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SHORT COMMUNICATION

FIRST RECORDS FOR SPAWNING OF CARIBBEAN ACROPORA SPECIES IN COLOMBIAN MPAs

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INTRODUCTION

Coral percent cover throughout the Caribbean Sea has declined precipitously in the last few decades, to as little as 10% of historical levels (Aronson and Precht 2001, Bruckner 2003, Gardner et al. 2003, Bruckner and Hill 2009, Bruckner 2012), with long-term shifts in composition observed in many cases (de Bakker et al. 2016, 2017). The major reef builders, *Acropora palmata* and *Acropora cervicornis*, experienced up to 99% mortality over the past 30 years (Aronson et al. 2008a, b). Disease outbreaks (Gil-Agudelo et al. 2009) make restoration more difficult, with an increased urgency of rescuing the survivors to maintain the genetic diversity of the population. While asexual propagation methods saw some success in restoring reefs in the region, they do not increase the genetic diversity of managed corals (Rinkevich 2005). These challenges make it imperative to strengthen efforts to develop infrastructure and local knowledge about sexual reproduction of corals throughout the Caribbean, especially where language barriers exist. Minor geographic variability exists for the timing of coral spawning in different parts of the Caribbean Sea (Fogarty et al. 2012, CARMABI 2019), and some locations have never documented a wild coral spawn for annually reproducing species. While spawning for these species is fairly consistent across the Caribbean (Szmant 1986, Van Woesik et al. 2006, Vargas-Ángel et al. 2006), the implementation of restoration work in the region will require a greater number of local observations to predict local patterns.

Challenges are extensive for advancing local observations of spawning events, mainly because of lack of capacity and the breakdown of reefs. Colombia's Caribbean reefs, even within Marine Protected Areas (MPAs), are highly degraded, with local estimates consistent with 10% remaining coral cover regionally (Sánchez et al. 2019). There are thousands

of square kilometers to map and patrol and few resources for scientific and restoration efforts. Historically, governmental resources were directed towards other priorities, to the detriment of MPAs. Diseases present in the greater Caribbean also ravaged South American reefs (Garzón-Ferreira et al. 2001, Gil-Agudelo et al. 2009, Sánchez et al. 2005, 2010, Navas-Camacho et al. 2010). Human activities in the marine parks degraded the reefs over the last few decades, and destructive fishing techniques remain a major issue in the region (Saavedra-Díaz et al. 2015). Anchoring on reefs and dynamite fishing are still common in Colombia (Garzón-Ferreira et al. 2000) and within the MPA (Zárate Arévalo pers. obs.), and many areas remain devoid of significant coral cover even after more than 40 years of park establishment.

Monitoring of spawning may become more imperative for reef restoration actions in the near future given the state of regional politics and development, and the scarcity of living colonies to work with for restoration. Pressure for development in Columbia has expanded in recent years, resulting in negative outcomes for reefs. The expansion of the 118 km Canal del Dique, which allows ships to traverse to the north-south Magdalena River corridor, caused a yearly influx of freshwater, silt, and sediments that settle on local reefs during the rainy season (Restrepo et al. 2006, 2017). Immediately outside Cartagena, the Arrecife Coralino de Varadero, a large swath of coral, is slated to be demolished to widen shipping lanes. This reef, despite intense anthropogenic pressures, has remarkably high coral cover and complexity (Pizzaro et al. 2017). Lastly, pressure on Colombian National Parks (Parques Nacionales Naturales) authorities to patrol these areas and advance scientific monitoring has remained difficult, so partnering with local communities to

actively support restoration and conservation is imperative. Colonies of either *A. palmata* or *A. cervicornis* were difficult to find in the location of this work, the result of continued anthropogenic pressure.

The observations reported in this investigation were made as part of a pilot-scale sexual coral restoration effort. The traditional downside cited for asexual restoration programs is that they borrow from one degraded reef to restore another. However, when there is little living material left, sexual propagation is advantageous because it allows for restoration without the risks associated with fragmentation and colony translocation (Guest et al. 2014, Chamberland et al. 2015). The demography and genetics of Colombian reefs remain under-studied, thus the potential for repopulation of corals from outside the national waters and established MPAs is yet unknown.

This record represents the first documented spawning for *A. palmata* in Colombia and the first observation of *A. cervicornis* spawning on natural reefs in Parque Nacional Natural Los Corales del Rosario y de San Bernardo (PNNCRSB), a 1,200 km² underwater national park and MPA established in 1977.

MATERIALS AND METHODS

Two areas within the northern part of PNNCRSB (Figure 1, arrow in inset) were investigated for coral spawning in

August 2019: Arrecife Luis Guerra, a fringing reef complex (10° 10.243' N, 75° 45.729' W), and the adjacent coral nursery of the Oceanario Islas del Rosario (10° 10.567' N, 75° 46.322' W) (Figure 1, satellite image), the latter of which encompasses a portion of the reef enclosed by underwater perimeter fencing. Only 8 colonies of *A. cervicornis* were present on Arrecife Luis Guerra, and no *A. palmata* were present.

Previous observations of the captive *A. cervicornis* in the Oceanario nursery, that were originally collected from fragments from surrounding islands, showed spawning 6 days after the full moon (DAFM) in August. Therefore, collection dives were planned for each night from 2 to 7 DAFM in August 2019. Collection nets were deployed on both wild colonies and the largest coral colonies in the nursery at the Oceanario, including one colony of *A. palmata* measuring about 0.6 m across. Conical collection nets made of 72 g/m² woven polyester fabric with 150 ml collection cups (Figure 2A, cups not shown) or 50 ml conical collection tubes (Figure 2B) were deployed on the 3 largest *A. cervicornis* wild colonies from Arrecife Luis Guerra to collect newly spawned gametes. Collection nets previously used at the Oceanario were of similar construction but made from clear polyethylene with 50 ml conical collection tubes (Figures 2C, D). SCUBA monitoring of collection nets on Ar-

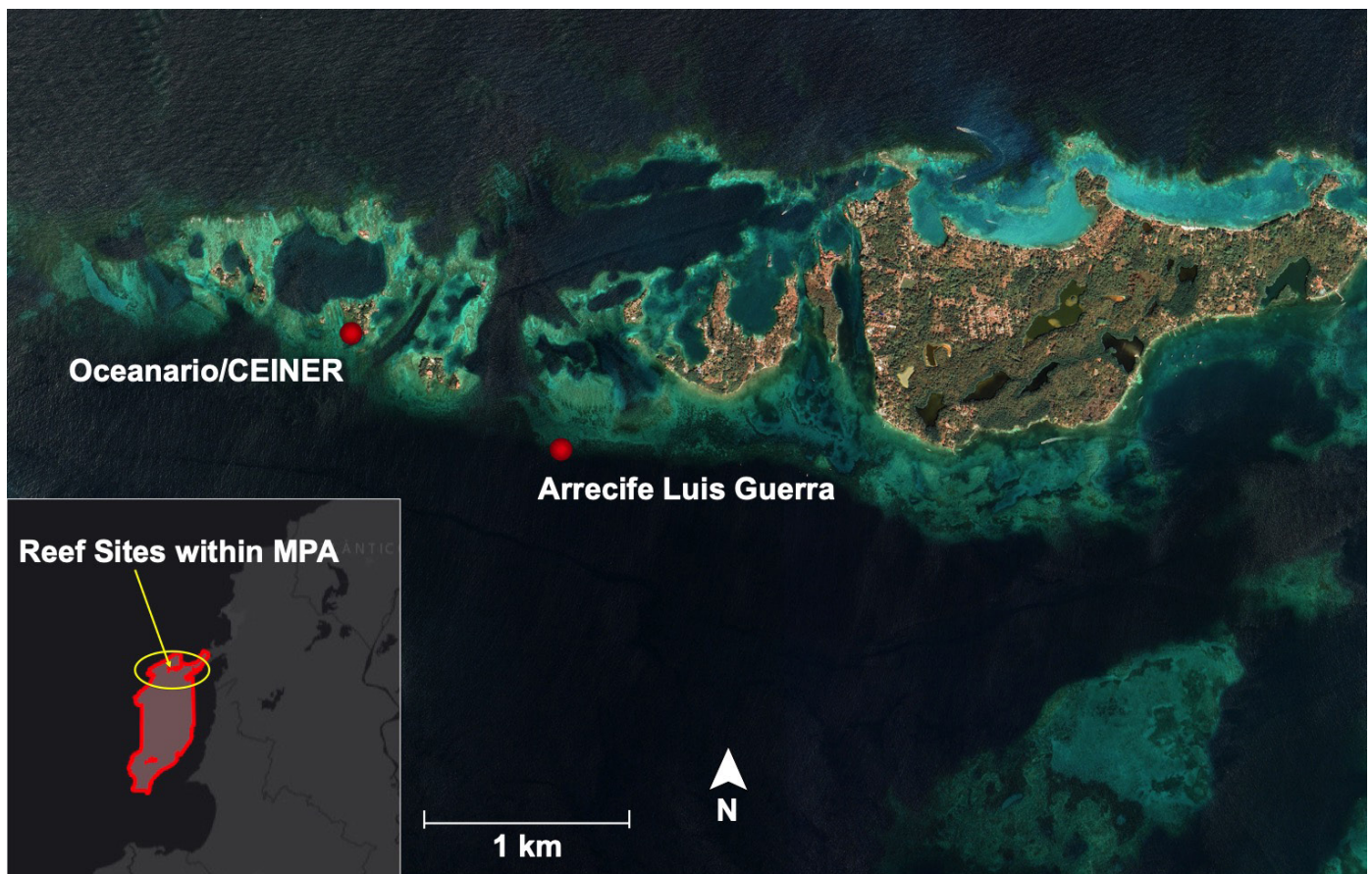


FIGURE 1. Collection locations for spawning events of *Acropora cervicornis* and *Acropora palmata* in Parque Nacional Natural Los Corales del Rosario y San Bernardo, Colombia. The national park is outlined in red in the inset, and the reefs monitored are indicated with the arrow.

recife Luis Guerra proceeded each night until spawning was observed and ceased; monitoring was discontinued after 7 DAFM. Within the Oceanario enclosure, the nets were monitored at 30-minute intervals from 20:00 to 22:00 h (102–222 min after sunset).

Coral gametes from the spawning events if both wild and nursery colonies were collected and cross-fertilized by diluting sperm from multiple colonies. Collected sperm was homogenized into one container, diluted with sterile seawater to a concentration of 10^5 cells/ml, and allowed a 60 min fertilization period. Viability was assessed by active embryogenesis at the end of the fertilization period. Counts of fertilization rates (viable coral embryos vs. unfertilized ova) were estimated on a well slide ($n = 10$) under a stereomicroscope. Since only a single colony of *A. palmata* spawned, and embryos resulting from self-fertilization suffer low survivorship (Baums et al. 2005a), the *A. palmata* eggs were fertilized with sperm from *A. cervicornis* to assess viability. Coral embryos and larvae were reared in polycarbonate pseudokreisels following Chamberland et al. (2015), and allowed to settle on aragonite reef rubble and ceramic tiles for outgrowth and replanting as part of a restoration project.

RESULTS

Both *Acropora* spp. were observed to spawn in the Oceanario nursery (20+ colonies), and wild *A. cervicornis* spawn was observed for the first time in 3 colonies of 5 total observed/monitored in the MPA (60% spawning in observed colonies, only 5 of the 8 colonies were large enough to

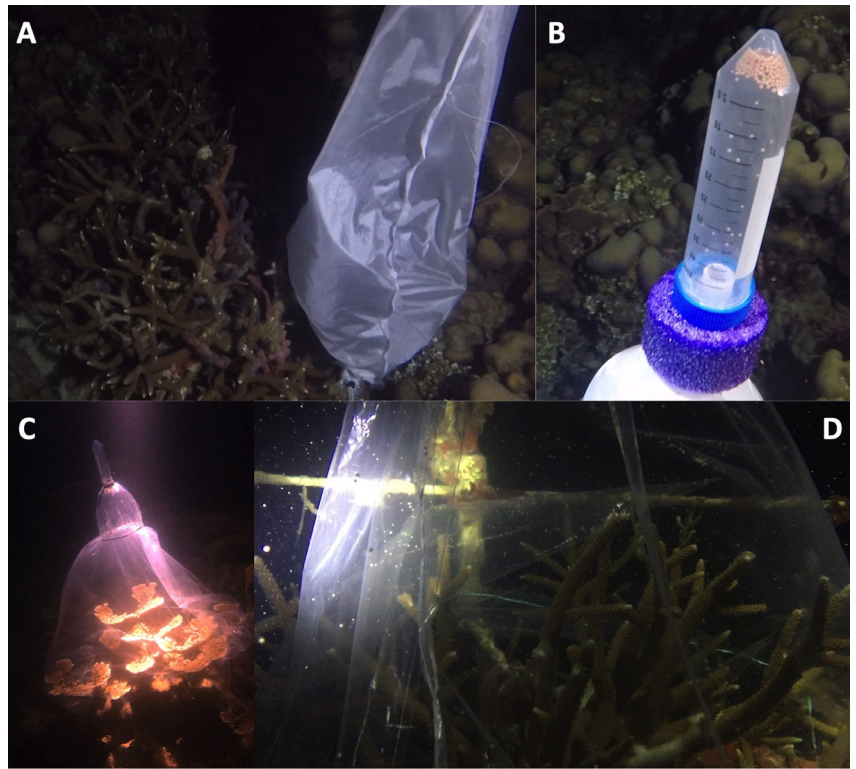


Figure 2. Spawning of *Acropora cervicornis* and *Acropora palmata* in Parque Nacional Natural Los Corales del Rosario y San Bernardo, Colombia. The full moon was 15 August 2019. A. Spawning collection of *A. cervicornis* at Arrecife Luis Guerra. B. *Acropora cervicornis* spawn. C. Spawn collectors on *A. palmata* at Oceanario. D. Spawning of *A. cervicornis* at Oceanario.

spawn; Table 1). The single *A. palmata* colony spawn represents a first record for Colombia. This colony grew to reproductive size from a fragment collected on Isla Grande inside PNNCRSB. Colonies of *A. cervicornis* in the Oceanario nursery were observed to spawn 6 DAFM in August for the third year in a row. During gamete staging/setting (emergence of egg-sperm bundles at the mouth of the in-

TABLE 1. Spawning timing for *Acropora palmata* and *Acropora cervicornis* in Colombia during August 2019. All times in minutes after sunset (MAS). Setting refers to the presence of a spawn packet that moves up into the mouth of the coral polyp immediately prior to spawn. Spawning refers to the observation of the release of that packet from the coral.

Date (Days After Full Moon)	Oceanario (Nursery) Corals	Arrecife Luis Guerra (Wild) Corals
	<i>A. palmata</i>	<i>A. cervicornis</i>
		<i>A. cervicornis</i>
Aug. 17 (+2)	No spawn or setting observed	No spawn or setting observed
Aug. 18 (+3)	No spawn or setting observed	No spawn or setting observed
Aug. 19 (+4)	No spawn or setting observed	Minor spawn: 192 MAS (1 colony) 222 MAS (2 colonies)
Aug. 20 (+5)	No spawn or setting observed	Minor spawn: 152 MAS setting, 162 MAS spawn (1 colony)
Aug. 21 (+6)	Spawn: 162 MAS to 207 MAS (1 colony)	Major spawn: 160 MAS (20+ colonies)
Aug. 22 (+7)	No observations	No observations
		Major Spawn: 150 MAS setting, 158 MAS to 163 MAS spawn (1 colony), 152 MAS setting, 160 MAS spawn (1 colony, same as Aug. 20)
		Minor spawn: 138 MAS setting, 153 MAS to 165 MAS spawn; 147 MAS setting, 160 MAS to 177 MAS spawn (1 colony); No spawn from Aug. 20 colony

dividual polyps) or spawning, an abundance of pelagic polychaete worms and sharpnose puffers (*Canthigaster rostrata*) were observed around the spawning colonies. On 22 August (7 DAFM) a number of ophiuroid species were observed spawning and releasing gametes from the upper branches of corals at 20:47 h (147 min after sunset). Eggs from *A. cervicornis* colonies at both sites produced viable embryos ($n = 127,480$) that displayed a mean fertilization rate of 92%. The single *A. palmata* colony produced $n = 184$ eggs, and the resulting hybrid acroporid (*Acropora prolifera*) embryos displayed 62% fertilization. Overall, viability of coral larvae was high; in *A. cervicornis* over 80% of embryos proved settlement-competent, with planulae settling and metamorphosing into primary polyps on ceramic tiles.

The Center of Research, Education, and Recreation (Centro de Investigación, Educación, y Recreación, or CEINER) previously registered *A. cervicornis* spawning in the Oceanario nursery on 1 September 2018 (6 DAFM, between 20:00–22:00 h, or 102–222 min after sunset) and on 13 August 2017 (6 DAFM, 21:07 h, or 169 min after sunset). This represents consistent spawning date and time for 3 consecutive seasons for *A. cervicornis*, with results here also indicating that viable larvae can be produced for restoration even with the few colonies remaining.

DISCUSSION

This report represents the first documented observation of *A. cervicornis* spawning in the wild in the PNNCRSB MPA and the first to document the spawning of *A. palmata* in Colombia. An initial observation of 3 large *A. palmata* colonies on Isla Tesoro to the north on 17 August 2019 (2 DAFM) produced no observed spawning. The 2019 spawning dates (6 DAFM) were the same detected in 2018 and 2017 past spawning observations by CEINER at Oceanario. This confirmation of reproductively competent colonies should allow for expansion of sexual propagation efforts by PNNCRSB authorities and partners beyond their successful spawning and outplanting efforts for *Orbicella faveolata* and *Orbicella annularis*. The technology transfer of collection and larviculture techniques used successfully elsewhere in the Caribbean (Chamberland et al. 2015) resulted in high fertilization and survival rates of *A. cervicornis* larvae, which were settled onto tiles and placed in a nursery for outplanting the next year. The technique was also well-deployed in producing a 62% fertilization of *A. prolifera*, which is higher than some previously recorded fertilization rates (Fogarty et al., 2012).

As coral reefs continue to degrade, spawning data are crucially important because there is not yet a complete model of the coral spawning patterns of the southwestern Caribbean, nor is it understood how Colombian populations may differ from each other and from other southwestern Caribbean populations. Published accounts on the spawning periodicity of reef building corals in Colombia are sparse

in comparison to Florida, Curacao, and other parts of the Caribbean Sea (Jordan 2018). Both Caribbean *Acropora* spp. have historically had fairly consistent reproductive cycles, undergoing gametogenesis from the fall to the spring, and spawning the following August (Szmant 1986), but more recent reviews have found that spawning in July or August is also recorded in the literature (Jordan 2018), and reproductive characteristics such as fecundity vary between populations (Vargas-Ángel et al. (2005).

The (limited) observations of Colombian *Acropora* spp. spawning in this investigation suggest that *A. cervicornis* seems to spawn later than other southern Caribbean *Acropora* spp. (CARMABI 2019), though the timing is largely consistent with aggregated reports from the greater Caribbean (Jordan 2018). As this is the first documented occurrence of *A. palmata* spawning in this region, it remains to be seen what trends may be present in Colombian populations.

Global stressors, such as climate change, have been shown to cause spawning asynchrony in the Red Sea (Fogarty and Marhaver 2019, Schlesinger and Loya 2019), which could serve to reduce the overall fitness of populations, especially for species similar to *A. palmata*, which has a highly variable window for gamete release (Jordan 2018). Miller et al. (2016) documented spawning variations in a population of *A. palmata* and noted that spawning asynchrony is particularly detrimental to populations with fewer individual genets, such as the depauperate Colombian reefs observed in this study. Spawning asynchrony, coupled with the loss of valuable genetic diversity and the stress of disease (Sokolow 2009), may reduce chances of recovery. In the context of recent findings on the interconnectivity of Caribbean reefs (Schill et al. 2015), this may portend a crisis of accelerated population decline greater than previously anticipated, as the Colombian reefs do not appear to be as strongly interconnected as other Caribbean reef systems.

To better ensure successful restoration efforts in Colombia, more spawning observations across a greater geographic area and time are needed to improve planning with limited resources. Yearly spawning variability is a logistical challenge for restoration efforts for *A. palmata*, as the species is known to spawn from 0–13 DAFM in the southern Caribbean (CARMABI 2019), and from 0–18 DAFM in the greater Caribbean (Jordan 2018). Moreover, the progress for sexual propagation of *A. cervicornis* and *A. palmata* as a means of effective coral reef restoration in Colombia, depends on locating enough healthy colonies of reproductive size in and around the MPA. Owing to the destructive pressures previously described above as well as associated reef degradation, *Acropora* spp. colonies are scarce, and therefore are likely too far apart to result in successful natural fertilization and recruitment. *Acropora cervicornis* is impacted by freshwater and sediment intrusion (Hands et al. 1993) and the effects of warming seas (Renegar and Riegl 2005, Enochs et al. 2018),

and demography shows that the species eventually reaches a level of functional extinction as populations decline (Mercado–Molina et al. 2015). Furthermore, the degree to which *A. palmata* populations are genetically connected to other regional reservoirs of the species has significant implications on the potential success of conservation and management strategies (Baums et al. 2005b). As reefs in this Colombian location are so heavily degraded (Sánchez et al. 2019) and more comprehensive assessments are still underway and unpublished (see Garzón–Ferreira and Rodríguez–Ramírez 2010), there is likely not enough living material for large–scale management and restoration programs focused on asexual fragmentation such as those in Florida and Puerto Rico (Lirman and Schopmeyer 2016, Schopmeyer et al. 2017) or on the Mesoamerican reef in México and Belize (Rodríguez–Martínez, 2008; Rodríguez–Martínez et al. 2014).

Further survival and reef recovery in PNNCRSB will depend on local community collaboration, as it is well–known that functioning MPAs provide faster recovery and resilience for reefs and associated fishes (Mellin et al. 2016). The location of a coral nursery within the MPA is highly advantageous

for a restoration program as spawn can be simultaneously collected from the wild corals and from nursery–housed local morphotypes (individual non–fusing colonies presumed to be disparate genotypes) and cross–fertilization allows for representation of a wider variety of individual corals. This means that local conservationists are able to repopulate reefs with more genetically–diverse individuals as they reach deployment size. Culturing and settling competent coral larvae *ex situ* comes with many challenges, but by continuing to nurture the exchange of information between researchers and coral culturists, these challenges can be overcome (Leal et al. 2014). Restoration efforts are particularly important for increasing coral cover, an important metric that allows reefs to accrete faster and assists with tracking sea level rise as a result of climate change (Perry et al. 2018). Combined, spawning and sexual propagation activities, along with concerted restoration efforts, will need to be undertaken in order to make measurable differences in the recovery of degraded reefs not only in Colombia, but in other under–studied areas throughout the southern Caribbean.

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