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SUPPLEMENT

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Active restoration efforts in the Central Mexican Pacific as a strategy for coral reef recovery

Violeta Martínez-Castillo[1]; https://orcid.org/0000-0003-3932-4646
Alma Paola Rodríguez-Troncoso[1]*; https://orcid.org/0000-0001-6243-7679
José de Jesús Adolfo Tortolero-Langarica[2,3]; https://orcid.org/0000-0001-8857-5789
Amílcar Leví Cupul-Magaña[1]; https://orcid.org/0000-0002-6455-1253

1. Laboratorio de Ecología Marina, Centro Universitario de la Costa, Universidad de Guadalajara, Puerto Vallarta, Jalisco, México, 48280; viomarcast@gmail.com, pao.rodriguezt@gmail.com (*Correspondence), amilcar.cupul@gmail.com
2. Laboratorio de Esclerocronología de Corales Pétreos, Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Puerto Morelos, Quintana Roo, México, 77580; adolfo.tl@bahia.tecnm.mx
3. Tecnológico Nacional de México / IT de Bahía de Banderas, Bahía de Banderas, Bahía de Banderas, Nayarit, México, 63734.

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ABSTRACT

Introduction: The 1997-98 El Niño event caused massive coral bleaching and mortality in the Central Mexican Pacific (CMP). Punta de Mita alone used to harbor more than 30 % of the coral coverage in this region, with a mono-specific *Pocillopora* coverage. The 1997-1998 ENSO event caused massive coral mortality reducing live coral coverage to < 5 %. Despite being considered a coral region unlikely to recover, recent restoration efforts have been implemented to rehabilitate the coral community.

Objective: To assess coral recovery by analyzing the coral growth and survival rates of branching *Pocillopora* species at Punta de Mita.

Methods: Healthy coral fragments of opportunity were re-attached to the natural substrata using zip ties and measured considering their growth in terms of maximum length and width (cm) to determine their annual extension rates.

Results: After 50 weeks, corals duplicated their size, with a mean growth of ~ 4 cm $year^{-1}$. After 100 weeks (2 years), corals triplicated their size, increasing on average 8–9 cm in each diameter.

Conclusions: Successful coral reef restoration activities in the Central Mexican Pacific are the result of *Pocillopora*'s physiological processes, such as fast growth rates, and recent life-history traits, like the ability to cope with thermal anomalies, which enable them to thrive in a dynamic region severely affected by natural and anthropogenic perturbations. Indeed, a region considered unlikely to recover has regained its live coral cover from < 5 % in 1998 up to 15 % in 20 years. This demonstrates the importance of assisting natural coral recovery with restoration efforts, especially in coral locations that, despite environmental perturbations, have proven to be resilient and may become coral refugia areas under the current climate change scenario.

Key words: Scleractinia; *Pocillopora*; ecosystem restoration; coral growth; active coral restoration.

RESUMEN

Esfuerzos de restauración activa en el Pacífico Central Mexicano como estrategia para la recuperación de los arrecifes de coral

Introducción: El evento El Niño de 1997-98 causó un blanqueamiento y mortalidad masiva de corales en el Pacífico Central Mexicano (CMP). Solo Punta de Mita albergaba más del 30 % de la cobertura coralina de esta región, con una cobertura monoespecífica de *Pocillopora*. El evento ENSO de 1997-1998 causó una mortalidad masiva de corales que redujo la cobertura de corales vivos a < 5 %. A pesar de ser considerada una región de coral con pocas probabilidades de recuperarse, se han implementado esfuerzos de restauración recientes para rehabilitar la comunidad coralina.
Objetivo: Evaluar la recuperación de coral analizando el crecimiento coralino y las tasas de supervivencia de especies ramificadas de *Pocillopora* en Punta de Mita.
Métodos: Fragmentos de oportunidad de coral sanos se volvieron a unir a los sustratos naturales usando bridas y se midieron considerando su crecimiento en términos de longitud y ancho máximos (cm) para determinar sus tasas de extensión anual.
Resultados: Después de 50 semanas, los corales duplicaron su tamaño, con un crecimiento promedio de ~ 4 cm año^{-1}. Después de 100 semanas (2 años), los corales triplicaron su tamaño, aumentando en promedio 8–9 cm en cada diámetro.
Conclusiones: Las actividades exitosas de restauración de arrecifes de coral en el Pacífico Central Mexicano son el resultado de los procesos fisiológicos de *Pocillopora*, tales como tasas de crecimiento rápido, y rasgos de historia de vida reciente, como la capacidad de hacer frente a anomalías térmicas, que les permiten prosperar en una región dinámica severamente afectada por perturbaciones naturales y antropogénicas. De hecho, esta región que se consideraba poco probable que se recuperara, ha recuperado su cobertura de coral vivo de < 5 % en 1998 hasta 15 % en 20 años. Esto demuestra la importancia de ayudar a la recuperación natural de los corales con los esfuerzos de restauración, especialmente en las ubicaciones de corales que, a pesar de las perturbaciones ambientales, han demostrado ser resistentes y pueden convertirse en áreas de refugio de corales ante el escenario actual de cambio climático.

Palabras clave: Scleractinia; *Pocillopora*; restauración de ecosistemas; crecimiento de corales; restauración de corales.

INTRODUCTION

Interest in coral restoration has increased in the last two decades due to the rapid global decline of coral reefs (Hoegh-Guldberg et al., 2007; Hughes et al., 2018). More recently, a special interest in the use of coral species or genotypes more tolerant to fluctuations in environmental conditions has emerged, as thermal anomalies associated with ENSO events are expected to increase in both frequency and intensity (Hughes et al., 2018; Rinkevich, 2014), reducing the time that these ecosystems have to recover from such disturbances (Boström-Einarsson et al., 2020). Therefore, it is important to identify those coral ecosystems that harbor scleractinian species capable of withstanding future disturbances from climate change and human activities, as they represent future coral refugia and may become sources of coral fragments for coral restoration programs. Identifying resilient communities requires ecological, physiological, and molecular studies to ensure that restoration strategies maintain and improve current restored areas and at least maintain coral diversity at ecological and genetic scales (Boström-Einarsoon et al., 2020; Montoya-Maya et al., 2016).

Within this context, it is important to prioritize resilient coral communities impacted by anthropogenic disturbances and climate change to evaluate their suitability to be restored and, eventually, rehabilitated. Along the Eastern Tropical Pacific (ETP), local coral communities have developed rapid acclimatization capacity and ability to remain stable over several years, despite being under the influence of moderate and severe El Niño Southern

Oscillation (ENSO) events that have triggered bleaching, but no mortality in recent years (Cruz-García et al., 2020; Nava et al., 2021; Romero-Torres et al., 2020). Within the ETP, Punta de Mita (located in the Central Mexican Pacific, CMP) harbors a coral community that historically lost over 90 % of its live coral cover during the 1997-98 El Niño massive bleaching and mortality event (Carriquiry et al., 2001), which caused researchers to consider its recovery uncertain. However, recent life-history traits of corals in the area have promoted an increase in their ability to cope and resist different stressful conditions: not only has been observed thermal tolerance threshold but also a natural recovery capacity as well (Martínez-Castillo, Rodríguez-Troncoso, Mayfield et al., 2022; Tortolero-Langarica et al., 2017), which results in an opportunity to implement restoration strategies that contribute to the already observed recovery (Tortolero-Langarica et al., 2014; Tortolero-Langarica et al., 2017), implementing protocols that allow it to be site-specific since coral reefs do not thrive under the same conditions, especially under the current climate change scenario. Here we evaluate coral reef recovery resulting from active restoration at Punta de Mita, a site that has shown a natural recovery capacity from natural and anthropogenic disturbances.

MATERIALS AND METHODS

Study site: Punta de Mita (20.7699 °N, 105.5412° W) is located within the CMP (Fig. 1), a region considered an oceanographic transition zone where three water masses converge: the cold California Current flowing southernly, the warm coastal Mexican current flowing northerly, and the warm and saline water from the Gulf of California flowing southernly (Pantoja et al., 2012). The convergence of these currents creates a dynamic region, in addition to seasonal upwellings,

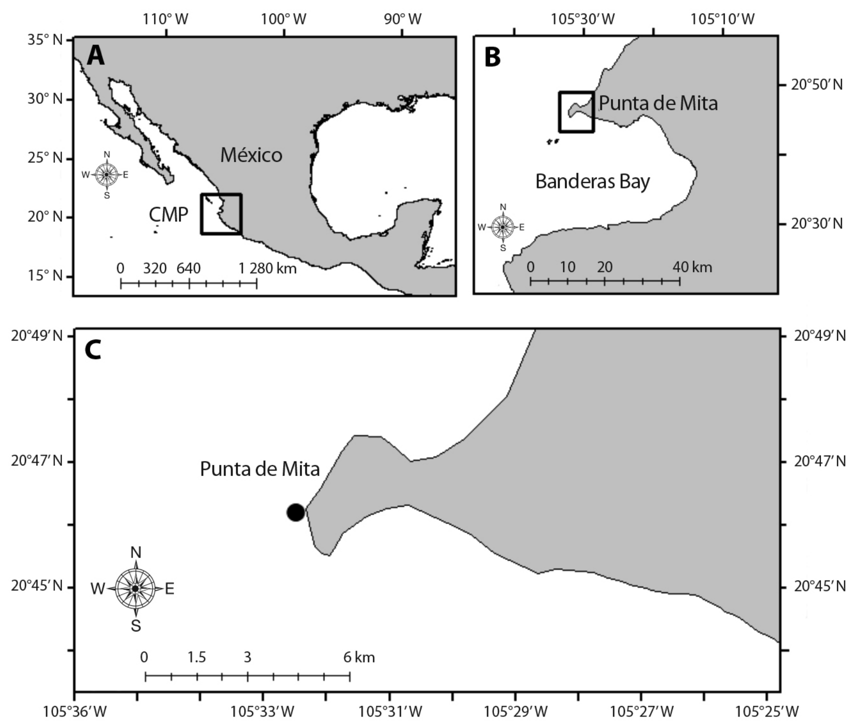

Fig. 1. A. The Central Mexican Pacific (CMP), **B.** Punta de Mita, North of Banderas Bay within the CMP, **C.** Coral restoration site at Punta de Mita.

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nutrient pulses, and internal waves, wide daily temperature fluctuations (± 5 °C) can be recorded (Plata & Filonov, 2007; Portela et al., 2016). Punta de Mita presents a well-formed coral reef patch that used to harbor ~ 38 % of live coral cover, which was impacted by the 1997-98 ENSO event resulting in a dramatic loss of this ecosystem (Carriquiry & Reyes-Bonilla, 1997; Carriquiry et al., 2001).

Coral restoration and monitoring: Coral restoration was performed in two different phases at a coral reef community that is at three meters depth: 1) the first in 2013 in order to validate the protocol, and 2) the second phase three years later in 2016. In each phase, a total of 50 *Pocillopora* fragments of opportunity, defined as fragments detached from an adult colony through natural processes such as water-motion, or bioerosion (Monty et al., 2006), were collected. Each coral fragment was individually examined to avoid signs of bleaching, damage, or algae overgrowth (such as turf and macroalgae) and then fixed to the natural substrate using zip ties within the same reef site (Fig. 2). All coral fragments restored during 2013 were tagged and measured for a two-year period (from November 2013 to October 2015), while those restored in 2016 were measured for one year (from January 2016 to February 2017) to record coral growth, i.e., the increase of fragment size (cm) maximum length (ML) and maximum width (MW) using a caliper (0.05 mm of precision). Also, survival of fragments was recorded.

Data analysis: Overall mean values of coral growth (± standard error) were calculated using Statistica 8.0 software (StatSoft Inc., 2007) and expressed as cm year^{-1}. Coral growth rates, defined as the average total increase in coral length and width, were calculated using

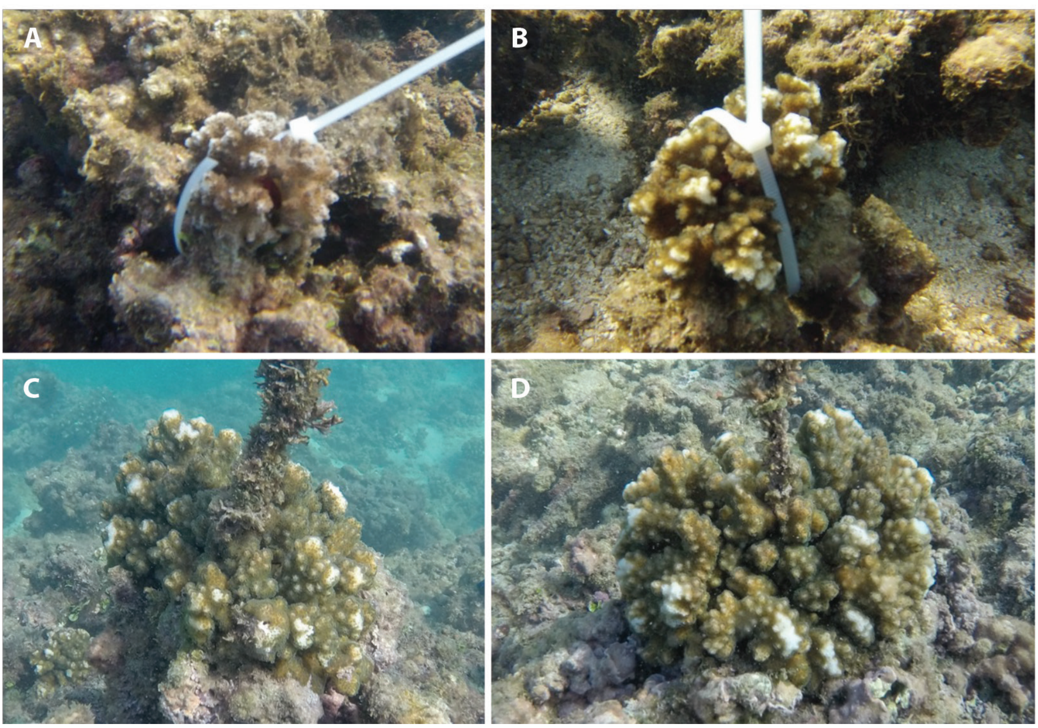

Fig. 2. *Pocillopora* spp. fragment of opportunity fixed to the natural substrata in Punta de Mita, México **A.** initial fragment size during the first restoration period (2013), and **B.** Second restoration period (2016). Final colonies size at the end of the **C.** first restoration (2015) and **D.** second restoration period (2017).

the original fragment size (cm ± standard error) for each restoration period. Also, the average and cumulative size increase in length and width (cm) within each period was estimated.

Simple linear regressions were calculated to evaluate the effect of changes in SST on coral growth rates. Mean monthly sea surface temperatures (SST) were obtained from the GIOVANNI database of the National Aeronautics and Space Administration of the United States (Li & Hegde, 2022). Regressions were calculated using Statistica 8.0 software (StatSoft Inc., 2007).

RESULTS

The overall mean coral growth rate was 4.25 ± 0.15 cm year^{-1} for maximum length and 3.71 ± 0.17 cm year^{-1} for maximum width. Further details of each restoration period are given below.

First restoration period: Coral fragments tripled their size after 100 weeks of being reattached with an accumulated growth in length and width of ~ 8-9 cm (Fig. 3A). During the first restoration phase, corals grew at a rate of ~ 3.5 cm year^{-1} (Table 1). While coral growth remained stable throughout the first restoration period, the highest coral growth in both axes occurred during the warmest season (August 2015). The increase in coral size remained at 3.79 ± 0.21 and 3.55 ± 0.40 cm year^{-1} for both ML and MW (Table 1, Fig. 3B). Coral fragments self-attached to the substrata one month after being restored, and the final proportion of surviving corals was 38 % (Fig. 4).

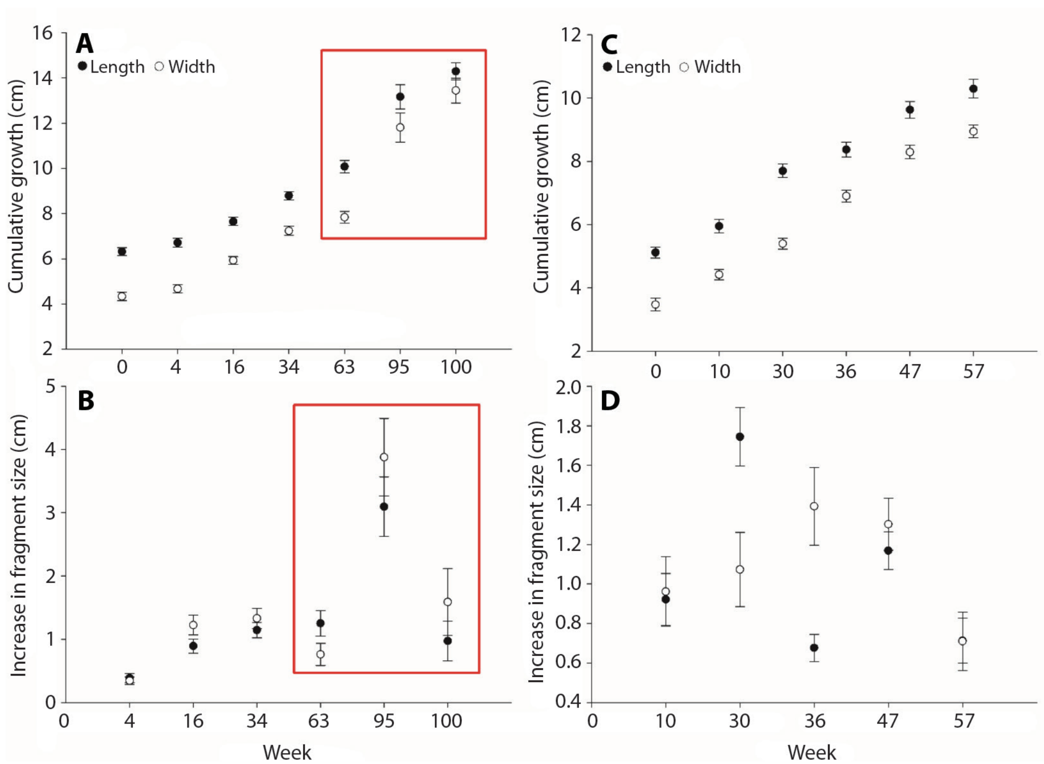

Fig. 3. A. Mean fragment size during the first restoration period (2013). **B.** Increase in coral size during the first period between measuring times. **C.** Mean fragment size during the second restoration period (2016). **D.** Increase in coral size during the second period between measuring times. Bars = SE. Red rectangles mark ENSO weeks during the first restoration phase.

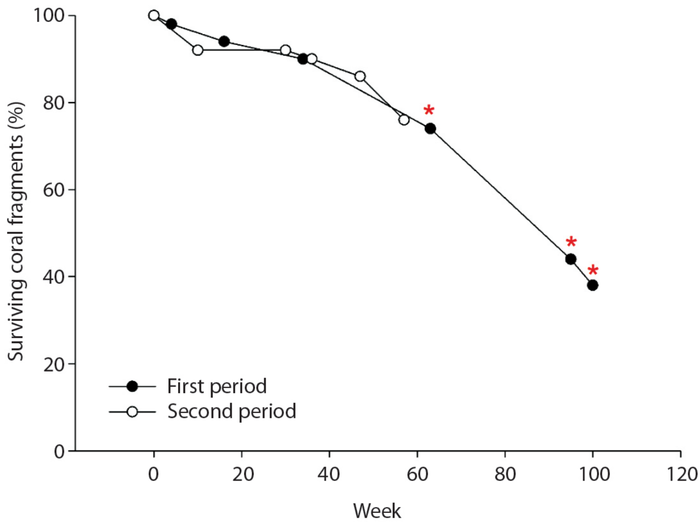

Fig. 4. Survival of restored *Pocillopora* spp. coral fragments during both restoration periods in Punta de Mita, México. Red asterisks signal ENSO weeks during the 2015-2016 El Niño event.

TABLE 1

Coral growth rates in length and width (cm $year^{-1}$) in each restoration period. ML: maximum length; MW: maximum width

Restoration period	ML			MW		
	Mean	Min	Max	Mean	Min	Max
First (2013)	3.79 ± 0.21	1.97	5.38	3.55 ± 0.40	0.90	7.14
Second (2016)	4.49 ± 0.19	1.94	7.33	3.78 ± 0.16	1.63	6.17

Second restoration period: Coral fragments almost doubled their size after 57 weeks following their re-attachment (Fig. 3C), with a maximum accumulated growth of ~ 5-6 cm in both length and width. The increase in coral size remained at 4.49 ± 0.19 and 3.78 ± 0.16 cm $year^{-1}$ for both ML and MW (Table 1), peaking around week 30, during the warm season of 2016 (August; Fig. 3D). Corals self-attached to the substrate within the first two months after their restoration, and the proportion of surviving corals after 56 weeks was 76 % (Fig. 4).

Sea surface temperature and coral growth: During the first restoration period, the mean monthly sea surface temperature ranged from 25.7 to 32.3 °C, whereas during the second period, the mean monthly SST ranged from 24.1 to 31.3 °C, coinciding with an El Niño event, causing thermal anomalies ≥ 2.8 °C (Fig. 5). When assessing the effects of sea temperature on coral growth parameters, both regressions were not significant; hence, coral growth was not significantly related to sea surface temperature ($R = 0.51$, $P = 0.10$).

DISCUSSION

The capacity of any ecosystem to recover from environmental perturbations depends on the ability of its organisms to adapt to new conditions, which is determined by their physiological traits, including regulatory mechanisms, performance, and environmental tolerance (Cooke & Suski, 2008); specifically for coral ecosystems, these physiological traits include coral growth rates and reproductive strategies, their acclimatization capacity, and the type of endosymbiont they harbor, among others. The

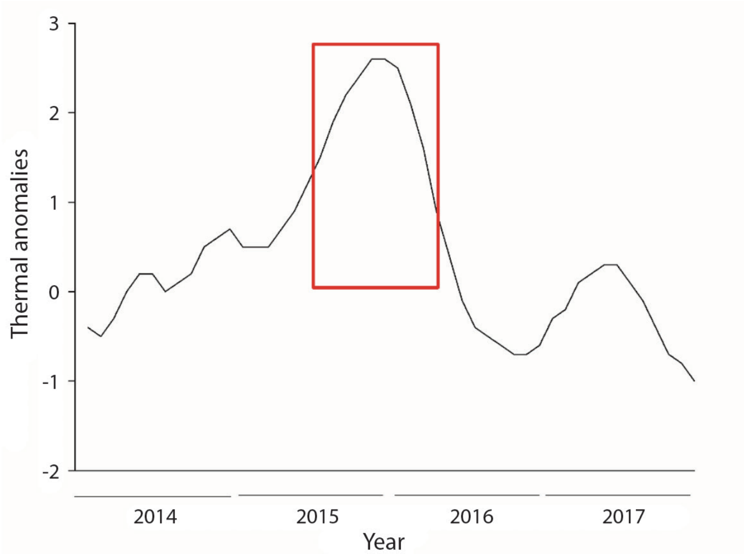

Fig. 5. Thermal anomalies (°C) caused by ENSO events across both restoration periods. The red frame signals positive thermal anomalies during the most recent and severe El Niño event. Thermal anomalies correspond to the Oceanic Niño Index (ONI) from the National Oceanic and Atmospheric Administration (NOAA, 2022).

Central Mexican Pacific is a region considered sub-optimal for coral development due to its wide ranges in temperature, nutrient pulses, and elevated sedimentation rates (Glynn, 2017). It is also a region where in the last two decades, at least three severe thermal anomalies have affected coral communities such as Punta de Mita (Hughes et al., 2018). In spite of this, recent studies have documented that live coral cover in this region is slowly recovering (Martínez-Castillo, Rodríguez-Troncoso, Mayfield et al., 2022), evidencing the potential of this particular site to be rehabilitated using active restoration protocols.

Coral fragments in our study almost doubled their size one year following their reattachment and increased three times their size after two years. *Pocillopora* has been characterized as a coral genus with one of the highest growth rates within the EP, a key physiological trait that has allowed this genus to remain as the most abundant species (Romero-Torres et al., 2020; Tortolero-Langarica et al., 2017). Mean extension rates of corals are ~ 3.5–4.5 cm y^{-1}, which will not only increase the fragment length or width but in the development of the three-dimensional complexity that other coral colonies have exhibited elsewhere within the CMP (González-Pabón et al., 2021; Tortolero-Langarica et al., 2014; Tortolero-Langarica et al., 2017; Tortolero-Langarica et al., 2020). Indeed, corals not only continued to grow, but they also exhibited extension rates that are among the highest recorded in the Eastern Tropical Pacific (Martínez-Castillo, Rodríguez-Troncoso, Mayfield et al., 2022); therefore, corals within this region increase coral cover and carbonate production, contributing to the recovery of these reef sites (Tortolero-Langarica et al., 2019).

Restoration, in its broad sense, aims to assist the recovery of a damaged or degraded ecosystem, and particularly for coral reefs, their recovery relays on the increase of live coral cover both in its area and in its three-dimensional structure, which directly depends on sustained coral growth (Rinkevich, 2014). The fact that restored corals continued to grow even during high thermal anomalies caused by recent ENSO events (as seen in this study), brings up the relevance of their physiological traits such as the acclimatization capacity, which have allowed corals at Punta de Mita to recover and remain stable under stress events, highlighting the CMP as an important EP refuge, not only for corals, but also for the organisms associated with them (Martínez-Castillo, 2020; Martínez-Castillo, Rodríguez-Troncoso, Mayfield et al., 2022; Rodríguez-Troncoso et al., 2016; Tortolero-Langarica et al., 2017).

Coral growth is influenced by abiotic factors from which sea surface temperature is considered the most important, and the threshold is determined by the local and regional acclimatization capacity of these organisms (Manzello et al., 2010; Martínez-Castillo et al., 2020). More important high temperatures also trigger bleaching response and may cause mortalities as observed previously in the region (Carriquiry et al., 2001); however, there was no significant relationship between coral growth or survival and sea temperature even under the influence of the most severe ENSO event recorded to date. After almost 60 weeks from coral re-attachment, survival rates in both restoration periods were above ~ 60 %, which is considered as successful as most restoration projects report between 60-70 % of survival (Boström-Einarsson et al., 2020), and it was even higher than other remote locations of the CMP with low influence of human activity (Tortolero-Langarica et al., 2020). Unlike those areas, Punta de Mita coral community is a coastal site 200 m distant from the shore, where there are luxury touristic complexes and gulf camps, with intense marine traffic and no regulation of touristic activities. The high mortality observed at the end of the first restoration period then may be due to two interacting factors: first, even though coral growth was not compromised by the 2015-2016 El Niño warm temperatures, the coral community must have suffered individual negative effects during its first stage (which coincides with the end of the first restoration period); second anthropogenic activity in Punta de Mita may also have played a role in coral mortality as this site lacks an official protection status. In spite of this, the growth rates of the surviving coral colonies were sufficient enough to prevent the loss of coral cover during this period, reinforcing the idea that the CMP harbor resilient coral communities (Cruz-García et al., 2020; Martínez-Castillo et al., 2020; Martínez-Castillo, Rodríguez-Troncoso, Tortolero-Langarica et al., 2022; Rodríguez-Troncoso et al., 2016; Tortolero-Langarica et al., 2017; Tortolero-Langarica et al., 2022). In this sense, the coral community at Punta de Mita may represent an important coral refuge in the near future as corals' in the region exhibit a high acclimatization capacity, a key feature of corals in the region that promotes the recovery of CMP coral ecosystems (Martínez-Castillo et al., 2020; Martínez-Castillo, Rodríguez-Troncoso, Mayfield et al., 2022; Martínez-Castillo, Rodríguez-Troncoso, Tortolero-Langarica et al., 2022; Rodríguez-Troncoso et al., 2016; Tortolero-Langarica et al., 2017; this study).

While restoration efforts at Punta de Mita have been successful so far, there is an urgent need for management policies to ensure that full ecosystem recovery can be achieved. Punta de Mita is located within Bandera's Bay, in an area that is planned to continue high-end urban development (Merchand-Rojas, 2012). A major threat to coral reefs are changes in land use caused by urban growth (Burke et al., 2011; Carpenter et al., 2008). Therefore, if there is no adequate management and regulation of recreative aquatic activities in Punta de Mita, corals will be resisting more stressors than they can withstand, and therefore, local or official protection of this resilient site is urgent. The present study gives insight into the efforts of coral restoration activities in the Central Mexican Pacific. It highlights the importance of considering ecological, biological, and physiological processes when developing restoration strategies and emphasizes the importance of identifying coral communities with evidence of both resistance and resilience capacity. In this sense, Punta de Mita represents an important site, as both natural and restored fragments have contributed to increase and maintain coral cover in a region unlikely to recover from thermal anomalies (Carriquiry et al., 2001). Moreover, recent ENSO effects have not negatively affected fragment growth rates, suggesting that this location is essential for coral recovery and a conservation priority as corals are more likely to withstand future environmental perturbations than other Eastern Pacific locations due to their biological and physiological traits.

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgements section. A signed document has been filed in the journal archives.

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REFERENCES

Boström-Einarsson, L., Babcock, R. C., Bayraktarov, E., Ceccarelli, D., Cook, N., Ferse, S. C., Hancock, B., Harrison, P., Hein, M., Shaver, E. & Smith, A. (2020). Coral restoration–A systematic review of current methods, successes, failures and future directions. *PloS One*, *15*(1), e0226631.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at risk revisited*. Washington DC. World Resources Institute.

Carpenter, K. E., Abrar, M., Abey, G. A. R. B., Banks, S., Bruckner, A., Chiriboga, A., Cortés, J., Delbeek, J. C., De Vantier, L., Edgar, G. J., Edwards, A. J., Fenner, D., Guzmán, H. M., Hoeksema, B. W., Hodgson, G., Johan, O., Licuanan, W. Y., Livingstone, S. R., Lovell, E. R., … Wood, E. (2008). One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, *321*(5888), 560–563.

Carriquiry, J. D., Cupul-Magaña, A. L., Rodríguez-Zaragoza, F., & Medina-Rosas, P. (2001). Coral bleaching and mortality in the Mexican Pacific during the 1997-98 El Niño and prediction from a remote sensing approach. *Bulletin of Marine Science, 69*(1), 237–249.

Carriquiry, J. D., & Reyes-Bonilla, H. (1997). Community structure and geographic distribution of the coral reefs of Nayarit. Mexican Pacific. *Ciencias Marinas, 23*(2), 227–248.

Cooke, S. J., & Suski, C. D. (2008). Ecological restoration and physiology: an overdue integration. *BioScience, 58*(10)*,* 957–968.

Cruz-García, R., Rodríguez-Troncoso, A. P., Rodríguez-Zaragoza, F. A., Mayfield, A., & Cupul-Magaña, A. L. (2020). Ephemeral effects of El Niño southern oscillation events on an eastern tropical Pacific coral community. *Marine and Freshwater Research*, *71*(10), 1259–1268.

Glynn, P. W. (2017). History of Eastern Pacific coral reef research. In P. W. Glynn et al. (Eds.), *Coral reefs of the Eastern Tropical Pacific: persistence and loss in a dynamic environment* (pp 1–37). Springer.

González-Pabón, M. A., Tortolero-Langarica, J. J. A., Calderon-Aguilera, L. E., Solana-Arellano, E., Rodríguez-Troncoso, A. P., Cupul-Magaña, A. L., & Cabral-Tena, R. A. (2021). Low calcification rate, structural complexity, and calcium carbonate production of *Pocillopora* corals in a biosphere reserve of the central Mexican Pacific. *Marine Ecology, 42*(6), e12678.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., Caldeira, K., & Knowlton, N. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, *318*(5857), 1737–1742.

Hughes, T. P., Anderson, K. D., Connolly, S. R., Heron, S. F., Kerry, J. T., Lough, J. M., Baird, A. H., Baum, J. K., Berumen, M. L., Bridge, T. C., & Claar, D. C. (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science, 359*(6371), 80–83.

Li, A., & Hegde, M. (2022). *Giovanni. The bridge between data and Science* (v. 4.38). National Aeronautics and Space Administration, United States of America. https://giovanni.gsfc.nasa.gov/giovanni/

Manzello, D. P. (2010). Coral growth with thermal stress and ocean acidification: lessons from the eastern tropical Pacific. *Coral Reefs, 29*, 749–758.

Martínez-Castillo, V., Rodríguez-Troncoso, A. P., Mayfield, A. B., Rodríguez-Zaragoza, F. A., & Cupul-Magaña, A. L. (2022). Coral recovery in the Central Mexican Pacific 20 years after the 1997–1998 El Niño event. *Oceans*, *3*(1), 48–59.

Revista de Biología Tropical, ISSN: 2215-2075 Vol. 71 (S1): e54795, abril 2023 (Publicado Abr. 30, 2023)

Martínez-Castillo, V., Rodríguez-Troncoso, A. P., Santiago-Valentín, J. D., & Cupul-Magaña, A. L. (2020). The influence of urban pressures on coral physiology on marginal coral reefs of the Mexican Pacific. *Coral Reefs, 39*, 625–637.

Martínez-Castillo, V., Rodríguez-Troncoso, A. P., Tortolero-Langarica, J. J. A., Bautista-Guerrero, E., Padilla-Gamiño, J., & Cupul-Magaña, A. L. (2022). Coral performance and bioerosion in Central Mexican Pacific reef communities. *Hydrobiologia*, *849*(10), 2395–2412.

Merchand-Rojas, M. A. (2012). Desarrollo inter-estatal turístico de Puerto Vallarta y Bahía de Banderas: México. *Problemas del Desarrollo*, *43*(168), 147–173.

Montoya-Maya, P. H., Schleyer, M. H., & Macdonald, A. H. (2016). Limited ecologically relevant genetic connectivity in the south-east African coral populations calls for reef-level management. *Marine Biology*, *163*(8), 1–16.

Monty, J. A., Gillian, D. S., Banks, K., Stout, D. K., & Dodge, D. E. (2006). Coral of opportunity survivorship and the use of coral nurseries in coral reef restoration. *Proceedings of 10th International Coral Reef Symposium, 2006,* 1665–1673.

Nava, H., López, N., Ramírez-García, P., & Garibay-Valladolid, E. (2021). Contrasting effects of the El Niño 2015–16 event on coral reefs from the Central Pacific coast of Mexico. *Marine Ecology, 42*(2), e12630.

NOAA (National Oceanic and Atmospheric Administration) (2022). *Cold & Warm Episodes by Season.* National Weather Service. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

Pantoja, D. A., Marinone, S. G., Parés-Sierra, A., & Gómez-Valdivia, F. (2012). Numerical modeling of seasonal and mesoscale hydrography and circulation in the Mexican Central Pacific. *Ciencias Marinas, 38*(2), 363–379.

Plata, L., & Filonov, A. (2007). Marea interna en la parte noroeste de la Bahía de Banderas México. *Ciencias Marinas*, *33(2)*, 197–215.

Portela, W., Beier, E., Barton, E. D., Castro, R., Godínez, V., Palacios-Hernández, E., Fiedler, P. C., Sánchez-Velazco, L., & Trasviña, A. (2016). Water masses and circulation in the tropical pacific off Central Mexico and surrounding areas. *Journal of Physical Oceanography, 46*(10), 3069–3081.

Rinkevich, B. (2014). Rebuilding coral reefs: does active reef restoration lead to sustainable reefs?. *Current Opinion in Environmental Sustainability, 7*, 28–36.

Rodríguez-Troncoso, A. P., Carpizo-Ituarte, E., & Cupul-Magaña, A. L. (2016). Physiological response to high temperature in the Tropical Eastern Pacific coral *Pocillopora verrucosa*. *Marine Ecology, 37*(5), 1168–1175.

Romero-Torres, M., Acosta, A., Palacio-Castro, A. M., Treml, E. A., Capata, F. A., Paz-García, D. A., & Porter, J. W. (2020). Coral reef resilience to thermal stress in the Eastern Tropical Pacific. *Global Change Biology*, *26*(7), 3880–3890.

StatSoft, Inc. (2007). *STATISTICA. Data analysis software system* (v. 8.0)[Computer software]. StatSoft. https://www.statsoft.com

Tortolero-Langarica, J. J. A., Cupul-Magaña, A. L., & Rodríguez-Troncoso, A. P. (2014). Restoration of a degraded coral reef using a natural remediation process: A case study from a Central Mexican Pacific National Park. *Ocean & Coastal Management, 96,* 12–19.

Tortolero-Langarica, J. J. A., Rodríguez-Troncoso, A. P., Cupul-Magaña, A. L., & Carricart-Ganivet, J. P. (2017). Calcification and growth rate recovery of the reef-building *Pocillopora* species in the northeast tropical Pacific following an ENSO disturbance. *PeerJ, 5,* e3191.

Tortolero-Langarica, J. J. A., Rodríguez-Troncoso, A. P., Cupul-Magaña, A. L., Alarcón-Ortega, L. C. & Santiago-Valentín, J. D. (2019). Accelerated recovery of calcium carbonate production in coral reefs using low-tech ecological restoration. *Ecological Engineering*, *128*, 89–97.

Tortolero-Langarica, J. J. A., Rodríguez-Troncoso, A. P., Cupul-Magaña, A. L., & Rinkevich, B. (2020). Micro-fragmentation as an effective and applied tool to restore remote reefs in the Eastern Tropical Pacific. *International Journal of Environmental Research and Public Health. 7*(18), 6574.

Tortolero-Langarica, J. J. A., Rodríguez-Troncoso, A. P., Cupul-Magaña, A. L., Morales-de-Anda, D. E., Caselle, J. E., & Carricart-Ganivet, J. P. (2022). Coral calcification and carbonate production in the eastern tropical Pacific: The role of branching and massive corals in the reef maintenance. *Geobiology, 20*(4), 533–545.