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Analysis of reef fish abundance in the Gulf of California, and projection of changes by global warming

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Abstract. The Gulf of California has high endemism and diversity of its reef fish fauna. This study analyzes the abundance of 20 dominant species in the region, and evaluates possible changes to be caused by temperature increments. Stationary censuses of fishes were done in six regions during 2006, and oceanographic information for each one, including mean, minimum and maximum surface temperature, photosynthetic pigments, and nitrate, phosphate and silicate concentrations, was gathered. These factors were included in stepwise regressions to evaluate its influence on individual species, and the equations were used to project change in abundance as a result of warming in accordance to three scenarios: +1°, +2° and +3°C. The models indicated that as temperature rises, 4 species may reduce their abundance, 14 increase it and 2 may remain stable; also, 6 species may extend their geographic ranges. At community level, richness, taxonomic distinctness, diversity and average trophic level will likely increase with temperature, but the latter two will eventually return to their original levels. In conclusion, the Gulf of California fish fauna will not react homogeneously to the warming; some species may change their distribution and shifts in composition and structure are expected. These events may cause an ecological imbalance in teleost assemblages, and consequently affect the functions of the reef ecosystem in the gulf.

Key words: Temperature increase, distribution, community structure.

Introduction

The Gulf of California is recognized by its high endemism, diversity and biomass (Roberts et al. 2002, Mora and Robertson 2005), and consequently this inner sea represents one of the main areas for reef fisheries in México (SAGARPA, 2000). The Gulf is home to about 800 fish species, 271 of which are resident of rocky and coral reefs (Thomson et al. 2000), and they play a key role in these systems because their abundance and biomass makes them key elements in local trophic webs, and in the energy flow between neighboring biomes (Mumby et al. 2007).

Studies of the Intergovernmental Panel of Climate Change mention that in the last 30 years the atmospheric temperature increased between 0.3° and 0.6°C, and different models show that it will rise between 1.4° and 5.5°C by the end of the century (IPCC 2007). The panel also suggests that each of 1°C atmospheric increase, will lead to an 0.5° increase in the ocean. Many have indicated that reef faunas will be much affected by warming (Roessig et al. 2004; Perry et al. 2005; McKenzie et al. 2007). Fishes can be particularly disturbed by higher temperatures because they are ectotherms and mobile, and thus modifications in their occurrence and abundance can be rapidly detected (Bellwood et al. 2006).

The increasing trend of sea temperature worldwide is not homogeneous, as local and regional conditions have a definite influence (IPCC 2007; Hayes and Goreau 2008). However, it is important to generate scenarios in order to predict the potential impact of warming in local ecosystems, and from there provide recommendations to managers and government officials. Under this perspective it is especially relevant to analyze the current distribution, abundance and richness of marine resources exploited by man, and to plan ahead; this can support preservation of the assemblages and sustainable development. This paper presents an analysis of the current state of the abundance of 20 common fishes from the Gulf of California; we prepared numerical models for each species to predict changes in abundance and distribution under different levels of temperature increase. The results indicate that each species will behave differently and thus it is not expected that the fish assemblages in the Gulf of California will change in unison in the near future. Because of this idiosyncratic situation, it is possible that that global change will eventually have a strong effect on the function of the reef fish faunas, even when their composition may not change that much.

Material and Methods

The work was conducted in The Gulf of California, México. It is an inner sea adjacent to the Pacific Ocean, with a mixture of tropical and sub tropical waters and considerable differences in temperature between the north (average ~22°C, range 14° to 31°C) and south (average ~25°C, range 18° to 30°. Thomson et al. 2000). Stationary census (N=147) were done in six regions (Fig. 1); Los Angeles Bay (28°N), Santa Rosalía (27°N), Loreto (26°N), La Paz Bay (24°N), Cabo Pulmo (23°N) and Los Cabos (22°N). Fish abundance was estimated by counting fishes moving across observations cylinders of 5 m radius (79 m^2 sampling area), in a time period of 15 minutes. Of this interval, 5 minutes were dedicated to register species, and the following 10 to count individuals (Villarreal-Cavazos et al. 2000). The censuses were conducted in 2006, at a depth range between 5 m and 15 m, where reef fish abundance is higher (Alvarez-Filip et al. 2005; Robertson and Allen 2006). The studied regions present predominantly rocky bottoms with low coral cover (ranging from 20% at Cabo Pulmo, to 2% or less from Loreto to Los Angeles Bay; Reyes Bonilla and López Pérez, in press).

Each surveyed site was referred to a single 1° x 1° latitude-longitude cell, and for each of the six quadrats we obtained the mean, minimum and maximum surface sea temperature (°C), from the Reynolds SST analysis (1982 to 2006; www.nhc.noaa.gov/aboutsst.shtml), average photosynthetic pigments concentration (mg/m^3) from the SeaWifs and MODIS satellites (www.science.oregonstate.edu/ocean.productivity/custom.php; 1997 to 2007), and the mean nutrient concentration (nitrate, phosphate and silicate; µM), from the World Ocean Atlas 2005 (http://www.nodc.noaa.gov/OC5/SELECT/woaselect/woaselect.html), from 1950 to 2004.

Before conducting the numerical analysis, we selected the 20 most abundant species of the full database which included over 80 taxa seen in the six visited regions, These 20 species belong to six families and as they occupy different reef habitats and present a variety of morphologies, food sources and life histories, we considered them as good representatives of the entire fish community. To generate models for prediction of abundance of each fish species in accordance with environmental factors, we used stepwise regressions; this technique also allowed us to quantify the influence of each oceanographic indicator on abundance. All data were standardized, and to avoid autocorrelations the regressions were run with the "ridge" routine, using a tolerance of 0.00001 (Neter et al. 1996).

The next step was to evaluate the possible impact of ocean warming on the targeted fish species, using three possible scenarios considered by the IPCC: increment of 1, 2 and 3°C. To do so, we directly replaced the value of the new coefficient of temperature in the regression equations, when this attribute was a part of the model. In addition, the coefficients of the remainder oceanographic features were adjusted correspondingly with the proposed warming by using the estimated value obtained from linear regressions of temperature and each factor, in order to predict its response to elevation of 1° to 3°C. With these corrections the final models were more complete and able to predict the joint effect of several environmental factors at the same time. When temperature was not selected by the stepwise procedure, we only used the modified parameters in the models of fish abundance.

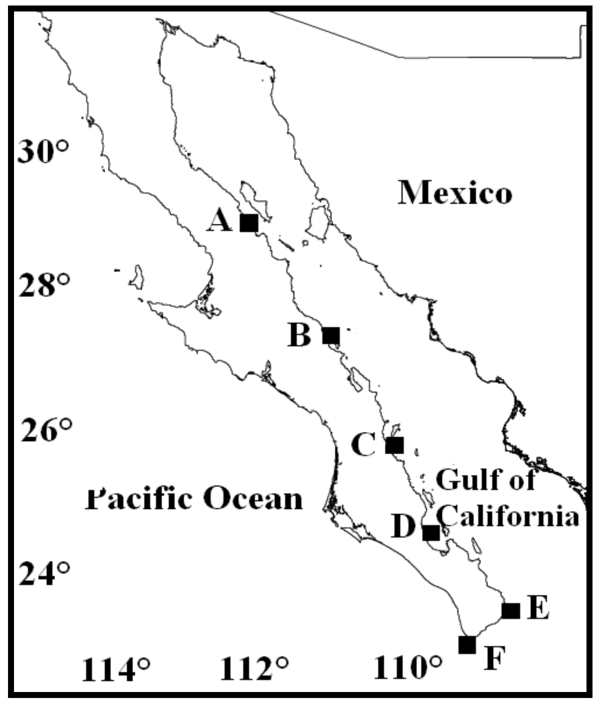

Figure 1: Study regions in the Gulf of California, Mexico; A) Los Angeles Bay, B) Santa Rosalía, C) Loreto, D) La Paz, E) Cabo Pulmo and F) Los Cabos.

Finally, we tested the consequences of changes in individual species at a higher hierarchical level by generating "future" communities from the predicted abundance of the 20 species. Then, for all regions and scenarios we calculated four ecological indices: richness, Shannon-Wiener diversity, taxonomic distinctness, and the similarity of the predicted communities to the actual data using the Bray-Curtis coefficient, and performed a cluster analysis, comparing all regions and scenarios.

Results

There were four different types of response in the 20 studied taxa. First, the models suggest that four species could reduce their abundance, including the now widespread damselfish *Abudefduf troschelli*. It is relevant to notice that the predictions point out to the eventual disappearance of a Gulf of California endemic *Chromis limbaughi*, the blue-yellow damselfish, in the northern gulf (Fig. 2).

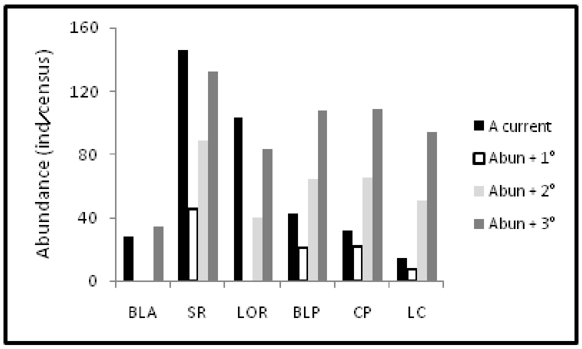

Figure 2. Current and predicted abundance of *Chromis limbaughi.*under three different scenarios of temperature increment

Other 13 species could increase their abundance and in some cases their numbers may become very similar in all areas of the Gulf (Table 1). One of them is very important for the aquarium trade (the Cortes angelfish *Holacanthus passer*), and among the rest there are two very common fishes: *Chromis atrilobata* (spot damselfish) and *Thalassoma lucasanum*, (the rainbow wrasse), as well as a key commercial species, the yellow snapper *Lutjanus argentiventris*. Finally, two species (a haemulid and a snapper) show no change caused directly or indirectly by the warming, possibly indicating a wide physiological tolerance.

Table 1 Predictions of change in abundance and geographical range of the 20 analyzed species, with temperature increases.

	Abundance		
Range	**Increase**	**Decrease**	**Same**
Increase	*P. punctatus*		
	C. puctactissima		
	S. flavilatus		
	C. oxycephalus		
	S. ghobban		
	T. grammaticum		
Decrease		*A. troschelli*	
		G. simplicidens	
		C. gracilis	
		C. limbaughi	
Same	*M. dentatus*		*P. colonus*
	H. passer		*H. maculicauda*
	B. diplotaenia		
	C. atrilobata		
	T. lucasanum		
	S. rectrifaenum		
	L. argentiventris		
	H. flaviguttatum		

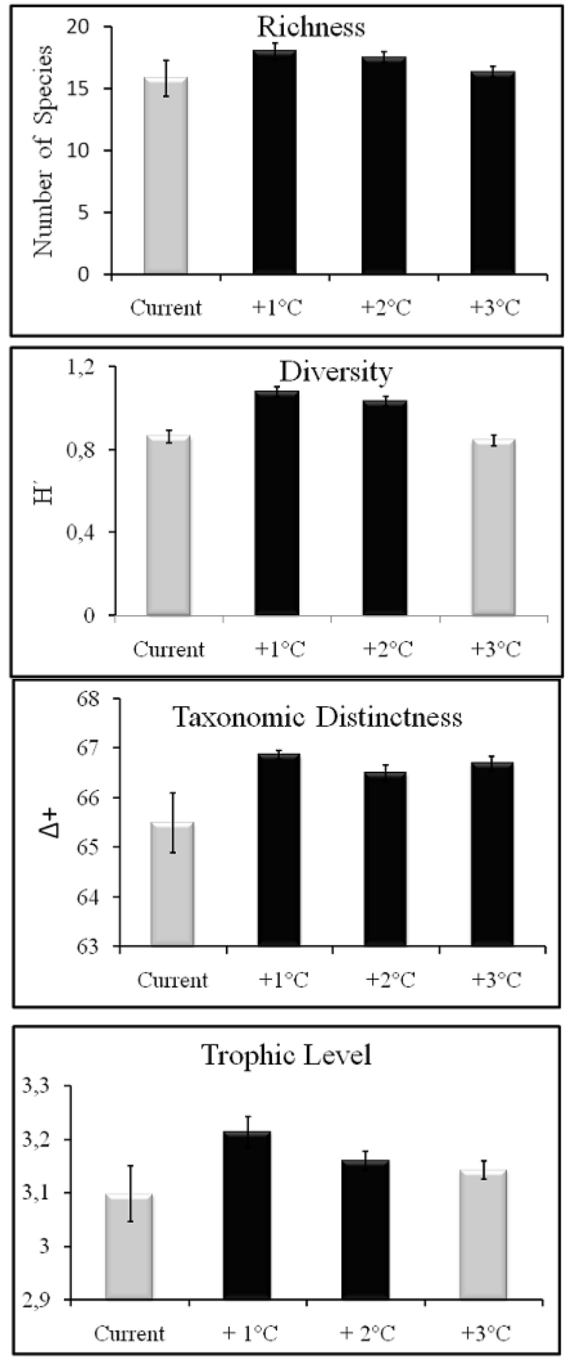

Figure 3. Changes in fish community structure according to three possible scenarios of global warming. Bars signal the average and SE, and those with the same color had no significant differences, according to Kruskal-Wallis tests.

Related to changes in distribution, six species could extend their ranges to areas where they are currently absent, in specific Los Angeles Bay. In this case we have a commercial species (*Scarus ghobban*) and a very important herbivore *(Prionurus punctatus*).

Another four species will likely have a more restricted range, and 10 apparently will be unaffected (Table 1).

The community analyses evidenced that richness, diversity, taxonomic distinctness and trophic level, significantly increase when the temperature rises 1°C. However, their values gradually lower, and in the case of diversity and trophic level at +3°C, they even return to approximately the same level they were before temperature changed (Fig. 3). Finally, the dendrogram (Fig. 4) shows that the fish communities will change depending on the temperature increase from their original condition (left side of the tree), to +3° (right side). Notwithstanding there will be a mix of assemblages since conditions starts to change, meaning that the compositional shift will not be completely ordered.

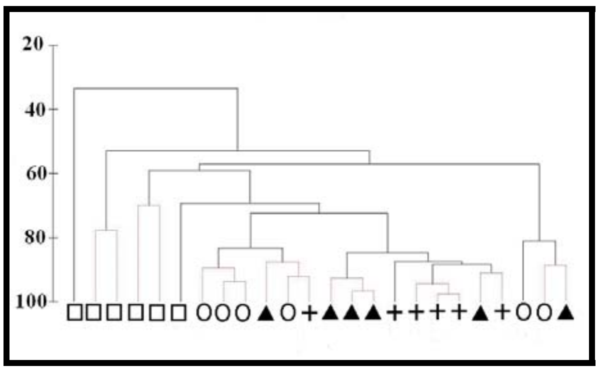

Figure 4. Dendogram showing the similarity in the current and the projected assemblages. Key: squares= actual assemblage, circles= +1°C, triangles= + 2°C; crosses= + 3°C.

Discussion

The model tested in this paper considers the response of 20 fish species to potential changes in a set of oceanographic variables including productivity and nutrient concentration; nevertheless, the forecasting is ultimately based on how sea surface temperature will increase in the Gulf of California. There are several reasons why this choice was made; first, global change models only consider sea temperature and salinity as there are excellent long-term data on the former factor, and the second can be predicted accurately from the first (IPCC, 2007). In addition (as it was done in this paper), the relation between temperature and other chemical forms in the ocean can be locally or regionally modeled (Kamykowski 2008; Silió-Calzada et al. 2008) but the link breaks at a global scale. Consequently, Donner et al. (2009) recommend that analyses of the response of reef faunas to global change should focus on temperature increase, and this justifies why most studies on the future of reef corals have also followed this approach (Sheppard 2003; Donner et al. 2005).

There are other variables which may affect the response of reef fishes to ocean warming (Baker et al. 2008; McClanahan et al. 2009). They include changes in habitat quality (specifically loss of coral cover and reef structure), in ocean circulation (which will affect dispersal and recruitment), and in acidity. Considering the first topic, reef coral cover is low along the Gulf of California (Reyes-Bonilla and López-Pérez, in press). As a consequence, most reef fish species of the Gulf of California do not depend on the presence of corals for their settlement, feeding or protection, as shown by their community stability even after severe bleaching and mortality events (Alvarez-Filip et al. 2006). For that reason we suggest that the ocean warming will not affect significantly the condition of the local fish habitats, and thus the factor was not examined here.

In relation to ocean acidity, there are worries that a lower pH can affect metabolism, larval development and other aspects of the life history of the ichtyofauna (Baker et al. 2008). Unfortunately the situation is still not clear, and Munday et al (2008) stated that any kind of prediction is still speculative as the experimental and field evidence is scant. Something similar can be said about ocean currents as there are contrasting views on the subject (IPCC 2007). Considering this, we decided not to include any of these factors in the regressions.

One of the key findings of this study is that the reef fishes of the Gulf of California will not react homogeneously to temperature increases. This was expected since the fish assemblages of the Gulf are formed by a mixture of tropical and temperate faunas (Thomson et al. 2000), with different niches and ecological requirements, and which will adjust differentially (or not at all) to oceanographic changes. Table 1 indicates that the most affected species (with reduced abundance and distribution range) are adapted to warm or cold water (*Abudefduf troschelli* and *Girella simplicidens*); probably the former will disappear because their upper temperature tolerance levels are reached, and the latter if the Gulf becomes too warm (Roessig et al. 2004; Perry et al. 2005). However, the models indicate that most species will benefits from the warming by either increasing their geographic range or their local population sizes (Table 1). A good explanation for this situation is that as practically all of the studied taxa are distributed in the Panamic Province, they are adapted to tropical conditions (Fiedler and Talley 2006) and then the ocean warming will provide them a more adequate habitat in the Gulf of California.

It was interesting that the ecological indices reach higher values with temperature increases (Fig. 3). This possibly results from the concurrent rise in richness and abundance of the fishes (especially in the northern Gulf), but the change is not "permanent" as diversity and average trophic level return to the values of 2006. This finding points out that the effects of global change may be subtler than imagined, and that as proposed by Bellwood et al. (2006), traditional ecological indices may not be good indicators of effects on ecosystem condition. However, note that taxonomic distinctness remained high, indicating a more homogeneous distribution of abundance and species richness in higher taxonomic groups in the future. This metric is recognized as a good indicator of biodiversity (Magurran 2004), and its response in this paper indicated that it can be a good choice to depict future changes in the fish faunas.

According to the dendrogram (Fig. 4), the compositional changes caused by higher temperature may be relatively orderly, but nevertheless the shift in ecological function of the resident species (shown by the average trophic level; Fig. 3), point out to possible ecological imbalances in reef fish assemblages of the Gulf in following decades; these in turn may translate to potential economic impacts. A similar statement has been done in relation to previous modifications in fish abundances along the Gulf, in particular the depletion of larger carnivores (Sala et al. 2004). The combination of unsustainable fisheries and global change may bring a bleak future for reefs in this region.

In conclusion, our results show that fish species of the Gulf of California might respond differently to increases in ocean temperature and thus the communities will not change as a unit. Because of these qualitative changes, global warming might have severe effects on the function and productivity of the local reef ecosystem.

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References

Alvarez-Filip L, Reyes-Bonilla H, Calderón-Aguilera L (2006) Community structure of fishes in Cabo Pulmo reef. Mar Ecol 27: 253-262

Baker AC, Glynn PW, Riegl B (2008) Climate change and coral reef bleaching: an ecological assessment of long-term impacts, recovery trends and future outlook. Est Coast Shelf Sci 80: 435-471

Bellwood DR, Hoey AS, Ackerman JL, Depcynzky M (2006) Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. Global Chan Biol 12: 1587-1594

Donner SD, Skirving WJ, Little CM, Oppenhemier M, Hoegh-Guldberg O (2005) Global assessment of coral bleaching and required rates of adaptation under climate change. Glob Change Biol 11: 2251-2265

Donner SD, Heron SF, Skirving WJ (2009) Future scenarios: a review of modeling to predict the future of coral reefs in an era of climate change. In van Oppen MJH, Lough JM (eds) Coral bleaching. Springer, Berlin, pp. 159-173

Fiedler PC, Talley LD (2006) Hydrography of the eastern tropical Pacific: a review. Prog Oceanog 69: 143-180

Hayes RL, Goreau TJ (2008) Satellite-derived sea surface temperature from Caribbean and Atlantic coral reef sites, 1984-2003. Rev Biol Trop 56 (suppl 1): 97-118

IPCC (2007) Cambio climático 2001. Informe de síntesis. Pachauri RK, Reisinger A (eds). IPCC/OPCC/PNUMA, Ginebra. p. 114

Kamykowski D (2008) Estimating upper ocean phosphate concentrations using ARGO float temperature profiles. Deep Sea Res part I 55: 1580-1589

Magurran AE (2004) Measuring biological diversity. Blackwell, Oxford. p. 256

McKenzie B, Gislason R, Möllmann H, Köster F (2007). Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Glob Change Biol 13: 1348-1367

McClanahan TR, Weil E, Cortés J, Baird AH, Ateweberhan M (2009) Consequences of coral bleaching for sessile reef organisms. In van Oppen MJH, Lough JM (eds) Coral bleaching. Springer, Berlin, pp. 121-138

Mora C, Robertson DR (2005). Factors shaping the range-size frequency distribution of the endemic fish fauna of the Tropical Eastern Pacific. J Biog 32: 277-286

Mumby PJ, Harborne AR, Williams J, Kappel CV, Brumbaugh DR, Micheli F, Holmes KE, Dahlgren CP, Paris CB, Blackwell PG (2007) Trophic cascade facilitates coral recruitment in a marine reserve. Proc Natl Acad Sci USA 104: 8362–8367

Munday PL, Jones GP, Pratchett MS, Williams AJ (2008) Climate change and the future for coral reef fishes. Fish Fisher 9: 261-285

Munday PL, Leis JM. Lough JM, Paris CB, Kingsford MJ, Berumen ML, Lambrechts J (in press) Climate change and coral reef connectivity. Coral Reefs 28(2)

Neter J, Kutner M, Nachtsheim C, Wassermann W (1996) Applied linear estatistical models. McGraw-Hill, New York, p 1408

Perry A L, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. Science 308: 1912-1914

Reyes-Bonilla H, López-Pérez RA (in press) Corals and coral reef communities in the Gulf of California. In Johnson ME, Ledesma-Vázquez J (ed). Atlas of coastal ecosystems in the Gulf of California. Past and present. University of Arizona Press, Tucson

Roberts CM, McClean CJ, Veron JN, Hawkins JP, Allen GR, McAllister DR, Mittermeier CG, Schueler FW, Spalding M, Wells F, Vynne C, Werner TB (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295: 1280-1284

Robertson DR, Allen GR (2006) Fishes of the tropical eastern Pacific. Smithsonian Institution. CD-ROM Version 2.0

Roessig JM, Woodley CM, Cech, Jr. JJ, Hansen LJ (2004) Effects of global climate change on marine and estuarine fishes and fisheries. Rev Fish Biol Fisher 14: 251–275

Sala E, Aburto-Oropeza O, Reza M, Paredes G, López-Lémus LG (2004) Fishing down coastal food webs in the Gulf of California. Fisheries 29: 19-25

Sheppard CRC (2003) Predicted recurrences of mass coral mortality in the Indian Ocean. Nature 425: 294-297

Silió-Calzada A, Bricaud A, Gentilli B (2008) Estimates of sea surface nitrate concentrations from sea surface temperature and chlorophyll concentration in upwelling areas: a case study for the Benguela System. Remote Sens Environ 112: 3173-3180

Thomson AD., Findley LT, Kerstitich AN (2000). Reef fishes of the Sea of Cortez. University of Texas Press, Austin. p. 353

SAGARPA (2000) Carta Nacional Pesquera. http://www.inp.sagarpa.gob.mx/CNP/anexo.htm

Villareal-Cavazos A, Reyes-Bonilla H, Bermúdez-Almada B, Arizpe-Covarrubias O (2000) Los peces del arrecife de Cabo Pulmo, Golfo de California, México: Lista sistemática y aspectos de abundancia y biogeografía. Rev Biol Trop 48: 413-424