Monitoring of an invasive octocoral (Carijoa riisei) in the two main port areas of the Colombian Pacific basin.

Monitoreo de un octocoral invasor (Carijoa riisei) en las dos principales zonas portuarias de la cuenca del Pacífico colombiano.

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Abstract: Within the framework of the Biological Port Reference Surveys (RBPR) carried out by the Colombian Maritime General Directorate (DIMAR), the distribution and association of Carijoa riisei with the port infrastructure of the two main port areas of the Colombian Pacific Basin were described: Buenaventura and Tumaco. C. riisei is an invasive octocoral that is considered to have been transferred via the Panama Canal through international maritime traffic to the Eastern Tropical Pacific, where it has established itself as a risk for the native benthic community of the region, generating massive deaths in this community. In this work, C. riisei was identified closely associated with port pilings, sunken ships and rocky outcrops and even growing on native fauna in the port area of Tumaco; while it was only observed in one of the eleven monitored signal buoys. On the other hand, in the port area of Buenaventura it was absent. The results of this research show the importance of monitoring this octocoral in the Colombian Pacific Basin (CPC), in order to implement measures to prevent dominance of coastal and strategic ecosystems in this region.

Keywords: International maritime transport, port facilities, bioinvasions, Transporte marítimo internacional, instalaciones portuarias, bioinvasiones.

Resumen: En el marco de los Estudios Biológicos Portuarios de Referencia (RBPR) realizados por la Dirección Marítima de Colombia (DIMAR), la distribución y asociación de Carijoa riisei a la infraestructura portuaria de las dos principales zonas portuarias de la cuenca del Pacífico colombiano: Buenaventura y Tumaco, fue descrito. C. riisei es un octocoral invasor que se considera que ha sido trasladado por el Canal de Panamá a través del tráfico marítimo internacional al Pacífico Oriental Tropical, donde se ha consolidado como un riesgo para la comunidad bentónica nativa de la región, generando muertes masivas en esta comunidad . En este trabajo se identificó a C. riisei en estrecha asociación con pilotes portuarios, embarcaciones hundidas y afloramientos rocosos, e incluso creciendo sobre fauna nativa en la zona portuaria de Tumaco; mientras que solo se observó en una de las once boyas marcadoras monitoreadas. En cambio, en la zona portuaria de Buenaventura estuvo ausente. Los resultados de esta investigación muestran la importancia del monitoreo de este octocoral en la Cuenca del Pacífico Colombiano (CPC) con el fin de implementar medidas para evitar su dominio en los ecosistemas costeros y estratégicos de esta región.

Introduction

Maritime transport has been the most effective means of transporting goods and services on a global scale (Ojala & Tenold, 2017). At the same time, it displaces biological species through ballast water and embedded in hulls (*Biofouling*), introducing them in areas outside their natural distribution, where they can acquire characteristics of an invasive organism and thus affect marine resources, public health and the economy (Molnar *et al.* , 2008; Otani et *al.* , 2007; Richardson & Pyšek, 2007; Ruiz *et al.* , 1997). For this reason, maritime traffic has been related to different events of introduction and invasion of exotic species (Hulme, 2009), mainly in areas with port activities of international scale (Carlton & Geller, 1993; Grosholz, 2002).

In marine ecosystems, invertebrates can represent the greatest cases of introduction of exotic species; for example, in Hawaii, 93% of introduced marine species correspond to these organisms (Coles & Eldredge, 2002; Grigg, 2003; Kahng, 2006). One of the best known cases of invasive marine invertebrates is the snowflake coral *Carijoa riisei* (Duchassaing de Fonbressin & Michelotti), which if not considered as a complex of cryptic species, would be the only coral species with native populations in both the Indo-Pacific and the Atlantic, including the Caribbean Sea and the Gulf of Mexico (Concepcion *et al.*, 2008). In Colombia this octocoral is cataloged as native in the Caribbean Sea, where it has been recorded associated with different substrates (Sánchez & Ballesteros, 2014).

Meanwhile, in the Colombian Pacific Basin (CPC) it is considered as an introduction event coming from the Caribbean, possibly through the Panama Canal via international maritime traffic (Quintanilla *et al.* , 2017; Sánchez & Ballesteros, 2014). There, *C. riisei* was detected for the first time in 2010 (Gutiérrez, 2010) and the record of its occurrences increases as biological surveys in this region increase, as it has been detected in coral areas of the Gorgona and Malpelo islands, as well as in Cabo Corrientes, where it has been evidenced that it generates massive death of native octocorals (Gutiérrez, 2010; Sánchez *et al.* , 2011; Sánchez & Ballesteros, 2014). It was recently recorded associated with submerged artificial structures in Juanchaco and Tumaco (Ahrens *et al.* , 2021), the first of these localities located in the vicinity of the access channel to the Regional Port Society of Buenaventura, while the second is the headquarters of the Regional Port Society of Tumaco. Despite this, little is known about the distribution of *C. riisei* in both port areas, which correspond to the two main ports of the CPC in relation to arrivals and departures of international maritime traffic.

In order to know the current status of *C. riisei* in both port areas and to generate preventive strategies to avoid the transfer of this species through ships arriving there, the objective of this research is to describe the frequency of occurrence and association of *C. riisei* to the port infrastructure of the two main port areas of the CPC.

Materials and methods

Study area

Tumaco port area

The city of Tumaco is located south of the CPC (Figure 1A) and is home to the second most important maritime terminal in the region (Ospina, 2015). The port terminal has a 300 m long pier, as well as an access channel composed of 20 marker buoys, with a depth ranging from 9-18 m (Caballero Gámez, 2013). Due to sediment discharges from the Curay, Colorado, Chagüi, Tablones, and Mexicano rivers, among others, the bay has turbid waters with a high organic matter load and, in general, particular bathymetric conditions (Garay-Tinoco *et al.*, 2006).

Buenaventura port area

It is located on the central coast of the CPC (Figure 1B) in the city of Buenaventura, where the maritime terminal presents a 31.5 km long access channel, with an average depth of 13.5 m at low tide and is made up of more than 60 marker buoys. This multipurpose port has an extension of 620 ha and has 14 piers that in total comprise a length of about 2 km (Castro C. *et al.* , 2017). Due to its proximity to the main cities of the country as well as to the main international traffic routes of the Asia-Pacific region, it is the maritime terminal with the highest number of arrivals in the CPC (Castro C. *et al.* , 2017; Escobar Gómez *et al.* , 2012; Serrano-Amaya & García, 2018). As a consequence of the interaction of the tides and the abundant fluvial discharges of the rivers that flow into the bay, salinity is generally low and presents important spatial variations (Otero Díaz, 2005).

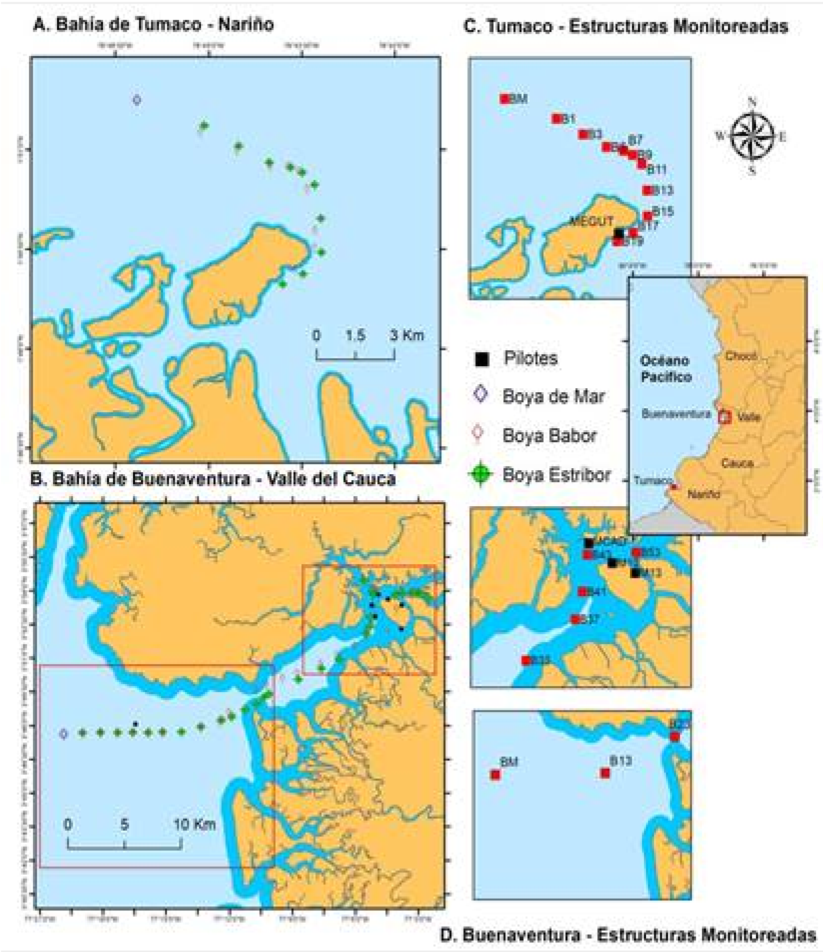

Figure 1

Figure 1.

Study Area A. Tumaco Bay B. Buenaventura Bay C. Buenaventura Bay Buenaventura Bay C. Structures monitored in Tumaco Bay, where: BM: Sea Buoy, B1: Buoy 1, B3: Buoy 3, B5: Buoy 5, B7: Buoy 7, B9: Buoy 9, B11: Buoy 11, B13: Buoy 13, B15: Buoy 15, B17: Buoy 17, B19: Buoy 19, and MEGUT: Pile 1 and 2 of the Tumaco Coast Guard Station Pier. D. Structures monitored in Buenaventura Bay, where: BM: Sea Buoy, B13: Buoy 13, B23: Buoy 23, B33: Buoy 33, B37: Buoy 37, B41: Buoy 41, B43: Buoy 43, B53: Buoy 53, MCAD: Agua Dulce Dock Pile, M10: Dock 10 Pile Sociedad Portuaria Regional de Buenaventura, and M13: Dock 10 Pile Sociedad Portuaria Regional de Buenaventura.

Port infrastructure monitoring

Through port biological surveys and *SCUBA* diving, eleven marker buoys and two piles were inspected in Tumaco in 2020 (Figure 1C), while eight buoys and three piles were monitored in Buenaventura in 2021 (Figure 1D). The inspections of the marker buoys included the floating structure, the mooring gear and the dead weight (Figure 2) since they differ in their roughness according to their composition (Table 1). Particularly in the access channel to the Tumaco port terminal, surveys were included in the area surrounding the port infrastructure. At those stations where *Carijoa riisei* was found, samples were obtained and preserved in 4% formalin. At the end of each dive, the presence or absence of the octocoral in each structure was recorded.

Taxonomic identification

The taxonomic identity of the collected colonies was performed under the keys of Devictor & Morton (2010) and confirmed by sclerite analysis, as well as the criteria of international experts supported by ca.
on-site audiovisual images.

Table 1

Table 1.

Structure	Composition
Pile	Concrete
Floating structure (Buoy)	Polyurethane
Anchor train (Buoy)	Stainless steel
Dead weight (Buoy)	Concrete

Composition of the monitored port structures.

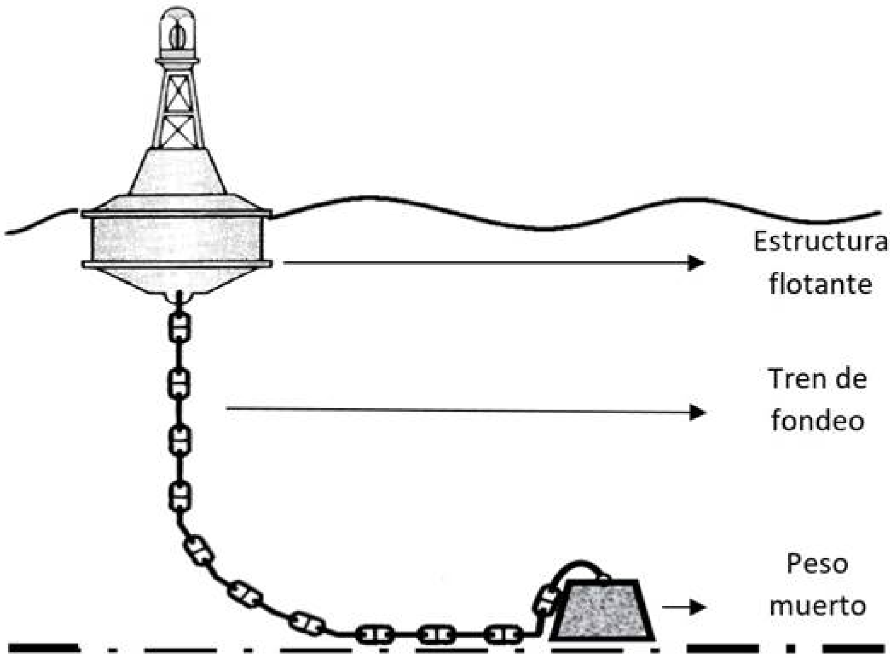

Figure 2.

Figure 2

Structures that make up the marker buoys.

Results

Densely branched colonies of *Carijoa riisei* with red-orange colorations and soft white polyps were observed (Figure 3A). The collenchymal sclerites of the collected specimens were white rod-shaped (Figure 3B - 3D) and fused rods (Figure 3E), thin, branched and spiny, agreeing with the descriptions of Devictor & Morton (2010), Dhivya *et al.* (2012) and Galván-Villa & Ríos-Jara (2018).

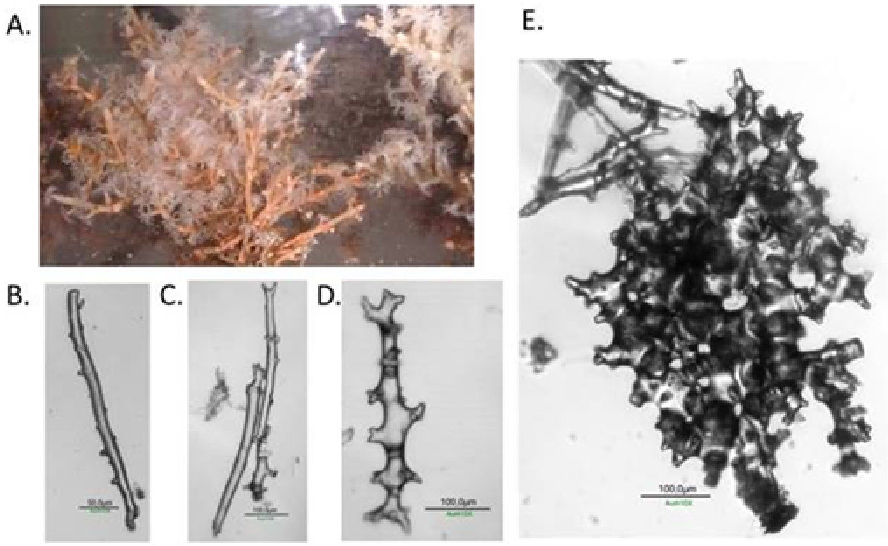

Figure 3.

Figure 3

Identification of Carijoa riisei in Tumaco Bay A. Colony structure, B.C. D. Rod-shaped sclerites "rods", E.fused rods "fused rods".

Colonies of *Carijoa riisei* were found on two piles at the Coast Guard dock in the El Morro naval complex, Tumaco port area (MEGUT, Figure 1C, Table 2) and on only one of the eleven signal buoys monitored (B19, Figure 1C, Table 2) in the port access channel. At this buoy, the presence of colonies was recorded only on the floating structure, while no evidence was found of associations between the octocoral with the mooring gear or with the dead weight which rested on soft bottoms (Figure 2). However, in the inspections carried out in the surroundings of the dead weight of this buoy, rocky outcrops and sunken boats were found with covers of this octocoral, being in fact the substrate where the largest colony sizes were observed (Figure 4A) and even, competition for space with the native octocoral *Leptogorgia alba* was observed (Figure 4B) evidencing growth on the branches of this species by *C. riisei*. The remains of some specimens of *L. alba* that had been detached from the substrate were also found and the partial destruction of the colony where the polyps of *C. riisei* were found (Figure 4C and Figure 4D). In the Buenaventura port area, no presence of this octocoral was recorded in any of the port structures monitored on the date of this monitoring (Table 2).

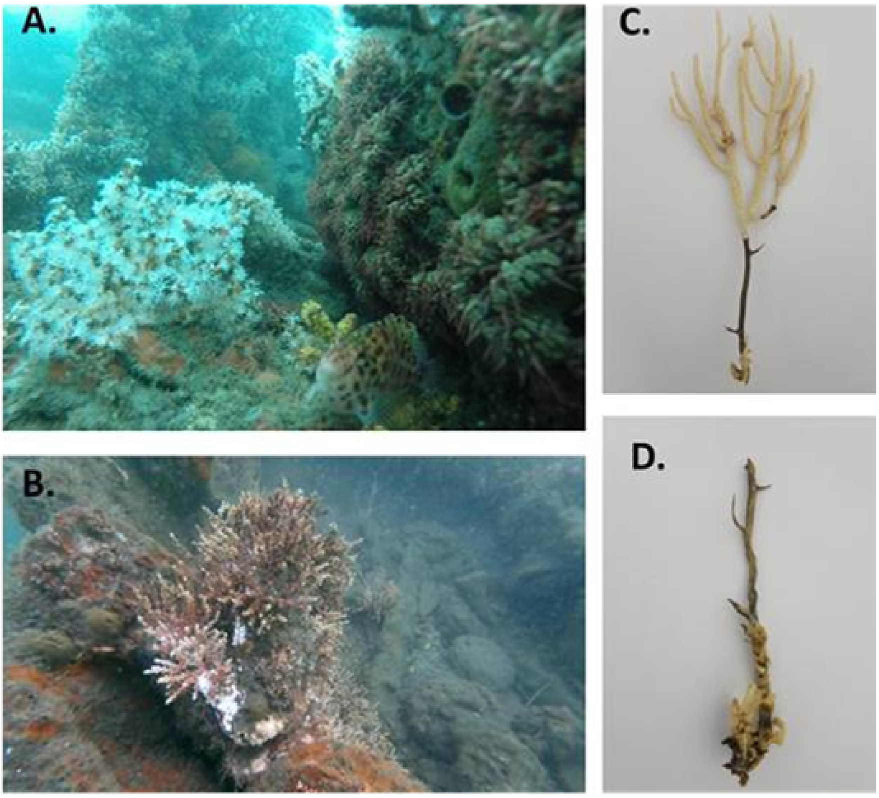

Figure 4.

Figure 4.

A. Colonies of Carijoa riisei on submerged artificial structures (boats) in Tumaco Bay. B. Presence of Carijoa riisei on Leptogorgia alba in submerged artificial structures. C. Remains of Leptogorgia alba with evidence of damage caused by the growth of C. riisei colonies on their structures. D. Polyps of C. riisei attached to the base of the remains of a colony of L. alba.

Table 2

Table 2.

Port structure Tumaco	Presence (+) Absence (-)	Buenaventura port structure	Presence (+) Absence (-)
BM	-	BM	-
B1	-	B13	-
B3	-	B23	-
B5	-	B33	-
B7	-	B37	-
B9	-	B41	-
B11	-	B43	-
B13	-	B53	-
B15	-	MCAD	-
B17	-	M10	-
B19	+	M13	-
MEGUT1	+		
MEGUT2	+		

Incidence of Carijoa riisei in the monitored structures.

The existence of previous records of *Carijoa riisei* on submerged artificial substrates in the port area of Tumaco, as well as in the vicinity of the port area of Buenaventura (Ahrens *et al.* , 2021), suggested that it was likely to find a high density of this octocoral in the infrastructure of the monitored maritime terminals, however, the results of this monitoring show a lower density than expected. Nevertheless, what was found in the port area of Tumaco coincides with what was stated by Sánchez & Ballesteros (2014), finding *C. riisei* on native octocorals such as *Leptogorgia alba* and with Colin & Arneson (1995), who describe it as a common species on buoy surfaces, docks, ship hulls and rocky or artificial reefs in environments with turbid waters. The presence of the species on the piles surveyed, as well as on submerged boats and rocky outcrops, i.e. the roughest substrates, suggests that the composition of the substrate influences the establishment of this octocoral. In Hawaii, Kahng & Grigg (2005) recorded *C. riisei* associated with substrates of variable roughness, such as rubber, nylon rope and rocky outcrops located in waters with high current flow, while the species was not detected on substrates where this flow was minimal, suggesting that the location and orientation of the substrate are more determinant factors than the composition of the substrate for the establishment of this octocoral.

In the CPC, *C. riisei* has been recorded in areas with high stream flow, however its presence does not persist over time in these areas (Sánchez & Ballesteros, 2014) and sometimes it has been detected in areas with lower flow intensity, therefore this does not seem to be a determining factor for the species to occupy any substrate. On the other hand, salinity is considered as a factor that limits the presence of *C. riisei*, since it has been recorded that it presents a limit range of tolerance between 15 - 20 UPS, due to the fact that in conditions below 15 UPS the colonies of this octocoral die in less than two hours (Kahng & Grigg, 2005). In the case of Buenaventura, salinity could be the cause of the absence of this octocoral, since it varies between 10 - 19 UPS between low and high tide respectively (Otero Díaz, 2005); in addition, rainfall in the area is high due to its geographical location within the intertropical convergence (Díaz-Ochoa & Quiñones, 2008). In previous surveys conducted by Ahrens *et al.* (2021), *C. riisei* was recorded on the piles of the Juanchaco lighthouse, near the outer bay where salinity varies between 16 UPS at low tide and 28 UPS at high tide (Otero Díaz, 2005).

Despite the above, asserting that the presence of *C. riisei* in the two main port areas of the CPC is determined by the factors considered here is premature, especially when dealing with such a particular species in biological and ecological terms (Kahng & Grigg, 2005; Otero Díaz, 2005), as well as taxonomic and phylogenetic (Concepcion *et al.* , 2008, 2010; Quintanilla *et al.* , 2017). However, there are features of its reproductive biology that can explain the dynamics of the occupation of this species such as asexual reproduction through stolonization, vegetative propagation, high fecundity, continuous gametogenesis throughout the year and its very rapid reproductive maturity compared to other octocorals species (Kahng *et al.* , 2008). These traits allow this species to easily colonize areas that present suitable temporal conditions and disappear when these change. Another feature of its reproductive biology that may be a clear advantage when colonizing artificial substrates is the asynchronous production of gametes with negative buoyancy, which forces sexual reproduction to be density-dependent, favoring its rapid and successful adhesion to the benthic bottom (Kahng *et al.*, 2008).

The presence of *C. riseii* in submerged artificial structures, mainly small boats, in port areas is a relevant finding, since it represents an ideal substrate for the growth of this octocoral, which may favor the establishment and maintenance of the population in the area and its subsequent dispersal to other areas as *fouling*through vectors such as coastal vessels or international traffic ships or as larval stages in ballast water. The relationship between these submerged artificial structures, such as shipwrecks or oil platforms and the expansion of invasive coral species has already been described in Brazil by Soares *et al.*(2020), where they showed that shipwrecks are key to the dispersal and range extension of *Tubastraea* species from the coast to *off-shore* platforms.

Conclusions

It is concluded then that the port area of Tumaco presents more favorable conditions for the presence of *C. riisei*, especially on port piles, sunken vessels and rocky outcrops. However, no close associations were found between octocoral and marker buoys. In contrast, in the Buenaventura port area it was not recorded in any of the structures surveyed, where salinity is believed to be the factor causing its absence. Monitoring should be contemplated with the measurement of environmental parameters *in situ*, as well as ecological and biological parameters of the species itself, in order to achieve an assessment closer to the reality of the dynamics of occupation and behavior of this species in these areas.

This research is consolidated as a scientific contribution for decision-making by national authorities, as it shows that the sinking of ships in port areas may favor the expansion of the distribution of *C. riisei* and increase the risk of transferring this octocoral from the port area of Tumaco. Likewise, these results show the importance of temporarily monitoring this invasive invertebrate, in order to expand the information on its status in port areas and implement preventive measures to avoid the domination of port and strategic ecosystems in this region that favor the implementation of safe port activities.

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