years. When landings of horse mackerel are excluded, a significant decline in *T_{Lm}* is found, at a rate of 0.175 per decade, which is higher than the global rate of 0.10 estimated by Pauly *et al.* (1998). Fisheries in Central Chile seem to have been fishing down the food web as the result of fishery-induced changes, since ENSO events do not seem to have induced a significant effect in this trend. Therefore, we suggest that landings of horse mackerel have masked the fishing down the food web process in local fisheries.

Key words: mean trophic level, fishery landings, Central Chile.

RESUMEN: CAMBIOS DE LARGO PLAZO EN EL NIVEL TRÓFICO PROMEDIO DE LOS DESEMBARQUES PESQUEROS EN CHILE CENTRAL. – Se exploran cambios de largo plazo en el nivel trófico promedio (*NT_p*) de los desembarques pesqueros en Chile central, utilizando una serie de tiempo de 21 años (1979-1999) de desembarques (Estadísticas Oficiales Servicio Nacional de Pesca) de 16 especies, que dan cuenta de un 95% del desembarque total, y su nivel trófico correspondiente estimado mediante análisis de contenido estomacal y un modelo trófico del ecosistema marino frente a Chile central. Debido a la marcada influencia del desembarque de jurel (*Trachurus symmetricus*), recurso pesquero trans-zonal (*sensu* FAO), en el desembarque total en Chile central y la ocurrencia periódica de eventos El Niño Oscilación del Sur (ENOS), se exploran los cambios en *NT_p* excluyendo los desembarques de jurel y el desembarque en años ENOS. Al excluir el efecto del desembarque de jurel se observa una disminución significativa de *NT_p* a una tasa de 0.175 por década, lo que es mayor que la tasa global de 0.10 estimada por Pauly *et al.* (1998). Esta tendencia se debería a cambios inducidos principalmente por la pesquería ya que ENOS no habría afectado significativamente. Por lo tanto, sugerimos que los altos desembarques de jurel habrían enmascarado el proceso de “fishing down the food webs” en Chile central, el que se habría producido en pesquerías más locales.

Palabras clave: nivel trófico promedio, desembarques pesqueros, Chile central.

INTRODUCTION

The mean trophic level of fishery landings (*T_{Lm}*) has been proposed by Pauly *et al.* (1998) as

an index of the impact of fishing. On a global scale, *T_{Lm}* has showed a decreasing trend for the last 45 years as a result of a gradual transition in landings from piscivorous, long-lived and high trophic level species to short-lived and low trophic level species (i.e. planktivorous pelagic fish and crustaceans).

*Received September 18, 2003. Accepted September 29, 2004.

This phenomenon is called ‘fishing down the food webs’ (FDFW) and, in an initial stage the transition in target species produces an increase in landings, followed in a more advanced stage by a decrease in landings that could reflect fishery-induced changes at the community and ecosystem levels (Pauly *et al.*, 1998).

Although FDFW constitutes a controversial issue, even the most reluctant scientists agree that FDFW could be one of the explanations for changes in fish populations on global scales (Caddy *et al.*, 1998; Caddy and Garibaldi, 2000). However, considering the complexity and high regional variability in world fisheries (Botsford *et al.*, 1997), analyses are needed to test whether FDFW is also occurring in more local fisheries.

For the South Pacific Ocean (FAO areas 81 and 87), Pauly *et al.* (1998) report wide amplitude fluctuations in TL_m , with landings continuing to increase as TL_m declined in recent years. Both features seem to be an exception to FDFW. A possible explanation is found in the Peruvian anchoveta fishery collapse and the later development of an important offshore fishery based on horse mackerel (*Trachurus symmetricus*), which is a migratory species at a high trophic level. Therefore, high landings of horse mackerel could have masked changes in more local fisheries in recent years (Pauly *et al.*, 1998).

The Humboldt Current System off Central Chile is a typical eastern boundary current system sustaining one of the most productive fisheries worldwide (FAO, 1995). By the late 1970s, the horse mackerel had become the most important fishery resource of Central Chile thanks to the development and later westward expansion of an important offshore fishery, mainly composed of an industrial purse-seine fleet. Consequently, landings of horse mackerel have influenced total landings in Central Chile in recent decades (Fig. 1). Although the ecosystem impacts of fishing on fish assemblages off Central Chile are poorly understood, evidence indicates that the most important fishery resources seem to have reached their maximum sustainable level, while others show clear signs of overexploitation (Cubillos *et al.*, 1999; Quiñones *et al.*, 2003).

It is acknowledged that El Niño Southern Oscillation (ENSO) is responsible for most of the inter-annual variability in the whole Eastern Pacific Ocean basin (Strub *et al.*, 1998). In Central Chile, ENSO induces changes in marine populations, especially fishes inhabiting the pelagic domain (Yáñez *et al.*, 1992; Arcos *et al.*, 2001), but also benthic

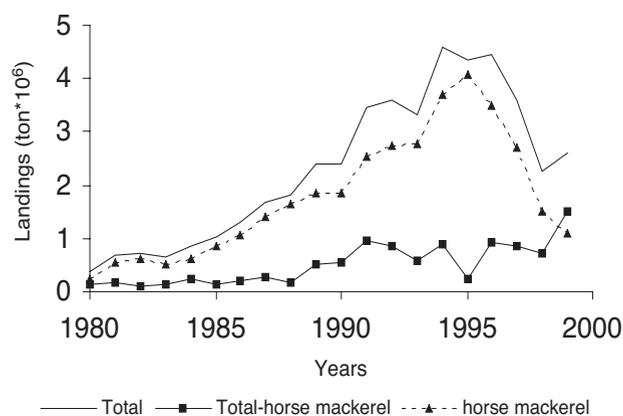


FIG. 1. – Total landings, total landings without including horse mackerel, and horse mackerel landings in Central Chile (1979–1999).

species (Gutiérrez *et al.*, 2000). This is important because landings off Central Chile are dominated mostly by pelagic fish species (Neira *et al.*, 2004).

Consequently, the objectives of the present study are: i) to examine long-term changes in TL_m of fishery landings from Central Chile, ii) to determine whether the long term trend of TL_m in Central Chile has been masked by landings of horse mackerel, and iii) to determine whether changes in TL_m are influenced by ENSO events.

MATERIAL AND METHODS

The study area (Fig. 2) represents the marine zone off Central Chile (33°S to 39°S), which was defined taking into account both fishery management units and the distribution patterns of the most important fishing fleets. The study area is also a biogeographic unit defined by the following oceanographic and topographic features: highly seasonal coastal upwelling events (Arcos and Navarro, 1986); high turbulence during summer due to south-westerly winds, but also during winter due to weather fronts crossing the region from the west; and high offshore transport levels during summer (Ahumada, 1989; Strub *et al.*, 1998).

Landing data by species (in tonnes wet weight) were obtained from the Chilean Fisheries Service Statistics Yearbooks (1979–1999; www.sernapesca.cl). Landings for the 16 selected species (Table 1) correspond to the sum of their landings from 33 to 39°S. The selected species comprise about 95% of the total landings in Central Chile.

The trophic level for species i (TL_i) was estimated using the available information on gut content

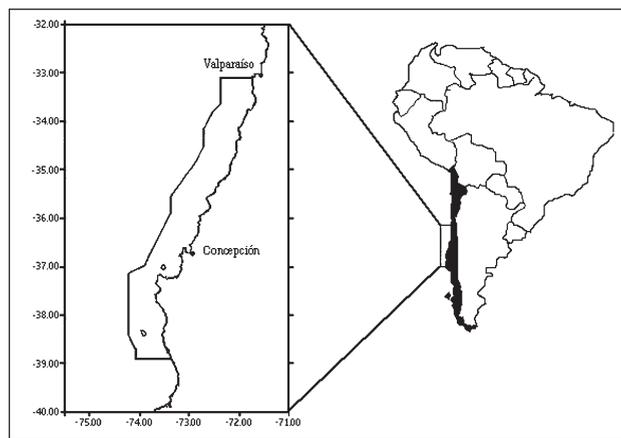


FIG. 2. – Study area. Marine zone off Central Chile (33°S-39°S).

analysis derived from surveys designed to obtain biomass estimates and diet for the target and by-catch species in fisheries off Central Chile and the Ecopath with Ecosim software version 5.0 (EwE; Christensen and Pauly, 1992; Walters *et al.*, 1997). Values of TL_i for mackerel, elephant fish and snoek were gathered from FishBase (Froese and Pauly, 2002), while TL_i for golden conger-eel and red conger-eel were assumed to be similar to TL_i estimated for black conger-eel (*G. maculatus*) using trophic models (see Table 1).

Following Pauly *et al.* (1998), estimates of the mean weighted trophic level of the catch (TL_m) for each year of the time series were calculated as:

$$TL_m = \sum_{i=1}^n TL_i * \left(\frac{Y_i}{Y_T} \right)$$

where TL_i is the trophic level of species i ; Y_i is the landing of species i in a given year; Y_T is the total landing of all species in the same year, and n is the number of years.

To account for the effect of horse mackerel on the long-term trend of TL_m , two analyses were carried out. First, we calculated TL_m considering all selected species. Then, we recalculated TL_m excluding landings of horse mackerel.

To account for ENSO-induced changes in TL_m , we recalculated TL_m excluding landings in years with ENSO events. Following the National Oceanographic and Atmospheric Administration (NOAA) definition of ENSO years (www.cdc.noaa.gov/map/clim/sst_olr/el_nino_anim.shtml), 1982-1983, 1991-1992, 1994-1995 and 1997-1998 were considered as ENSO warm events, while 1984, 1988-1989, 1995-1996 and 1998-1999 were considered as ENSO cold events.

Table 1. – List of the species included in this study and their corresponding trophic level. (a): estimated in this study using gut content analysis (Lillo *et al.*, 1993; Arancibia, 1992; Arrizaga, 1983; Arrizaga *et al.*, 1993; Cordova *et al.*, 1999) and the Ecopath with Ecosim software; (b): assigned assuming these species have a diet composition similar to *G. maculatus*, which was estimated in this study; (c): FishBase (Froese and Pauly, 2002).

Common name	Scientific name	Trophic Level
Pacific sandperch	<i>Prolatilus jugularis</i>	3,77 ^a
cardinal fish	<i>Epigonus crassicaudus</i>	3,72 ^a
horse mackerel	<i>Trachurus symmetricus</i>	3,72 ^a
snoek	<i>Thyrstites atun</i>	3,70 ^c
common hake	<i>Merluccius gayi</i>	3,49 ^a
red conger-eel	<i>Genypterus chilensis</i>	3,43 ^b
golden conger-eel	<i>Genypterus blacodes</i>	3,43 ^b
black conger-eel	<i>Genypterus maculatus</i>	3,43 ^a
mackerel	<i>Scomber japonicus</i>	3,30 ^c
elephant fish	<i>Callorhynchus callorhynchus</i>	3,20 ^c
skates	<i>Raja spp.</i>	3,00 ^a
anchovy	<i>Engraulis ringens</i>	2,02 ^a
sardine	<i>Sardinops sagax</i>	2,02 ^a
common sardine	<i>Strangomera bentincki</i>	2,02 ^a
red squat lobster	<i>Pleuroncodes monodon</i>	2,00 ^a
yellow squat lobster	<i>Cervimunida johni</i>	2,00 ^a

Spearman's rank correlation (r_s) was used to establish a significant relationship between TL_m and year and TL_m and landings.

RESULTS

The maximum TL_i (near $TL=4$) was found in Pacific sandperch (*Prolatilus jugularis*), while the lowest value (near $TL=2$) was shared by planktivorous fish (anchovy, sardine and common sardine) and detritivorous benthic crustaceans (red squat lobster and yellow squat lobster) (Table 1).

Changes in TL_m in Central Chile are shown in Figure 3. TL_m of all landings did not show a significant decreasing trend ($r_s=-0.15$, $p=0.493$) (Fig. 3a). The greatest TL_m value for the time series was found for 1988 ($TL_m=3.58$). The lowest values are in the first (1979; $TL_m=3.23$) and the last year of the time series (1999; $TL_m=2.67$), and are related mostly to the low horse mackerel landings in those years (Fig. 1). In fact, at the beginning of the time series, the horse mackerel fishery was hardly exploited, while at the end it was heavily over-exploited (Quiñones *et al.*, 2003). However, when landings of horse mackerel were excluded, TL_m showed a significant decline ($r_s=-0.70$, $p<0.001$) (Fig. 3b). ENSO events did not seem to have greatly affected the long-term trend of TL_m . In fact, when landings in ENSO years are eliminated, the correlation improves ($r_s=-0.93$, $p<0.001$) (Fig. 3c). Therefore, a significant negative correlation

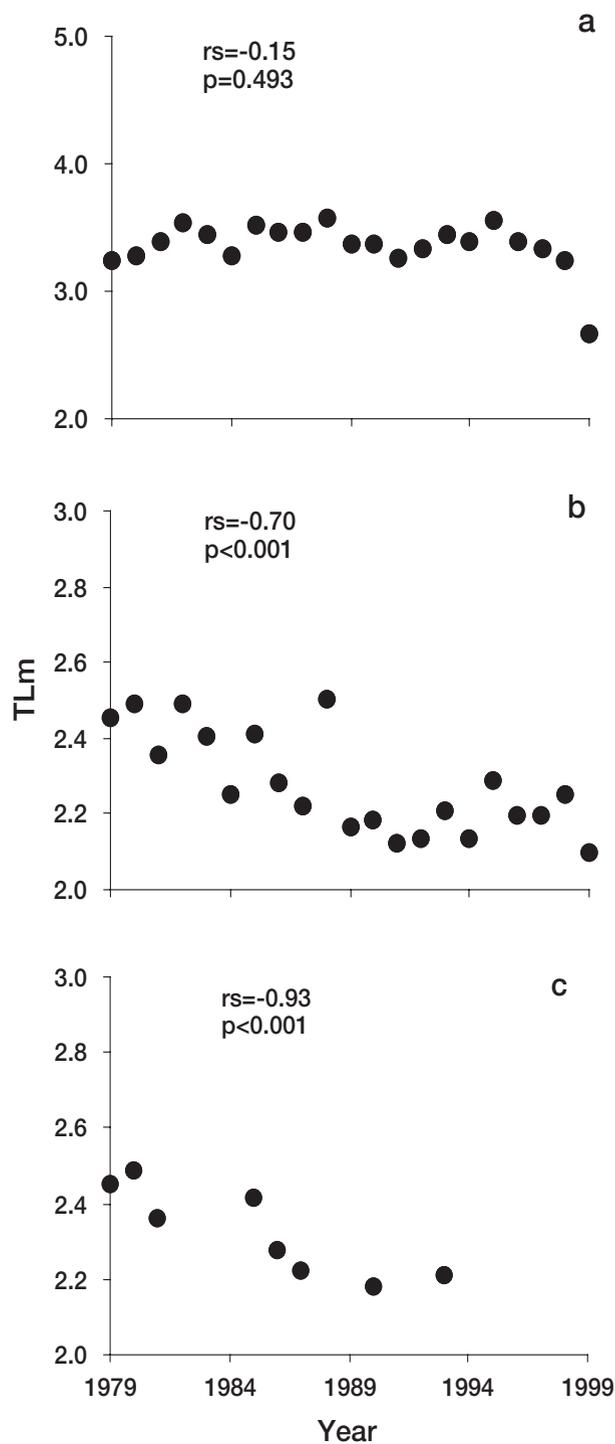


FIG. 3. – Mean trophic level of fishery landings (TL_m) in Central Chile (33°S-39°S). a) Total landings; b) excluding landings of horse mackerel; c) excluding landings of horse mackerel and landings in years affected by El Niño Southern Oscillation.

between TL_m and time is found. This could reveal the effect of FDFW once the effects of horse mackerel and ENSO are removed.

There was no significant relationship between total landings and corresponding mean trophic levels ($rs = 0.03$; $p = 0.902$; Fig. 4a). Landings

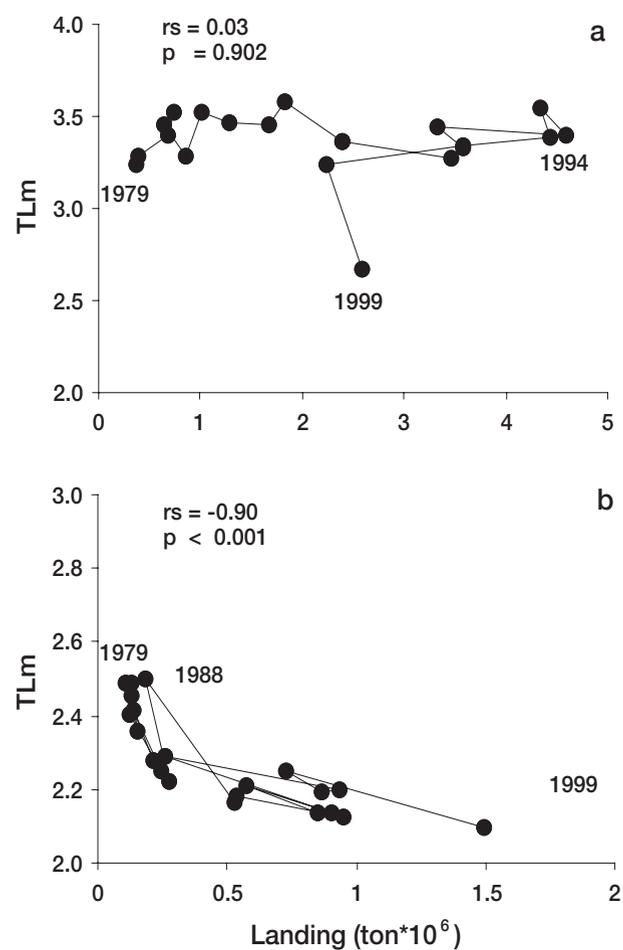


FIG. 4. – Trophic level of fishery versus landings in Central Chile (33°S-39°S). a) Total landings; b) excluding landings of horse mackerel.

increased until 1994 without great changes in TL_m . At this point, the relationship tends to revert due to a decline in total landings. When horse mackerel landings are excluded from the analysis (Fig. 4b), a clear inverse relationship between TL_m and landings is observed ($rs = 0.90$; $p < 0.001$). In this case, landings are still increasing while mean trophic level of the fishery decreases. The increase of TL_m in year 1988 is mainly related to the dramatic drop in landings of the sardine (*S. sagax*), a species of a low trophic level, from more than 100 thousand tonnes in 1997 to about 50 thousand tonnes in 1998.

DISCUSSION

There are some potential limitations in our analysis. The number of species included in this study is small when compared to similar published analyses (e.g. Pauly *et al.*, 1998; Pinnegar *et al.*, 2003).

However, the selected species comprise 95% of landings and therefore we can argue that landings of those species not included in the present analysis are almost insignificant. Therefore, we consider that the potential impact of not including more species on the calculations and observed trends is weak.

We consider that the estimation of TL_i could be the factor that incorporates the highest uncertainty into our analysis. TL_i values were estimated using quantitative information of gut contents obtained from research surveys designed to estimate stock size for the main fishery resources in Central Chile. Unfortunately, gut content analyses for the most of the groups in the study area have been sporadic and short-term. Consequently, it was not possible to estimate the TL_i variance. The assumption of assigning a single trophic level to a species is problematic, as pointed out by Caddy *et al.* (1998), since ontogenetic change in diet, and consequently in trophic level, is common in marine species. However, considering that most species feed at lower trophic levels when they are smaller, and fishing pressure usually reduces the mean size of fish, the effect can be considered as conservative (Pauly *et al.*, 1998; Pinnegar *et al.*, 2003).

We acknowledge that alternative and independent methods, such as using stable isotopes of nitrogen (Post, 2002), are available to establish TL in aquatic organisms. However, although the estimation of TL using gut contents can induce bias, some studies have shown a significant correlation between TL s estimated using gut content and those estimated using radioisotopes (Kline and Pauly, 1998; Pinnegar *et al.*, 2003).

Another factor that could have biased the observed trend in TL_m is the relatively low trophic level of small pelagic fish in Central Chile ($TL=2.02$) compared to TL s of similar species in comparative ecosystems (Jarre-Teichmann *et al.*, 1998). The low TL of small pelagic fish in Central Chile is explained by the fact that, in this system, unlike other upwelling systems, these species seem to feed almost exclusively on phytoplankton (Arrizaga, 1983; Arrizaga *et al.*, 1993). However, when TL_m is recalculated under the assumption that small pelagic fish feed 50% on phytoplankton and 50% on zooplankton (i.e. $TL=2.5$), a significant decreasing trend in TL_m is still observed ($r_s=-0.65$; $p=0.001$).

Since fishing activity in Central Chile started before the period covered by our 21-years data series, it is possible that populations of top predators

that are not present in landings today could have been overexploited before 1979. In fact, in this area both sperm whale (*Physeter catodon*) and sea lion (*Otaria flavescens*) used to be hunted (Aguayo-Lobo *et al.*, 1998). However, the hunting activities of both species were stopped after their populations had been severely depleted. Therefore, our study can be viewed as summarising the trends in TL of the catches of fish off Central Chile (because harvesting of mammals in early years is excluded), with the exception of swordfish (*Xiphias gladius*). This species sustained an important inshore artisan fishery from 1952 to 1986 (Barbieri *et al.*, 1998). After that, landings of swordfish have corresponded mostly to individuals captured by an industrial fleet of long-liners operating beyond the Chilean Exclusive Economic Zone (i.e. offshore of 200 nautical miles).

When horse mackerel landings are excluded from the analysis, it is observed that, over time, the long-term TL_m shows a decreasing trend, in accordance with what is predicted by the hypothesis of FDFW. Fisheries landings in Central Chile are highly dependent on fish species, especially small-sized pelagic fishes such as common sardine and anchovy, which are located at low trophic levels (Neira *et al.*, 2004).

The increasing importance of small pelagic fish in the Central Chile fishery landings could be explained by a change in fishery preferences (due to the lack of more valuable species), high fishing mortality and good recruitment (SSP, 2001; Quiñones *et al.*, 2003). In addition, both abundance and availability of common sardine and anchovy are also related to interannual and long-term changes in the environment (Yáñez *et al.*, 1992). Fishing removal of both common sardine and anchovy is likely to impact the whole food web, since wasp waist control exerted by small pelagic fishes is hypothesised to be characteristic feature in upwelling ecosystems (Cury *et al.*, 2000).

In conclusion, our analysis confirms that landings of horse mackerel have masked a FDFW process in inshore fisheries off Central Chile, as suggested by Pauly *et al.* (1998). In addition, we suggest that fisheries in Central Chile have been fishing down the food web as a result of fishery-induced changes rather than environmental changes associated with ENSO events. In Central Chile, TL_m has declined at a rate of 0.175 levels per decade, from 2.45 in 1979 to 2.10 in 1999, which is higher than the global rate of 0.10 levels per decade estimated by Pauly *et al.* (1998). This trend is also higher than the decreasing trend estimated, for instance, for the

Gulf of Thailand, an ecosystem in which fisheries resources have been depleted by human activities (Christensen, 1998).

ACKNOWLEDGEMENTS

We are grateful to the EU INCO-DC Concerted Action Project "Placing fisheries in their ecosystem context", through which funding was granted for both a workshop in Sao Paulo, Brazil (December 1998) and a conference in the Galapagos Islands (December 2000). We also thank two anonymous referees for their comments on an earlier version of this paper.

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Scient. ed.: L. Hutchings