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Research Article

A test of the efficacy of wrapping to manage the invasive corals *Tubastraea tagusensis* and *T. coccinea*

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Abstract

Tubastraea tagusensis and *T. coccinea* (Scleractinia: Dendrophylliidae) are two corals that have invaded and impacted the southwest Atlantic since the 1980s. Here, we investigated experimentally the use of plastic and raffia sheets, simulating the use of wraps, as an effective method to kill the invasive corals. We showed that by seven days all polyps of the invasive corals were dead in both treatments, probably from lack of oxygen, food and/or due to physical attrition with the wraps. *Tubastraea tagusensis* was more resistant than *T. coccinea*, probably due to its different form. The use of plastic sheets was found to be more efficient for killing but raffia was easier to manipulate underwater and allowed an extended period for decomposition of the corals tissues. The use of wraps was demonstrated to be an efficient way of killing and may be added to the management toolbox for the control and eradication of *Tubastraea* spp. along with fresh water treatment and manual removal.

Key words: applied research, biological invasion, control, eradication, non-indigenous species, pest management, removal

Introduction

Biological invasions are recognized as a major threat to marine and coastal ecosystems. Invasive species have the potential to cause change in ecosystems resulting in loss of biodiversity, decline of native and commercial species, changes the function and structure of communities and ecosystems (Carlton 1985; Carlton and Geller 1993; Ruiz et al. 1997; Mack et al. 2000) and costs or loss of livelihoods (Pimentel et al. 2005) which may cause social impacts.

Tubastraea coccinea Lesson, 1929 and *Tubastraea tagusensis* Wells, 1982 (Scleractinia: Dendrophylliidae) represent the first introductions of scleractinia corals into the Southwest Atlantic (de Paula and Creed 2004). Azooxanthellate, they were found and reported as fouling organisms on oil and gas platforms in the Campos Oil Basin, off the State of Rio de Janeiro, in 1980s (Castro and Pires 2001). Subsequently they established on and invaded tropical rocky shores along the Brazilian coastline and are expanding their range (Ferreira 2003; Mantelatto et al. 2011; Sampaio et al. 2012), including into marine protected areas (Silva et al. 2011) and regions with sensitive coral reef ecosystems (Sampaio et al. 2012). Where established they are also increasing their abundances over large areas (Silva et al. 2014).

Both species effect the structure of the native communities (Lages et al. 2011), can cause necrosis to the endemic corals such as *Mussismilia hispida* Verrill, 1901, thus reducing or excluding the native coral (Creed 2006; Santos et al. 2013) and also grow among and over commercially exploited

mussels beds and farms (Mantelatto and Creed 2014). Both non-indigenous species produce chemicals which have antifouling properties and are deterrent to predation by fish (Lages et al. 2010); they also lack generalist predators within their invaded range (Moreira and Creed 2012). Furthermore they also use a suite of different reproductive strategies, which results in high fecundity and precocious reproduction (de Paula et al. 2014), contributing to their rapid establishment and range expansion.

In terms of substratum type *Tubastraea* spp. are generalists, with the ability to recruit on natural substrata such as rocky and coral reefs (Creed and de Paula 2007; Sampaio et al. 2002) as well as on various types of artificial materials such as Formica (Vermeij 2006), cement, steel and tiles (Creed and de Paula 2007), sunken airplanes, wrecks, docks and piers (Fenner 2001; Mangelli and Creed 2012). They are also found extensively on oil/gas rigs, drill ships, mono buoys and riser sustentation buoys, which represent the primary and secondary vectors of introduction in Brazil (Castro and Pires 2001; de Paula and Creed 2004; Ferreira et al. 2006; Mizrahi 2008). *Tubastraea coccinea* has also been reported on many oil/gas platforms in the Gulf of Mexico and East Atlantic (Gabon) (Fenner 2001; Fenner and Banks 2004; Sammarco et al. 2004; Sammarco et al. 2010; Friedlander et al. 2014): more recently a third congener *Tubastraea micranthus* (Ehrenberg, 1834) has also been reported on oil platforms in the Gulf of Mexico (Sammarco et al. 2013). These vectors are regularly moved around the world or from offshore to onshore locations, where they cause new invasions (Yeo et al. 2009; Wanless et al. 2010). There is an urgent need to consider alternative management options for these artificial structures.

The Convention on Biological Diversity states that consenting parties should prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitats or species (Brasil 1998). Williams and Grosholz (2008) reviewed a number of control and eradication programs in estuarine and coastal water, most of which were successful. A number of different physical, chemical and biological tools or agents have been used. However, traditionally little has been done to stop, prevent, control and eradicate invasive marine species, especially in the southwest Atlantic. Nevertheless, a management initiative (involving government agencies, non-government organizations and volunteers), called the Sun Coral Project, is using a mixed approach of eradication and control by manually removing corals from the shores and reefs and subsequently use freshwater to kill them, in order to slow the spread and reduce the impacts of the invasive corals *Tubastraea* spp. along the Brazilian coast; more than 200,000 colonies (> 8 tons) have been eliminated since 2006 (Moreira et al. 2014). The Project has become a national model for the control of invasive marine fouling species in the southwest Atlantic.

One method, based on wrapping or enclosure, involves the application of an impermeable barrier which completely encloses the underwater surface of artificial structures, isolating them from the surrounding water. The method removes biofouling organisms from food, light and/or dissolved substances such as oxygen, resulting in the death of the biofoulers (Ministry of Agriculture and Forestry 2009). The wrapping method has been successfully used on the tunicate *Styela clava* Herdman, 1881 on pilings in New Zealand (Coutts and Forrest 2005), on the ascidian *Didemnum vexillum* Kott, 2002, over wharf piles in New Zealand (Coutts and Forrest 2007), and on docks fouled by the non-native solitary tunicate *Ciona savignyi* Herdman, 1882, in Elliott Bay Marina at Seattle, USA (Pool et al. 2013).

The aim of this study was to experimentally simulate the use of the wrapping method to investigate its effectiveness in killing the pest corals, recognizing that a larger toolbox of control methods for *Tubastraea* spp. is desirable as it allows for greater flexibility regarding different management scenarios, including vector treatment.

Methods

The study was conducted between June and August 2012 at Macacos Island (23°04′36″S, 44°13′47″W) and Abraãozinho (23°08′07″S, 44°09′05″W), Ilha Grande Bay, Brazil. The region was invaded by the corals *T. coccinea* and *T. tagusensis* in the 1990s (de Paula and Creed 2004) and the invaders have increased their distribution and abundance throughout the area (Silva et al. 2014). Colonies were collected at Macacos Island, a tropical rocky shore, and the experiment was conducted at Abraãozinho, which is a shallow, easy access and wave protected site.

A total of 600 colonies of each of *T. tagusensis* and *T. coccinea*, > 3 cm, were manually collected using SCUBA, with a hammer and chisel. The corals were transported and immediately transplanted to the experimental site. From previous transplant experiments (Santos et al. 2013; Moreira et al. 2014)

Table 1. Results of MANOVA test for differences in the condition (proportion of healthy, necrosed, skeleton and fouled polyps) of colonies of *Tubastraea* spp. between times, wraps and species.

Factor	Condition	df	Mean Square	F	P
Times	Healthy	4	43518.040	198.124	< 0.001
	Necrosed	4	79280.690	259.761	< 0.001
	Skeleton	4	213527.412	1014.376	< 0.001
	Fouled	4	397.363	6.245	< 0.001
Wraps	Healthy	1	1889.552	8.603	0.003
	Necrosed	1	19907.299	65.226	< 0.001
	Skeleton	1	8873.184	42.153	< 0.001
	Fouled	1	2.026	0.032	0.858
Species	Healthy	1	8332.766	37.936	< 0.001
	Necrosed	1	23980.660	78.572	< 0.001
	Skeleton	1	4878.810	23.177	< 0.001
	Fouled	1	23.336	0.367	0.545
Times × Wraps	Healthy	4	1794.630	8.170	< 0.001
	Necrosed	4	10939.602	35.843	< 0.001
	Skeleton	4	11629.338	55.246	< 0.001
	Fouled	4	543.277	8.538	< 0.001
Times × Species	Healthy	4	7914.170	36.031	< 0.001
	Necrosed	4	8210.739	26.902	< 0.001
	Skeleton	4	5959.144	28.309	< 0.001
	Fouled	4	61.649	0.969	0.424
Wraps Species	Healthy	1	25.882	0.118	0.731
	Necrosed	1	403.613	1.322	0.250
	Skeleton	1	115.762	0.550	0.459
	Fouled	1	30.340	0.477	0.490
Times Wraps × Species	Healthy	4	24.582	0.112	0.978
	Necrosed	4	2018.360	6.613	< 0.001
	Skeleton	4	2393.979	11.373	< 0.001
	Fouled	4	13.652	0.215	0.930

it is known that these corals are insensitive to collection and transport over short periods. For each species sixty experimental units were created by placing ten colonies into two types of experimental wraps made from: 1. sheet polyethylene plastic; 2. raffia (woven polyethylene plastic). The sheet wraps were expected to impede water and light and create hypoxic conditions while the raffia wraps allowed some water movement. All experimental units were transplanted back into the shallow subtidal (5m depth) where they were attached to previously placed moorings. All colonies were checked and found to be healthy at the start of the experiment. Seawater temperature varied from 21–23ºC and salinity from 35–36 during the study. Five replicates of each treatment (wraps type and species) were removed 3, 7, 14, 21, 30 and 45 days after the start of the experiment.

Each colony in each replicate had the number of polyps counted and classified into categories used by Moreira et al. (2014): healthy (live, normal), necrosed (necrotic tissue, dying), skeleton (recently dead, showing septa and other skeletal features) and fouled (covered with biofouling organisms, so dead for some time). A colony was considered dead when 100% of the polyps were classified as necrosed, skeleton or fouled. Multivariate analysis of variance (MANOVA) was carried out on arcsine transformed categorized data to test for significant differences between categories and treatments, the factors being Species (2 levels, fixed), Time (6 levels, fixed) and Wrap type (2 levels, fixed).

Results

One and five raffia experimental units, all *T. tagusensis*, were lost after 3 and 45 days respectively, so were not used in the analyses. Figure 1 shows the change in condition of *T. coccinea* and *T. tagusensis* over time in the experimental units and Figure 2 shows the condition of polyps as % of colonies of *T. coccinea* and *T. tagusensis* under different wraps and times. Healthy polyps were found only up to 3 days. After (a maximum) of seven days the condition of all polyps had

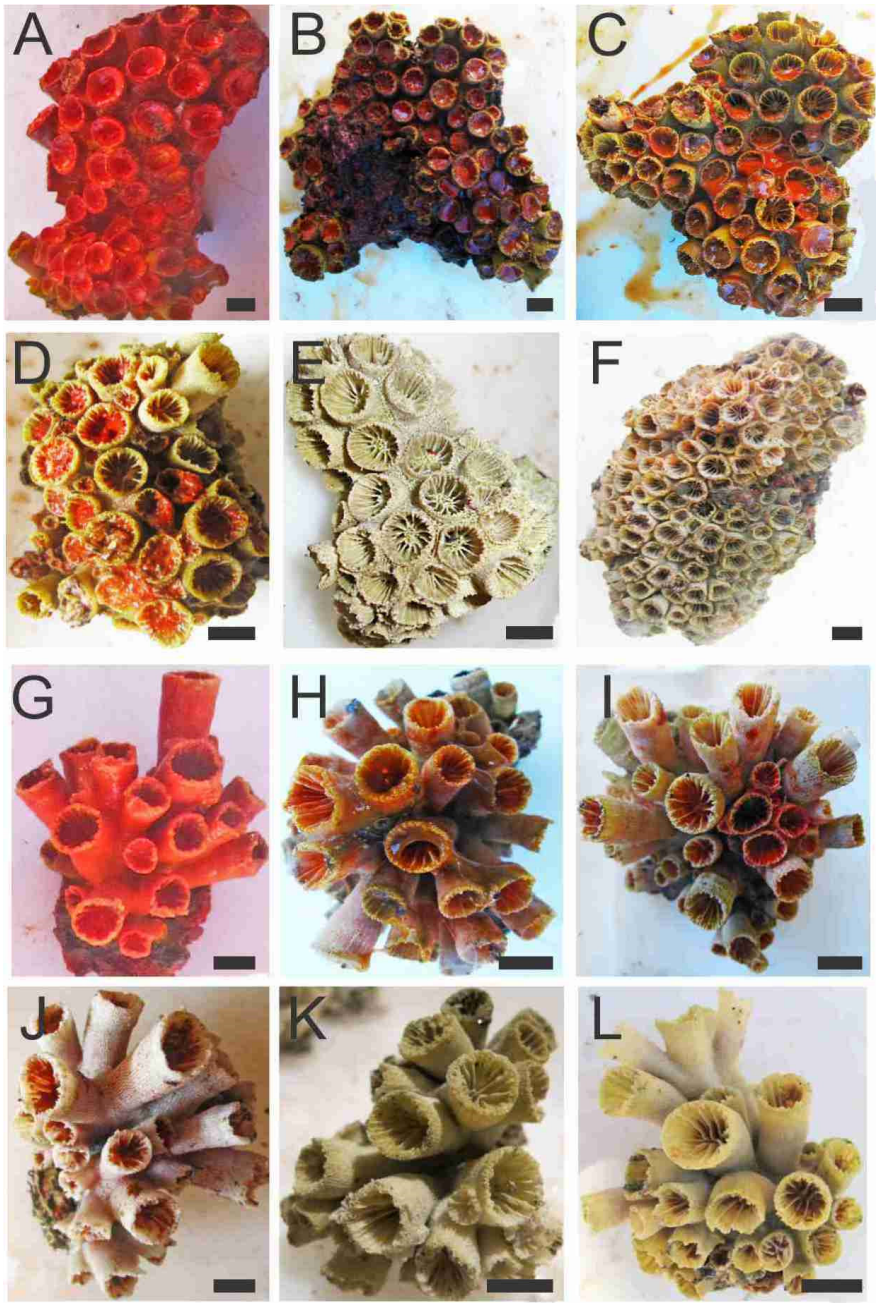

Figure 1. *Tubastraea coccinea* (A-F) and *Tubastraea tagusensis* (G-L) under wraps after 3 (A and G), 7 (B and H), 14 (C and I), 21 (D and J), 30 (E and K) and 45 (F and L) days. Bars = 1cm. Photographs by Larissa Marques Pires and Giselle Joana Gregório de Oliveira.

transitioned to dead (necrosed, skeleton or fouled). Greatest quantities of necrosed polyps were found after 3 days; the skeleton condition was most common between 7 and 45 days and epibionts were mostly seen after 21 days (under raffia) and after 30 days (under sheet plastic).

MANOVA confirmed the significance of subtleties in the transition process (Table 1). The live coral only showed a Time × Species interaction because 3 days after treatment significantly more corals were alive than subsequent times and more *T. tagusensis* (57.5%) was scored as alive than was *T. coccinea* (22.3%) at this time, irrespective of wrap type; subsequently no differences between species was found. The necrosed corals showed a Time × Wrap type × Species interaction because 3 days after treatment there was significantly more necrosis on *T. coccinea* under sheet polyethylene

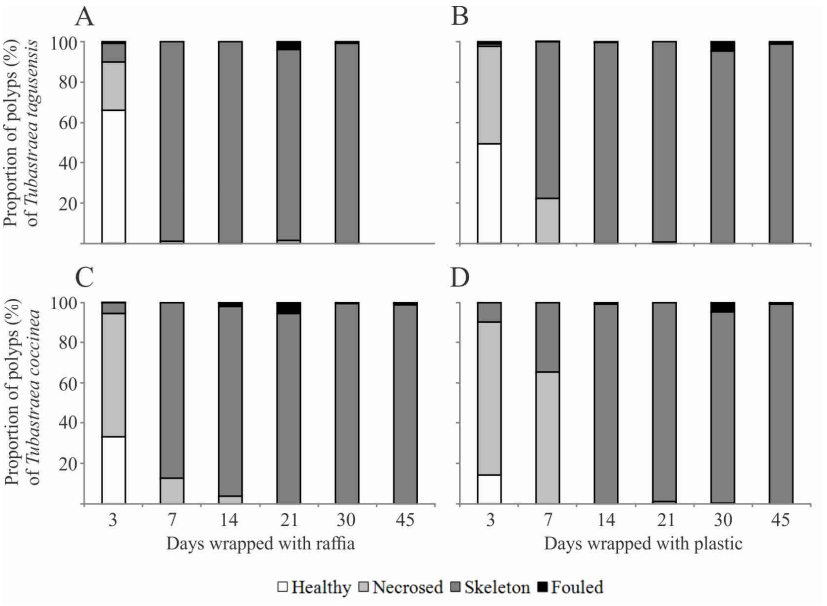

Figure 2. State of *Tubastraea* spp. (% polyps) after 3, 7, 14, 21, 30 and 45 days: (a) *T tagusensis* with raffia, (b) *T. tagusensis* with plastic, (c) *Tubastraea coccinea* with raffia and (d) *T. coccinea* with plastic.

wraps (mean 64.4%) than under raffia (mean 54.1%); there was also significantly more necrosis on *T. tagusensis* under sheet polyethylene wraps (mean 44.1%) than raffia (mean 24.5%); under equivalent wraps necrosis in *T. coccinea* was significantly greater than in *T. tagusensis*. After 7 days the same overall pattern remained: significantly more necrosis occurred on *T. coccinea* under sheet polyethylene wraps (mean 57.5%) than under raffia (mean 12.9%); there was also significantly more necrosis on *T. tagusensis* under sheet polyethylene wraps (mean 22.2%) than raffia (mean 1.7%); under equivalent wraps necrosis in *T. coccinea* was significatly higher than in *T. tagusensis*. While necrosis on *T. coccinea* under sheet polyethylene wraps did not differ significantly between 3 and 7 days, in all other treatments the proportion of necrosed colonies decreased over this time. Subsequently no significant differences in necrosed colonies were found between wrap type, species or over time.

Corals showing skeleton also showed a Time × Wrap type × Species interaction because 3 days after treatment under sheet polyethylene wraps there was significantly more skeleton showing on *T. coccinea* (mean 14.1%) than *T. tagusensis* (mean 2.4%) but under raffia wraps the corals showed similar intermediate proportions of skeleton (*T. coccinea* 8.4%; *T. tagusensis* 9.7%); despite the fact that after seven days significantly more skeleton was showing in all treatments than after 3 days, the pattern inverted, as under sheet polyethylene wraps there was significantly less skeleton showing on *T. coccinea* (mean 32.5%) than *T. tagusensis* (mean 67.8%); the same was true under raffia wraps - significantly less skeleton showing on *T. coccinea* (mean 77.1%) than *T. tagusensis* (mean 88.3%). Subsequently (day 14 onward) no significant differences in skeleton state were found between wrap type, species or over time.

Corals showing epibionts showed a Time × Wrap type interaction because differences between wrap types were only significant after 21 days (mean epibionts under sheet polyethylene wraps was 0% vs. 5.0% under raffia); after 30 days this pattern inverted (mean epibionts under sheet polyethylene wraps was 4,83% vs. 0.62% under raffia); after 45 days no significant difference between wrap types was found. Under raffia epibiont cover was significantly higher after 21 days than at previous times and under sheet polyethylene was significantly higher after 30 days than any other time. Epibiosis was species independent.

Discussion

The present study demonstrated that wrapping *Tubastraea* spp. is an effective way of killing them. In a maximum of seven days all polyps of the invasive corals *T. coccinea* and *T. tagusensis*

were dead under the wraps. The corals probably died from a combination of a lack of oxygen, increased carbon dioxide, lack of food and physical attrition with the wraps and among corals due to water movement (making tentacle extension difficult).

A lack of oxygen in a marine environment can deplete benthic communities or even eliminate the entire macrofauna (Sala and Knowlton 2006). Experiments conducted on a sublittoral soft-bottom showed that even at the beginning of anoxia communities collapse and biodiversity is lost (Riedel et al. 2012). In an experiment conducted to evaluate the effect of hypoxia and physiological tolerances to low concentrations of dissolved oxygen (DO) the non-native solitary tunicate *Ciona savignyi* showed lower survivorship with decreasing DO levels in bioassays as well as highly hypoxic levels and low survivorship with increased wrap time on docks (Pool et al. 2013). Our results compare well with the results of a polyethylene wrapping method used to treat wharf piles infected with *Didemnum vexillum* where a six day period was almost completely effective (Coutts and Forrest 2007).

Tubastraea spp. are exclusively azooxanthellate, so do not depend on light for survival, and their energy needs are supplied exclusively by heterotrophy. Thus another effect of wrapping may have been to perturb feeding, which is severely impeded under wraps because the corals are separated from their plankton food source and because physical contact between corals and wraps obstructs polyp opening. Furthermore, the wraps suffer some drag and movement thus increasing friction between surfaces and target species.

The data indicated that *T. tagusensis* was slightly more resistant than *T. coccinea*, with higher proportions of healthy polyps. This result is the contrary to that of Moreira et al. (2014) who experimentally determined that *T. coccinea* was more tolerant to freshwater or low salinities than its congener. They attributed this fact to the different colony morphologies that the two species possess. According to de Paula and Creed (2004) and Creed and de Paula (2007) both species have different shapes, as the corallites of *T. tagusensis* project further from the coenosteum than *T. coccinea* (5–35 vs. 2–13 mm respectively) and are also more spaced apart (see Fig. 1). This results in a greater vertical development in *T. tagusensis* than in *T. coccinea*, which has more compact, flat and encrusting corallum form. According to Moreira et al. (2014) the more open form of *T. tagusensis* presents a higher surface area:volume than its conspecific and this makes it more susceptible to the killing agent they used. Here it might well be the opposite is the case and smothering is less effective on the more open form of *T. tagusensis* because more voluminous spaces will be preserved between the polyps when compared to *T. coccinea*.

The difference reported here between the two studied species and the contrary observations with fresh water suggests that:

(1) Different killing tools can have species specificities.

(2) Form or degree of projection of the fouling community from the surface may be a factor determining the killing efficiency of wrapping.

Other organisms are known to behave differently to wraps. For example, in the current study, some sponges that were associated with the studied corals appeared healthy until the seventh day; the non-native solitary tunicate *Ciona savignyi* maintained 80% survivorship after 10 days in experimental wraps in docks (Pool et al. 2013). If the greater sensitivity of *Tubastraea* spp. when compared to other species is confirmed in future experiments it may allow for more targeted management, as wrapping could be carried out for a period short enough to kill the invasive target corals but spare other more resistant (native) species.

For both species the proportions of healthy polyps were higher and proportions of necrosed polyps were lower using raffia when compared to sheet plastic. The raffia material is permeable, so permits some free movement of the water, gas exchange and passage of microorganisms. In contrast the plastic sheet impeded water movement, which helped kill the corals quickly. Thus, the use of plastic sheets was more efficient in killing the invasive corals. However, raffia was also highly effective in killing the corals, and raffia material is also durable, cheaper and far easier to manipulate underwater due its lower resistance to the water. Another advantage of raffia is that after death the organic matter of wrapped organisms is decomposed and released into the water column gradually which contrasts with the sudden release and potential impact on nearby habitats of unwrapping and releasing anoxic nutrient rich waters retained under sheets.

The experimental setup effectively simulated in situ wrapping of vectors or natural substrata and demonstrated the feasibility and efficiency of wrapping as a management tool for the control and eradication of the invasive corals *T. tagusensis*

and *T. coccinea*. The wrapping method is particularly promising for use on vectors of non-indigenous marine species (e.g., drill ships, oil platforms, barges, buoys, etc.) as well as over areas of rocky shore or reef or submerged artificial structures (piers, docks, decks, wrecks etc.) with high densities of the corals. Although the wrapping method does not require additional agents, the fact that wrapping isolates the area gives it the additional advantage of facilitating the addition of chemicals to accelerate treatment times, should this be considered desirable. As another alternative method for control and eradication the wrapping method is being added to the *Tubastraea* management toolbox, which already contains manual and freshwater protocols for killing the corals. An adaptation of the smothering method has also been successfully used to substitute freshwater which was previously used to kill manually removed corals on board before returning them to the sea. The current protocol, of sealing the corals in bags and leaving them on site bottom for a period before return to the seabed, has been successfully applied to more than 12,000 pest corals from the Tamoios Marine Protected Area. Future studies will scale up treatment areas.

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