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SHORT COMMUNICATION

New record of the endemic coral *Porites sverdrupi* (Gulf of California): do fluctuations in seawater temperature regulate its southernmost range limit?

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Abstract Rising seawater surface temperatures worldwide may cause reef coral species to shift their geographical range towards cooler environments. Information on such shifts, however, remains scarce. The scleractinian coral *Porites sverdrupi* (Durham, 1947) is endemic to the Gulf of California, and is considered a threatened species due to its vulnerability to local impacts, low abundance, and limited and fragmented distribution range. Although its historical range extends from the northern Gulf (29°N) to Bahía de Banderas in the south (20°N), to date only two extant populations have been reported in the central portion (25-26°N). Here we report a new record of *P. sverdrupi* from south of Bahía de La Paz. In 2013, colonies were observed at depths of 5–9 m close to a restored coral area south of Bahía de La Paz, which has been monitored since 2004. Events of local extinction and contraction of the distribution range were related to warm ENSO events (1982 and 2010), while expansion occurred after cold ENSO events in 2008 and 2011. Our results suggest that *P. sverdrupi* may tolerate the narrowest range of temperatures in its genus, and that the newly recorded range limit may be linked to the physiological limit of temperature tolerance for this species.

Keywords Threatened species · Temperature tolerance · Eastern Pacific · ENSO · Geographical range

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Introduction

Coral reef-builders are predominantly long-lived organisms that are extremely sensitive to fluctuations in seawater temperature. Growth and survival of corals in reef communities outside the tropics has generally been limited by cold water temperatures (Abdo et al. 2012). Rising temperatures worldwide, however, may cause coral species to shift their geographical range towards cooler environments (Yamano et al. 2011; Makino et al. 2014). Nevertheless, available information on such range shifts remains scarce. Shifts in the ranges of reef coral species and their ability to persist in new environments are expected to have important implications for their resilience in light of projected climate change (Angert et al. 2011; Smale and Wernberg 2013; Makino et al. 2014). Changes in environmental conditions may have significant ramifications on the distribution range of threatened or endemic species, as they are frequently restricted to specific habitats and to relatively small areas with low population sizes (Jones et al. 2013).

The scleractinian coral *Porites sverdrupi* (Durham, 1947) is endemic to the Gulf of California and is considered threatened according to the IUCN [International Union for Conservation of Nature] Red List of Threatened Species due its vulnerability to local impact, low abundance, and fragmented population at only a few localities (Chiriboga et al. 2008). This coral species is associated with rhodolith beds at depths of 5–20 m, and its natural history suggests that, together with *Porites panamensis* (Verrill, 1866), it is better adapted to cool water than other stony corals in the Eastern Pacific (López-Pérez et al. 2003; Saavedra-Sotelo et al. 2013). Its reported distribution (Fig. 1) extends from the upper Gulf at 29°N toward Bahía de Banderas at 20°N (López-Pérez et al. 2003; Chiriboga et al. 2008). However, this species disappeared locally from coral communities south of the peninsula in the

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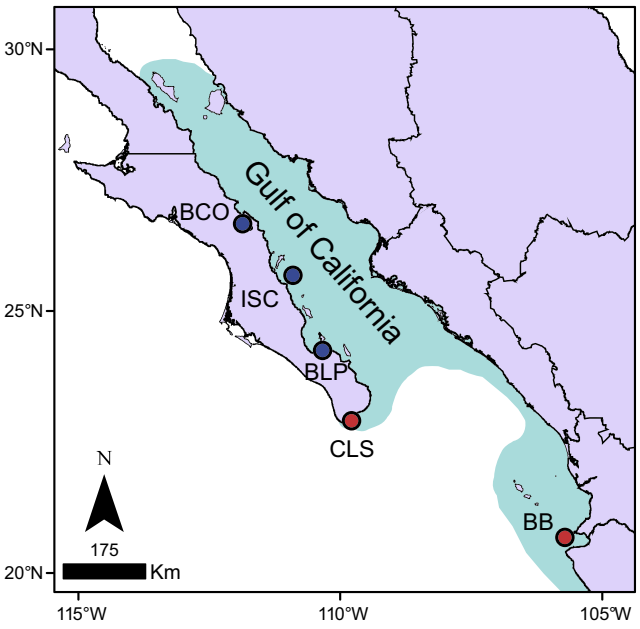

Fig. 1 Distribution of *Porites sverdrupi* in the Gulf of California. Locations of extant populations (*blue circles*, including new population record at BLP) and locally extinct populations (*red circles*). Light blue background indicates the historical distribution of *P. sverdrupi* (López-Pérez et al. 2003; Chiriboga et al. 2008). *BB* Bahía de Banderas, *BCO* Bahía Concepción, *BLP* Bahía de La Paz, *CSL* Cabo San Lucas, *ISC* Isla Santa Catalina

early 1980s (López-Pérez et al. 2003) and from the northern Gulf in the early 2000s (Reyes-Bonilla et al. 2008). To date, colonies have been observed in just two extant populations restricted to the middle of the Gulf of California: Bahía Concepción at 26°N and Isla Santa Catalina at 25°N (López-Pérez et al. 2014). Here we report a new population settlement of *P. sverdrupi* discovered in October 2013 south of Bahía de La Paz, and we show that population contraction and expansion in this species may be driven by warm and cold El Niño/Southern Oscillation (ENSO) events, respectively.

Materials and methods

Surveys of *Porites sverdrupi* colonies were conducted close to a restored coral area as part of an ongoing monitoring program initiated in 2004 (Balart et al. 2010). Briefly, this program included surveys in four coral communities: San Lorenzo channel (24°22'48.41"N, 110°19'17.66"W), San Gabriel, Isla Espíritu Santo (24°25'35.67"N, 110°22'6.02"W), Punta Diablo (24°18'44.3"N, 110°20'10.7"W), and El Portugués (24°44'48.00"N, 110°40'50.00"W). Densities of marine invertebrates in each coral community were measured along three replicate belt quadrats of 25x1 m^2. After the first record of *P. sverdrupi* was made during surveys at San Lorenzo channel, more intensive surveys were conducted in October 2013 and August 2014 to confirm population records for this species in the area. These intensive surveys consisted of search, visual identification, and photographic records of *P. sverdrupi* colonies by two divers, each searching for 45 minutes, in areas between *Pocillopora* corals and at the edge of the coral community. Photos were taken in situ with a Canon PowerShot A630 with underwater housing. Colony diameters were measured from collected fragments with a dial caliper (±0.1 mm) and from photographs using ImageJ 1.34. Images were calibrated with a grid of known dimensions.

To compare the contraction and expansion population records of *P. sverdrupi* with the magnitude of warming and cold water events, we utilized data from 1980 through 2014 available on the Multivariate ENSO Index (MEI) through the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (www.esrl.noaa.gov). This multivariate index provides a complete and flexible description of ENSO events and is composed of six main observed variables over the tropical Pacific: sea level pressure, zonal and meridional components of the surface winds, sea surface temperature, surface air temperature, and sky cloud cover (Wolter and Timlin 2011). Positive and negative values in the MEI indicate warming and cold water events, respectively.

Results and discussion

In this study, we report a new settlement of *Porites sverdrupi* discovered at the southern end of Bahía de La Paz, consisting entirely of free-living coral colonies. They were observed in low densities (<0.06 colonies/m^{-2}) on a sandy/rocky bottom at depths of 5–9 m (Fig. 2) in the San Lorenzo channel, an area with strong currents, at the edge of a coral community

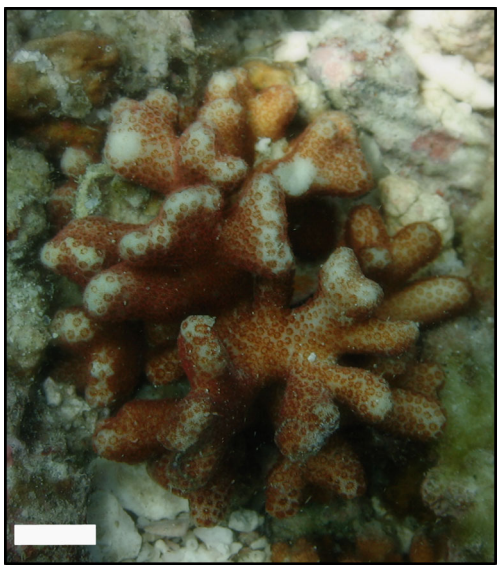

Fig. 2 Photograph of a *Porites sverdrupi* coral taken October 2, 2013, in Bahía de La Paz (BLP) at a depth of 5–9 m. Scale bar = 1 cm

comprising predominantly *Pocillopora* corals. Colonies were 5.6±1.0 cm (±SD, n=35) at their largest diameter. Although growth rates have not been reported in *P. sverdrupi*, growth extension of 1.17±0.40 cm/year^{-1} was reported in its close relative *Porites panamensis* at Bahía de La Paz (Cabral-Tena et al. 2013). If the rate is similar in *P. sverdrupi,* the colonies that were found were approximately 5 years old and would have settled in 2008.

Colonies of *P. sverdrupi* settle among small bivalve shells, in rhodolith beds, or on sandy substrates. As they grow larger, however, because of their branch morphology, they usually become detached and lie on the substrate (Reyes-Bonilla et al. 1997; López-Pérez et al. 2003). The branch morphology, low abundance, and free-living behavior of the coral colonies were all in agreement with the species description and ecological features of *P. sverdrupi* (López-Pérez et al. 2003, 2014). This free-living behavior is usually associated with some degree of sphericity or capacity of corals to fragment themselves, and while it has increasingly been recorded from scleractinian reef corals elsewhere (i.e. Glynn 1974; Fisk 1981; Roff 2008; Hoeksema and Waheed 2011a; Capel et al. 2012; Hoeksema 2012a; Denis et al. 2015), this trait has traditionally been attributed to corals that become detached from a hard substrate, including mushroom corals (Gittenberger et al. 2011; Hoeksema and Waheed 2011b; Hoeksema and Yeemin 2011) and two West Atlantic species (Meesters et al. 2013). The capacity to become free-living enables corals to colonize all kinds of substrates (Goreau and Yonge 1968; Hoeksema 2012b), which may also have helped *P. sverdrupi* to settle on unconsolidated substrate at its newly recorded locality.

Acute warm or cold water events can cause shifts of coral species distribution boundaries in reef communities that develop at the tolerance limits of their environmental conditions (Yamano et al. 2011; Bridge et al. 2014). Here, we show that the contraction and expansion of *P. sverdrupi*'s geographical range may be driven by extreme warm and cold ENSO events, respectively. A population contraction of *P. sverdrupi* was recorded in the early 1980s, when the population at Cabo San Lucas (CLS, 22°52'N) became locally extinct (López-Pérez et al. 2003). This local extinction coincided with a warm ENSO event (Figs. 1 and 3). In February 2009, a geographic expansion was recorded in Bahía de Banderas (BB, 20°38'N), when small colonies were observed at monitored sites, although these corals had died by the next year, in 2010 (Medina-Rosas pers. comm.), when a warm ENSO event occurred (Figs. 1 and 3). In contrast to these events coinciding with warm-water intervals, expansion events at Bahía de Banderas and Bahía de La Paz have occurred after periods of cold water events since 2008 (Fig. 3).

These results suggest that *P. sverdrupi* responds differently to warm and cold ENSO events. For example, during warming events, the coral was susceptible to bleaching and became locally extinct (López-Pérez et al. 2003), supporting the hypothesis that corals can shift poleward in response to a warming climate (Yamano et al. 2011), and consistent with the projected distribution of *P. sverdrupi* in response to warming temperatures (López-Pérez et al. 2014). In contrast, during a period of cold ENSO events, physiological and habitat requirements may co-occur, allowing this coral to expand southward temporally (i.e. from 2008 to 2014). The cold habitat requirements of *P. sverdrupi* may be similar to those of *Porites panamensis*, the only other *Porites* species occurring in the Gulf of California (Saavedra-Sotelo et al. 2013). In addition, studies examining niche tracking suggest that species distribution range shifts may be driven by the net effects of concordant changes in multiple climatic variables (Angert et al. 2011). Here we show that population contraction and expansion of *P. sverdrupi* coincide with Multivariate ENSO Index indicators of warming and cold water events, respectively. This suggests that the temperature range tolerance of *P. sverdrupi*

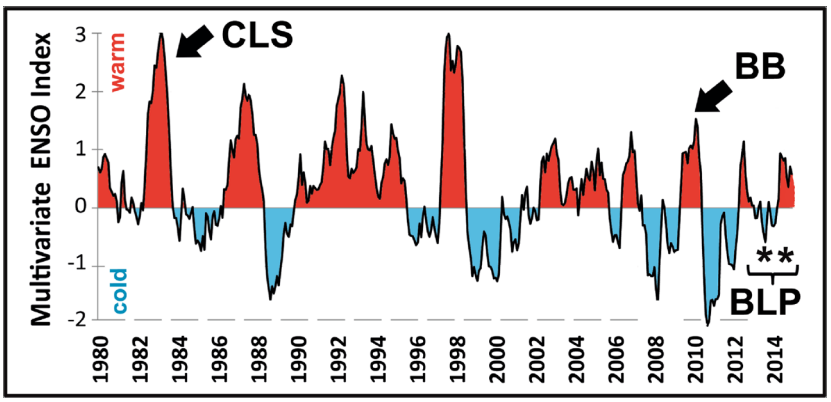

Fig. 3 ENSO events from 1980 through 2014 in the Gulf of California. Warm and cold water events are indicated by positive and negative values, respectively, in the Multivariate ENSO Index. *Arrows* indicate warm events when *P. sverdrupi* suffered local extinction at Cabo San Lucas (*CLS*) and Bahía de Banderas (*BB*) locations. *Asterisks* indicate new population records in 2013 and 2014 at Bahía de La Paz (*BLP*)

may be the narrowest among its congeners, and that the new settlement reported here may occur at the physiological tolerance limit for this species.

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