Latin American Journal of Aquatic Research, 50(4): 596-609, 2022
DOI: 10.3856/vol50-issue4-fulltext-2915

Research Article

Climate variability and small-scale fisheries of the Albuquerque Cays Island, insular Colombian Caribbean

María Alejandra Doria González[1,4], Daniel Pérez Ferro[2], Frank C. Olaya[3] José Luis Payares Varela[1] & Juan Carlos Ortiz Royero[5]
[1]Faculty of Physical Oceanography, Naval Academy "Almirante Padilla"
Research Group in Oceanology- GIO, Cartagena de Indias, Colombia
[2]Tropical Fisheries Science and Technology Research Group (CITEPT)
University of Magdalena, Santa Marta, Colombia
[3]Faculty of Marine Sciences, Universidad Autónoma de Baja California, Baja California, México
[4]Scientific Research, Technological Development and Innovation Area
Colombian Caribbean Oceanographic and Hydrographic Research Center (CIOH)
Cartagena de Indias, Colombia
[5]Department of Physics and Geosciences, Universidad del Norte, Barranquilla, Colombia
Corresponding author: María Alejandra Doria González (mariadoriagonzalez@gmail.com)

ABSTRACT. The relationship between climate variability and the small-scale fishery (SSF) of the Albuquerque Cays was studied from 2004 to 2018. The environmental variables analyzed were: sea surface temperature (SST), wind magnitude, and chlorophyll (Chl-α). The fishery is multi-species; 410 individuals were identified, belonging to 4 orders, 15 families, and 62 species, of which 38.7% are reef, 35.5% demersal, and 25.8% pelagic. The most dominant species were *Caranx latus*, *Elagatis bipinnulata*, *Coryphaena hippurus*, *Lutjanus vivanus*, *Ocyurus chrysurus*, *Thunnus atlanticus*, *Sphyraena barracuda*, *Canthidermis sufflamen*, *Etelis oculatus*, *Acanthocybium solandri*, *Lutjanus jocu*, *Balistes vetula*, *Lutjanus buccanella*, followed by *Rhomboplites aurorubens* and *Mycteroperca bonaci*. The pelagic species that contribute the most in biomass and commercial importance are *S. barracuda*, *A. solandri*, *T. atlanticus*, and *E. bipinnulata*, the most important due to their high market value. A significant correlation was found among SST, Chl-α, wind magnitude, and catch per unit effort (CPUE) anomalies. The highest CPUE values occurred in January, March, June and September were associated with the passage of cold fronts and hurricanes, giving way to new fishing opportunities and conservation of some resources.

Keywords: fisheries; CPUE; climate variability; Albuquerque Cays; Caribbean insular

INTRODUCTION

The San Andres, Providencia, and Santa Catalina Archipelago has one of the highest rates of marine biodiversity in the insular Colombian Caribbean, as well as important ecosystems in which coral reefs stand out (Posada & Ospitia 2011, Gómez-López et al. 2012). It has the third-largest barrier reef in the world with great richness and diversity of fish, corals, sponges, gorgonians, macroalgae, snails, lobsters, birds, as well as seagrasses and mangroves (Poveda 2004, Samonte 2008), which makes it one of the most productive coastal environments in the Caribbean basin.

In this archipelago, the most important sources of income are the fishing sector, on an industrial and artisanal scale, and tourism (Prato & Newball 2015). The small-scale fishery (SSF) is the main source of food security for the population, making it a key activity that contributes to the demand of local markets on San Andres Island (Sánchez-Jabba 2012).

Corresponding editor: Yassir Torres

Albuquerque Cays, one of the islands that make up the Archipelago, possesses valuable marine biodiversity and is known as the fishing pantry of San Andres Island (Prato & Newball 2015).

The increase in the number and magnitude of climatic factors in Latin America and globally, acting on multiple temporal and spatial scales (Hall 2011), has generated the need to understand how climate variability and anthropogenic effects affect the performance of SSFs (Defeo et al. 2014). The understanding of climate variability includes processes in a wide range of spatial and temporal scales, the correlation of these processes concerning anthropogenic activities, such as fishing, has scientific importance (Poveda 2004).

The Colombian Caribbean's climate is influenced mainly by direct solar radiation due to its proximity to the equatorial line. There is a tropical climate with two marked seasonal periods defined by the rainfall and easterly trade winds patterns: the low rainfall season from December-May and the high rainfall season from April to November, which are modulated by the displacement of the Intertropical Convergence Zone (ITCZ, Ortiz-Royero et al. 2013). In the Archipelago of San Andres, Providencia, and Santa Catalina, the climate is influenced by different processes such as the displacement of the ITCZ, the physiographic characteristics of the area, the northeast (NE) trade winds, and also by the Caribbean Current that heads to the Yucatan coast, passing to the north of the Guajira Peninsula and extends to the Gulf of Mexico until it joins the Gulf Stream (Andrade 2000, Montealegre 2005). Likewise, it is also affected by macro and mesoscale processes such as tropical waves from the east, tropical storms, hurricanes (from June to November), and the passage of cold fronts (December-March), the latter being the major generators of climate variability throughout the year (Gómez-López et al. 2012, Ortiz-Royero et al. 2013).

In recent years, climate variability has been reported to influence the different organizational levels of species, including populations, communities, and ecosystems, as well as the abundance and biogeography of organisms (Stenseth et al. 2002, Cheung et al. 2012), operating directly on their distribution, migration, and abundance. However the interaction of these processes with each other (Werner et al. 2005, Ottersen et al. 2010) and the effect they have on food webs and the ecosystem (Cury & Shannon 2004, Kenny et al. 2009) is still unknown.

It is estimated that in addition to the negative repercussions, climate variations could create possible opportunities and have positive effects on some fisheries (Daw et al. 2009). For example, in Peru, during the El Niño (El Niño Southern Oscillation or ENSO) phenomena from 1982 to 1983 and from 1997 to 1998, penaeid shrimp and rock lobsters emerged from the Panamic Province (Glynn 1990, Arntz et al. 2006). These species, together with the mahi-mahi (*Coryphaena hippurus*), tuna (*Thunnus* sp.), and diamondback or shortfin mako sharks (*Isurus oxyrinchus*), created new opportunities for the SSF sector (CAF 2000). However, despite the distribution of species that have been recorded, the effects experienced by fisheries have yet to be largely distinguished from pre-existing phenomena of climate variability and anthropogenic impacts such as overexploitation, market fluctuations, poverty, inequality, food insecurity, disease, and globalization (Daw et al. 2009).

Given that the presence of many species is attributable to different sources of stress, mostly human-made (Hare 2003), it remains to be discerned how the relative effects of fishery exploitation and climate forcing are jointly involved in the exploited populations (Ortega et al. 2013). Climate causes changes in the fisheries management system, and in turn, fisheries exploitation can also interfere with the ability of a stock to withstand or adjust to climate variability (Ortega et al. 2013). Therefore, the present study aims to analyze the trends of SSFs and evaluate their relationship with climate variability in Albuquerque Keys Island in the insular Colombian Caribbean. As a contribution to long-term fisheries planning in the study sector, considering anthropogenic activities in the system.

MATERIALS AND METHODS

Study area

Albuquerque Cay, also known as South-Southwest Cay, is located in the southern part of the Archipelago of San Andres, Providencia, and Santa Catalina (Gómez-López et al. 2012), 35 km from the southwestern part of the San Andres Island and around 190 km east of Nicaragua, between the 12°10'N and 81°51'W (Fig. 1). It is the closest Colombian island to Nicaraguan waters, has a diameter of more than 8 km, is surrounded by an important reef system, and is the only atoll in the archipelago with a circular environment with two cays: North Cay and South Cay (Gómez-López et al. 2012).

It is located in the Seaflower Biosphere Reserve, which covers an area of approximately 180,000 km^2, corresponding to the extension of the archipelago, 480

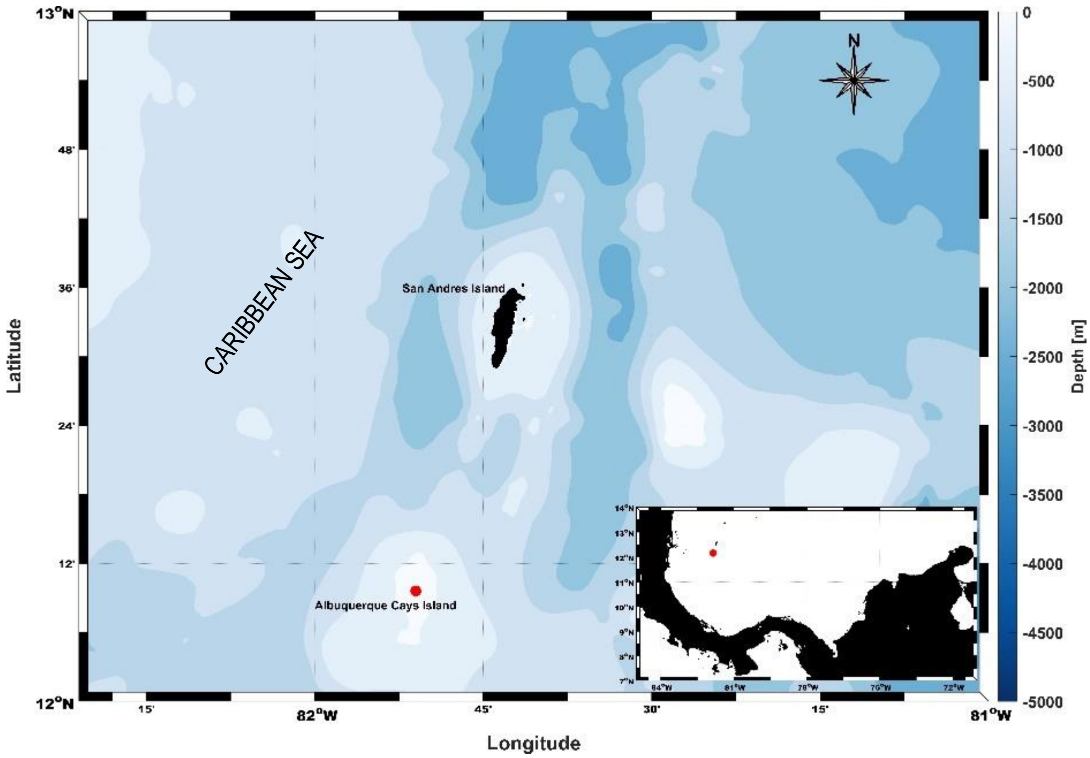

Figure 1. Study area: the bathymetry of the insular Colombian Caribbean off the coast of Nicaragua is shown in colormap (https://www.gebco.net, accessed March 2, 2022). The island of Cays Alburquerque is indicated with a red dot.

miles northwest of the national mainland between 12-16°N and 78-82°W (Gómez-López et al. 2012).

According to the 2005 Seaflower Marine Protected Area Integrated Management Plan, the Alburquerque artisanal fishing zone (artisanal fishing with traditional methods and users) is located in the southern part of the island. A no-entry zone (use is restricted to research and monitoring) and a no-take zone (only non-extractive activities are allowed) are also delimited (Sánchez-Jabba 2012).

Satellite data

The sea surface temperature (SST) data corresponded to the Multi-scale Ultra-high Resolution (MUR) product. These daily images with 1 km spatial resolution represent measurements from different satellites and *in situ* observations, free of cloudiness, with L4 processing level for 15 years, from January 1, 2004 to December 31, 2018 (http://mur.jpl.nasa.gov). MODIS images were also obtained, monthly chlorophyll (Chl-α) images with 2.5 km spatial resolution for 12 years, comprised between February 15, 2006 to December 16, 2018 (https://coastwatch. pfeg. noaa.gov).

Monthly reanalysis data of the zonal (u) and meridional (v) wind components with L3 processing levels were obtained from the Cross-Calibrated Multi-Platform (CCMP) database for the same period as the Chl-α data (https://climatedataguide.ucar.edu).

The presence of the ENSO was quantified through the Southern Oscillation Index (SOI). SST, and Chl-α anomalies were calculated and plotted with the SOI (https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/).

The spatial location of the data series used is 12.7-12°N and 81.6-82.19°W. Once obtained, the closest point to the island (Euclidean distance) was extracted, and multiannual and interannual scale climatology was performed for each time series using MATLAB R2019a programming language.

Fishing data

Monthly records of artisanal fishery landings expressed in kilograms (kg) and fishing effort in the number of fishing operations were obtained from the information provided by the Secretariat of Agriculture and Fisheries of San Andres and Providencia from 2004 to 2018. The fishing gear reported was a hand line for each species throughout the study period. The work's scope is limited to the fact that during the study period, differences in sample size were identified in the fishery monitoring, and in some cases, information gaps between the months of the different years analyzed.

The data were standardized to catch per unit effort (CPUE) in kilograms per fish per day (kg fish d^{-1}). CPUE was calculated by dividing the total weight of the catch per species (kg) by the fishing effort, the latter measured in the number of fishing days, as shown below.

$$CPUE = \frac{B}{f} \quad (1)$$

where *B* is the total weight and f is the fishing effort.

Statistical analysis

A cluster analysis using the similarity index and Bray-Curtis group linkage (Bray & Curtis 1957) was performed to detect similarities among species in the small-scale fishery from the Alburquerque Cays Island fishery during the study period. For each fish species, the frequency of occurrence (%F), biomass (kg), and CPUE (kg trip d^{-1}) were calculated. In addition, a non-metric multidimensional scaling ordination (NMDS) based on the Bray-Curtis similarity measure (Clarke et al. 2014) was performed to dimensionless and visualized each data point's relationship to another. The similarity percentage (SIMPER) procedure (Clarke 1993) was employed to identify the contribution of each species to dissimilarities between years (Gotelli & Ellison 2012). All analyses were performed with the Primer 5.2.2 statistical program (Clarke & Gorley 2001).

On the other hand, landings between 2004 and 2018 were analyzed. Fifteen species were selected from the fisheries that accounted for between 73 to 100% F, respectively.

Differences between CPUE and years were evaluated by applying the Kruskal-Wallis nonparametric test (Gotelli & Ellison 2012). A Bonferroni was applied to determine significant differences in CPUE among years (Bonferroni 1935). Lastly, Pearson's correlation (Pearson 1987) was applied to determine the relationship between CPUE and the selected environmental variables.

RESULTS

Climate variability

The pattern of monthly wind variability for Albuquerque Cays Island showed a bimodal trend. The first highest wind value was observed in July with a value close to 7 ± 1.27 m s^{-1} (mean ± standard deviation), while the second highest wind value occurred between December and January with values close to 8 ± 0.62 m s^{-1} (Fig. 2a). The lowest wind value occurred in September and October with speeds of 3.25 ±1.04 m s^{-1}, followed by a second lowest value of 5.0 ±1.14 m s^{-1} during May (Fig. 2a).

The SST mean values ranged from (27.14 ± 0.38°C) in February to the highest values in October (29.30 ± 0.57°C) (Fig. 2b). The Chl-α presented concentrations that ranged between 0.60-0.94 mg m^{-3}, during February and October, were the months when the minimum and maximum concentration values were detected (Fig. 2c).

Interannual variability

Positive SST anomalies values range between +0.13 and +0.53°C while negative anomalies average -1°C (Fig. 3a). Notable positive anomalies were observed in 2005 (+0.27), 2010 (+0.31), 2016 (0.32), and 2017 (+0.53); negative anomalies were detected between 2009 (-0.39) and 2014 (-0.26), with a maximum in 2009. The SOI recorded very marked events in 2008 (-0.75), 2010 (-0.46), 2011 (-0.83), and 2015 (+1.48), with a maximum in 2011 (corresponding to La Niña or cold phase of ENSO) and 2015 (corresponding to El Niño or warm phase of ENSO). After the La Niña event in 2010, the wind fields increased in intensity, causing negative SST anomalies, which continued until 2015, when El Niño occurred, showing positive anomalies from the year's second half until 2018 (Table 1). The Chl-α anomalies had a similar trend to the SST anomalies (Fig. 3b).

Fishery characterization

A total of 410 individuals were identified, belonging to 4 orders, 15 families, and 62 species, from which 38.7% were reef-dwelling, 35.5% demersal, and 25.8% pelagic. The most dominant species were *Caranx latus*, *Elagatis bipinnulata*, *Coryphaena hippurus*, *Lutjanus vivanus*, *Ocyurus chrysurus*, *Thunnus atlanticus*, *Sphyraena barracuda*, and *Canthidermis sufflamen*, with a 100% of occurrence (%F) throughout the study period. The second group of species with high %F were *Etelis oculatus* (93%), *Acanthocybium solandri* (93%), *Lutjanus jocu* (87%), *Balistes vetula* (87%), *Lutjanus buccanella* (80%), *Rhomboplites aurorubens* (73%) and *Mycteroperca bonaci* (73%), Sixteen percent (16%) of all species represented frequencies below than 10%. The highest values of total biomass were represented by *S. barracuda* (12,324 kg), *C. sufflamen* (11,976 kg), *O. chrysurus* (11,061 kg) and *B. vetula*

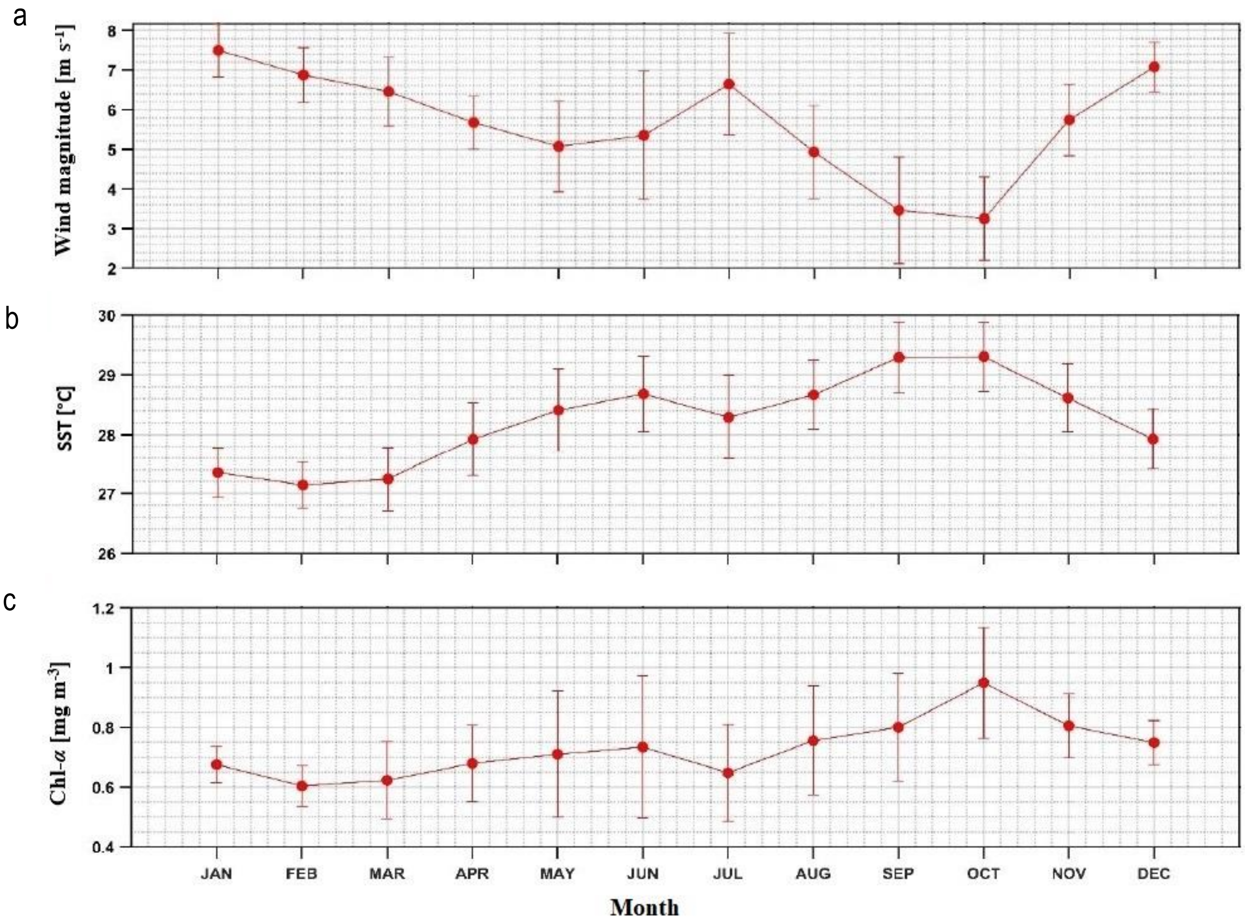

Figure 2. Mean and standard deviation of a) the wind magnitude, b) sea surface temperature (SST), and c) chlorophyll (Chl-α) in Alburquerque Cays Island during the study period.

Table 1. Sea surface temperature (SST), chlorophyll (Chl-α), and wind magnitude, annual values for the study period.

Year	SST (°C)	Chl-α (mg m^{-3})	Wind magnitude (m s^{-1})
2004	28.1		
2005	28.5		
2006	28.1	0.17	6.2
2007	28.4	0.17	5.0
2008	28.0	0.16	5.9
2009	27.9	0.13	5.4
2010	28.5	0.26	5.4
2011	28.3	0.16	6.3
2012	28.1	0.14	4.9
2013	28.4	0.20	5.1
2014	28.0	0.12	5.8
2015	28.2	0.15	5.7
2016	28.5	0.14	6.2
2017	28.7	0.22	6.4
2018	28.1	0.13	5.7

(1358 kg). The species with the highest CPUE recorded were *Canthidermis maculatus* (123 kg trip d^{-1}), *Hyporthodus flavolimbatus* (121 kg trip d^{-1}), *O. chrysurus* (116 kg trip d^{-1}), *E. oculatus* (112 kg trip d^{-1}), followed by *C. sufflamen* (86 kg trip d^{-1}) and *S. barracuda* (80 kg trip d^{-1}) for the entire study period (Table 2).

The annual fishery trends show three maximum peaks of fishing effort with values of 288 (trips d^{-1}) for 2009, 175 (trips d^{-1}) for 2014, and 176 (trips d^{-1}) for 2017, and catches with values of 18,802 kg, 15,533 kg and 8405 kg for the years 2009, 2010, and 2014, respectively (Fig 4).

The highest CPUE values, were obtained in 2010, 2007, 2008 and 2012, with values 137, 136, 116 and 96 kg trip d^{-1}, respectively (Fig 4).

Statistical analysis Kruskal-Wallis indicated significant differences between CPUEs and years analyzed ($P < 0.01$). Bonferroni statistical analysis yielded that 13

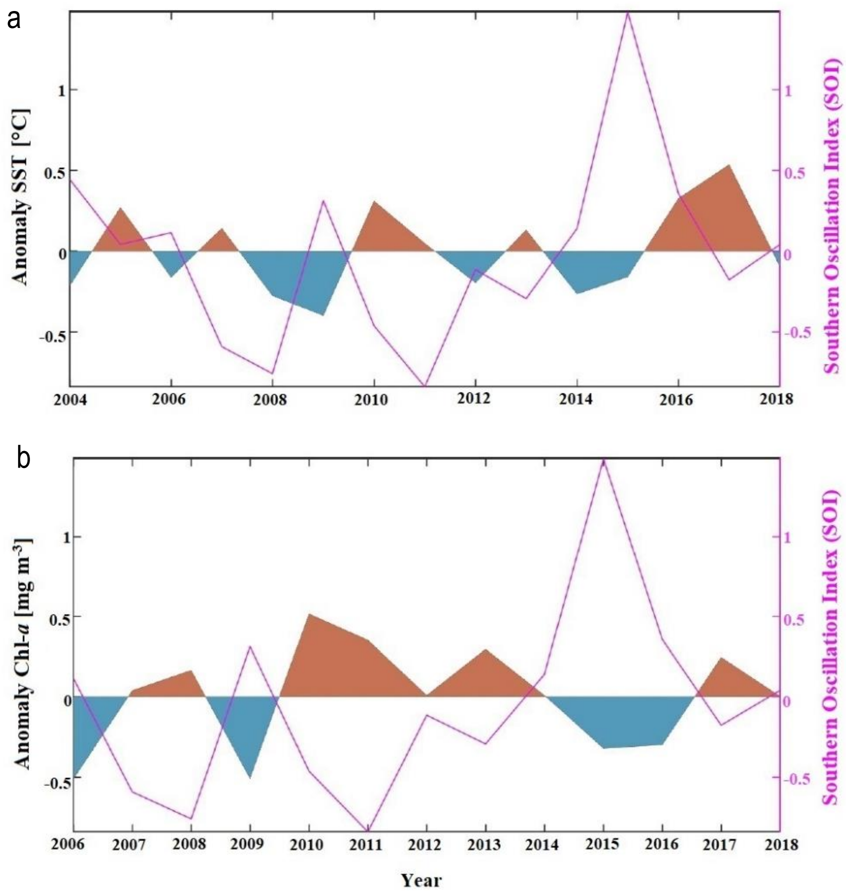

Figure 3. Anomalies of a) the sea surface temperature (SST) and the Southern Oscillation Index (SOI) during El Niño and La Niña events in Alburquerque Cays Island recorded during the 2004-2018 period, and b) of the chlorophyll (Chl-*α*) and the Southern Oscillation Index (SOI) during El Niño and La Niña events in Alburquerque Cays Island recorded during 2006-2018 period.

of the comparisons [2004-2008; 2004-2010; 2004-2011; 2004-2011; 2004-2013; 2007-2017; 2008-2017; 2008-2017; 2008-2018; 2009-2017; 2010-2017; 2010-2017; 2010-2018; 2011-2017; 2012-2017 and 2013-2017] are statistically significant at the 95% confidence level.

The pattern of fishing effort indicates a decrease from 2004 to 2008, while catches and CPUE showed higher values (Fig. 4). In 2009, there was an increase in the fishing fleet with a higher catch and lower CPUE, characterizing that year as the most productive of the study period. The most abundant species were *O. chrysurus*, *C. sufflamen*, *S. barracuda*, *E. bipinnulata*, *T. atlanticus*, and *A. solandri*, which contributed to 67.4% of the total catches. In this same year, the lowest SST anomalies were recorded in the entire study period, which may have favored the high occurrence of these species (Fig. 3a). From 2010 onwards, there was a concordance between effort, catches, and CPUE, showing the lower number of operations, lower catches, and CPUE, which allowed to infer that there was a decrease of the resource (Fig. 4).

The cluster analysis and the NMDS indicated the presence of three main groups of years (Bray-Curtis similarity of 65%). The first groups include 2015-2016, and 2018 and are separated from the second cluster that corresponds to the years 2011 and 2013, and the third group includes 2004 to 2010, 2012, 2014, and 2017 (Fig. 5a). The three main sets were also identified in the NMDS analysis (Fig. 5b).

According to the SIMPER análisis, the dominant species were: *C. sufflamen*, *S. barracuda*, *E. oculatus*, *E. bipinnulata*, and *T. atlanticus* for group 1 (average similarity 37.07); *O. chrysurus*, *S. barracuda*, *E. bipinnulata*, *A. solandri*, *T. atlanticus*, *B. vetula* and *C. sufflamen* for group 2 (average similarity 46.34) and *S. barracuda*, *C. sufflamen*, *T. atlanticus*, *A. solandri*, *O. chrysurus*, *E. bipinnulata* and *E. oculatus* for group 3

Table 2. Frequency of occurrence (%F), biomass (B) (kg), catch per unit effort (CPUE; kg trip d^{-1}), habitat, and conservation status (EC): Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least concern (LC), Data deficient (DD), Not evaluated (NE) of the artisanal fishery resource of the Alburquerque Cays Island-Colombian Caribbean insular. *International Union for Conservation of Nature and Natural Resources (IUCN), +Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Taxa	% F	B (kg)	CPUE (kg trip d^{-1})	Habitat	EC
Chordata					
Actinopterygii					
Beloniformes					
Exocoetidae					
Parexocoetus hillianus (Gosse, 1851)	7	23	5	Pelagic	LC*
Perciformes					
Carangidae					
Alectis ciliaris (Bloch, 1787)	7	5	2	Pelagic	LC*
Caranx bartholomaei (Cuvier in Cuvier & Valenciennes, 1833)	47	266	16	Reef	LC*
Caranx crysos (Mitchill, 1815)	20	49	12	Demersal	LC*
Caranx hippos (Linnaeus, 1766)	40	466	27	Demersal	VU
Caranx latus (Agassiz in Spix & Agassiz, 1831)	100	2830	46	Demersal	LC*
Caranx lugubris (Poey, 1860)	60	148	11	Reef	LC*
Caranx ruber (Bloch , 1793)	60	363	15	Reef	LC*
Elagatis bipinnulata (Quoy & Gaimard, 1825)	100	6990	64	Pelagic	LC*
Seriola dumerili (Risso, 1810)	47	683	53	Pelagic	LC*
Seriola fasciata (Bloch, 1793)	47	299	21	Pelagic	LC*
Seriola rivoliana (Valenciennes, 1833)	47	1047	75	Pelagic	LC*
Coryphaenidae					
Coryphaena hippurus (Linnaeus, 1758)	100	2220	41	Pelagic	LC*
Haemulidae					
Haemulon album (Cuvier in Cuvier & Valenciennes, 1830)	60	1388	38	Reef	DD*
Haemulon flavolineatum (Desmarest, 1823)	13	44	22	Reef	LC*
Haemulon plumieri (Lacepede, 1802)	33	304	34	Reef	LC*
Kyphosidae					
Kyphosus sectatrix (Linnaeus , 1758)	20	27	9	Demersal	LC*
Labridae					
Lachnolaimus maximus (Walbaum, 1792)	20	349	58	Reef	VU*
Scarus coeruleus (Bloch, 1786)	7	7	7	Reef	EN+
Scarus guacamaia (Cuvier, 1829)	7	1	1	Reef	EN+
Sparisoma chrysopterum (Bloch & Schneider, 1801)	7	31	31	Reef	LC*
Sparisoma viride (Bonnaterre, 1788)	20	150	37	Reef	NT+
Lobotidae					
Lobotes surinamensis (Bloch, 1790)	13	8	4	Demersal	LC*
Lutjanidae					
Apsilus dentatus (Guichenot, 1853)	40	143	25	Reef	LC*
Etelis oculatus (Valenciennes, 1828)	93	5587	112	Reef	DD*
Lutjanus analis (Cuvier in Cuvier & Valenciennes, 1828)	20	223	37	Demersal	VU +
Lutjanus apodus (Walbaum, 1792)	33	166	33	Demersal	LC*
Lutjanus buccanella (Cuvier, 1828)	80	954	53	Demersal	DD*
Lutjanus campechanus (Poey, 1860)	27	169	42	Demersal	VU*
Lutjanus dentatus (Duméril, 1861)	40	428	61	Demersal	DD*
Lutjanus jocu (Bloch & Schneider, 1801)	87	2736	58	Demersal	DD+
Lutjanus purpureus (Poey, 1866)	33	908	61	Demersal	NE*
Lutjanus synagris (Linnaeus, 1758)	13	74	37	Demersal	NT*
Lutjanus vivanus (Cuvier, 1828)	100	3410	85	Demersal	LC*
Ocyurus chrysurus (Bloch, 1791)	100	11061	116	Reef	NT+
Pristipomoides macrophthalmus (Müller & Troschel, 1848)	60	581	45	Demersal	LC*

Continuation

Taxa	% F	B (kg)	CPUE (kg trip d-1)	Habitat	EC
Rhomboplites aurorubens (Cuvier, 1829)	73	1867	85	Demersal	VU*
Malacanthidae					
Malacanthus plumieri (Bloch, 1786)	7	1	1	Demersal	LC*
Mullidae					
Mulloidichthys martinicus (Cuvier, 1829)	7	28	28	Reef	LC*
Scombridae					
Acanthocybium solandri (Cuvier in Cuvier & Valenciennes, 1832)	93	9133	98	Pelagic	NT+
Auxis thazard (Lacepede, 1800)	33	547	55	Pelagic	LC*
Euthynnus alletteratus (Rafinesque, 1810)	33	84	14	Pelagic	LC*
Katsuwonus pelamis (Linnaeus, 1758)	47	387	26	Pelagic	DD+
Scomberomorus cavalla (Cuvier, 1829)	40	925	49	Pelagic	LC*
Thunnus atlanticus (Lesson, 1831)	100	7175	52	Pelagic	LC*
Thunnus obesus (Lowe, 1839)	7	36	18	Pelagic	VU+
Serranidae					
Cephalopholis fulva (Linnaeus, 1758)	13	24	12	Reef	LC*
Epinephelus adscensionis (Osbeck, 1765)	7	14	14	Reef	LC*
Epinephelus guttatus (Linnaeus, 1758)	47	537	22	Reef	LC*
Epinephelus itajara (Lichtenstein, 1822)	13	138	34	Demersal	CR+
Epinephelus morio (Valenciennes, 1828)	20	132	22	Reef	VU*
Epinephelus striatus (Bloch, 1792)	33	86	12	Demersal	CR+
Hyporthodus flavolimbatus (Poey, 1865)	13	242	121	Demersal	VU*
Mycteroperca bonaci (Poey, 1860)	73	1449	76	Reef	NT*
Mycteroperca tigris (Valenciennes, 1833)	7	115	38	Reef	DD*
Mycteroperca venenosa (Linnaeus, 1758)	47	594	59	Reef	VU+
Sparidae	0	0			
Calamus bajonado (Bloch & Schneider, 1801)	20	20	7	Demersal	LC*
Calamus calamus (Valenciennes, 1830)	13	21	11	Reef	LC*
Scombriformes					
Sphyraenidae					
Sphyraena barracuda (Edwards, 1771)	100	12324	80	Pelagic	NT+
Tetraodontiformes					
Balistidae					
Balistes vetula (Linnaeus, 1758)	87	1358	27	Demersal	EN+
Canthidermis maculatus (Bloch, 1786)	20	370	123	Pelagic	LC*
Canthidermis sufflamen (Mitchill, 1815)	100	11976	86	Reef	LC*

(average similarity 37.07). The average dissimilarity among the three groups was 60.42 between groups 2 and 1 (*A. solandri*, *O. chrysurus*, *C. sufflamen*, *T. atlanticus*, *L. jocu*, *B. vetula*, *E. bipinnulata*, *S. barracuda*, *C. hippos* and *E. oculatus*), 71.05 between group 3 and 1 (*B. vetula*, *S. barracuda*, *O. chrysurus*, *C. sufflamen*, *A. solandri*, *T. atlanticus*, *E. bipinnulata*, *E. oculatus* and *L. vivanus*) and 62.14 between group 3 and 2 (*B. vetula*, *C. sufflamen*, *O. chrysurus*, *S. barracuda*, *A. solandri*, *E. oculatus*, *E. bipinnulata*, *T. atlanticus*, *L. vivanus* and *L. jocu*).

Climate variability and fisheries

A direct relationship was found between SST, Chl-α, and CPUE, with the highest CPUE values in January, March, June, and September (Fig. 6). The species that represented the highest catches in terms of biomass for these months were *L. jocu*, *T. atlanticus*, *C. sufflamen* and *O. chrysurus* between December and March and *E. oculatus* and *Haemulon album* between June and November.

However, the relationship between temperature anomalies and CPUE showed negative correlations for dolphin fish (*Coryphaena hippurus*), bluefin tuna (*T. atlanticus*), ocean triggerfish (*C. sufflamen*), queen snapper (*E. oculatus*), and queen triggerfish (*B. vetula*), demonstrating an inverse relationship (Table 3). In the case of the relationship with Chl-α anomalies, there are positive correlations with high coefficients ($P > 0.5$) for the rainbow runner (*E. bipinnulata*), silk snapper

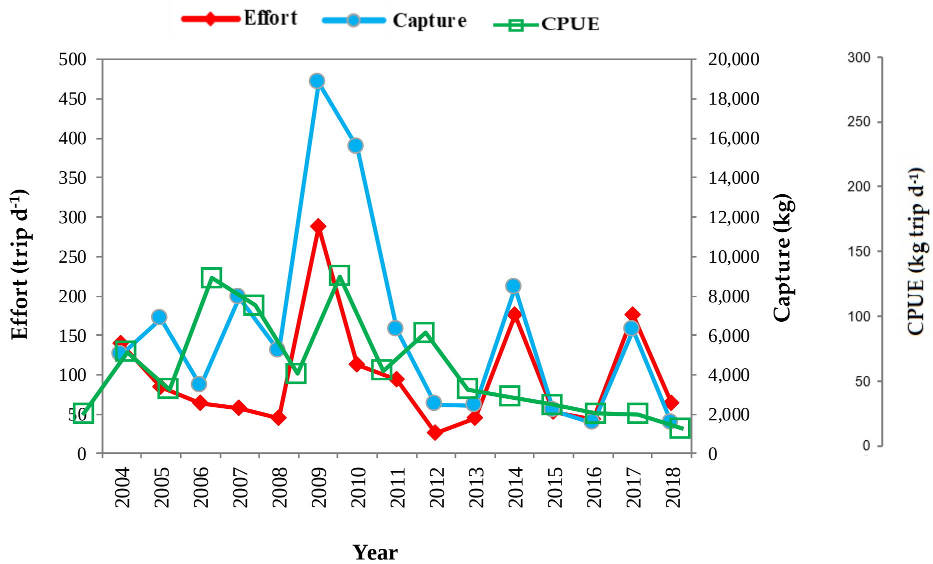

Figure 4. Analysis of the artisanal fishery of Albuquerque Cays Island from January 2004 to December 2018. CPUE: catch per unit effort.

(*L. vivanus*), and vermilion snapper (*R. aurorubens*); the high correlation values with the species great barracuda (*S. barracuda*) and black grouper (*Mycteroperca bonaci*) stand out. The CPUE and wind magnitude yielded positive correlations, although very low, for horse-eye jack (*C. latus*), bluefin tuna (*T. atlanticus*), red snapper (*E. oculatus*), wahoo (*A. solandri*), sessile snapper (*L. buccanella*) and red snapper (*Rhomboplites aurorubens*) (Table 3). However, it was impossible to establish a pattern between CPUE and the anomalies of wind magnitude, SST, and Chl-*α* due to the intermittent data collection by the fishing authority in the study area and the little variation in environmental variables. Abrupt changes were only evident with the influence of hurricanes and cold fronts that bring a greater circulation of nutrients, which causes abundance to increase after these events.

DISCUSSION

The monthly increase in SST responds to the wind regime analyzed above, which is influenced by the NE trade winds since when these decrease, the automatic cooling effect on the waters of the region is mitigated (Andrade 2000), a result that coincides with that reported by Gómez-López et al. (2012) and Ricaurte-Villota & Bastidas-Salamanca (2017), for the SST in the Colombian Caribbean Island zone.

The Chl-*a* recorded in the Archipelago of San Andres, Providencia, and Santa Catalina, including the Albuquerque Cays, is characteristic of oligotrophic oceanic water. It should be noted that a large part of this condition is caused by the low influence of Caribbean Surface Waters (CSW) (Márquez & Herrera 1986, Garay et al. 1988).

The patterns of the SST and Chl-*a* anomalies during the warm phases (El Niño) in 2010 may be associated with the manifestation of La Niña, which occurred during the same year in the Equatorial Pacific, an event in which the NE trade winds weaken in the Caribbean incursions into the equatorial Pacific through the Isthmus of Panama (Montealegre 2007). However, Valencia & Osorio (1999) and Navarro-Monterroza et al. (2019) indicate that the El Niño and La Niña episodes lack a determining relationship with the climate of San Andres, although there is a general effect on the climate indicating a greater incidence of climatic extremes during these episodes which denotes notable alterations in the normal climate regime.

The fishing effort pattern indicates the resource's growth or stability. The high variability in the composition and abundance of the fishery in the study period (2004-2018) is influenced by the measures established against industrial activity in different areas of the biosphere reserve and the use of different fishing techniques that have caused fishermen to migrate to areas that were little assisted by artisanal fishing in some years of the study. Such a result may be attributable to the fact that in 2000, the archipelago was declared a Seaflower Biosphere Reserve (BR). In 2005,

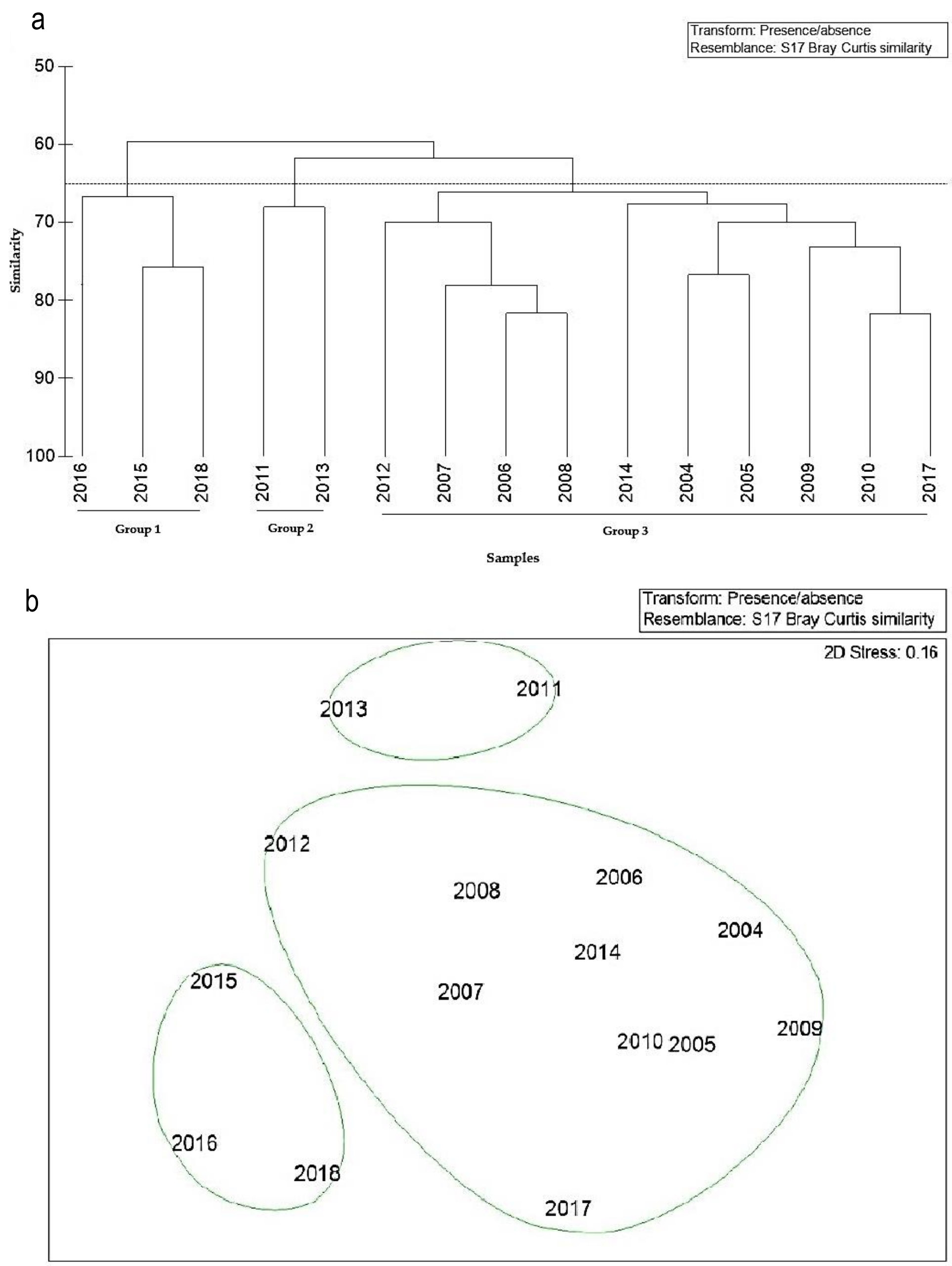

Figure 5. a) Cluster analysis using the Bray-Curtis similarity index between CPUE and years in artisanal fishery species groups of Alburquerque Cays Island, b) Non-metric multidimensional scaling plot (NMDS) plot artisanal fishery species groups of Alburquerque Cays Island, 65% similarity in both cases.

the Ministry of Environment and CORALINA (the environmental authority of the islands) designated three large sections (65,000 km^2) within the BR as Seaflower Multiple Use Marine Protected Area (MPA), within which Albuquerque is located (Castro 2005).

Resolution 3114 of 2009 (Regulating fishing in the BR) brought about a decrease in the industrial fleet with diving equipment, prohibiting fishing with this equipment in waters adjacent to the BR (Serranilla, Quita sueño, Serrana), which resulted in a migration of artisanal fishermen to the cays Bolivar and Albuquerque. This situation was reflected in our results, finding that 2009 was the most productive year of the study period; behavior was also documented by Alonso et al. (2012), who indicated that hand line activity for that same year was almost 20 times higher than previous years.

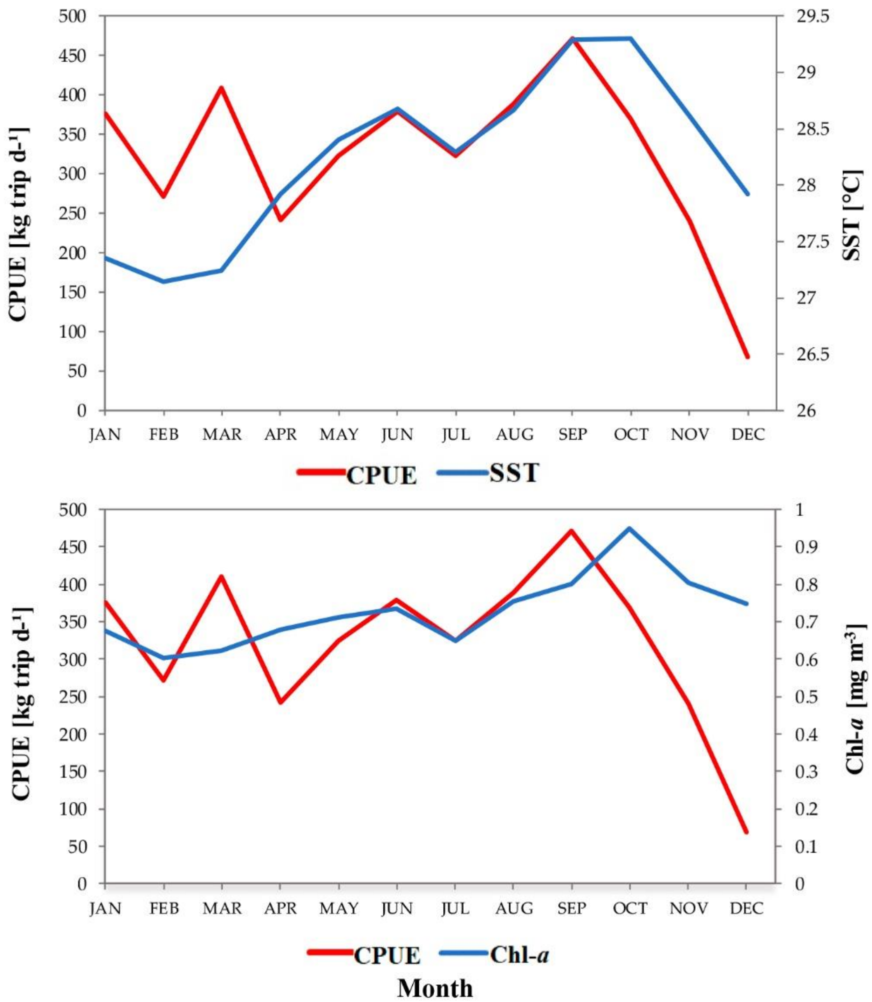

Figure 6. Catch per unit effort (CPUE) *vs*. monthly averages of a) sea surface temperature (SST, °C) and b) chlorophyll (Chl-*α*, mg m^{-3}) for Alburquerque Cays Island during the period 2004-2018.

The influence of climate variability on the abundance and biogeography of fisheries causing migration and abundance has been documented (Stenseth et al. 2002, Cheung et al. 2012). Climate variability makes it possible to identify and manage opportunities for fishing and conservation of the resource. Taking into account the different times of the year and the different physical, biological and oceanographic events in the study area, the highest CPUE values reported in this study were in January, March, June, and September, which coincides with the presence of macro and mesoscale patterns, identified as the main drivers of climate variability at all temporal levels in the insular Colombian Caribbean (Ortiz-Royero et al. 2013). The high CPUE values recorded during January and March coincide with the passage of cold fronts (December-March), while the high CPUE of June and September coincide with the tropical waves from the east, tropical storms, and hurricanes (June to November) (Gómez-López et al. 2012, Ortiz-Royero et al. 2013).

On the other hand, the existing relationship between the different variables analyzed (SST, Chl-α, wind magnitude, and CPUE anomalies) and the correlations coincide with results reported by Grandas-Olarte & Castro-González (2004). They mention that the inverse relationship of the environmental variables may be given by enrichment processes generated by local microsurgences and nutrient-rich continental waters from the Nicaraguan elevation, discharges from the Magdalena River Orinoco, and Amazona. The waters of the latter affect the surface layers of the central and eastern Caribbean and the upwelling systems of the Colombian coast (Márquez & Herrera 1986, Garay et al. 1988, Díaz et al. 1996).

Table 3. Pearson correlation (R) between catch per unit effort per year of selected species and environmental variables (2004-2018). SST: sea surface temperature, Chl-α: chlorophyll-α.

Species	Wind magnitude (m s^{-1})	SST (°C) anomalies	Chl-α (mg m^{-3}) anomalies
Caranx latus	0.033	0.002	0.363
Elagatis bipinnulata	-0.083	0.009	0.553
Coryphaena hippurus	-0.620	-0.071	0.072
Lutjanus vivanus	-0.562	0.106	0.560
Ocyurus chrysurus	-0.280	0.024	-0.088
Thunnus atlanticus	0.181	-0.098	0.403
Sphyraena barracuda	-0.221	0.190	0.838
Canthidermis sufflamen	-0.070	-0.033	0.431
Etelis oculatus	0.049	-0.088	0.438
Acanthocybium solandri	0.188	0.087	0.380
Lutjanus jocu	-0.502	0.182	0.391
Balistes vetula	-0.248	-0.342	-0.288
Lutjanus buccanella	0.298	0.208	0.378
Rhomboplites aurorubens	0.004	0.173	0.540
Mycteroperca bonaci	-0.050	0.249	0.710

It is recommended to study other important variables and events: ocean waves, precipitation rates, hurricanes, and cold fronts, to guide the management of fisheries in the region in the medium and long term, considering anthropogenic activities in the system, accompanied by monitoring and control of fishery resources continuously that allows having databases with as much information as possible, allowing sustainable management of resources.

ACKNOWLEDGMENTS

The Colombian Navy supported this work under Project 65030 -Characterization of the morphology of the seabed and its relationship with physical processes of the ocean, which is part of the Portfolio of Strengthening R+D+i of ARC-2018 and to the Francisco José de Caldas Fund- MINCIENCIAS, which was executed by the Faculty of Physical Oceanography of the Naval Cadet School "Almirante Padilla". Authors also thank the Colombian Ocean Commission for its commitment to generating scientific expeditions to update information on biodiversity and the seabed present in the Seaflower Biosphere Reserve; to the General Maritime Directorate - DIMAR, for providing support with platforms for marine scientific research. Thanks to the Science and Technology Corporation for the Development of the Maritime and Inland Waterway Marine Industry Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval Marítima y Fluvial - COTECMAR, for the logistics administered to the project. Finally, we also thank the Directorate of Science and Technology of the Colombian Navy for the interlocution between all project entities and the Secretary of Agriculture and Fisheries of San Andres and Providencia for providing data on artisanal fishing in Albuquerque Cays Island.

REFERENCES

Alonso, D., Bastidas, M., Rueda, J., Arteaga, E., Chasqui, L., Rueda, M., et al. 2012. Estudio línea base ambiental y pesquera en la Reserva de Biosfera Seaflower (Archipiélago de San Andrés, Providencia y Santa Catalina) como aporte al conocimiento y aprovechamiento sostenible de los recursos para la región. INVEMAR, Magdalena.

Andrade, C. 2000. The circulation and variability of the Colombian Basin in the Caribbean Sea. Ph.D. Thesis, University of Wales, Cardiff.

Arntz, W.E., Gallardo, V.A., Gutiérrez, D., Isla, E., Levin, L.A., Mendo, J., et al. 2006. El Niño and similar perturbation effects on the benthos of the Humboldt, California, and Benguela Current upwelling ecosystems. Advances in Geosciences, 6: 243-265. doi: 10.5194/adgeo-6-243-2006

Bonferroni, C.E. 1935. II Calcolo delle assicurazioni su gruppi di teste. Studi in onore del professore Salvatore Ortu Carboni, Roma.

Bray, J.R. & Curtis, J.T. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27: 326-349. doi: 10.2307/1942268

Corporación Andina de Fomento (CAF). 2000. El fenómeno El Niño 1997-1998. Memorias, retos y soluciones. CAF, Caracas.

Castro, E. 2005. Caracterización del régimen de pesca artesanal en la Isla de San Andrés, Caribe Colombiano: inferencias sobre la estructura de la comunidad íctica. Tesis de Magíster, Universidad Nacional, Bogotá.

Cheung, W.W., Meeuwig, J.J., Feng, M., Harvey, E., Lam, V.W., Langlois, T. & Pauly, D. 2012. Climate change induced tropicalization of marine communities in Western Australia. Marine and Freshwater Research, 63: 415-427. doi: 10.1071/MF11205

Clarke, K.R. 1993. Non parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117-143.

Clarke, K.R. & Gorley, R.N. 2001. PRIMER v5: User Manual/Tutorial.PRIMER-E. Plymouth Marine Laboratory, Plymouth.

Clarke, K.R., Gorley, R.N., Somerfield, P.J. & Warwick, R.M. 2014. Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E: Plymouth, 3: 246-256.

Cury, P. & Shannon, L. 2004. Regime shifts in upwelling ecosystems: observed changes and possible mechanisms in the northern and southern Benguela. Progress in Oceanography, 60: 223-243. doi: 10.1016/j.pocean.2004.02.007

Daw, T., Adger, W.N., Brown, K. & Badjeck, M.C. 2009. El cambio climático y la pesca de captura: repercusiones potenciales, adaptación y mitigación. In: Cochrane, K., De Young, C., Soto, D. & Bahri, T. (Eds.). Consecuencias del cambio climático para la pesca y la acuicultura: visión de conjunto del estado actual de los conocimientos científicos. FAO Documento Técnico de Pesca y Acuicultura, Rome.

Defeo, O., Castrejón, M., Ortega, L., Kuhn, A.M. & De Álava, A. 2014. Variabilidade climática e seu impacto em pescarias de pequena escala de invertebrados na América Latina. Desenvolvimento e Meio Ambiente, 32: 29-39. doi: 10.5380/dma.v32i0.36217

Díaz, J.M., Díaz-Pulido, G., Garzón-Ferreira, J., Geister, J., Sánchez, J.A. & Zea, S. 1996. Atlas de los arrecifes coralinos del Caribe colombiano. Litoflash, Magdalena.

Garay, J., Castillo, F., Andrade, C., Aguilera, J., Niño, L., De la Pava, M., et al. 1988. Estudio oceanográfico del área insular y océanica del Caribe colombiano - Archipiélago de San Andrés y Providencia y cayos vecinos. Boletín Científico CIOH, 9: 3-73. doi: 10.26640/01200542.8.3_73

Glynn, P.W. 1990. Global ecological consequences of the 1982-83 El Niño-Southern Oscillation. Elsevier, New York.

Gómez-López, D.I., Segura-Quintero, C., Sierra-Correa, P.C., Garay-Tinoco, J., Taylor-Jay, E. & Bent-Zapata, O. 2012. Atlas de la Reserva de Biósfera Seaflower. Archipiélago de San Andrés, Providencia y Santa Catalina. CORALINA-INVEMAR, Magdalena.

Gotelli, N.J. & Ellison, A.M. 2012. A primer of ecological statistics. Sinauer Associates, Massachusetts.

Grandas-Olarte, Y. & Castro-González, E. 2004. Régimen de captura y esfuerzo en la pesquería artesanal de especies pelágicas en la Isla de San Andrés, Caribe Occidental. Proceedings of the Gulf and Caribbean Fisheries Institute, 55: 223-235.

Hall, S. 2011. Climate change and other external drivers in small-scale fisheries: practical steps for responding. Small-scale fisheries management: frameworks and approaches for the developing world. CABI, 8: 105-132. doi: 10.1079/9781845936075.0132

Hare, B. 2003. Assessment of knowledge on impacts of climate change - contribution to the specification of article 2 of the UNFCCC: impacts on ecosystems, food production, water, and socio-economic systems. WBGU, Berlin.

Kenny, A.J., Skjoldal, H.R., Engelhard, G.H., Kershaw, P.J. & Reid, J.B. 2009. An integrated approach for assessing the relative significance of human pressures and environmental forcing on the status of large marine ecosystems. Progress in Oceanography, 81: 132-148. doi: 10.1016/j.pocean.2009.04.007

Márquez, G. & Herrera, M. 1986. Estudio de la biomasa fitoplanctónica y su distribución geográfica durante el crucero Oceáno Área I: archipiélago levantamiento providencia en el Caribe colombiano. Universidad Nacional de Colombia, 2: 145-156.

Montealegre, J.E. 2005. Atlas climatológico de Colombia. Ministerio de Ambiente, Vivienda y Desarrollo Territorial - Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Bogotá.

Montealegre, J.E. 2007. Modelo institucional del IDEAM sobre el efecto climático de los fenómenos El Niño y La Niña en Colombia. IDEAM, Bogotá.

Navarro-Monterroza, E., Arias, P. & Vieira, S. 2019. El Niño-Oscilación del Sur, fase Modoki, y sus efectos en la variabilidad espacio-temporal de la precipitación en Colombia. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 43: 120-132. doi: 10.18257/raccefyn.704

Ortega, L., Celentano, E., Finkl, C. & Defeo, O. 2013. Effects of climate variability on the morphodynamics of Uruguayan sandy beaches. Journal of Coastal Research, 29: 747-755. doi: 10.2112/JCOASTRES-D-13-00003.1

Ortiz-Royero, J.C., Otero, L.J., Restrepo, J.C., Ruiz, J. & Cadena, M. 2013. Cold fronts in the Colombian Caribbean Sea and their relationship to extreme wave events. Natural Hazards and Earth System Sciences, 13: 2797-2804. doi: 10.5194/nhess-13-2797-2013

Ottersen, G., Kim, S., Huse, G., Polovina, J. & Stenseth, N.C. 2010. Major pathways by which climate may force marine fish populations. Journal of Marine Systems, 79: 343-360. doi: 10.1016/j.jmarsys.2008.12.013

Pearson, H. 1987. Practical reading. Reading, 21: 178-184. doi: 10.1111/j.1467-9345.1987.tb00641.x

Posada, B. & Ospitia, G. 2011. Informe del estado de los ambientes marinos y costeros en Colombia. INVEMAR, Magdalena.

Poveda, G. 2004. La hidroclimatología de Colombia: una síntesis desde la escala interdecadal hasta la escala diurna. Revista de la Academia Colombiana Ciencias Exactas, Físicas y Naturales, 28: 201-222.

Prato, J. & Newball, R. 2015. Aproximación a la valoración económica ambiental del Departamento Archipiélago de San Andrés, Providencia y Santa Catalina, Reserva de la Biósfera Seaflower. SECCO, CORALINA, Magdalena.

Ricaurte-Villota, C. & Bastidas-Salamanca, M.L. 2017. Regionalización oceanográfica: una visión dinámica del Caribe. INVEMAR, Magdalena.

Samonte, G. 2008. Economic values of coral reefs, mangroves, and seagrasses. A global compilation. Center for applied biodiversity science. Conservation International, Arlington.

Sánchez-Jabba, A.M. 2012. Manejo ambiental en Seaflower, reserva de biosfera en el Archipiélago de San Andrés, Providencia y Santa Catalina. Documentos de Trabajo Sobre Economía Regional y Urbana-Banco de la República, 176: 40 pp. doi: 10.32468/dtseru.176

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K.-S. & Lima, M. 2002. Ecological effects of climate fluctuations. Science, 297: 1292-1296. doi: 10.1126/science.1071281

Valencia, I.D. & Osorio, F. 1999. Variabilidad climática interanual e interdecadal en la Isla de San Andrés. Cuaderno de Geografía. Revista Colombiana de Geografía, 1: 136-146.

Werner, F.E., Aretxabaleta, A. & Edwards, K.P. 2005. Modelling marine ecosystems and their environmental forcing. Oxford Scholarship, 13: 150-159. doi: 10.1093/acprof:oso/9780198507499.001.0001

Received: March 23, 2022; Accepted: August 5, 2022