HOLOS ENVIRONMENT

TEMPORAL BEHAVIOR OF AIR AND SEA SURFACE TEMPERATURE IN A MARINE PROTECTED AREA OF CUBA: THE JARDINES DE LA REINA NATIONAL PARK

COMPORTAMENTO TEMPORAL DA TEMPERATURA DA SUPERFÍCIE DO AR E DO MAR EM UMA ÁREA MARINHA PROTEGIDA DE CUBA: O PARQUE NACIONAL JARDINES DE LA REINA

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Abstract: The Cuban Archipelago -particularly its coastal zones- is exposed to Global Warming. The rise of air and sea surface temperature value is a good indicator of its consequences to biodiversity. Air temperature was measured using an Automatic Meteorological Station at the Jardines de la Reina National Park between 2016 and 2017. Sea surface temperature was measured using temperature data loggers twice in the years 2000 (January and September) and 2016 (from January to June) in coral, mangrove and seagrass habitats. Air and sea surface temperature satellite data of the same studied sites were analyzed in the period 2003-2017 using *in situ* measurements. Results showed that all temperature values were similar to those reported in similar studies in Cuba and the Caribbean, and that extreme values were within the tolerance ranges previously reported for the studied habitats. Air temperature did not have a significant trend; however, sea surface temperature had a significant increase (0.01 °C) during the studied period. These results show the great influence of the Caribbean Sea over the marine waters and climate of this area. A combined monitoring system was proposed using *in situ* data logger measurements and satellite data temperature analysis to watch this important marine reserve of the Caribbean Region.

Keywords: Air temperature. Sea surface temperature. Coral. Seagrass. Cuba.

Resumo: O arquipélago cubano -especialmente suas zonas costeiras- está exposto ao aquecimento global. O aumento do valor da temperatura da superfície do ar e do mar é um bom indicador de suas consequências para a biodiversidade. A temperatura do ar foi medida usando uma Estação Meteorológica Automática no Parque Nacional Jardines de la Reina entre 2016 e 2017. A temperatura da superfície do mar foi medida usando registradores de temperatura duas vezes nos anos 2000 (janeiro e setembro) e 2016 (de janeiro a junho) em habitats de corais, manguezais e ervas marinhas. Dados de satélite de temperatura do ar e da superfície do mar dos mesmos locais estudados foram analisados no período 2003-2017 usando medições in situ. Os resultados mostraram que todos os valores de temperatura foram semelhantes aos relatados em estudos semelhantes em Cuba e no Caribe, e que os valores extremos estavam dentro das faixas de tolerância relatadas anteriormente para os habitats estudados. A temperatura do ar não teve uma tendência significativa; no entanto, a temperatura da superfície do mar teve um aumento significativo (0.01 °C) durante o período estudado. Esses resultados mostram a grande influência do Mar do Caribe sobre as águas marinhas e o clima desta área. Foi proposto um sistema de monitoramento combinado usando medições in

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situ de registradores de dados e análise de temperatura de dados de satélite para observar esta importante reserva marinha da região do Caribe.

Palavras-chave: Temperatura do ar. Temperatura superficial do mar. Coral. Pastos marinhos. Cuba

1 INTRODUCTION

Global mean surface temperature increased 1.5 °C in the period 2006-2015 relative to 1850-1900, and some climate models project a similar increase for the next years. For oceans, temperature rise could be greater than 2.0 °C in some regions. A high percentage (70- 90 %), of tropical species as corals could disappear even if surface temperature rise is below 1.5 °C (IPCC, 2018).

The role of sea surface temperature (SST) over marine life has been well documented. Some studies have evaluated the impacts of this important oceanographic factor over seagrasses (DÍAZ-ALMELA *et al.,* 2007; JORDÀ *et al.,* 2012; HALL *et al.,* 2016, CARLSON *et al.,* 2018), corals (BAKER *et al*., 2008; LOUGH *et al.,* 2018; HUGHES *et al.,* 2018; MUÑIZ-CASTILLO *et al.* 2019) and fish assemblages and fisheries (CONAND *et al.,* 2007; RIJNSDORP *et al.,* 2010; CHEUNG *et al.* 2013; JONES *et al.,* 2015; MAHARAJ *et al.,* 2018).

In the Caribbean Region, Glenn *et al.* (2015) documented the increase of surface temperature between 1982 and 2012, as the biggest changes in last 15 years of this period. The marine biodiversity of the Caribbean has been affected and will be affected by climate change (including increase of temperature) (MAHARAJ *et al.,* 2018). Coral reefs are one of the most impacted marine ecosystems in the Caribbean region. According to Muñiz-Castillo *et al.* (2019) Caribbean reefs have been exposed to heat stress during the last 30 years, with major events in 1998, 2005, 2010-2011, 2015 and 2017 and a change point in 2002-2004.

The Cuban Archipelago, located at the center of the Caribbean Region, is exposed to the same threats than the rest of the Caribbean. Consequently, the marine and coastal resources of Cuba have been affected by the increase of temperature as a result of climate change. Mean annual temperature in Cuba increased 0.9 °C from the last decade of the 20th century to 2008, but the behavior of SST has not been studied (PLANOS *et al.,* 2012). In Cuba, the studies on SST are scarce. Most of them have focused on marine waters around the island (CERDEIRA-ESTRADA *et al.,* 2005, SOMOZA *et al.,* 2006, PIÑEIRO-SOTO; COBAS-GÓMEZ, 2010). Betanzos-Vega *et al.* (2019) found a SST increase of 0.7

°C in the Gulf of Batabano (southwest of Cuba) during the 2006-2016 period with respect to the 1959-1970 period. Garcés Rodríguez *et al.* (2014) did not find any relationship between SST and shrimp fisheries in the Ana Maria Gulf (close to our study zone). Alcolado (2011) reported that coral bleaching in Cuba was strong in 1995, 1998, 2005, 2009 and 2010 due to sea water warming in the Caribbean Region. However, Alcolado *et al.* (2011) suggested that on the southern coast, coral reefs are healthier than others around Cuba. Most of these studies used SST data from punctual samplings performed by oceanographic cruises and satellite images, mainly from NOAA 12 and NOAA 14.

Marine Protected Areas (MPAs) are one of the best tools to protect not only marine and terrestrial biodiversity, but also for ecological monitoring using future climatic scenarios (BRUNO *et al.,* 2018). Thus, the protection and management of marine resources are important to increase their resilience to present and future impacts of climate change (MAHARAJ *et al.,* 2018).

About 30% of coral reefs, 24% of the seagrass beds, and 35% of mangroves are legally protected through the system of MPAs in Cuba; one of these areas is the Jardines de la Reina National Park (JRNP) (PERERA-VALDERRAMA *et al.,* 2018).

The main objective of this study was to assess air and sea surface temperature temporal behavior at some marine ecosystems of the largest Marine Protected Area of the insular Caribbean: The Jardines de la Reina National Park. This evaluation of air and sea temperature includes samplings in some years as scientific relevance to knowledge of this poorly studied archipelago on abiotic behaviors (as temperature).

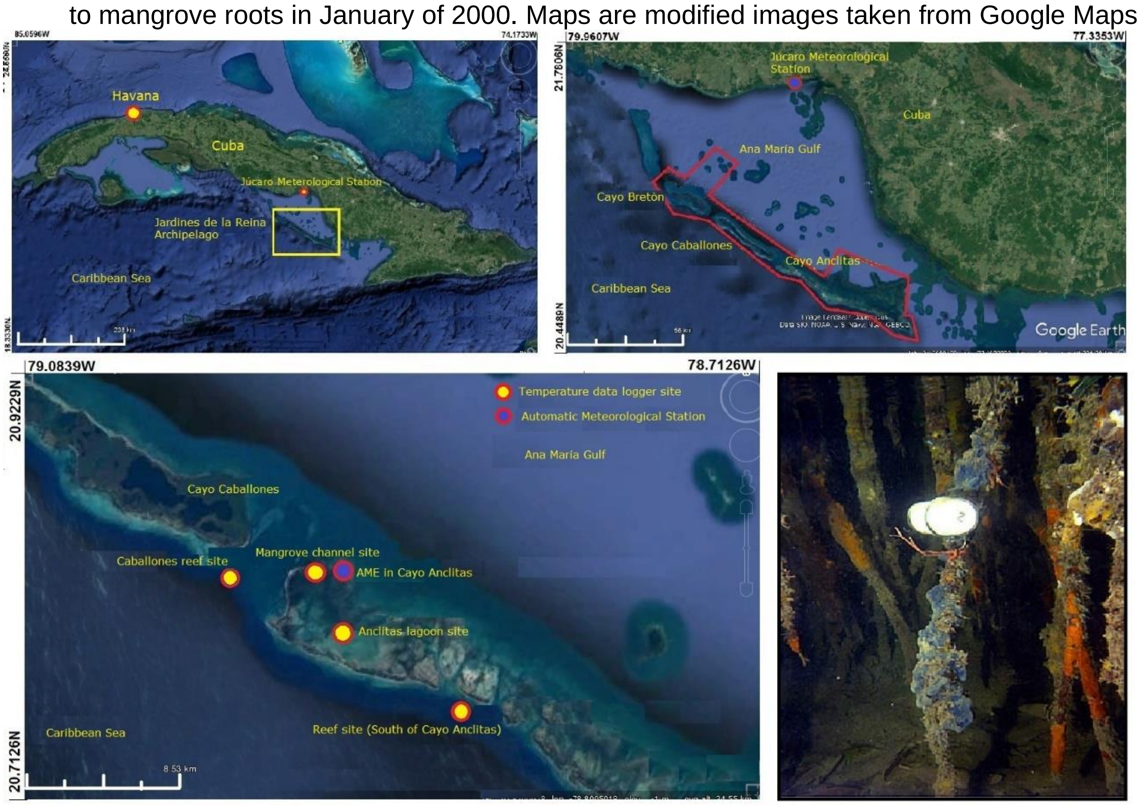
2 MATERIALS AND METHODS

2.1 Study area

The Jardines de la Reina (JR) Archipelago is located on the southeastern region of Cuba, bordering the southern limit of the Gulf of Ana María (Figure 1). The archipelago is formed by a long chain of cays with mangrove forests in the shore line and coral reefs facing the Caribbean Sea that stretch from the northwest to the southeast. Fore reefs are mainly structured in two zones: reef terrace and spur and groove formations. Reef terrace zones (~5-10 m depth) are followed by a gentle slope that ends in a sandy flat. The cays have many lagoons covered with seagrasses and mangroves. Water flows into the cays through tide channels during ebb and flow tides. Water exchange is important for the thermohaline conditions of the Ana Maria Gulf, one of Cuba's important fisheries (CLARO *et al.,* 2001).

Due to its well preserved marine and coastal resources, this archipelago was declared a Marine National Park (JRNP) in 2010, turning the largest Marine protected Area in the insular Caribbean. Tides are semidiurnal, and tourism (diving and catch and release fishing) is the only economic and social activity in the area. In Cuba, dry conditions prevail from December to April (coinciding with winter), and wetter conditions from May to November (coinciding with summer).

Figure 1 - Location of study area and temperature measurement sites. Red line in second map represents the limits of the Jardines de la Reina National Park (JRNP). Actual picture of data logger attached to mangrove roots in January of 2000. Maps are modified images taken from Google Maps



2.2 Air temperature data

Air temperature data were obtained from two sources: in situ, from an Automatic Meteorological Station (AMS) located in Cayo Anclitas (20.828 W, 78.929N) (Figure 1) and from the National Aeronautics and Space Administration (NASA) database.

The Automatic Meteorological Station is an HOBO U30 Station No Remote Communication (NRC). The HOBO U30 Station is a data logging and monitoring device that can be easily reconfigured and adapted to a wide variety of applications (temperature, precipitation, direction and speed of the wind, atmospheric pressure, radiation). The sensor measures temperature between -40.0 and 60.0 °C, and has a resolution/precision of 0.02 °C. Previous to the installation of the AMS in Cayo Anclitas, all sensors were calibrated at a weather station of the Institute of Meteorology of Cuba.

Air temperature data from the NASA database were obtained using Giovanni´s features (https://giovanni.gsfc.nasa.gov/giovanni/), which allows work with satellite temperature data and in situ observations.

Air temperature data from AME were obtained between October 2016 and July 2017 (registered every hour), and daily air temperature data from NASA database between 2003 and 2017. The measured air temperature values with AME in Cayo Anclitas, were compared with measured air temperature values from Meteorological Station in Júcaro town (located 90 km from Cayo Anclitas) (Figure 1).

2.3 Water temperature recorders

Data loggers that record temperature were StowAway XTI models from the ONSET Company. These loggers measure temperatures between -40.0 and 75.0 °C, and have a resolution/precision of 0.01 °C. Before measuring temperatures at the sites, data loggers were calibrated in Weather Station 339, located in Cayo Coco, Cuba. Deviation was less than ±0.05 °C in respect to readings from the calibrated thermometer. All data loggers were initialized for work using specific software through a specific interface. All loggers have autonomy and were programmed with measuring interval of 30 min (ONSET, 1999).

Three data loggers were installed for nine days in January of 2000. One at a reef site in Caballones channel, another at a mangrove channel in Cayo Anclitas, and the other at a seagrass habitat (*Thalassia testudinum*) in Anclitas Lagoon (Figure 1) (Table 1). All loggers were installed between the surface and a depth of 2 m.

Two similar data loggers were installed (for 11 days) at a reef site in Caballones Channel (at 2 and 8 m of depth) in September of 2000 (Figure 1) (Table 1).

Two similar data loggers were installed during the January-June period in 2016. One at the same reef site in the Caballones Channel, and the other at a reef site on the southern coast of Cayo Anclitas (Figure 1) (Table 1).

All data loggers installed at coral reef sites were tied to a mooring cable using diving boats.

Table 1 - Descripion of sea surface temperature monitoring sites in Jardines de la Reina National Park

Site	Date	Depth of data logger	Total depth (m)	Habitat
Caballones channel	January and September of 2000 January – June of 2016	-2 m in January of 2000 - 2m and 7 8 m (two data loggers) in September of 2000 - 2m in January – June of 2016	20	Fore reef
Reef site, south coast of Cayo Anclitas	January – June of 2016	- 2m in January – June of 2016	30	Fore reef
Mangrove tidal channel	January of 2000	2 m	3	Tidal channel inside mangrove forest
Seagrass at Anclitas lagoon	January of 2000	2 m	3	Seagrass habitat inside coastal lagoon.

2.4 Satellite data

The two reef sites sampled in 2016 were chosen to document SST variations in the JRNP. Average daily and monthly temperature from 2003 to 2017 was taken from the website <https: //worldview.earthdata.nasa.gov>. The MODIS L3 SST 4km layer shows global daytime sea surface temperature (SST) at a depth of a few micrometers with ranges from -1.8 to 32 °C. The SST is derived with a Thermal (Long-Wave) SST Algorithm that uses MODIS bands 31 and 32 at 11 and 12 μm. This Level 3 product is derived from native 1 km Level 2 SST observations mapped to a global 4.63 km grid. The temporal resolution of this MODIS L3 SST is daily (MINNET *et al.,* 2004).

2.5 Statistical analysis

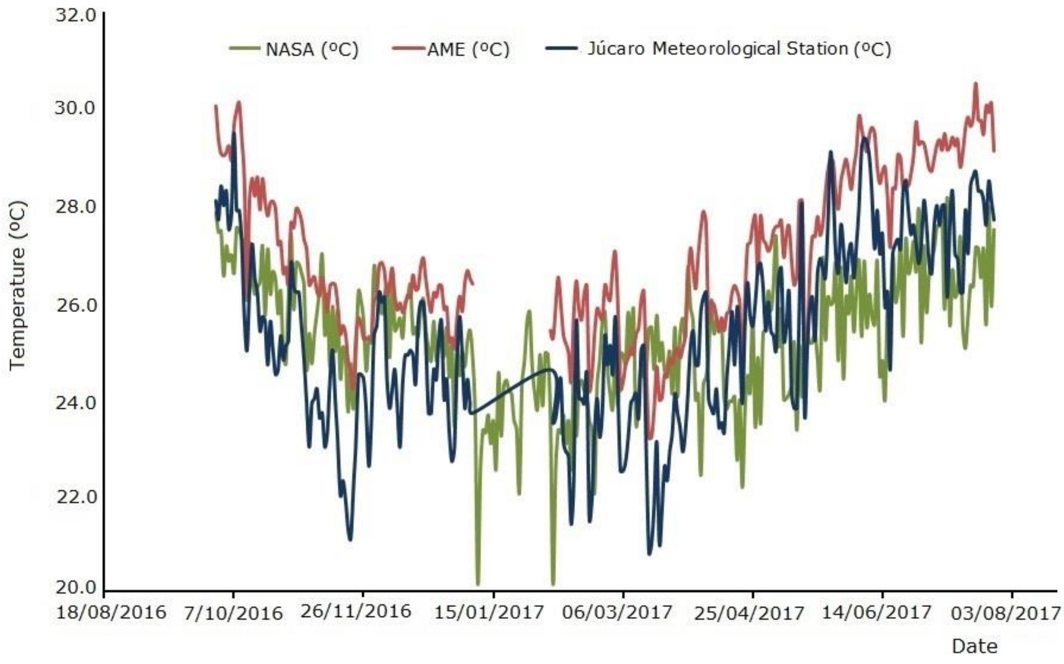
To assess normality, data were processed using the Shapiro-Wilk and Bartlett Tests. For data that did not meet normality standards, the nonparametric Kruskal-Wallis Test was used. For correlation, the nonparametric Spearman correlation was used. Temperature trend analysis (air and sea surface) was made using the Mann-Kendall test. All statistical analyses were made using the XLSTAT Program Version 2016.02.28451.

3 RESULTS

3.1 Daily air temperature at the JRNP in the period 2016-2017

The Figure 2 shows the daily temperature values from three sources (AMS, NASA and Júcaro Meteorological Station) between October 2016 and July 2017, except for AMS, which did not record values from January 8 to February 5 in 2017. AMS temperature data measured in situ (27.02 ± 1.6 °C) were higher (significantly different; K-W= 116.96, $P < 0.05$) than temperature data from the NASA database (25.4 ± 1.2 °C) and Júcaro Meteorological Station (K-W=96.62, $P < 0.05$). However, both (NSA database and Júcaro Meteorological Station) had a significant Spearman correlation (0.597 and 0.913, respectively) with measured values at Cayo Anclitas. For the period measured with AMS, mean daily temperature was 27.02 ± 1.6 °C. The maximum air temperature value was in July of 2017 (30.52 °C) and the minimum in March 2017 (23.20 °C).

Figure 2 - Daily air temperature (in °C) during the 2016 – 2017 period in Cayo Anclitas (JRNP). In red, daily air temperature from AMS; in green, daily air temperature from NASA, and in blue, daily air temperature from Júcaro Meteorological Station. Blank space in the red line indicates that no measurements were taken

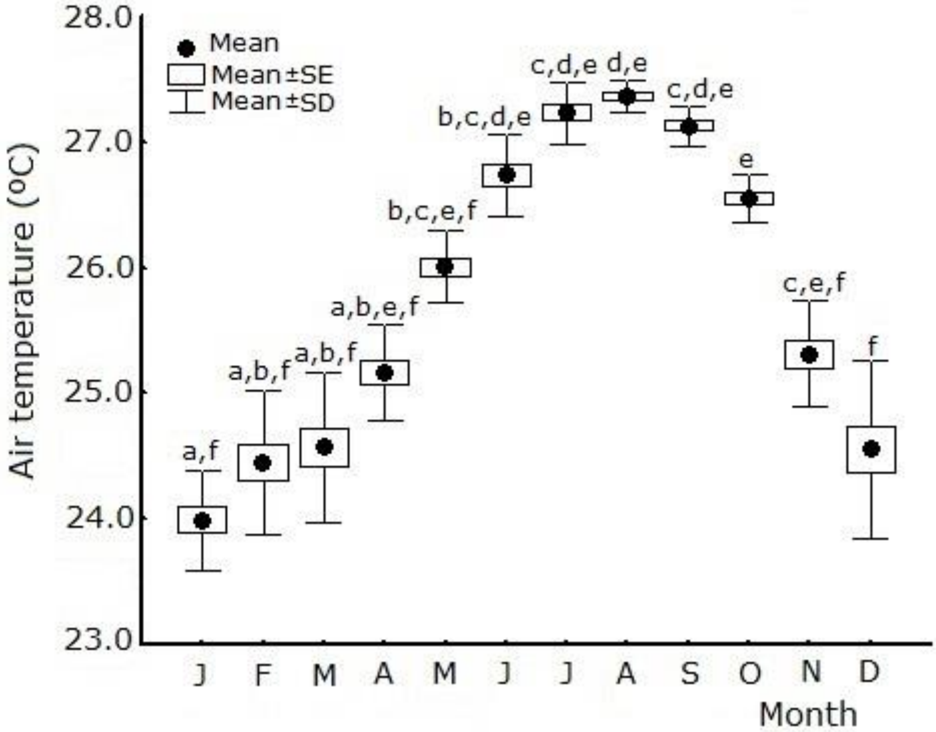


3.2 Air temperature trend in the period 2003-2017 (from the NASA Data)

Mean air temperature for the period 2003-2017 was 25.75 ± 1.24 °C. No significant differences among mean annual temperatures were documented in this period. No statistically significant temperature trend was observed (*P*-value= 0.31).

Months with significant high mean temperature were from June to October; lower mean temperatures were recorded in January, February, March and December (Figure 3).

Figure 3 - Annual cycle of air temperature in the Jardines de la Reina National Park in the period 2003-2017. Boxes show mean ±SE. Vertical bars show mean ±SD. Lower case letters show significant differences

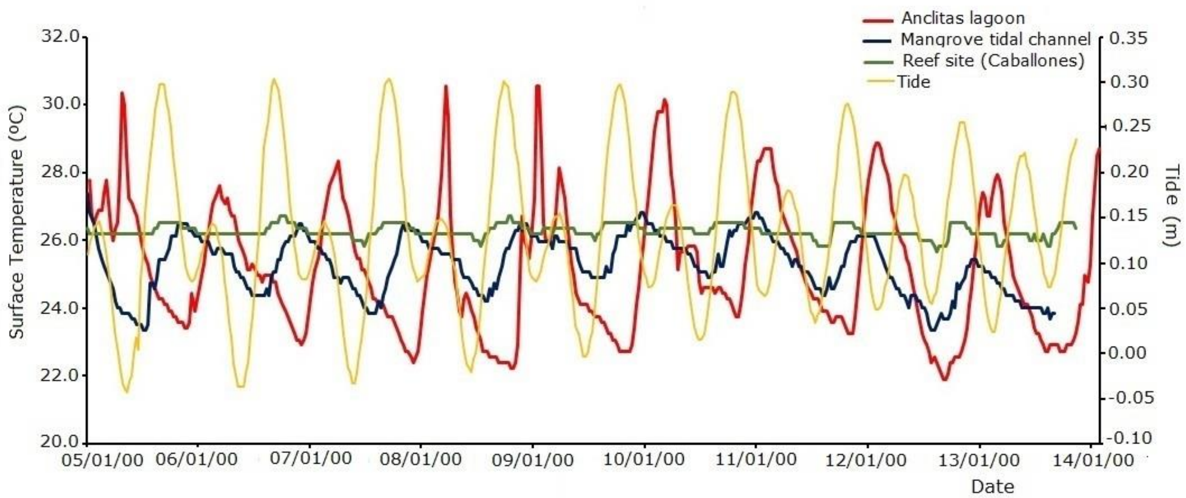


3.3 Sea Surface Temperature in 2000

January 2000 mean SST in a reef site was 26.26 ± 0.18 °C (25.66-26.71 °C) and significant Spearman correlation with tides (R= 0.65, $P < 0.05$) (Figure 4). At the same site, but in September of 2000, mean SST was 30.33 ± 0.45 °C (29.79-31.68 °C) at a depth of 2 m. Like in the January sampling, SST had significant Spearman correlation with tide (R=-0.10, $P < 0.05$). At 8 m, mean SST was significantly lower ($p<0.05$) than at 2 m, 30.24 ± 0.39 (29.74-31.26 °C) (Figure 4) and SST had significant Spearman correlation with tides (R= -0.14, $P < 0.05$).

Mean SST at a mangrove tidal channel was 25.27 ± 0.86 °C (23.34-27.37 °C) and significant Spearman correlation with tides (R= 0.44, $P < 0.05$). Kruskal-Wallis test showed significant differences between SST in the mangrove tidal channel and in the reef site ($P < 0.05$). However, at mangrove tidal channel, mean SST was similar to that of the lagoon site (although more variable), with a mean value of 25.17± 1.95 °C (21.90-30.55 °C).

Figure 4 - Sea Surface Temperature (in °C) measured every 30 minutes at three sites of the JRNP in January of 2000. The red line represents Anclitas Lagoon; the blue line, mangrove channel and the green line, the reef site at the Caballones Channel. The yellow line is the tide (in meters). Step-like "curves" reflect longer intervals between data points

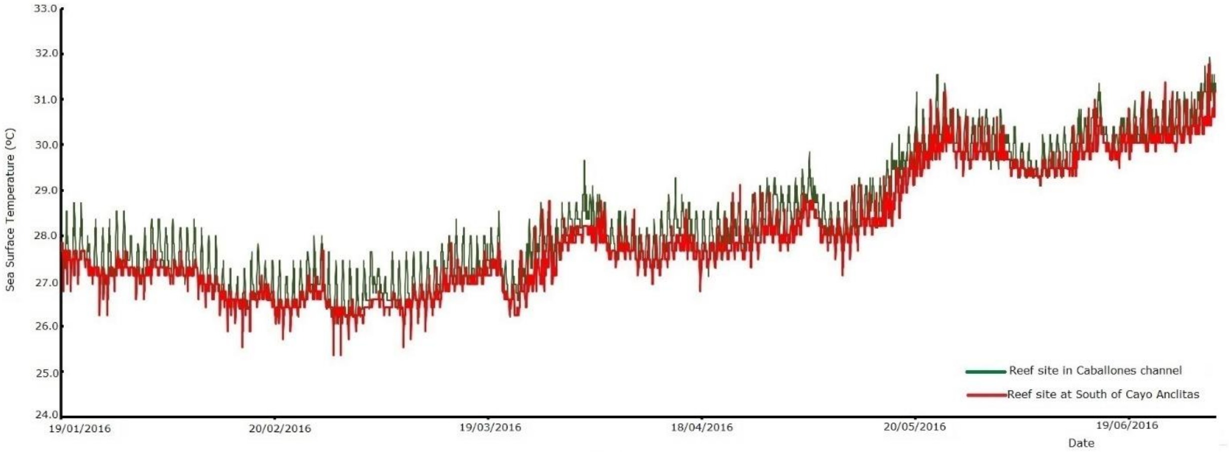


3.4 Sea Surface Temperature in 2016

In 2016, data loggers remained at two reef sites in the JRNP for more than five months. At the Caballones Channel site (same site sampled twice in January and September of 2000) mean SST was 28.34 ± 1.33 °C (25.69-31.93 °C) with lower SST in March (26.85 ± 0.47 °C) and higher in June (30.22 ± 0.52 °C). Like in January and September of 2000, SST had significant Spearman correlation with tide (R= 0.05, $P < 0.05$) at this site.

At the reef site located south of Cayo Anclitas, mean SST was significantly lower ($P < 0.05$) than SST at the Caballones Channel site, 28.02 ± 1.31 °C (25.37-31.77 °C). Of all the months studied, the lowest mean SST was in February (26.59 ± 0.37 °C) and the highest in June (30.04 ± 0.45 °C) (Figure 5).

Figure 5 - Sea surface temperature (SST) measured at two reef sites in the JRNP in 2016 (between January and June). The green line represents SST at Caballones Channel and the red line represents SST at Cayo Anclitas



3.5 Sea Surface Temperature trend in the period 2003-2017

Monthly mean SST from the NOAA reports at the reef sites sampled in 2016 were statistical analyzed, and there was significant increasing trend of SST at the JRNP (Mann-K τ= 0.211, *P*-value < 0.05, Sen´s slope of 0.01) (Figure 6).

The mean value of the two sites was used for every statistical analysis. Annual SST for the evaluated period had a mean value of 28.29±1.34 °C. Significant differences of mean SST among years were not found (p>0.05). However, in some years (2003, 2013, 2014, 2015, 2016 and 2017) mean SST was over the mean value of the period 2003-2017. The highest mean values were recorded in 2015 (29.21 ± 1.45 °C) and 2016 (29.07 ± 1.41 °C), coinciding with a Very Strong El Niño Event (Figure 7).

Figure 6 - Sea surface temperature (SST) trend between 2003 and 2017 in the JRNP

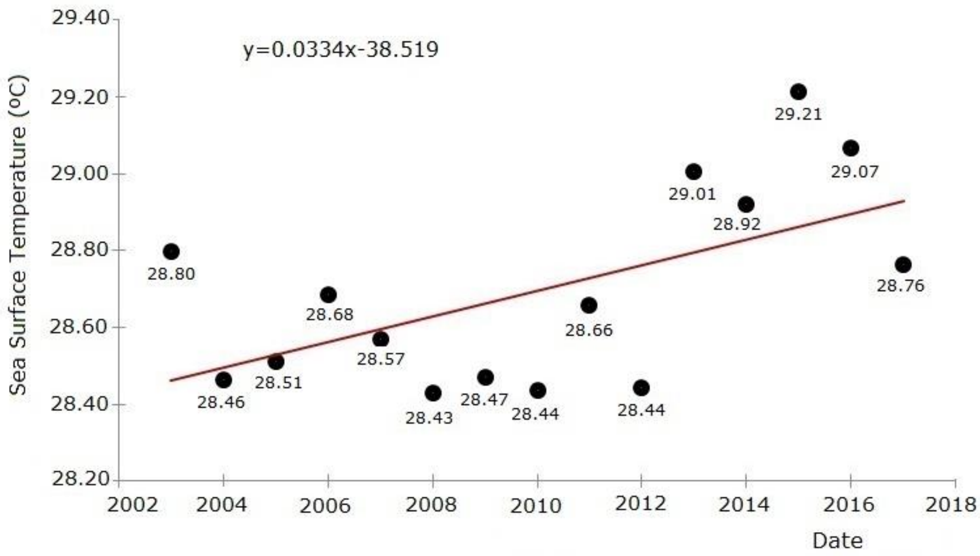
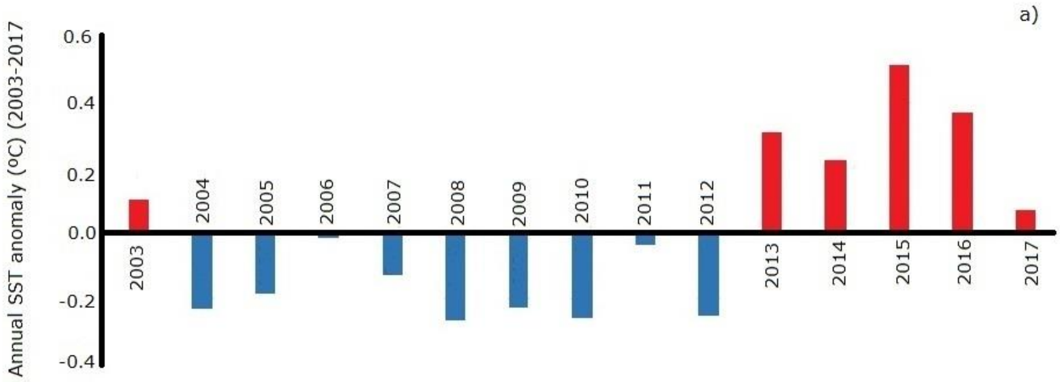
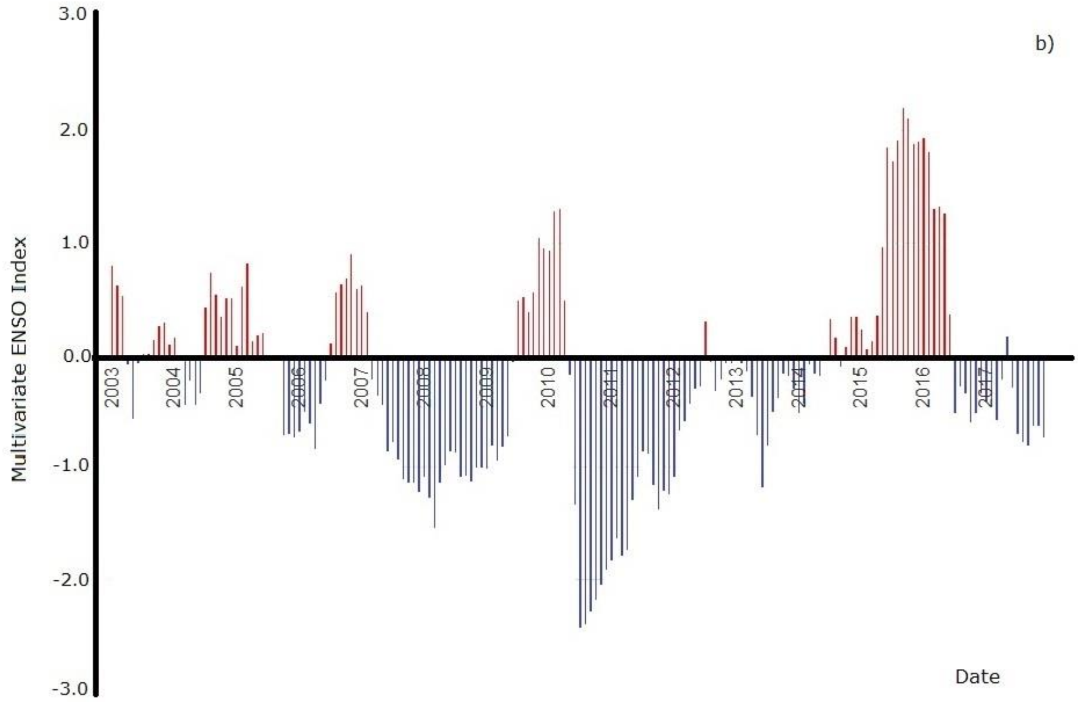


Figure 7 - a) Annual anomalies of SST (ºC) in Jardines de la Reina National Park in the studied period (2003-2017), b) bimonthly ENSO Index in the studied period (2003-2017)





4 DISCUSSION

4.1 Air temperature

The climate of Cuba could be defined as tropical, seasonally wet, with strong maritime influence and some semi-continental behaviors (IÑIGUEZ; MATEO, 1980). Mean annual temperature is 26.0 °C in plains and 24.0 °C in mountains. In coastal zones of Cuba as Cayo Coco, mean monthly temperature varies from 23.3 °C in January to 28.7°C in July (ALCOLADO *et al.,* 1998), mean annual temperature is 26.1 °C (MONTES-MARTÍN *et al.,* 2020). However, there are no studies of stable measurements of air temperature in the study area. González-De Zayas *et al.* (2006) occasionally studied air temperature in the JRNP in 1997. These authors reported that in summer, temperature was between 26.0 °C and 27.0 °C in the morning and to 31.0 °C in the afternoon. In winter, temperature fell to 24.0 °C in the morning and between 27.0 °C and 28.0 °C in the afternoon.

Values air temperature measured by the AMS at the JRNP were in range and values similar to those reported in Cayo Coco, and to others studies in Cuba (INSMET 2020, PLANOS; GUTIERREZ, 2020; MONTES-MARTÍN *et al.,* 2020).

Air temperature values from NASA in the period 2003-2017 show that as described for Cuba (IÑIGUEZ; MATEO, 1980), the highest temperatures occurred from May to October and the lowest from November to April.

Like in Cuba (PLANOS; GUTIERREZ, 2020), there was not a significant air temperature trend at the JRPN. No relations between mean annual temperatures with the ENSO index during period 2013-2017 were found, so this relation may not be important for this parameter at the JRNP. The stable tendency of air temperature at the JNRP could be good for the biodiversity of the study area in the context of global warming.

4.2 Sea surface temperature (SST)

This is the first SST study based on temperature data loggers at reef sites in Cuba. Mean SST values measured at reef sites of the JRPN in 2000 and 2016 were in the ranges reported by previous studies at Jardines de la Reina Archipelago (EMILSSON; TÁPANES 1971; LLUIS-RIERA, 1977; GONZÁLEZ- DE ZAYAS *et al.,* 2006; BUSTAMANTE LÓPEZ *et al.,* 2018; HERNÁNDEZ-FERNÁNDEZ *et al.,* 2019a). Mitrani-Arenal and Díaz-Rodríguez (2004) found around Cuban oceanic waters mean SST of 28.0 °C or greater than this value from May to November (between 1966 and 1993) that are similar to the measured SST values of this research. For all studies, in situ SST measurements were taken during the sampling campaigns without serial times, so SST values were related with some factors such as hour of sampling, tidal phase, kind of thermometer (GONZÁLEZ-DE ZAYAS *et al.,* 2006).

Sea surface temperature at the reef site in the Caballones Channel had a significant correlation with tide for all sampling periods. In January 2000 (dry and winter season), when in the Ana María Gulf SST are lower than in oceanic waters of the Caribbean Sea, this correlation was positive (The flow tide brought higher SST to the reefs and the ebb tide, cooler waters from the Ana María Gulf, lowering the SST values). In September 2000 (summer), this relationship (SST *vs* tides) was negative. Our results confirmed that the Caribbean Sea has an important influence over the environmental conditions of the Jardines de la Reina Archipelago (LLUIS-RIERA, 1977).

Many authors suggested the impacts of temperature rise over reef physiology are mainly related with coral bleaching (MCWILLIAMS *et al.,* 2005; EAKIN *et al.,* 2009; PRECHT *et al.,* 2016; MEYER *et al.,* 2019). According to Hernández – Fernández *et al.* (2019b), *Acropora palmata* crests in the JRNP were healthier west (approximately to 2000 m away) of the greatest tidal channels of the region (Caballones and Boca Grande). These authors suggested it could be due to an ideal balance of nutrients and light and organic matter that favors reef stability, but taking into account our results, temperature could also be added to those factors that contribute to reef health.

Fluctuations of SST at reef sites were small: less than 2.0 °C daily for both sampling periods of 2000 and for two data logger measurements taken in 2016. The most significant monthly fluctuations at both reef sites (around 4.0 °C), were in May, but for the entire sampling period, monthly SST fluctuations were between 2.0 and 3.0 °C.

Sea Surface Temperature variation during days-weeks-months considerably influences the coral reef life cycle at the JRNP. The SST stability in different time scales is an important driving factor of reef health at the JRNP. Between 2003 and 2016, the National Coral Reef Watch of Cuba, reported some poor - to - moderate level bleaching episodes at the JRNP (2006, 2007, 2009, 2010, 2011, 2012, 2014, and 2016). In 2015, bleaching level was moderate to high, and only one year (2005) had a bleaching episode that ranged from moderate to very high, and occurred mainly in reef crests (shallow waters). However, some authors reported that coral reef recovered rapidly from these episodes at the JRNP, even after the high level bleaching of 2005 (HERNÁNDEZ-FERNÁNDEZ *et al.,* 2011). Many other environmental factors such as the absence of pollution sources, commercial fishing and human stressors, could have contributed to this rapid recovery (HERNÁNDEZ–FERNÁNDEZ *et al.,* 2019a). Hernández-Fernández *et al.* (2019a) concluded that there was not a clear benthic community structure gradient along the fore reef tract of the JRNP, and suggested that small scale variability could be due to drivers acting at local scale. They suggested that global change, as ocean warming, did not have perceptible impacts over the fore reefs of the JRNP.

Our results for mangrove tidal channel and seagrass habitats are the first obtained with this kind of measurement at the JRPN (Figure 2). Although the SST range at these two sites was wider than at reef sites, SST values were above the proposed thermal stress thresholds (35.0 °C) for the seagrass *Thalassia testudinum* (KOCH *et al.,* 2013). *Thalassia testudinum* was the principal seagrass species at both sites. According to Guimarais *et al.* (2012), density of this species at the JRNP is higher than at other seagrass sites of the Caribbean Region.

Sea surface temperature values at mangrove channel sites were within the range measured at reef sites in January 2000. These results could suggest that SST is not a limiting factor to the diversity of corals attached to mangrove roots in the JRNP (HERNÁNDEZ-FERNÁNDEZ, 2015).

Annual mean SST from satellite data showed that there is an increasing tendency (from 2003 to 2017) of sea surface temperature (in 0.01 °C) in the study area. Although annual mean SST did not show significant differences, 2015 was the warmest year, followed by 2016. Muñiz-Castillo *et al.* (2019) found that in the Caribbean Region, the Bahamian, Floridian and Greater Antilles (including Cuba) were the ecoregions least exposed to heat stress in last 30 years were. However, these authors classified our study zone as an emerging heat-stress region that could be affected by a new and strong heat episode, because of the major episode that took place during the 2014-2017 period. In fact, after the great bleaching event that affected the JRNP and in the entire Caribbean region in 2005, the event of 2015 ranks second regarding bleaching levels in the JRNP (ALCOLADO; REY-VILLIERS, 2016).

Two studies on coral reefs were conducted at the JRNP during September and November of 2017 (HERNÁNDEZ-FERNÁNDEZ *et al.,* 2019a, b) and both reported low coral bleaching levels. So, the bleaching event reported in 2015 could have ended between 2015 and 2017.

We used monthly mean SST (only between February and June of 2016) taken from satellite data to be compared with that of data loggers moored at the Caballones and Anclitas reefs, and significant Spearman correlation for this 5 months at the two sites (R= 0.38 and R= 0.41, $P < 0.05$, respectively) were found. Some authors have been compared SST from satellite with in situ measurements of SST, and most of them concluded that we can use SST data from satellite as an acceptable estimator for activities as marine management in MPAs (CERDEIRA *et al.,* 2005; SOMOZA *et al.,* 2006; BALDOCK *et al.,* 2014).

However, the possibility of in situ SST measurements using data loggers combined with satellite data could be a useful tool to improve studies on thermal stress and coral tolerance to climate change, particularly in tropical regions and MPAs with economic limitations for marine research.

In conclusion, the Jardines de la Reina National Park is the largest marine protected area of the insular Caribbean. This zone is of great important to do research on marine and coastal resources. Air temperature showed a stable behavior during the study period with higher temperatures in summer al lower temperatures in winter. According to González Díaz *et al.* (2018), the park is one of the best preserved reef sites in Cuba. Our results show that the strong influence of the oceanic conditions of the Caribbean Sea determines the stability of environmental behaviors such as the SST of this zone. However, it is necessary to establish a temperature monitoring system to create serial time data that could improve research on reef, mangrove and seagrass response to climate change and its consequences. Temperature values were still within the tolerance range for some marine habitats, but we found that there is a significant increasing tendency and that more available data is required to conduct deeper studies.

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