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RESEARCH ARTICLE

Acropora cervicornis (Lamarck, 1816) spawning at Guanahacabibes National Park, Western Cuba.

Desove de *Acropora cervicornis* (Lamarck, 1816) en el Parque Nacional Guanahacabibes, occidente de Cuba.

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Abstract

Coral reefs are in decline, expecting to get even worse if protection and restoration actions are not established immediately. Coral restoration´s efforts assist the recovering of coral colonies in degraded areas of the reef. Although it has been proven that fragmentation methods contribute to restore coral cover, it limits the formation of new genotypes through genetic recombination. Using sexually derived corals for restoration would allow a high genetic heterogeneity and resilience of nurseries' coral colonies. Date and timing of coral spawn must be recorded for areas where this restoration method will be applied. There is no scientific report about *Acropora cervicornis* spawning in Cuba. In 2018 and 2019, mature colonies with high probability to spawn were monitored at Guanahacabibes National Park (GNP), Western Cuba. In July-August 2018, 20 colonies were monitored and none of them spawned. In August 2019, 31 colonies were monitored and three spawned partially and isolated in time. The most evident cause of this behavior in *A. cervicornis* populations of GNP in 2019 seems to be high temperatures followed by bleaching events.

Keywords: *Acropora cervicornis*, coral spawning, Guanahacabibes, Cuba.

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Resumen

Los arrecifes de coral están en declive y se espera que su estado empeore aún más si no se establecen medidas de protección y restauración de manera inmediata. Los esfuerzos en la restauración de corales asisten la recuperación de las colonias de corales en áreas degradadas del arrecife. Aunque se ha comprobado que los métodos que utilizan la fragmentación contribuyen a la restauración de la cobertura de corales, esta vía limita la formación de nuevos genotipos a través de recombinación genética. Usar corales obtenidos de reproducción sexual para la restauración permitiría aumentar la heterogeneidad genética y, además, la resiliencia de las colonias cultivadas. La fecha y hora del desove de coral deben ser registradas en las áreas donde se aplicará este método de restauración. No existe reporte científico sobre el desove de *Acropora cervicornis* en Cuba. En 2018 y 2019, se monitorearon colonias maduras con alta probabilidad de desovar en el Parque Nacional Guanahacabibes (PNG), Occidente de Cuba. En julio-agosto del 2018, 20 colonias fueron monitoreadas y ninguna de ellas desovaron. En agosto del 2019, 31 colonias se monitorearon y tres de ellas desovaron parcialmente y de manera aislada en el tiempo. La causa más evidente de este comportamiento en las poblaciones del PNG en 2019 parece ser las altas temperaturas seguidas de eventos de blanqueamiento.

Palabras clave: *Acropora cervicornis*, desove de corales, Guanahacabibes, Cuba.

Introduction

Coral reefs give a high economic contribution mainly in terms of coastal protection, tourism and fishing (Carpenter *et al.*, 2009; Grafeld *et al.*, 2017; Spalding *et al.*, 2017). It is estimated that, globally, the net value of these ecosystems is $9.9 trillion USD (Costanza *et al.*, 2014). Despite of their importance, coral cover has decreased significantly in the last decades due to a synergic effect of anthropogenic and natural causes (Jackson *et al.*, 2014; De Bakker *et al.*, 2016). Some authors suggest that coral reefs will be able to survive just for a few decades, if there is no immediate protection from human exploitation (Pandolfi *et al.*, 2003; Gattuso *et al.*, 2015).

In this context, several techniques have been tried out to restore coral cover in areas that have been affected before (Yeemin *et al.*, 2006; Marhaver *et al.*, 2015; Rinkevich, 2019). "Coral gardening" is among the most used of the novel strategies for active restoration of coral reefs (Johnson *et al.*, 2011; Young *et al.*, 2012; Rinkevich, 2019). In this practice the asexual reproduction via fragmentation is the main tool for the construction of coral nurseries. It consists in taking fragments from a healthy wild coral colony to make *ex situ* or *in situ* coral nurseries (Johnson *et al.*, 2011; Rinkevich, 2019). This technique is effective as it only requires one coral fragment, and in most cases requires less energy.

Although asexual reproduction through fragmentation can be used to recover locally coral cover, it may limit dispersal capacity and may generate genotypic incompatibility, which could decrease fertilization success (Baums *et al.*, 2013; Miller *et al.*, 2016). Using propagation through assisted sexual reproduction instead, would maintain a high genetic heterogeneity through genetic recombination. In addition, it would increase the resilience of nurseries' coral colonies and cause little or no damage to donor reef community (de la Cruz & Harrison, 2017; Randall *et al.*, 2020). Actions to increase genetic variability are an imminent need to increase coral resilience against climate change threats.

Genetic diversity is crucial for a better adaptation of corals to the constantly changing environmental conditions now at days in Caribbean reefs (Johnson *et al.*, 2011; Baums *et al.*, 2013). This fact is especially important for a successful sexual reproduction of species like *Acropora cervicornis* (Lamarck, 1816) which have physiological barriers to prevent the crossing of parental gametes. Under this condition, different parent genotypes are required for gamete fertilization to occur.

A. cervicornis was a dominant reef-builder at intermediate depths (5-25m) of shallow reefs in the Caribbean (Aronson & Precht, 2001; Weil *et al.*, 2002). However, in the late 70s the populations of this species suffered a great decline in the region mainly due to the white band disease (Aronson & Precht, 2001). This led to the inclusion of *A. cervicornis* in the IUCN Red List of threatened species under the category of critically endangered, and in the US Act of Endangered Species as threatened (Aronson *et al.*, 2008). Its abrupt decline, on top of the fact that this species is an extremely fast-growing branching coral with high annual productivity rates (Lirman *et al.*, 2014), makes it an excellent choice to use in coral propagation. *A. cervicornis* is a broadcast spawning hermaphrodite, with one gametogenic cycle per year, culminating with spawning activity during mid-summer (Szmant, 1986). The spawning time for this species is from July to September, peaking in August, from the third throughout sixth days after the full moon (DAFM) and from 30 to 257 minutes after sunset (Jordan, 2018).

Date and timing of coral spawning must be recorded for areas where assisted sexual reproduction will be applied because most coral species release gametes on only a limited number of days per year (Szmant, 1986; Harrison, 2011; Jordan, 2018) and coral eggs and sperm remain viable for only minutes to hours after they are released (Levitan *et al.* 2004; Fogarty *et al*. 2012). The spawning of different species has been monitored in several countries providing data to make predictions and calendars of this process. International forums (e.g., Coral Spawning Research Facebook page) and data bases (e.g., Coral Spawning Database) have even been created, making it possible to compile information for a greater view of coral spawning around the world (Lin & Nozawa, 2017; Jordan, 2018; Shlesinger & Loya, 2019; Baird *et al*., 2021).

On the other hand, there is evidence of recent spawning asynchrony in some coral species influenced by temporal and spatial changing factors (Fogarty & Marhaver, 2019). In Cuba there is no knowledge of any scientific report about *A. cervicornis* spawning. To carry out this task, the main aim of this study was to monitor colonies of *A. cervicornis* in Guanahacabibes National Park (GNP) to record data about their spawning.

Materials and methods

Study location

The study area was Bahía de Corrientes in GNP, Pinar del Río, Western Cuba (Fig. 1). Anthropogenic effects such as contamination, commercial fisheries and massive tourism are minimized in concordance with the regulations of this protected area (Cobián & Chevalier, 2009; Perera *et al*., 2013). Bahía de Corrientes is protected from wind action and has favorable environment for corals considering its condition indicators: maximum diameter, species richness, diseases and mortality (Perera *et al*., 2013; Caballero *et al*., 2019).

Spawning prediction and area selection

Exploratory dives were made to select the best places to monitor considering the highest numbers of healthy adult (maximum colony diameter >10 cm, according to Harris *et al*. 2014) *A. cervicornis* colonies that were in them. In the selected sites, a branch of each colony of interest was cut to identify individuals with gamete bundles (Baria *et al*., 2012). The colonies with gamete bundles were labeled with buoys, indicating those in which gamete bundles were observed inside their calices.

In 2018 Acuario site (20 colonies labeled) was selected to be monitored, and in 2019 the choosen ones were Acuario (21 colonies labeled) and Yemayá (10 colonies labeled) sites. Acuario (21° 47′ 70′′ N; 84° 30′87′′ W) is a patch reef of about 5m depth and Yemayá (21° 50′ 04′′ N; 84° 29′ 87′′ W) has a shallow patch reef of about 7m and a deep fringe reef of about 12m.

Monitoring dates

Field trips were carried out during the months of July-August in 2018 and August in 2019. The approximate monitoring time was from 21:22 to 23:30 h. In 2018, colonies were monitored the fourth and the fifth day after July′s full moon, and, in 2019, from the first until the sixth day after August′s full moon. In 2019, due to logistics reasons, on the second and third DAFM the surveys were carried out at the first site and the rest of the days at Yemayá (fourth to sixth DAFM).

Environmental conditions

Records of the weather available on different meteorological websites were used to estimate environmental conditions at GNP during the surveys period in 2018

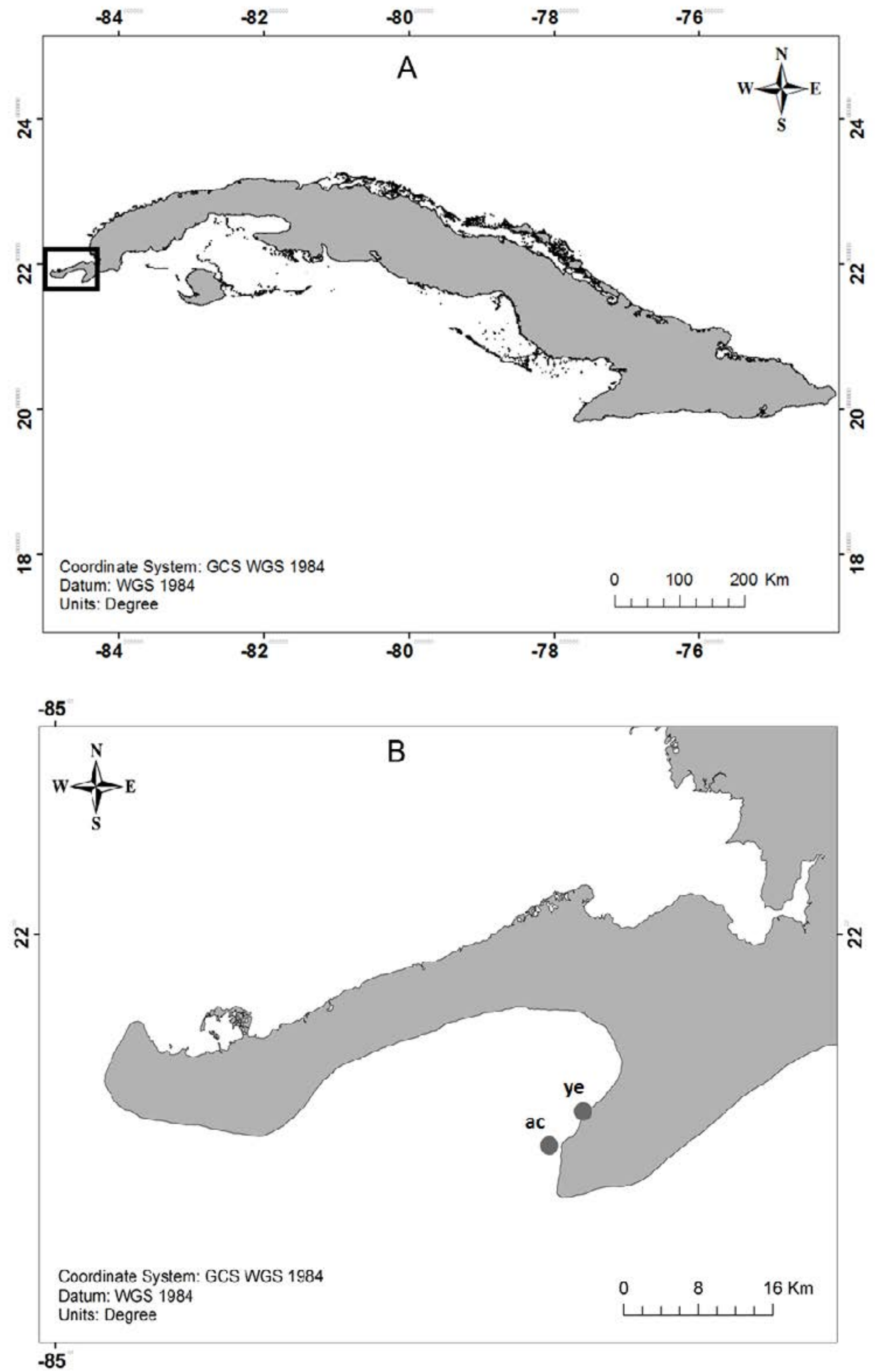

Fig. 1. A: Map of Cuba. B: Guanahacabibes National Park Map; ac: Acuario site (21 47´ 70 N; 84 30´´87 W); ye: Yemayá site (21 50´ 04 N; 84 29´´ 87 W).

and 2019. Daily data of wind speed and sea superficial temperature were collected, respectively, from Time and Date and the NASA (National Aeronautics and Space Administration) Earth Observation (NEO) official websites.

In 2019 cloud cover was nightly measured *in situ* in okta, which estimates how many "eights" of the sky are covered by clouds (World Meteorological Organization, 2009). These *in situ* measurements were later corroborated with data from National Oceanic and Atmospheric Administration (NOAA) official website.

Results and discussion

Over the past decade studies about coral spawning have become more frequent describing their synchronization, spawning time, environmental factors, etc. (Levitan *et al*., 2011; Jordan, 2018; Fogarty & Marhaver, 2019; Shlesinger & Loya, 2019; Baird *et al*., 2021). In this regard, data collection is very important for a better understanding of this process.

In this study, none of the 20 selected colonies spawned neither of the two nights of surveys in July-August, 2018 (Table 1). This result may be related to the selection of the monitoring dates, since they belong to the July's full moon and not August's (spawning peak). In relation to the previous idea, records from the forum Coral Spawning Research (2018) show that the magnitude of *A. cervicornis* spawning associated to July's full moon is lower than August's. For example, by the end of July and early August "dribble" spawn was registered in Georgia (U.S.A.) and Little Cayman (Cayman Islands), whereas, by the end of August and early September (peak) mass spawning events occurred in Little Cayman, Bonaire, Colombia and Saint Barthelemy (Caribbean French colony) (Table 2).

In August 2019, 31 colonies were monitored, and three of them spawned during the surveys in Yemayá site (no spawning reported at Acuario site). Partial gametes release occurred approximately between 22:45 and 23:10 h on August 19th and 21st of 2019, four and six DAFM, respectively (Table 1). On August 19th one of monitored colonies spawned at 7m depth. On August 21 two of the monitored colonies spawned, one at 7m with less than 20 bundles, and the other at 12m depth with just three malformed bundles. Just a few gamete bundles were released isolated in time, so assisted fertilization could not be performed.

Selected sites had similar environmental conditions during the monitoring periods: cloudy, low-wind nights with high temperatures (Table 3). Registered wind speed reached up to 4 km/h in 2018 and 5,5 km/h in 2019. Sea superficial temperature obtained varied from 29.55 to 30.45°C in 2018, and from 30.15 to 31.5°C in 2019. The cloudiness measured *in situ* in 2019 was relatively constant over the surveys nights

Table 1. Environmental parameters registered for Guanahacabibes National Park in July/August, 2018 and August, 2019 (NEO, 2021; NOAA, 2021; Time and Date, 2021).

Dates	Nightly wind speed (km/h)	Sea surface temperature (°C)	Daily cloud cover (okta)	Cloudiless monthly mean (okta)
31/07/2018	2	29.55-29.70	ND	4.6
01/08/2018	4	30.30-30.45	ND	4.1
16/08/2019	5.5	31.35-31.5	4	4.1
17/08/2019	4	31.20-31.35	4	4.1
18/08/2019	4	30.30-30.45	4	4.1
19/08/2019	4	30.60-30.75	4	4.1
20/08/2019	4	30.15-30.30	4	4.1
21/08/2019	4	30.30-30.45	5	4.1

Table 2. *Acropora cervicornis* spawning data collected in August 2018 and 2019 at Guanahacabibes National Park. NS: no spawning; DAFM: days after the full moon.

Date	DAFM	Site	Depht(m)	Monitored colonies	Colonies that spawn	Spawning time
31/07/2018	4	Acuario	5	20	0	NS
01/08/2018	5	Acuario	5	20	0	NS
16/08/2019	1	Acuario	5	21	0	NS
17/08/2019	2	Acuario	5	21	0	NS
18/08/2019	3	Yemayá	7	7	0	NS
18/08/2019	3	Yemayá	12	3	0	NS
19/08/2019	4	Yemayá	7	7	1	22:46-23: 05
19/08/2019	4	Yemayá	12	3	0	NS
20/08/2019	5	Yemayá	7	7	0	NS
20/08/2019	5	Yemayá	12	3	0	NS
21/08/2019	6	Yemayá	7	7	1	22:45-23:10
21/08/2019	6	Yemayá	12	3	1	22:45-23:10

and corresponded to the monthly mean (4,1) obtained from the NOAA official website (2021). Despite of not having measured zooplancton density and water turbidity, it was observed that both parameters were quite elevated during the expeditions in 2019, especially at the beginning of the monitoring dives.

To ensure success on coral sexual reproduction, a certain level of synchrony among colonies is crucial to achieve cross-fertilization (Sola, 2018). Some authors suggest the genetic and chemical cues play a role in fine scale spawning (Levitan *et al*., 2004; Levitan *et al.,* 2011). Nevertheless, a precise combination of environmental variables is needed for a spawning event to occur, including temperature (van Woesik *et al.,* 2006; Keith *et al.,* 2016; Jordan, 2018), light (Babcock *et al.,* 1994) and wind (Mangubhai & Harrison, 2006). The variation of these factors could lead to reproductive asynchrony within a population (van Woesik *et al*. 2006). On the other hand, stochastic factors that influence coral health, *i.e*., coral bleaching, disease, and hurricanes, could affect spawning synchrony too (Levitan *et al*. 2014; Jordan, 2018).

The mentioned elements might have influenced *A. cervicornis* spawning process at GNP in July-August of 2018 (none spawning registered) and August of 2019 (low spawning). However, the sea temperature seems to be the main factor, since it reached high values of up to 32 °C during August 2019 (Cobián, 2019). Acroporids follow an hourglass biological clock spawning model, which makes them especially sensitive to environmental changes (Lin & Nozawa, 2017). Specifically, for *A. cervicornis*, water temperature is one of the main factors that cause variability in spawning time (van Woesik *et al.,* 2006; Jordan, 2018). It has been estimated that for every one-degree Celsius increase in water temperature, the odds of spawning decreased by a factor of about 0.27 (Jordan, 2018). Other authors suggest that the shift in sea surface temperature, rather the actual temperature, affects mass spawning events (Keith *et al.,* 2016).

In August 2019, spawning magnitude and weather conditions found for *A. cervicornis* at Acuario and Yemayá, GNP were similar to other reports for the same month in other Caribbean reefs (Coral Spawning Research, 2019) (Table 2). No spawning

Table 3. *Acropora cervicornis* 2018 (July-August) and 2019 (August) spawning monitoring reports compiled from Coral Spawning Research site. GNP: Guanahacabibes National Park. (-): not specified. Low: ≤1/4 of the monitored colonies spawned; Mid: >1/4 and <3/4; Mass: ≥3/4

Date	Place	Magnitude
29/07/2018	Georgia, United States	Low
29/07/2018	Akumal, Mexico	-
30/07/2018	Georgia, United States	Low
30/07/2018	Akumal, Mexico	-
31/07/2018	Akumal, Mexico	-
31/07/2018	Little Cayman, Cayman Islands	-
01/08/2018	Akumal, Mexico	-
02/08/2018	Akumal, Mexico	-
03/08/2018	Akumal, Mexico	-
04/08/2018	Akumal, Mexico	-
04/08/2018	Little Cayman, Cayman Islands	-
05/08/2018	Little Cayman, Cayman Islands	-
07/08/2018	Little Cayman, Cayman Islands	Low
29/08/2018	Bonaire	-
29/08/2018	Little Cayman, Cayman Islands	Low
30/08/2018	Little Cayman, Cayman Islands	Low
30/08/2018	Bonaire	Mass
31/08/2018	Cartagena, Colombia	Mid
01/09/2018	Saint Barthélemy (Caribbean French colony)	Mass
01/09/2018	Cartagena, Colombia	Mass
02/09/2018	Little Cayman, Cayman Islands	Mass

Date	Place	Magnitude
19/08/2019	GNP, Cuba	Low
21/08/2019	GNP, Cuba	Low
17/08/2019	Bonaire	Mass
18/08/2019	Bonaire	Mass
19/08/2019	Bonaire	Mass
16/08/2019	Grand Cayman, Cayman Islands	Low
18/08/2019	Grand Cayman, Cayman Islands	Mass
19/08/2019	Little Cayman, Cayman Islands	Mass
17/08/2019	Florida, United States	Low
18/08/2019	Florida, United States	Low
19/08/2019	Florida, United States	Low
20/08/2019	Florida, United States	Low
21/08/2019	Florida, United States	Low
21/08/2019	Florida Keys, United States	Low
22/08/2019	Florida Keys, United States	Mid
23/08/2019	Florida Keys, United States	Mass
24/08/2019	Florida Keys, United States	Mass
20/08/2019	Belize	Low
19/08/2019	St. Barts French West Indies	Low
20/08/2019	St. Barts French West Indies	Mass
20/08/2019	Dominican Republic	Mass
21/08/2019	Dominican Republic	Mass

was reported in Belize, Bahamas, Mexico and Curaçao Sea Aquarium reef (Coral Spawning Research, 2019) for August 2019. On the other hand, some reports from Florida, Florida Keys and Saint Barts French West Indies also showed *A. cervicornis* low spawning, very few colonies and small number of bundles per colony, on August 19th and 21st (five and six DAFM, respectively), which concurs with data from GNP 2019. However, mass spawning events were registered for those same days in Bonaire, Cayman Islands and the Dominican Republic. It is possible that the factors discussed above may have specific local characteristics, causing spatial and temporal differences in coral spawning synchrony.

In August 2019, temperature fluctuated between 30 and 32 °C in GNP, where a massive coral bleaching event occurred with 50-75% of colonies affected by the month of September (Cobián, 2019). The fact that just a few numbers of coral colonies spawned at GNP in August 2019 and the ones that did released a small number of bundles could suggest that although selected colonies were apparently healthy, they could have been undergoing thermal stress (Shlesinger & Loya, 2019). Some authors suggest that the reabsorption of unspawned gametes could be a mechanism when conditions for spawning become less favorable (Sier & Olive, 1994; Neves & Pines, 2002; Mangubhai, 2007). On the other hand, bleaching events have been related to decline in metabolically-intensive processes such as reproduction (Szmant & Gassman, 1990; Baird & Marshall, 2002; Jordan, 2018). For certain Indo-Pacific *Acropora* species it has been found that after bleaching stress some colonies did not develop eggs (Marshall & Baird, 2000) and some others had a decrease in eggs volume and sperm numbers under high temperature rates, even when bleaching has not occurred yet (Paxton *et al*., 2015). Paxton *et al*. (2015) also obtained that spawning could start earlier under high temperatures.

Monitoring dates coincided with windy nights of low wind speed at GNP in 2018 and 2019. Mangubhai and Harrison (2006) suspect wind to affect coral spawning while observing several spawning events from different *Acropora* species during low-wind periods on a reef near the equator off the coast of Kenya. However, Jordan (2018) did not found wind to affect weather spawning occur for *A. cervicornis* and other scleractinian corals in the Caribbean, Western Atlantic, and Gulf of Mexico.

Our results suggest that the increase in water temperature may be interfering with the process of gamete production and release of *A. cervicornis* in GNP. This would affect new genotypes formation through genetic recombination during fertilization and therefore, reduce genetic diversity of this species′ population. In this scenario, the response capacity of *A. cervicornis* populations to environmental changes would decrease too. However, a higher data collection would be needed for further and more accurate findings.

This study represents the first scientific report of *A. cervicornis* spawning in Cuba, and it would be a starting point to increase the success of assisted sexual reproduction of this species in GNP.

Author contributions

Conceptualization, S.D. and P.P.C; Investigation, S.D. and P.P.C ; Data Curation, S.D., P.P.C., D.R., R.I.C., H. C. and A.P.; Writing (original draft), S.D.; Writing (review & editing), P.P.C, R.I.C., H.C., D.R. and X.E.; Visualization, S.D. and P.P.C.; Supervision, P.P.C.; Project administration, P.P.C; Funding Adquisition, P.P.C. and X. E.

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Conflicts of Interest

The authors have declared that no exist financial or non-financial competing interests relevant to the manuscript content.

Bibliography

Aronson, R.B., Precht, W.F. (2001). Applied paleoecology and the crisis on Caribbean coral reefs. *Palaios, 16*(3), 195-19 6.

Aronson, R., Bruckner, A., Moore, J., Precht, B., Weil, E. (2008). *Acropora cervicornis*. The IUCN Red List of Threatened Species 2008: e. T133381A3716457.

Babcock, R.C., Wills, B.L., Simpson, C.J. (1994). Mass spawning of corals on a high latitude coral reef. *Coral Reefs, 13* (3), 161-169.

Baird, A.H., Marshall, P.A. (2002). Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef. *Mar. Ecol. Prog. Ser., 237*, 133-141.

Baird, A.H., Guest, J.R., Edwards, A.J., Bauman, A.G., Bouwmeester, J., Mera, H., Abrego, D., Alvarez-Noriega, M., Babcock, R.C., Barbosa, M.B., Bonito, V., Burt, J., Cabaitan, P.C., Chang, C.F., Chavanich, S., Chen, C.A., Chen, C. J., Chen, W. J., Chung, F.C., Yusuf, S. (2021). An Indo-Pacific coral spawning database. *Nature*, *8*, 35.

Baria, M.V., De la Cruz, D., Villanueva, R., Guest, J. (2012). Spawning of three-year-old *Acropora Millepora* corals reared from larvae in northwestern philippines. *Bull. Mar. Sc., 88* (1), 61-62.

Baums, I.B., Devlin-Durante, M.K., Polato, N.R., Xu, D., Giri. S., Altman, N.S., Ruiz, D., Parkinson, J.E., Boulay, J.M. (2013). Genotypic variation influences reproductive success and thermal stress tolerance in the reef building coral, *Acropora palmata*. *Coral Reefs, 32* (3), 703-717.

Caballero Aragón, H., Armenteros, M., Perera Valderrama, S., Rey Villiers, N., Cobián Rojas, D., Campos Verdecia, K., & Alcolado Menéndez, P.M. (2019). Ecological condition of coral reef assemblages in the Cuban Archipelago. *Mar. Biol. Res*., *15*(1), 61-73.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Díaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan J., Scholes, R.J., Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci., 5,* (106).

Cobián, D., Chevalier, P.P. (2009). Evaluación de las asociaciones de peces de los arrecifes coralinos del Centro Internacional de Buceo María la Gorda, Parque Nacional Guanahacabibes, Cuba. *Rev. Cien. Mar. Cost., 1*, 111-125.

Cobián, D. (2019). *Reporte y Alerta sobre blanqueamiento en los arrecifes coralinos del Parque Nacional Guanahacabibes*. ECOVIDA, CITMA. 9 de octubre, 2019.

Coral Spawing Research. (2018-2019). Public group available at: https://www.facebook.com/groups/270783472935805/, accessed online on September 22nd, 2019.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Faber, S., Turner, R.K. (2014). Changes in the global value of ecosystem services. *Glob. Environ. Change, 26*, 152-158.

de la Cruz, D. W., Harrison, P. L. (2017). Enhanced larval supply and recruitment can replenish reef corals on degraded reefs. *Sci. Rep.,* 13985.

De Bakker, D.M., Meesters, E. H., Bak, R., Nieuwland, G., Van Duyl, F. (2016). Long-terrm shifts in coral communities on shallow to deep reef slopes of curaçao and Bonaire: are there any winners? *Front. Mar. Sci., 3*, 247.

Fogarty, N.D., Lowenberg, M., Ojima, M.N., Knowlton, N., Levitan, D.R. (2012). Asymmetric conspecific sperm precedence in relation to spawning times in the *Montastraea annularis* species complex (Cnidaria: Scleractinia). *J. Evol. Biol., 25*, 2481-2488.

Fogarty, N.D., Marhaver, K.L. (2019). Coral spawning, unsynchronized. *Science, 365* (6457), 987-988.

Gattuso, J.P., Magnan, A., Billé, R., Cheung, W.W.L., Howes, E.L., Joos, F., Allemand, D., Bopp, L., Cooley, S.R., Eakin, C.M., Hoegh-Guldberg, O., Kelly, R.P., Pörtner, H.O., Rogers, A.D., Baxter, J.M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., Sumaila, U.R., Treyer, S., Turley, C. (2015). Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. *Science, 349* (6243).

Grafeld, S., Oleson, K.L.L., Teneva, L., Kittinger, J.N. (2017). Follow that fish: Uncovering the hidden blue economy in coral reef fisheries. *Plos One, 12* (8), e0182104.

Harris, A., Wilson, S., Graham, N., Sheppard, C. (2014). Scleractinian coral communities of the inner Seychelles 10 years after the 1998 mortality event. *Aquatic Conserv.: Mar. Freshw. Ecosyst., 24* (5), 667-679.

Harrison, P. L. (2011). Sexual reproduction of scleractian corals. In Z. Dubinsky and N. Stambler (eds), *Coral Reefs: An Ecosystem in Transition* (pp. 59-85). The Netherlands: Springer Nature.

Jackson, J. B. C., Donovan, M. K., Cramer, K. L., Lam, V. V. (eds). (2014). *Status and Trends of Caribbean Coral*

Reefs: 1970-2012. Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland.

Johnson, M.E., Lustic, C., Bartels, E., Baums, I.B., Gilliam, D.S., Larson, E.A., Lirman, D., Miller, M.W., Nedimyer, N., Shopmeyer, S. (2011). *Caribbean Acropora restoration guide: best practices for propagation and population enhancement*. The Nature Conservancy, Arlington, VA.

Jordan, A. C. (2018). *Patterns in Caribbean Coral Spawning*. Thesis submitted in fulfilment of the academic requirements for the degree of Master of Marine Biology, Nova Southeastern University, Florida, United States of America.

Keith, S.A, Maynard, J. A., Edwards, A.J., Guest, J.R., Bauman, A.G., Van Hooidonk, R., Heron, S.F., Berumen, M.L., Bouwmeester, J., Piromvaragorn S. (2016). Coral mass spawning predicted by rapid seasonal rise in ocean temperature. *Proc. R. Soc. B, 283*, 20160011.

Levitan, D.R., Fukami, H., Jara, J., Kline, D., McGovern, T.M., McGhee, K.E., Swanson, C.A., Knowlton, N. (2004). Mechanisms of reproductive isolation among sympatric broadcast-spawning corals of the *Montastraea annularis* species complex. *Evolution, 58*, 308-323.

Levitan, D.R., Fogarty, N. D., Jara, J., Lotterhos, K. E., Knowlton, N. (2011). Genetic, spatial, and temporal components of precise spawning synchrony in reef building corals of the *Monstastrea annularis* species complex. *Evolution 65*(5)*,* 1254-1270.

Levitan, D. R., Boudreau, W., Jara, J., Knowlton, N. (2014). Long-term reduced spawning in *Orbicella* coral species due to temperature stress. *Mar. Ecol. Prog. Ser., 515*, 1-10.

Lin, C.H, Nozawa Y. (2017). Variability of spawning time (lunar day) in *Acropora* versus merulinid corals: a 7-yr record of in situ coral spawning in Taiwan. *Coral Reefs, 36,* 1269-1278.

Lirman, D., Schopmeyer, S., Galvan, V., Drury, C., Baker, A.C., Baums, I.B. (2014). Growth Dynamics of the Threatened Caribbean Staghorn Coral *Acropora cervicornis*: Influence of Host Genotype, Symbiont Identity, Colony Size, and Environmental Setting. *Plos One, 9* (9), e107253.

Mangubhai, S., Harrison, P.L. (2006). *Seasonal patterns of coral reproduction on equatorial reefs in Mombasa, Kenya*. Proceedings of 10th International Coral Reef Symposium, Okinawa, Japan. Japanese Coral Reef Society, Japan.

Mangubhai, S. (2007). *Reproduction and recruitment of scleractinian corals on equatorial reefs in Mombasa, Kenya*. Thesis submitted in fulfilment of the academic requirements for the degree of Doctor of Philosophy, Southern Cross University, Australia.

Marhaver, K., Vermeij, M., Medina, M. (2015). Reproductive natural history and successful juvenile propagation of the threatened Caribbean Pillar Coral *Dendrogyra cylindrus*. *BMC Ecol., 15* (1),9.

Marshall P.A., Baird, A.H. (2000). Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. *Coral Reefs, 19,*155-163.

Miller, M.W., Williams, D.E., Fisch, J. (2016). Genet-specific spawning patterns in *Acropora palmata*. *Coral Reefs, 35* (4), 1393-1398.

NASA (National Aeronautics and Space Administration) Earth Observation (NEO). (2021). *State of the Ocean* Version 4.6. http://podaac-tools.jpl.nasa.gov/soto; searched on May 24th, 2021.

Neves, E.G., Pires, D.O. (2002). Sexual reproduction of Brazilian coral *Mussismilia hispida* (Verrill, 1902). *Coral Reefs*, *21,* 161-168.

NOAA (National Oceanic and Atmospheric Administration) Coast Watch. (2021). *The Environmental Research Division* ERDDAP Version 2.12 http://coastwatch.pfeg.noaa.gov/erddap/griddap/; searched on May 14th, 2021.

Pandolfi, J. M., Bradbury, R.H., Sala, E., Hughes, T.P., Bjorndal, K.A., Cooke, R.G., McArdle, D., McClenachan, L., Newman, M.J.H., Paredes, G., Warner, R.R., Jackson, J.B.C. (2003). Global trajectories of the long-term decline of coral reef ecosystems. *Science, 301* (5635), 955-958.

Paxton, C.W., Baria, M.V.B., Weis, V.M., Harii, S. (2015). Effect of elevated temperature on fecundity and reproductive timing in the coral *Acropora digitifera*. *Zygote,* 1-6.

Perera, S., Alcolado, P., Caballero, H., de la Guardia, E., Cobián, D. (2013). Condition of coral reefs in the Guanahacabibes National Park, Cuba. *Revista Marina Costera, 5,* 69-86.

Petersen, D., Carl, M., Borneman, E., Brittsan, M., Hagedorn, M., Laterveer, M., Schick. (2008). Noah's Ark for the threatened Elkhorn coral *Acropora palmata*. *Coral Reefs, 27* (3), 715.

Randall, C. J., Negri, A. P, Quigley, K. M., Foster, T., Ricardo, G. F., Webster, N. S., Bay, L. K., Harrison, P. L., Babcock, R. C., Heyward A. J. (2020). Sexual production of corals for reef restoration in the Anthropocene. *Mar. Ecol. Prog. Ser.*, *635*, 203–232.

Rinkevich, B. (2019). The Active Reef Restoration Toolbox is a Vehicle for Coral Resilience and Adaptation in a Changing World. *J. Mar. Sci. Eng., 7,* 201.

Shlesinger T., Loya, Y. (2019). Breakdown in spawning synchrony: A silent threat to coral persistence. *Science, 365*, 1002 (2019).

Sier, C.J.S. Olive, P.J.W. (1995). Reproduction and reproductive variability in the coral *Pocillopora verrucora* from the Republic of Maldives. *Mar. Biol., 118,* 713-722.

Sola, E. (2018). *Reproductive synchrony and recruitment ecology of scleractinian corals at Vamizi Island, northern Mozambique*. Thesis submitted in fulfilment of the academic requirements for the degree of Doctor of Philosophy, University of Kwazulu-Natal, South Africa.

Spalding, M., Burke, L., Wood, S.A., Ashpole, J., Hutchison, J., Ermgassen, P. (2017). Mapping the global value and distribution of coral tourism. *Mar. Policy, 82,* 104-113.

Szmant, A.M. (1986). Reproductive ecology of Caribbean reef corals. *Coral Reefs, 5,* 43–54.

Szmant, A.M., Gassman, N.J. (1990). The effects of prolonged 'bleaching' on the tissue biomass and reproduction of the reef coral *Montastrea annularis*. *Coral Reefs, 8*, 217 – 224.

Time and Date (2021). *Weather* http://www.timeanddate.com/weather/; searched on May 14th, 2021.

van Woesik, R., Lacharmoise, F., Köksal, S. (2006). Annual cycles of solar insolation predict spawning times of Caribbean corals. *Ecol. Lett., 9* (4), 390-398.

Weil, E., Hernández-Delgado, E.A., Bruckner, A.W., Ortiz, A.L., Nemeth, M., Ruiz, H. (2002). Distribution and status of Acroporid coral (Scleractinia) populations in Puerto Rico. *Proceedings of the Caribbean Acropora workshop: potential application of the US endangered species act (ESA) as a conservation strategy.* NOAA-NMFS and NCORE-RSMAS (pp. 71-92) U. of Miami.

World Meteorological Organization (WMO). 2009. Manual on codes: International codes volume I. 1, part A-Alphanumeric codes, WMO-No. 306, Geneva, Switzerland.

Yeemin, T., Sutthacheep M., Pettongma R. (2006). Coral reef restoration projects in Thailand. *Ocean Coas. Manag., 49* (9), 562-575.

Young, C.N., Schopmeyer, S.A., Lirman, D. (2012). A review of reef restoration and coral propagation using the threatened genus *Acropora* in the Caribbean and western Atlantic. *Bull. Mar. Sci., 88*, 1075-1098.

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