EVOLUTIONARILLY DISTINCT & GLOBALLY ENDANGERED

Survival Blueprint

Boulder star coral & Mountainous star coral
Orbicella annularis & Orbicella faveolata
Venezuela

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1. STATUS REVIEW

1.1 Taxonomy: The genus *Orbicella* was classified before as *Montastraea* and three species within the genus, *Orbicella annularis*, *Orbicella faveolata* and *Orbicella franksi* were classified as the *Montastraea annularis* complex until 1994 (Weil & Knowlton, 1994). This fact makes temporal comparisons for each species difficult. The genus changed to *Orbicella* in 2012 after Budd *et al.* (2012). Currently, taxonomy is as follows: Class: Anthozoa; Subclass: Hexacorallia; Order: Scleractinia; Family: Merulinidae; Genus: *Orbicella*; Species: *Orbicella annularis* and *Orbicella faveolata*; species name author: Ellis & Solander, 1786; common names: boulder star coral and mountainous star coral, taxonomic sources: Ellis, J.; Solander, D. (1786); Hoeksema, B. W.; Cairns, S. (2019).

1.2 Distribution and population status: *Orbicella annularis* and *O. faveolata* are distributed throughout over 30 countries in the Caribbean, Southern Florida, Bahamas, Bermuda and the Gulf of Mexico. After the decline of *Acropora palmata* species in the in the early 1980s (Aronson and Precht, 2001), *Orbicella* has been considered the most important genus of shallow reef building corals in the Caribbean region. Nevertheless, their populations have been suffering a drastic decline caused by bleaching events, disease episodes and negative impacts caused by anthropic activities. In general, the population of these species are decreasing with numerous studies reporting the reduction of coral cover and colony abundance (Quan-Young and Espinoza-Avalos, 2006; Garzón – Ferreira et al, 2001; Cervino et al, 2001;Sutherland et al 2004, Brandt and MacManus, 2009; Edmunds, 2015; Van Woesik and Randall, 2017).

Figure 1. Global distribution of *Orbicella* coral species. Modified image from Aronson *et al.* (2008).

1.2.1 Global distribution:

Country	*Distribution*	*Population trend*	*Population status*
Jamaica	**(1)**More than 300 km of Jamaican coastline **(Hughes 1994)**	Decreasing (**Hughes 1994)**	**(1)Hughes (1994):** 90% cover reduction between 1980 and 1994.
	(2) Pinnacle I **(Hughes and Tanner, 2000**	Decreasing **(Hughes and Tanner, 2000)**	**(2)Hughes and Tanner (2000):** -16 year study using size-based transition matrices. Registered declines in rates of survival, population growth and recruitment of *M. annularis* complex. -Just one recruit observed, and recruitment calculations required to maintain population size were estimated between 35 and 73. -Year 1976. Eighty-six to forty colonies estimated in 1993, with an increment in colonies' number by fission. Increase in the number of colonies was a symptom of population decline and not population growth. Coral cover decreased as large colonies were being dismembered into small remnants, and then being covered by algae. Three time periods: in the first period: higher survival with population growth rates of eigenvalues λ of (1.074), this is an annual population growth rate equivalent to 1.4% by year; in the following period, the value dropped to 0.85%, and finally a third period with a value of just 0.39%, this is (i.e., a decline of more than 95% every 20 yr).
Mexico	Akumal Reefs	*M.annularis* complex Decreasing **(Roy, 2004)**	**Roy (2004):** Almost 50% reduction in tissue cover.
St. John, U.S. Virgin Islands	Yawsi Point	Decreasing **(Edmunds and Elahi, 2007)**	**Edmunds and Elahi (2007):** - Coral cover declined from 41% to 12% (72% decline) but unchanged over the following five years.

			-Reduced colony abundance from 47 colonies/m^2 to 20 colonies/m^2.
Curacao	Leeward coast western end of Curacao	Decreasing **(Bruckner and Bruckner, 2006)**	**Bruckner and Bruckner (2006):** *O.annularis* and *O.faveolata* abundance declined from 46% (1998) to 38% (2005). Increase in partial mortality by 85% from 1998 to 2005: - average tissue loss of 40% for both species Abundance declined from 46% (1998) to 38% (2005) Average tissue loss of 40% for both species *O.annularis* and *O.faveolata*(Bruckner & Bruckner, 2006)
Martinique	Three sites: Jardin Tropical; Pointe Borgnesse and Fondboucher	Decreasing **(Cowan, 2006)**	**Cowan (2006):** Coral reefs health assessment: post-bleaching event (year 2005) and record of mortality and diseases. Dominance of *Orbicella* species: 76.75% of total coral colonies at Pointe Borgnesse and 42.4% at Jardin Tropical. <u>Disease prevalence and bleaching susceptibility</u>: - 25% of colonies of *Orbicella* spp. affected by white plague disease. Percentage of colonies affected: **-Pointe Borgnesse:** *O. annularis* 36.43%; *O.faveolata*: 35.66%. **- Jardin Tropical:** *O. annularis* 11.11%**;** *O.faveolata:* 23.61%. - Post bleaching mortality: *O.annularis* (n=13 colonies with partial mortality and 4 dead colonies. *O. faveolata* (n=13 colonies with partial mortality and n= 6 dead). Both *Orbicella* species were among the species group with higher mortality rates and were found to be the most susceptible to post-bleaching mortality. Because of this situation, Martinique reefs may experience a decreased

			dominance of *O.annularis* and *O.faveolata*.
Dominica	**(1)**Sixteen sites **(Steiner and Kerr,2008)**	Decreasing (for coral reefs in general) **Steiner and Kerr (2008)**	**Steiner and Kerr (2008):** Record of the most severe bleaching episode of north-eastern and eastern Caribbean in 2005 and assessment post bleaching in 2007. <u>Percentage (%) of bleached colonies:</u> *O.annularis*: 63% (2005) and 43% (2007). *O.faveolata:* 82% (2005) and 46% (2007). <u>Percentage (%) of recent mortality:</u> *O.annularis*: 1% (2005) and 11% (2007) *O.faveolata:* 1% (2005) and 23% (2007). General decline of coral cover of 28% and 65% decrease in recruit abundance.
	(2) West, North and East and South Coast **(Steiner,2015)**	Decreasing **(Steiner,2015)**	**Steiner (2015):** *Orbicella* live tissue continuously decreasing, caused mainly by bleaching episodes
Tobago	**(1)**North West of Tobago **(Harding et. al 2008).** **(2)**Six locations: Kariwak, Buccoo, Mt. Irvine; Culloden; Little Englishman´s bay and sisters	Decreasing, *O.faveolata* **(Mallela and Crabbe, 2009)**	**(1)Harding et. al (2008):** *Orbicella* genus affected by three diseases: Yellow Blotch Disease, White Plague Disease and Dark Spot Disease, been one of the most affected genus. YBD disease prevalence varied between 43% and more than 60%; and White Plague, 41% and more than 50% **Mallela and Crabbe (2009):** Reconstruction and interpretation of historical and modern-day recruitment patterns. Influence of hurricanes, storms and bleaching events on recruitment. - *O. faveolata* recruitment since 1983: 17%, but after the bleaching event from 2005-2006 drop to 0. - *Orbicella faveolata* was the main framework builder in Tobago Reefs but its coral cover decreased after the 2005 bleaching event and subsequent outbreak of YBD and

	(Mallela and Crabbe, 2009).		there wasn`t recruitment during this study.
Puerto Rico	**(1)**Culebra Island **(Hernandez-Pacheco *et al.* 2011)**	Decreasing Authors highlight that viability of *O. annularis* is seriously compromised **(Hernandez-Pacheco *et al.* 2011)**	**Hernandez-Pacheco *et al.* (2011):** -Measured vital rates of *O.annularis* during the sequence of a bleaching event (pre-during and post). -Bleaching as the cause of an increase of small colonies in the area by colony fragmentation. Use of size-based transition matrices with 399 colonies. -Authors pointed out that sexual recruitment was unlikely to support the recovery of affected populations. Also, in the projection of a stochastic simulation indicated that after 100 years an annual probability of bleaching in excess of 6% would cause a population decrease (λ_s<1.0) of 54% in colony abundance.
	(2) Carlos Rosario, Palomino **(Soto-Santiago *et al.* 2017).**	Decreasing Colony shrinkage more common than colony growth. **(Soto-Santiago *et al.* 2017).**	**Soto-Santiago *et al.* (2017):** Decline in *Orbicella annularis* population growth rates (λs 0.80 to 0.70) despite no major negative environmental conditions in the area.
Colombia	Marine Protected Area (MPA) Natural National Park Corales del Rosario and San Bernardo: Reefs from Isla Grande (degraded) and Isla Tesoro (less degraded)	Decreasing **(Alvarado-Chacon and Acosta, 2009)**	**Alvarado-Chacon and Acosta (2009):** Study of the size structure of *Orbicella* at two reefs: (1) degraded and (2) less degraded: 102 colonies and 9,646 ramets. -They found a population with presence of few small colonies and dominance of medium sized colonies. This population characteristic increases the presence of small old non reproductive ramets because older colonies are more prone to partial mortality. -They argue that detriment of vital functions depends on individual ramets that are non-reproductive or less fertile. In this sense they found a

			low percentage of ramets completely reproductive: - 1% (in degraded reef) and 6% (in less degraded) -Combination of a lack of recruitment of sexual individuals, dominance of small sized ramets and presence of local stressors make *O.annularis* population unsustainable over time in both studied sites.
Cuba	**(1)**Archipelago Jardines de la Reina **(Busutil *et. al* 2016)**	Decreasing **(Busutil *et. al* 2016)**	**(1)Busutil *et. al* (2016):** -Authors found a replacement of typical species like *Orbicella.* (cover <10%). -Bleaching identified as the main detrimental factor for coral reefs and cause of the species dominance change; with more bleaching resistant species dominating: highest colony number and cover of opportunistic species. <u>*Orbicella* live cover and abundance:</u> *Orbicella annularis* found in only three of seven shallow sites surveyed and in front reef: - Shallow sites: live cover among 1% and 4.8% and relative abundance of 3.2% - Front reefs: live cover of 1.2% and 7.1%. and relative abundance of 1% and 9.1%. *Orbicella faveolata* only found in front reefs: - Live cover from 4.5% to 30.6% and relative abundance between 7.9% and 26.2%.
	(2) Cayo Diego Perez **(Rey-Villiers *et. al* 2016)**	Decreasing (**Rey-Villiers *et. al* 2016)**	**(2)Rey-Villiers et. al (2016):** *Orbicella* complex relative abundance from 41.5 % to 6.9%.
	Morrocoy National Park Mero	Decreasing **(Villamizar,2000)**	**Villamizar (2000):** *O.annularis* cover for 1995: 12.99% (canal zone) and 14.81% (protected zone) *O.annularis* cover for 1996 (after the massive die off): 1.07%

Venezuela	Morrocoy National Park - Caiman - Sombrero	Decreasing **(Bone et al. 2001:**	**Bone et al (2001):** Caiman (data from 1994 to 1996) - *O.annularis* cover 43.35% (year 1994) and dropped to less than 5% after the massive die off event (year 1996) Sombrero: (data from 1996 to 2000) - *O.annularis* cover 25% approx. (1997) to less than 20% (2000)
	Morrocoy National Park Peraza		**Lopez and Rodríguez (2010):** *O. faveolata* mean cover: 3.9% for year 2009
	Dependencia Federal Archipiélago Los Roques - Dos Mosquises Sur (DMS) - Cayo de Agua	Decreasing **(Bastidas et al. 2012)**	**Bastidas et al. (2012):** Significant loss of coral cover (%) by a bleaching event in 2010. Mean lost from 44.9 (%) in 2010 to 30.6% in 2011. In Dos Mosquises Sur dominated by *Orbicella* species (Yranzo, 2009) the coral cover dropped from 47.4% to 29.1%.
	Dependencia Federal Archipiélago Los Roques - Madrisquí - Dos Mosquises Sur (DMS) - Boca de Cote - Cayo Sal - La Pelona		**Villamizar et al (2014):** Dominance of *Orbicella annularis* Relative abundance: -Madrisquí shallow strata: 30.90%; -Dos Mosquises Sur shallow strata: 40.44% and deep strata:15.51%. Coral cover loss recorded for three reefs in two survey: (1) year 2005-2006 and (2) year 2011 -Cayo Sal: 37.1% to 19.82 % -Boca de Cote: 61% to 29.01% -DMS: 66 % to 29.50 (%) *O.annularis* and *O.faveolata* among most affected coral species as a consequence of the bleaching event that happened in 2010. Coral paleness was frequent, with % of colonies affected between 25% (La Pelona) to 36% (DMS). Diseases were the second deleterious factor (White Plague Disease, Yellow Band Disease and Dark Spot Disease).

Venezuela	Dependencia Federal Archipiélago Los Roques - Madrisqui - Dos Mosquises Sur (DMS) - Boca de Cote - Cayo Sal - La Pelona		**Yranzo and Villamizar (2015):** Partial mortality (%) increased in both species: -*O.annularis:* 30.65% in 2009 to 45.16% in 2011. -*O.faveolata:* 23.64% in 2009 to 50.13% in 2011. Diseases, paleness and bioerosion were the main deleterious factors for *Orbicella* species. *O.faveolata* colonies were most affected by diseases (17,49% of colonies (X^2= 66,939; gl= 3; α= 0,05) and *O.annularis* by paleness (21,34%; X^2= 53,181 ; gl= 3; α= 0,05).
Venezuela	Recopilation of reports: Presence of *O.annularis* in most of the country's reefs, and predominance in the oceanic islands and bays of the central-western region with a decrease in abundance in the eastern region. Highlighted sites: Cuare Wildilfe Refuge Morrocoy National Park Los Roques National Park	Decreasing, however it is necessary to extend the evaluations **(Cróquer et al. 2015)**	**Cróquer et al.(2015):** - Relevance of *O.annularis* in Venezuelan reefs. - *O.annularis* threatened by various factors including bleaching and diseases. - Two events pointed out as the main deleterious for *O.annularis* population in Venezuela that caused their live cover drop: (1) massive die off in Morrocoy National Park (1996) and (2) bleaching event of 2010.

1.2.2 Local distribution:

Region / province	*Site*	*Level of Protection*	*Population size*	*Reference(s)*
Dependencia Federal Archipiélago Los Roques	Reported for the following sites: Madrisqui, Francisqui, Boca de Cote, Cayo Sal, Dos Mosquises, La Pelona, Yonqui, Selesqui, Noronquises, Crasqui La Venada, La Pelona de Rabusqui, Sarqui, Cayo de Agua Decrease in coral cover at some reefs after 2010 bleaching event (i.e. Dos Mosquises)	MPA: National Park	Unknown	Villamizar *et al.* (2003; 2008; 2014) Croquer *et al.* (2009) Eakin *et al.* (2010) Bastidas et al (2012)
Morrocoy, Estado Falcon	*O.annularis* colonies observed in the following sites: Mesa de Borracho, Patch reef near Borracho, Varadero, Peraza, Sombrero, Pescadores, Los Juanes, Boca Seca, Playuelita, Mero Paicla, Sanarito, Caiman *O.faveolata* colonies observed in the following: Mesa de Borracho, Patch reef near Borracho, Cayo Sal Peraza, Sombrero, Pescadores, Los Juanes, Before Boca Grande, Boca Grande, 11 Palmeras, Boca Seca, Playuelita, Mero, Paicla, Sanarito, Boca grande 2, Caiman, Bajo Loco	MPA: National Park	*O.annularis* average density (col/m2): Mero: 0.02 (±0.04) Caiman: 0.01 (±0.03) Borracho: 0.01 (±0.03) *O.faveolata* average density (col/m2): Sombrero: 0.47 (±0.19) Playuelita: 0.52 (±0.27) Pescadores: 0.55 (±0.23) Peraza: 0.17 (±0.19) Paicla: 0.34 (±0.29) Mero: 0.20 (±0.18) Caiman: 0.26 (±0.17) Borracho: 0.35 (±0.31)	Bone *et al.* (2001) Laboy-Nieves *et al.* (2001) Villamizar (2008) Croquer *et al.* (2009) Current Project Yranzo *et al.* (Data collected between 2018 and 2020)
Cuare, Estado Falcón	Cayo Sur, Cayo Medio Cayo Norte	MPA: Wildlife Refuge	*O.annularis* average density (col/m2): Cayo Sur 0.03 (±0.07) Cayo Norte 0.05 (±0.05) *O.faveolata* average density (col/m2): Cayo Sur: 0.50 (±0.22) Cayo Norte: 0.47 (±0.14)	Villamizar (2008) Croquer *et al.* (2009) Current Project Yranzo *et al.* (Data collected between 2018 and 2020)
Mochima, Estado Sucre	*Only *Orbicella annularis* Cautaro and between Mochima bay and Manzanares river mouth	MPA: National Park	Unknown	Sant *et al.* (2004) Ramírez-Villaroel (2001)

San Esteban, Estado Carabobo	Isla Larga, Santo Domingo - Alcatraz	MPA: National Park	Unknown	Guevara, 2014
Estado Sucre	*Only *Orbicella annularis* Golfo de Cariaco	None	Unknown	Sant (2007)
Estado Carabobo	*Only *Orbicella annularis* El Palito Isla Raton Puerto la Cruz Bahia de Bergantin	Some sites within San Esteban National Park	Unknown	Ramírez-Villaroel, (2001)
Dependencia Federal Archipiélago Las Aves	La pared	None	Unknown	Yranzo & Villamizar, unpublished data
Dependencia Federal La Orchila	*Only *Orbicella annularis* El Burrito	None, Restricted activity due to Military base	Unknown	Ramírez-Villaroel, (2001)
Dependencia Federal La Tortuga	*Only *Orbicella annularis*	None. Reefs mostly degraded	Unknown	Del Monaco *et al.* (2010)
Dependencia Federal La Blanquilla	*Only *Orbicella annularis* Boca de Palo Los Mogotes Los Chaguaramos Boca de Cangrejo Los Tortuguillos	None	Unknown	Ramírez-Villaroel, (2001)
Nueva Esparta	*Only *Orbicella annularis* Coche, Cubagua and Margarita	None. Intense fishing activities on reefs	Unknown	Ramírez-Villaroel, (2001)
Dependencia Federal	Los Frailes	None. Intense fishing activities on reefs	Unknown	Ramírez-Villaroel, (2001)
Estado Anzoátegui	Isletas de Piriru	None	Unknown	Yranzo and Romero, (2014) unpublished data
Dependencia Federal Isla de Aves	Reefs slopes and terraces	MPA: Wildlife Refuge and Military base	Unknown	Yranzo *et al.* (2014)

1.3 Protection status:

Both *Orbicella annularis* and *O.faveolata* are included in the IUCN Red List as Endangered Category (A2ace). They are also in CITES**-** Appendix II and the SPAW Protocol from Cartagena Convention. Within this protocol, they are included in Annex III aimed at corals in general and Annex II, specific for both *Orbicella* species. In 2014, the National Marine Fisheries Services from United states (NMFS) included *Orbicella* at the Endangered Species Act (ESA). At national level, Venezuela is a signatory party to the CITES convention and is also a signatory state of the Convention of Biological Diversity. *Orbicella* species are present in some of Venezuelan MPAs and although the creation of these protected areas do not include the direct protection of *Orbicella* species, they intend to protect the different ecosystems including coral reefs. This is the situation for the Management Plan and Use Regulation (PORU by its acronym in Spanish) of Morrocoy National Park. Only *Orbicella annularis* is included in the *Red Book of Venezuelan Wildlife* (National IUCN list, Libro Rojo de la Fauna Venezolana, Cróquer *et al.* 2015) and is classified as Vulnerable. There are numerous laws and programs assigned to the protection of biodiversity in the country (Venezuelan Constitution, National Strategy of Biological Diversity, and the Law on Management of Biological Diversity among others).

1.4 Ecology, behaviour and habitat requirements:

Orbicella annularis colonies are column-shaped at the top, where the largest proportion of their living tissue grows. They are found from shallow (1m) to deep (20m) areas being more common in the shallow locations (Dustan 1975; Van Veghel et al, 1993; Weil & Knowlton, 1994)**.** *Orbicella faveolata* is characterized by its massive or layered shape with "skirt" edges. They are commonly found between 1m and 15 m depth (Weil and Knowlton, 1994) although they can also be found up to 30 m (Van Veghel *et al.* 1993) or deeper. Given the large dimensions of their colonies, these species contribute to the structural complexity of reef systems providing habitat heterogeneity (Roy, 2004).

In general, these two species have slow growth rates: 0.2 to 1.1 cm/ year (Hubbard and Scaturo,1985; Runnalls and Coleman, 2003) and low recruitment rates. There is no knowledge about their longevity, but it is probably longer than ten years (Aronson *et al.* 2008). Both species are hermaphroditic external fertilizers with annual mass spawning, four to eight days after the full moon in late summer or early fall, depending on latitude and the lunar period calendar date (Szmant, 1991). Usually colonies larger than 200 cm^2 are fully reproductive (*Montastraea annularis* complex; Szmant, 1985).

As all Scleractinia, *Orbicella* corals have a high susceptibility to environmental stress (Tomascik and Sander, 1987; Runnalls and Coleman, 2003). Among the main factors that regulate the development of corals are temperature, salinity, pH, oxygen, turbidity, depth, light, and sedimentation (Nybbaken, 2001). *Orbicella* species belong to the group of corals that have symbiont microalgae (zooxanthellae) within their tissues. That means they obtain energy from two sources: heterotrophic assimilation through zooplankton feeding and translocation from autotrophic endosymbiotic algae (zooxanthellae photosynthesis). Although they have a great plasticity in their feeding behaviour and the predominance of one energy source or the other varies between colonies and environmental conditions (zooplankton abundance, light availability, among others) the contribution of zooxanthellae to the *Orbicella* colonies energy budget is very important (Teece *et al.* 2011). So, light availability (on which depends zooxanthellae photosynthesise) and the stability of temperature within their tolerance range are very important to their survival. If temperature is too high or has abrupt changes, it can cause zooxanthellae being expelled from the coral colony, causing what is commonly known as bleaching (Glynn,1991).

The survival of *Orbicella* colonies as for the rest of coral species, depends largely on the extent and intensity of factors that change the water quality where they live (i.e. pollution, sediment discharges, etc.) and other factors like overfishing, coral fragment extraction, etc. (Tomascik and Sander, 1985; Miller and Cruise, 1995; Flood *et al.* 2005; Jackson *et al.* 2014).

1.5 Threat analysis:

Threat	**Description of how this threat impacts the species**	**Intensity of threat** *(low, medium, high, critical or unknown)*
Diseases	Since 1980 there have been numerous diseases documented that affect both *Orbicella* species: Yellow Band Disease (YBD), White Plague Disease (WPD), Dark Spot Disease (DSD), Black Band Disease (BBD), Folliculinid Ciliate, white syndromes, among others (Garzón – Ferreira et al, 2001; Cervino et al, 2001; Sutherland et al 2004; Bruckner and Bruckner, 2006; Van Woesik and Randall, 2017). The tissue rate mortality caused by these diseases is seriously affecting both species. For YBD, tissue lost oscillate between 0.6 and 2 cm by month (Garzón – Ferreira et al, 2001; Bruckner and Bruckner, 2003). For White Plague, Borger and Steiner (2005) recorded an infection rate of 1.73 mm /day, with tissue losses of 28,043 cm^2 in *O. faveolata* and 11,717 cm^2 in *O. annularis*, over a period of three years. For BBD the reported advance rates vary between 0.03 and > 1 cm/day in colonies of *O. annularis* (Rutzler et al, 1983; Bruckner; 1999) and 0.4 cm in O. *faveolata* (Griffin, 1998). Rutzler *et al.* (1983) reported between 64 and 746 cm^2 of tissue loss over a period of 41 days for *O.annularis*, while Bruckner (1999) recorded the loss of 1.3 cm^2 of tissue/day for this species, and for *O. faveolata* a loss of 107-1329 cm^2 over a period of 46 to 220 days. The most recent: Stony Coral Tissue Loss Disease (SCTLD) reported in 9 Caribbean sites until now, and *Orbicella* are considered as *intermediately susceptible species.* (https://www.agrra.org/coral-disease-identification). In Morrocoy National Park (MNP) previous studies have reported Black Band Disease in *O. annularis* (Ramos Flores, 1983) Yellow Band Disease and Folliculinid Ciliate in *O.annularis* and *O.faveolata* (Croquer and Bone, 2003; Croquer *et al.* 2006). During the first stage of the project YBD, WPD were recorded in colonies of both species and DSD, BBD and Folliculinid Ciliate only for *O.faveolata.*	High- direct
Climate change	The increment of temperature worldwide has been causing what is called the most visible sign of global warming: the coral bleaching events, which have increased in frequency and intensity (Eakin et al, 2010). With the expel of zooxanthellae, corals not only lose their colour, but they also have vital functions like growth (Goureau and Macfarlane,1990) and reproduction affected (Szmant and Gassman, 1990; Levitan *et al.* 2014). Corals affected by	High- direct

	bleaching show a reduction in the density of zooxanthellae and disorganization of the gastrovascular cavity of polyps (Hayes and Bush, 1990). Szmant and Gassman (1990) reported *O. annularis* complex colonies with bleaching failed to complete gametogenesis during the reproductive season. The high energy expenditure used for food generated a decrease in the energy needed to complete this reproductive process. In Panama, Levitan *et al.* (2014) reported a reduction of 95% in spawning rates for *O.annularis* caused by a bleaching event in 2010. In colonies that survived bleaching, studies suggest this kind of event can seriously affect the maintenance of *Orbicella* population because of a long-term reduction in their reproduction (Levitan *et al.* (2014). Similarly, in colonies of *M. annularis*, Goureau and Macfarlane (1990) showed that bleaching can affect the skeletal extent of the colonies. Likewise, Meesters and Bak (1993), when evaluating the regeneration of lesions in colonies of *M. annularis complex*, recorded lower regeneration rates in bleached colonies, which increased mortality in corals affected by this phenomenon. In general, corals that have undergone bleaching have been documented to have increased susceptibility to other stressors, like disease (Brandt and Mc Manus, 2009) Another effect of climate change is ocean acidification that can cause a decrease in calcification rates of corals among other organisms, with negative consequences in the role and function of coral reefs and the services they bring to human populations (Anderson and Gledhill, 2012). Susceptibility to acidification varies with coral species (Manzello, 2010). For example, in *Orbicella faveolata*, it can affect fertilization efficiency (Albright, 2011). In the project's study site, research examining the effects of climate change have been limited to reports of several bleaching episodes: 1987 (Losada, 1988), 1998 and 2005 (Rodriguez *et al.* 2010). During the first stage of the project just a few bleached *Orbicella* colonies were recorded. For *O.annularis* there is just one record of paleness corresponding to the last survey (January 2020). For *O.faveolata* the proportion of pale or partially bleached colonies varied between 0,44% (survey from November 2018) to 4,31% (January 2020). From the surveyed sites, the lowest proportion of colonies affected were found in Playuelita reef (3,57%) during July 2018 and the highest in Bajo Grande bank (25%) in July 2019. Among all the surveys, paleness was seen in more reefs in the January 2020 survey (40% of the surveyed reefs).	

	In addition among the tagged colonies, 3 colonies (1 *O.annularis* and 2 *O.faveolata*) had partial bleaching in Caiman (2) and 1 in Peraza.	
Overfishing	Algae are one of the main marine benthic groups that compete with corals for space (Hughes, 1989). They can cause tissue mortality in many coral species, including *Orbicella* species (Bythell *et al.*1993; Quan-Young and Espinoza-Avalos 2006). For example, Roy (2004) registered a tissue lost rate of 0.86 ± 0.84 cm/year in *O. faveolata* interacting with turf algae sediments mats, and Quan-Young and Espinoza-Avalos 2006 found a reduction in the density of zooxanthellae, the thickness of colony tissue and the chlorophyll concentration in *O. faveolata* colonies interacting mixed turf algae. Overfishing of herbivores that control algae growth cause the proliferation of macroalgae (Lirman, 2001), affecting coral larvae settlement (Jackson *et al.* 2012), and *Orbicella* health, even its fecundity (Foster *et al.* 2008). Parrotfish are considered the most effective grazers of the Caribbean region with research (Jackson *et al.* 2014) reporting overfishing as one of the main drivers of coral cover decline in the Caribbean. At the study site, during the first stage of the project, a low abundance of fishes have been registered. From 10 reef where fish survey were done, key commercial fish (snappers and groupers) had a critical health score (category 1; SIRHI, Healthy Reefs Initiative*****) in 50% of the sites and a poor score in 20% of them. In regards to key herbivores fish (parrotfishes and surgeonfishes) 40% of the sites had a poor condition category. This situation is likely the result of illegal fishing with harpoon. This activity has been increasing in the area because of the economic crisis and for example parrotfish sales are becoming more frequent in fishmongers (both local and national level).	High- indirect
Inadequate coastal development	Uncontrolled development of coastal infrastructure including that for touristic purposes, river discharges with high sediment loads and metals, agricultural waste and untreated sewage can affect coral reef health and *Orbicella* species (Tomascik and Sander, 1985; Flood *et al.* 2005. In the study area, many studies have documented low water quality and sediment load, including the presence of numerous heavy metals and nutrients (Bone et al. 1993; Bastidas, Bone et al. 1999; García *et al.* 2011). Heavy metals have even been detected inside the skeleton of two coral species studied: *Porites astreoides* and *Orbicella faveolata* (Bastidas and García 1997; Bastidas and García 1999). This	High- direct

	situation occurs as a result of constant anthropogenic pressure near the coastal areas (Bastidas *et al.* 1999), including hotels and lodges without treatment plants, illegal constructions, and industries, among them the state oil industry (PDVSA- Petroleos de Venezuela). Currently a new luxury resort development has dredged a canal across a mangrove/wetland inside the Cuare Wildlife Refuge.	
Lack of knowledge and inefficient management of Morrocoy National Park and Cuare Wildlife Refuge	Despite the relevance of coral reefs worldwide, there is still a general lack of knowledge about them. Not only local communities, also local authorities have insufficient information about coral reefs, and that of *Orbicella* species specifically. This is the case in the study site where most people do not know what a coral is, including tourists that visit the National Park. From the project social survey done in the village of Chichiriviche (one of the main village from the area) we documented that almost 40% of tourists (some of them regular visitors that have travelled 8 hours by car to the national park) think that corals are rocks, and none of these tourists had heard about *Orbicella* before. There is even a disconnection between the concepts of coral reefs and corals. Among other social groups, according to our project interviews fishermen were the group with the most knowledge on corals. Similarly, Ramirez (2017) in a study also done in Chichiriviche village found little knowledge about coral reefs among stakeholders (boat captains, fishermen and tourists) caused by the absence of associated environmental education programs. In this study, fishermen were also the group with more knowledge. Apparently this lack of information also extends to the local authorities which has consequences on the management of the area.	High- direct
Massive die off event in the study site	For the study area, the massive die off event that happened in 1996 and killed 90% of the benthic fauna (Losada & Klein, 1996) has been the major threat. Although this event has not since been repeated, its effects are still being felt.	High- direct

* Simplified Integrated Reef Health Index: SIRHI (Healthy Reefs Initiative from the Mesoamerican Healthy Reefs Program, 2012) This INDEX includes five (5) health categories Scores between 1 and 5: Critical (1); Poor (2); Fair (3); Good (4); Very Good (5).

1.6 Stakeholder analysis:

Country	Stakeholder	Stakeholder's interest in the species' conservation	Current activities	Impact *(positive, negative or both)*	Intensity of impact *(low, medium, high or critical)*
Venezuela	Hotel owners and staff	Main economic activity depends on tourists that visit Morrocoy National Park, where coral reefs are one of the main attractions. Results from interviews conducted with tourists, confirmed that most of them spend their time at the beach; very few snorkel, although they commented that they would like to do it. However, this comment could be biased (related to pleasing the interviewer).	Hosting service for tourist	Positive or negative They can have a positive impact because of their good disposition but is still necessary to include most of them and not only those from Chichiriviche village. Hotels and lodges from Tucacas should also be included. It can also be negative if they do not have knowledge about responsible tourism.	High/critical - Some hoteliers have knowledge about coral reefs and their relevance but others have limited information. If a hotel has a snorkelling package included without caring about the tourist behaviour it would be negative.
	Fishermen (n=740) (local fishermen associations)	Main economic activity depends on natural resources of MNP, including coral reefs.	Artisanal fishing but also spearfishing (illegal). Easy catchable fish species like parrotfishes.	Negative if there is overfishing or they continue fishing herbivorous fish like parrotfishes. Positive if they shift target species.	High/critical - Because they are in direct contact with coral reefs.
	Dive operators Frogman Dive Center- Tucacas (currently the only operator)	Main economic activity depends directly on coral reefs in the area.	Recreational diving activities	Positive because they have knowledge about coral reefs relevance and promote their conservation.	High/critical - Direct contact with coral reefs and with tourist divers.

Venezuela	Boat Captains (local boat driver associations)	Main economic activity depends on natural resources of MNP, including coral reefs.	Tourist transport along Morrocoy National Park.	Positive if they anchor in appropriate sites. Negative if the anchor over live coral.	High/critical - Because the direct contact with coral reefs.
	Recreational boating jetties (n=3)	Main economic activity depends on natural resources of MNP, including coral reefs.	Boat parking service.	Positive or negative depending in their actions.	High/critical - As they are directly related with boat captains.
	NGO Foundation for the Defence of Nature FUDENA	As an Environmental NGO, one of their main interests is the protection of the biodiversity of MNP and CWR.	Established in the area since 1988 it is an organization focused on the conservation of marine resources from the MNP and CWR.	Positive because they work to preserve coastal marine ecosystems and have been working with the community since 1988.	High/critical - They have great influence on the different groups that make up the community.
	Local authorities: INPARQUES Municipality INEA, Biological Diversity National Office INSOPESCA National Guard Navy	Sustainable management of the Morrocoy National Park (INPARQUES) and Cuare Wildlife Refuge (MINEC). Availability of very useful information that can contribute to authorities in the Park's coral reef management.	In theory: Morrocoy National Park and Cuare Wildlife Refuge Management. In reality, there is an inefficient management characterized by poorly trained personnel, lack of regulation and control of restricted/ prohibited activities in both protected areas.	Neutral or negative Some government institutions do not implement conservation management plans , allowing activities that can cause environmental damage, instead of local environmental protection.	High/critical - Because their actions can highly impact the environment, and as local authorities they can be seen as examples to follow by some community members.
	Business owners	Although they do not have direct contact with coral reefs they are an important part of the community.	This group is one of the most extensive from the study site as there are numerous	Positive If they get involved.	Medium - Because they generally have no direct contact with coral reefs

		Interest in corals is not specific to them but the idea is to arouse their interest and engagement.	shops and restaurants in the village, many of them are visited by tourists (they shop there before going to the beach).		but can be high if they get involve because they can have influence in other social groups.
Venezuela	Students	As society's next generation, the children of the different community stakeholders are fundamental to the impact that the project can achieve. The behaviour changes are Believed to be undoubtedly more effective in children and adolescents and they can influence the other members of the community.	Students at different age levels.	Positive as they can learn quickly, and they have a natural curiosity that can help engagement.	High - As they can influence parents and the rest of the family.
	Teachers	Educators have a very important role in the whole community because they are partially in charge educating the next generation. They can be responsible for setting an example for the rest of the community.	They teach at different age levels of education.	Positive Because of their influence on students and other social groups.	Critical - Because of the scope their actions can have.

1.7 Context and background information that will affect the success of any conservation action for this species:

	Description	Barriers to conservation	Opportunities for conservation
Socio-cultural effects and cultural attitudes	There are two aspects of the socio cultural effects worth mentioning: 1) the majority of tourists that visit MNP have a lack of knowledge, even of the existence of coral reefs. ; 2) the local population have in general at least basic knowledge about coral reefs and some of the benefits they provide, so for them this ecosystem has some value, but reinforcement is needed. Also, fishermen seem to have a good knowledge about coral reefs. No aspect of the observed knowledge was related to the species of *Orbicella*, but in general to the marine environment.	Lack of knowledge and the economic situation are the main barriers to conservation. The national crisis is affecting every basic aspect of Venezuelan people´s life (food, electricity, water, oil services). This situation means people are focused on covering their basic needs, and the environment is perceived as something less important to everyday necessities.	Despite the barriers mentioned, there is really a positive attitude to learn about natural resources from Morrocoy National Park. There is a very good general reception to 'talking about another topic', for example a positive subject, in the middle of the general crisis. In the current crisis the need for local positive news is evident.
Economic implications	Coral reefs provide numerous ecosystem services as food resources, tourism attraction, and coastal protection. As the main reef builders, *Orbicella* species provide these services and their protection has a positive economic impact in the local community.	The acquirement of fast economic benefits can be the main barrier. For example, the MPA's mismanagement of monetary interests can negatively impact conservation.	Members of local community from the tourist sector and commercials stores are interested in the protection of coral reefs. This interest must be reinforced and scaled up to other community members.

		Although economic value of coral reefs has been estimated (e.g. Ahmeda et al. 2007; Ferrario et al. 2014) it can be difficult to visualize or perceived by the general public as their benefits are complex and in a long term scale.	
Existing conservation measures	Morrocoy was declared a National Park in 1974 and Cuare as a Wildlife Refuge in 1972. Cuare is also a RAMSAR site since 1998. Through regulations included on these MPAs, *Orbicella* species are protected as part of the biodiversity. The management of these areas are the responsibility of the Parks National Institute (INPARQUES): Morrocoy National Park, and the Biological Diversity National Office (Cuare Wildlife Refuge). At the national level, there are numerous laws and programs assigned to the protection of biodiversity. Though enforcement is non-existent at the moment. At the regional and global level, protection of marine ecosystems are included in the Convention of Biological Diversity, of which	There is a general unfulfillment of MPA regulations, corruption and a state of 'paper MPAs'. The combination of ignorance, lack of resources and economic interests are a significant barriers.	Some people that work at the institutions in charge of the MPA management are interested in conservation and fulfilling their work. These individuals should be engaged to drive conservation in the MPAs.

	Venezuela is a signatory state, and also, in the United Nations Sustainable Development Goals under Goal 14, life below water. *Orbicella* species are included on international regulations like CITES, SPAW Protocol, ESA act,		
Administrative/political set-up	Two Institutions are responsible for the management of Natural Protected areas in Venezuela: one for National Parks (National Parks Institute (INPARQUES)); and the other for the remaining protected areas (Biological Diversity National Office from Ministry of Popular Power for Eco-socialism). The first institution manages Morrocoy National Park and the second manages, Cuare Wildlife Refuge. In general, protected area management follows centralised national guidelines. Although there are regional agencies protected area management is largely coordinated from the national headquarters in Venezuela's capital. In the study area there is only one agency of INPARQUES and it is only located in Tucacas (a village near Morrocoy and Chichiriviche).	Centralized resources and lack of planned actions are a limitation. Poor training and high staff turnover.	The lack of strong institutional capacity brings the opportunity to develop actions to address and fill those gaps.

Local expertise and interest	Foundation for the Defence of Nature FUDENA. Environmental NGO established in the area since 1988. This organization is focused on the conservation of marine resources from the MNP and CWR. The diving operator and group of locals that were included in the project are interested in promoting the conservation of coral reefs and *Orbicella* species. Institute of Tropical Zoology and Ecology-Central University of Venezuela are interested in sustainable management of the National Park. This includes the conservation of *Orbicella* species and coral reefs from MNP, wider marine biological diversity protection and the long-term sustainability of marine resources.	Social, political and economic national situation. Lack of resources for scientific research.	Staff are highly engaged and motivated. Actively involved in every activity related to the protection of marine ecosystems and species, specially Orbicella species.
Resources	There are no financial resources for protecting *Orbicella* species and people working with coral species are limited.	Social, political and economic national situation. General lack of awareness about their relevance.	FUDENA activities with the local community have generated an interest in the conservation of marine environments, including coral reefs. In this sense they participate every year in the world beach cleaning day, an activity that takes place on all coasts worldwide and that FUDENA organizes in Chichiriviche since 1996.

2. ACTION PROGRAMME

Vision (30-50 years)	
Persistence of *Orbicella* populations and coral reefs in Morrocoy National Park and Cuare Wildlife Refuge, Venezuela	
Goal(s) (5-10 years)	
Improve local management and awareness of coral reefs and *Orbicella* populations in Morrocoy National Park and Cuare Wildlife Refuge, Venezuela	
Objectives	**Prioritisation** *(low, medium, high or critical)*
Promote an updated Management plan for MNP, based on novel scientific knowledge, to include special zoning for key reefs where *Orbicella annularis* colonies still occur	High
Improve local knowledge about the importance of *Orbicella* species and coral reefs for their wellbeing and livelihoods	Critical
Design and implement a monitoring program of *Orbicella* species to update information on the status of this subpopulation to inform management and conservation strategies	Critical
Design and implement a program to monitor spatial and temporal changes in land-based pollution and thermal stress to coral reefs	Critical

Activities	**Country / region**	**Priority** *(low, medium, high or critical)*	**Associated costs (currency)**	**Time scale**	**Responsible stakeholders**	**Indicators**	**Risks**	**Activity type**
Objective 1 Promote an update of the Management plan for MNP, to include special zoning for key reefs where *Orbicella annularis* colonies still occur								
Collection of information, preparation of the report and presentation to stakeholders	Venezuela/Capital District Caracas	High	100	3 months	Institute of Tropical Zoology and Ecology	Report and presentation	Basic services deficiency	Education & Awareness
Meeting with local authorities and managers of both Marine Protected Areas to promote a proposal for a special regulation for Sombrero and Pescadores reefs (restricted access in specific areas) For Cuare the inclusion of *Orbicella* information as a relevant component to reinforce the restricted access already currently established	Venezuela/ Falcon State	High	2000	1 -5 years (depends on political will)	Local Government	Publication of *Orbicella* information and local regulation	Lack of interest or commitment of authorities and managers	Law & Policy

Establishment of a good relationship with lobbying for the inclusion of re-zoning of reefs within the Division of Ordenación Territorial de Zonas Costeras (Territorial Planning Division of Coastal Zones) from MINEC)	Venezuela/ Falcon State	Critical	300	Strongly dependent on political will	Government	Meetings, communication letters, email	Lack of interest or commitment by authorities and managers	Law & Policy
Objective 2: Improve local knowledge about the importance of *Orbicella* species and coral reefs for their wellbeing and livelihoods								
Inclusion in the conservation awareness raising program of a greater number of lodges and hotels and other key social groups in the area, including other communities such as Tucacas (including stakeholders such as fishermen, students, teachers, boat captain, merchants and authorities). Design plan and carry out tailor group activities and campaigns to:	Venezuela/ Falcon State	Critical	72,500.00	5 years	Lodge and hotels managers and workers. Fishermen, boat captain and merchant associations. Schools directors and higher education institutions	Pre-post evaluation	Lack of interest, basic services deficiency	Education & Awareness

- Increase knowledge on the species and its importance - Increase knowledge about relevance of Marine Protected Areas: main features, benefits - Increase awareness of sustainable fishing practices. - Increase knowledge about benefits of protecting coral reefs and follow rules from Marine Protected Areas - Increase awareness on the status of the species and coral reefs to strengthen support for the inclusion of special regulations in the management Plan								
Establishment of a museum to be visited by both tourists and local residents	Venezuela Falcon State	Medium	80,000.00	Permanent space	Higher education institutions Ministry of tourism, Local government	Museum and number of visitors	Lack of interest, logistics	Education & Awareness

Objective 3: Design and implement a monitoring program of *Orbicella* species in order to have updated information about the status of this subpopulation and inform management and conservation strategies								
Continue the biological monitoring of *Orbicella* species including reproductive biology, genetic, microbiology, standardising methods and publishing manuals for implementation and data analysis	Venezuela Falcon State	Critical	40,000.00	2 years	Research Institutes, Universities and NGOs	Updated National Red List, publications	Bad weather conditions, logistic difficulties	Improving Knowledge
Publish and maintain freely accessible online databases including imagery and reports	Venezuela Falcon State	High	10,000.00	4 years	Research Institutes, Universities and NGOs	Databases, number of people using resources	Technical skills might not be available locally	Improving Knowledge
Design a structure for the implementation of the monitoring program and build a plan to secure financial sustainability for at least 10 years	Caribbean	Critical	5,000.00	2 years	Research Institutes, Universities, NGOs and local stakeholders	Financial resources available for the program	Finding income streams and funding for monitoring programs is challenging	Improving Knowledge
Inclusion of techniques for disease management (i.e..epoxy use)	Venezuela Falcon State	High	8,000.00	5 years	Research Institutes, Universities and NGOs	Number of diseased colonies recovered/survived	Permit denied by National authorities	Improving Knowledge

Objective 4: Design and implement a program to monitor spatial and temporal changes in land-based pollution and thermal stress								
Diagnostic evaluation of tourist and non-tourist infrastructure in relation to the disposal of its wastewater (e.g. inventory of how many tourist operators have treatment plants)	Venezuela/ Falcon State	Critical	5,000.00	5 years	Research Institutes, Universities in conjunction with government agencies	Report, publications Parameters within the ranges established by sanitary and water quality standards	Lack of interest, lack of resources, lack of political will	*Land/Water Management*
Evaluation of characteristics of waste thrown into freshwater bodies that flow into Morrocoy National Park from its basin of origin. Subsequent sanitation program.	Venezuela/ Falcon State	Critical	3,000.00	1 year	Research Institutes, Universities in conjunction with government agencies	Report, publications.	Lack of interest, lack of resources, lack of political will	*Land/Water Management*
Develop and implement a sanitation program based on data collected on waste run-off.	Venezuela/ Falcon State	Critical	3,000.00	1 year	Research Institutes, Universities in conjunction with government agencies	Report, publications Parameters within the ranges established by sanitary and water quality standards	Lack of interest, lack of resources, lack of political will	*Land/Water Management*
Design, plan and implement a water quality monitoring program for biological and chemical pollutants and sedimentation (including sedimentation input rates)	Venezuela/ Falcon State	Critical	10,000.00	5 year	Research Institutes, Universities in conjunction with government agencies	Report, publications	Lack of interest, lack of resources, lack of political will Economic interest	Land/Water Management

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