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# Temperature and massive fish deaths in southern South America

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**Abstract:** Based on a compilation of data on massive fish deaths occurred in southern South America during the Twentieth Century, we assessed the importance of climatic variables on these phenomena. We found a strong relationship ($R^2$ =0.68) between these massive fish deaths and the mean monthly air temperature. Along the annual temperature range there is a central range (14.6° C to 20.0° C), where the probabilities that a fish community suffers massive deaths is very low. Its central point (17.3° C) is very close to the mean annual value (17.2° C) of air temperature variation. We considered this agreement as corroboration at community level of Pianka's theory on physiological optima. This relationship allows to monitoring the influence of climate changes, because the environmental variation and the zones of mortality and no mortality will change with predicted changes of the mean monthly values of air temperature.

**Key words:** environmental change, fish communities, freshwater fish, massive fish deaths, temperature, Argentina.

**Resumen: Temperatura y mortandades masivas de peces en el sur de Sudamérica.** Basado en la recopilación de datos de mortandades masivas de peces ocurridas en el sur de Sud América durante el Siglo XX, se evaluó la importancia de las variables climáticas en estos fenómenos. Se encontró una fuerte relación ($R^2$=0,68) con la temperatura media mensual del aire. A lo largo del rango de temperaturas anuales hay un rango central (14,6° C a 20,0° C) donde las probabilidades que una comunidad de peces sufra mortandades masivas son muy bajas. Su punto central (17,3° C) es muy cercano al valor medio anual (17,2° C) de la variación de temperatura del aire. Se considera esto como una corroboración a nivel de comunidad de la teoría del óptimo fisiológico de Pianka. Esta relación permite monitorear la influencia de los cambios climáticos, dado que la variación ambiental y las zonas de mortalidad y no mortalidad cambiarán con las variaciones predichas de los valores medios mensuales de la temperatura del aire.

**Palabras clave:** cambio ambiental, comunidades de peces, peces de agua dulce, mortandades masivas, temperatura, Argentina.

## INTRODUCTION

Massive fish deaths are relatively common phenomena in central and northern parts of the Argentine territory and other parts of the world (AFS, 1992). Often, they are related with one or several climatic variables, and rarely they occur because of a single factor, such as cold (Freyre, 1967) or heat (Kangur *et al.,* 2007).

In the Florida Península (UF, 2003) and Australia (Dawson, 2002), the lethal factor associated to high temperatures are the strongly seasonal rains that bring alochthonous material to water bodies and the decomposition of organic matter in that material provokes suddenly strong oxygen depletion. Though numerous causal factors are known, it is considered that temperature plays a fundamental role in these processes.

The massive fish deaths (MFD) considered in this paper affected both, lentic and lotic environments within an area measuring 1.4 million km$^2$, ranging 1300 km along the north-south axis from the Iguazú Falls (25° 41' S) to the Dolores Pond (36° 21' S), and 1200 km along an east-west direction, from the Atlantic coast (52° 30' W) to the Río Tercero Dam (64° 10' W). This area includes environments belonging to the Argentine section of the zoogeographic Guayano-Brazilian subregion (*sensu* Ringuelet, 1961). Fish species living in the area and susceptible to MFD are considered Paranoplatensean or Pampasic (Ringuelet, 1975), and their distribution and general ecology are discussed in Menni (2004).

Ecological theory establishes that "for each environmental variable there is a physiological optimum, where the biological efficiency of the organism is a maximum" (Pianka, 1983). This statement may be conceptually derived from principles referred to fishes under laboratory conditions (Fry, 1971) and it explains numerous situations. Notwithstanding, its application to concrete data is difficult, because of the different statistical distribution of environmental variables, and because the wide concept of "biological efficiency" only may be interpreted, for the time being, as survival, growth or reproduction. Here we examine MFD as related to the Pianka's statement on optimal values, obtaining a quantitative precise generalization related to environmental change.

## MATERIALS AND METHODS

Sixty six MFD were examined from Argentina and southern Brazil, occurred between 1912 and 2007 (n= 25 from Gómez (1996); n=19 from MAA (2000) and n= 22 from personal communications and personal observations, news reporting from the Argentinean newspapers Clarín, La Nación and El Día). These MFD were attributed to very different causes including heat (Gómez, 1986), cold (Freyre, 1967), toxic algae blooming (Colautti *et al.*, 1998), hypoxia, toxic spills, management mistakes (Domitrovic *et al.,* 1994) and organic matter excess.

For this analysis we used climatic statistics from 1961 to 1970, which is the first decade previous to the detection of global climatic change in Argentina (IPCC, 2002; Barros *et al.*, 2006). Data were obtained from the meteorological station Aero Buenos Aires, placed at 6 m. above sea level at 34° 34' S and 58° 25' W (SMN, 1985). This station is representative of the climate variation of the Paranense and Pampasic areas in the southern parts of the Guayano-Brazilian subregion.

## RESULTS

MFD have been registered throughout the year except April. The relationships between the number of monthly MFD and the monthly oscillation of temperature (°C), rainfall (mm) and atmospheric pressure (mb) (Fig. 1) show that

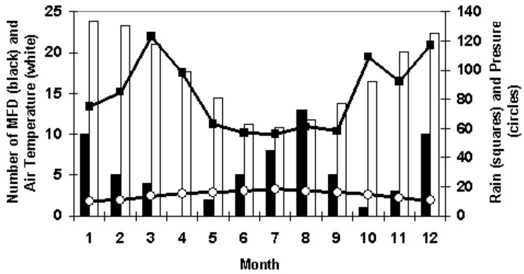


Fig. 1. Relationship between massive fish deaths (MFD) and climatic variables along the annual cycle during 95 years. Rainfall in mm, air temperature in °C and pressure in mb – 1000.

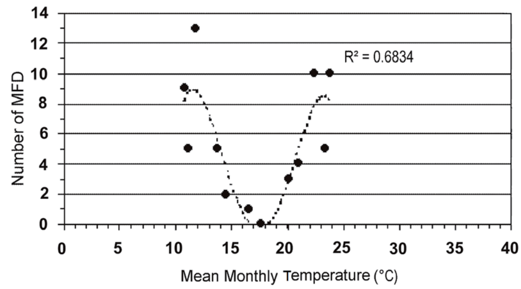


Fig. 2. Relationship between number of monthly massive fish deaths (MFD) (dotted line) and the mean monthly air temperature along 95 years.

MFD have a random distribution with respect to rainfall (r=0.2795) and pressure (r=0.1338), but they have an evident relationship (Pearson's coefficient) with the mean monthly air temperature (MMT) observations in spring and summer (r=0.6056, $p<0.05$), and in autumn and winter (r=-0.5801, $p<0.05$).

MFD are more frequent in summer and winter. If the same data are represented as the absolute frequency of MFD in relation with the mean monthly air temperature (MMT) corresponding to the month of occurrence along to 95 years of observations (Fig. 2), the data fit a bell-shaped curve that shows the occurrence of more than one MFD within the range below 14.5° C and over 20.1° C. This curve has a high determination coefficient ($R^2$=0.68), with more than 65% of the variance of the number of MFD explained by the variation of MMT.

A zone of no mortality (NMZ) corresponds to the temperature ranging from 14.6° C to 20.0° C, with a central point at 17.3° C. This point is a physiological optimum (PO), where species have a maximum of efficiency and where the probability of suffering a MFD due to temperature is very low.

For the bulk of Paranensean and Pampasic fis-

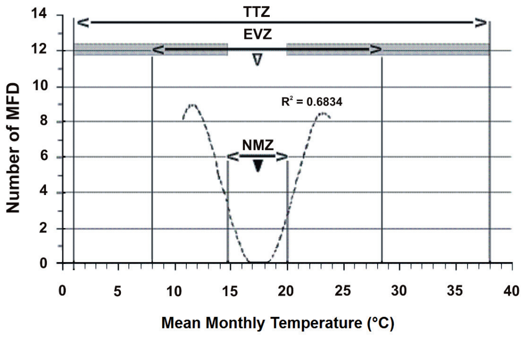


Fig. 3. Thermal zones: Relationship between monthly number of MFD and mean monthly temperatures (see Fig. 2). TTZ: thermal tolerance zone (1° C to 38° C). EVZ: environmental variation zone of air temperature (18° C to 28° C, the white triangle is the mean value 17.2° C). NMZ: non mortality zone (14.6° C to 20° C, the triangle is the physiological optimum 17.3° C = PO). Grey zones: temperature values associated to death (1° C to 14.6° C and 20° C to 38° C).

hes, the thermal tolerance zone (TTZ) measured in laboratory has a range between 1° C to 38° C (Gómez, 1996). The environmental variation (EV) is less, ranging from 8.0° C to 28.4° C (SMN, 1985), with a mean annual value of 17.2° C.

## DISCUSSION

The NMZ here calculated based on field data (14.6° C to 20.0° C) is included within the TTZ measured in laboratory (1° C to 38° C). The difference between these intervals (1.0° C to 14.6° C and 20.0° C to 38° C) is a range where temperature is an important factor associated with death. For example, a temperature of 8° C is not directly lethal, but fishes become weak and developed pathologies due to chronic exposure to sublethal levels, which brings them to death. At the other extreme, a non lethal temperature of 32° C increases metabolism and accelerates oxygen-consuming degradation of organic matter, finally causing fish death by asphyxia.

Usually, the optimal values of a variable for a given species are obtained from individuals under experimental conditions. Here, we use an indirect reasoning based on the range where massive deaths occur, implying communities or part of them, to validate and to extend Pianka's theory. MFD and temperature data are, in this case, independent in space and time.

The calculated physiological optimum of temperature (PO=17.3° C) does not present significant differences ($p<0.005$, two-tailed T test; $t=-0.019795$; $p=0.978648$) with the mean annual value of the environmental variation of air temperature (17.2° C) of the environments inhabited by the considered species in the studied area (Fig. 3). During the last 40 years in the Salado Basin in Argentina (36°S), the mean minimum annual temperature have risen from 8.9° C to 10.1° C and the total annual rainfall have increased from 700 to 950 mm (Gómez & Menni, 2005). These changes have resulted in the formation of new fish communities in water bodies formed in previously dry areas (Gómez *et al*., 2004).

Temperature increase attributed to global change is considered one of the most important factors in producing changes in freshwater systems (Meisner & Shuter, 1992; Gooseff *et al.,* 2005; Ficke *et al.,* 2007). Other factors such as the available amount of water, oxygen diminution and dryness should also be considered.

The generalization proposed here may be used to predict MFD and to assess the impact of climate change on freshwater fish communities, since the values of the NMZ and the EV will change along with changes of the mean monthly air temperature.

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