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Tolerance to high temperatures and potential impact of sea warming on reef fishes of Gorgona Island (tropical eastern Pacific)

Abstract Knowledge of upper thermal-tolerance limits of marine organisms in the tropical eastern Pacific (TEP) is important because of the influence of phenomena such as El Niño and global warming, which increase sea temperature. Laboratory experiments were conducted to determine the critical thermal maximum (CTM) of reef fishes from the TEP. In 15 reef fishes of Gorgona Island (TEP) the CTM was between 34.7°C and 40.8°C. None of these CTMs was exceeded by sea temperature in the TEP during any of the strongest El Niño events in this century (32°C during El Niño 1982–1983 and 1997–1998), which indicates that all species studied here may tolerate El Niño maximum temperatures. In addition, the CTM of the least-tolerant species was 8°C above the current mean sea temperature in a wide range of latitudes in the TEP. This suggests that fishes live far from their upper thermal tolerance limits and that the current global-warming trend is still unlikely to be dangerous for these species. If sea temperature continues to increase at the current rate, in about a century sea temperature could exceed the thermal tolerance of some reef fishes and threaten them with extinction. Such risk, however, might occur sooner if the sea temperature during El Niño also increased in steps with the global warming, but also because other processes involved in maintaining population, such as reproduction, can be affected at lower temperatures. The possible ability of reef fishes to adapt to increases in sea temperature is discussed.

Introduction

Temperature is one of the most important environmental factors affecting marine organisms. It can affect the function of cell molecules (Somero 1969), mortality, growth and reproductive rates of individuals (Brey 1995), size and distribution (local and geographical) of populations (Moore 1975; Wilson 1981; Grove 1985; Arntz and Fahrbach 1996) and structure of communities and ecosystems (Glynn 1988).

In the tropical eastern Pacific (TEP), El Niño and global warming are recognised as the principal causes of increasing sea temperature (Barber and Chavez 1983; Jokiel and Coles 1990; Roemmich 1992; Urban 1994; Cortés 1997; Strong et al. 2000). During El Niño, sea-surface temperature in the TEP has briefly (days to months) reached 30–32°C (4–5°C above normal high levels). On the other hand, as a consequence of the global warming, increments of 0.5–1°C per decade in sea temperature in the TEP have been reported (Jokiel and Coles 1990; Roemmich 1992; Strong et al. 2000). The knowledge of upper temperature-tolerance limits of marine organisms in the TEP becomes important, since sea warming related either to global warming or to El Niño has been associated with negative changes in several marine populations, such as those of certain mammals, birds, fishes and invertebrates (Barber and Chavez 1983; Grove 1985; Glynn 1988, 1991; Arntz and Fahrbach 1996; Veit et al. 1996; Urban and Tarazona 1996). High-temperature-tolerance studies in the TEP, however, are scarce and generally limited to invertebrates and especially corals (Coles et al. 1976; Glynn and DCroz 1990; Urban 1994; Mate 1997). These studies indicate that most of the coral-reef species live near their upper thermal limits, which threatens them, considering the current global-warming trend (Jokiel and Coles 1990; Glynn 1991, 1993). On the other hand, high temperatures during El Niño have exceeded the upper thermal-tolerance limits of corals; therefore, temperature has been considered as responsible for massive...
bleaching and death in corals in the TEP during this phenomenon (Glynn and DCroz 1990). In contrast, populations of bivalves from Peru, although decreasing their density during El Niño events (Urban and Taranzona 1996), seem to be tolerant of high El Niño temperatures (Urban 1994). Thus, the importance of high El Niño temperatures may not be relevant to all organisms in the TEP.

Because reef fishes have a juvenile and adult benthic phase, high temperatures may particularly affect them; they cannot escape from thermal conditions by moving to other areas, as pelagic species might do. In fact, some reef-fish populations have decreased, and have even locally disappeared during El Niño events (Grove 1985); however, the cause of these changes remains unknown. Changes in reef-fish populations related to global warming have not been reported, perhaps because of the lack of long-term monitoring. In populations of birds and corals monitored for a long time, decreasing trends in density have been related to global warming (Glynn 1991, 1993; Veit et al. 1996). In this paper we determine the critical thermal maximum (CTM) of 15 reef fishes of Gorgona Island in the TEP, in order to identify reef-fish tolerance of high El Niño temperatures and the possible impact of global warming on these species.

Materials and methods

This research was carried out in Gorgona Island national park (2°58’N, 78°11’W). Gorgona is a typical locality of the TEP; its surface temperature and salinity are representative of a broad portion of this region (Glynn et al. 1982, Cortés 1997). Within-year water temperature remains between 25°C and 27°C, but occasionally low (<19°C) and high (32°C) temperatures are recorded during, respectively, upwelling and El Niño events (Glynn et al. 1982; Vargas et al., in press). Salinity varies between 24 ½‰ and 30 ½‰. As in other localities in the TEP, the reefs of Gorgona are small and less diverse than central and Indo-Pacific reefs (Cortés 1997).

The reef-fish species studied were Thalassoma lucasanum, Halichoeres displus (Labridae), Lutjanus guttatus (Lutjanidae), Apogon pacifici, A. doii (Apogonidae), Coryphopterus urosplius, Bathygobius ramosus (Gobiidae), Magil curema (Mugilidae), Malacotenes zonifer (Labrisomidae), Eucinostomus gracilis (Gerreidae), Stegastes acapulcoensis, Chromis atrirolata (Pomacentridae), Haemulon steindachneri (Haemulidae), Plagiothodes azaleus (Blenniidae), and Cirrhithichthys oxycephalus (Cirrhitidae). All species are common on reefs, and M. curema, M. zonifer and B. ramosus are typically present in intertidal ponds also. The 15 species are widely distributed in the TEP, from the Gulf of California to the northern coast of Peru; moreover, C. oxycephalus is trans-Pacific and M. curema is cosmopolitan.

Description of temperature-tolerance methods

Thermal tolerance of fishes can be quantified in the laboratory using either static or dynamic methods. Although we used a dynamic method, a brief synopsis of both methods is provided here in order to justify our choice. More details of the approaches and assumptions of the methods can be found in Hutchison (1976), Bennett and Judd (1992) and Bennett and Beitinger (1997).

The static method quantifies time-dependent mortality of fishes suddenly plunged into high static temperatures near their upper lethal limits. The static high lethal temperature (SHLT) for 50% of the sample is then interpolated from a regression of percentage mortality on static temperature. Dynamic trials estimate the CTM by exposing fishes to a constant rate of water-temperature increase, until a non-lethal end-point (e.g. loss of equilibrium or onset of muscular spasm) is reached. The CTM is calculated as the arithmetic mean of the collective thermal points at which the end-point is reached. Because techniques and end-points differ between both methods, they do not yield similar values (Bennett and Judd 1992). Normally, in a given species, the SHLT is lower than the CTM (Bennett and Judd 1992; Bennett and Beitinger 1997). Thermal shock and handling stress are additional factors that reduce thermal tolerance in the static trials (Bennett and Judd 1992). Although dynamic methods do not have these problems, the CTM of one species may vary depending on the temperature-change rate chosen (Hutchison 1976; Elliott and Elliott 1995). However, recent studies have demonstrated that using rates slower than 1°C/h controls this problem because, above this rate, the CTM does not change significantly (Elliott and Elliott 1995; Mora and Ospre, unpublished data). Different authors argue that the static method provides useful standards for physiological comparison between species, while dynamic trials are more relevant for predictors of responses of fishes to natural thermal conditions (Bennett and Judd 1992; Bennett and Beitinger 1997). Dynamic trials are better at simulating temperature changes as they occur in nature than are static methods; furthermore, fishes have been found in natural environments at temperatures that are lethal according to static indices but tolerable according to dynamic indices. Therefore, since our purpose was to determine the thermal tolerance of some reef fishes and assess the impact of sea warming on them, we preferred the dynamic method at a rate of 1°C/h. An additional advantage of the CTM is that, considering a sublethal, rather than a lethal, temperature as a reference of tolerance, it takes into account possible chronic or delayed lethal effects of temperature, which leads to a conservative measurement of thermal tolerance.

Fish were collected with hand nets on the reefs of Gorgona Island and then transported to the laboratory (10–15 min). Fishes, principally juveniles (number and sizes by species are shown in Fig. 1), were randomly separated and placed into six 100-l aquaria (each species was tested separately). After handling, fishes were left 24 h to acclimate to the experimental conditions. Aquaria were 50% flushed with fresh salt water before each experiment. Water was maintained at a temperature equal to that of the sampling site (26.5 ± 0.5°C). Adequate aeration of the aquaria permits a high oxygen concentration and a continuous mix of water. Additionally, aquaria were covered with lids to prevent evaporation and consequent salinity changes. At the end of the acclimation period, in each of three aquaria randomly selected, temperature was gradually increased by 1°C/h with electronic heaters (+0.1°C precision). The other three aquaria were kept at a stable temperature and were used as experimental controls. Aquaria were monitored all the time in order to record the temperature at which fishes reached their end-points. CTM was calculated as the arithmetic mean of these collective thermal points.

Results

There was no evidence of stress in fishes, either in all aquaria during the acclimation period or in the controls during the experiment. Therefore, the response of fishes to these experiments likely resulted from the influence of temperature and not of other factors.

Loss of equilibrium was the principal end-point found in all the reef-fish species studied. Non-vigile and demersal fishes, such as Cirrhithichthys oxycephalus, Coryphopterus urosplius, Bathygobius ramosus and Malacotenes zonifer, were stimulated with a ruler to