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Research article - *CORRECTED PROOF*

A new coral species introduced into the Atlantic Ocean - *Tubastraea micranthus* (Ehrenberg 1834) (Cnidaria, Anthozoa, Scleractinia): An invasive threat?

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Abstract

Over the past 60-70 years, the invasive Indo-Pacific coral *Tubastraea coccinea* (Lesson 1830; Cnidaria, Scleractinia) has colonized the western tropical Atlantic Ocean - the Americas, the Antilles, northern Gulf of Mexico (GOM), and many of its 3,600 oil/gas platforms. It is now the single, most abundant coral on artificial substrata in the GOM, with hundreds of thousands of colonies on a single platform. Here, we report for the first time the observation of a closely related congener in the western Atlantic – the Indo-Pacific azooxanthellate *Tubastraea micranthus* (Ehrenberg 1834) – and suggest that it may pose a threat similar to *T. coccinea*. A total of 83 platforms, including deep-water, toppled, Rigs-to-Reefs structures, were surveyed in the northern Gulf of Mexico between 2000 and 2009, from Matagorda Island, Texas to Mobile, Alabama, USA, between the depths of 7 and 37 m, by SCUBA divers. Five platforms were surveyed by Remotely Operated Vehicle (ROV) to depths of up to 117 m. *T. micranthus* was found on only one platform – Grand Isle 93 (GI-93), off Port Fourchon, Louisiana, near the Mississippi River mouth, at the cross-roads of two major safety fairways/shipping lanes transited by large international commercial ships. The introduction appears to be recent, probably derived from the ballast water or hull of a vessel from the Indo-Pacific. If the growth and reproductive rates of *T. micranthus*, both sexual and asexual, are similar to those of *T. coccinea*, this species could dominate this region like its congener. It is not known whether this species is an opportunist/pioneer species, like *T. coccinea*, a trait protecting benthic communities from its dominance. The question of rapid-response eradication is raised.

Key words: coral, *Tubastraea coccinea*, *Tubastraea micranthus*, introduction, invasive species, Atlantic Ocean, Indo-Pacific

Introduction

In recent times, intentional species introductions have been of concern because of their secondary impacts on the natural environment and local species (Secord 2003). Of even greater concern are accidental introductions that have proven to be detrimental to ecosystems that they have colonized (Roberts and Pullin 2008). Invasive marine species are of particular concern because of the ease with which they can disperse and colonize nearby habitats once they have established a new population (Griffiths 1991; Johnson and Carlton 1996; Wonham et al. 2000). Vectors of transport for invasive marine or freshwater species (Kerr et al. 2005) include ballast water of barges or ships (Chesapeake Bay Commission 1995; ICES 2002), the hulls of the same (Minchin and Gollasch 2003), the towing of oil and gas platforms to new sites (Hicks and Tunnell 1993), accidental release of exotic species from mariculture operations (Sapota 2004), and deliberate release of exotics by aquarium hobbyists (Weidema 2000; Christmas et al. 2001; Hindar et al. 2006).

An example of an introduced species widely distributed from the northern temperate waters through western Atlantic tropical coral reefs (Chapman 1999) is the Japanese/Siberian marine alga *Codium fragile* (Suringar; Hariot 1889), now common throughout the western Atlantic (Trowbridge 1998; Pederson 2000; Williams 2007). Another example is the Indo-Pacific volitan lionfish (*Pterois volitans* Linnaeus 1758), released into western Atlantic waters $\geq$ 10 years ago (Whitfield et al. 2002; Hamner et al. 2007) and now distributed from New York through the Caribbean.

Recently, there has been concern about invasive species occurring in the Gulf of Mexico (Osman and Shirley 2007). Species of interest include the Australian scyphozoan *Phyllorhiza punctata* (von Lendenfeld 1884), which have occurred in high enough densities (Perry and Graham 2000) to dramatically suppress ichthyoplankton and invertebrate larval densities (Graham et al. 2003; Graham and Bayha 2008). *Didemnum perlucidum* (Monniot 1983), an Indo-Pacific colonial encrusting didemnid ascidean, was also introduced to the Gulf during the 1990s and has proven to be an impressively strong competitor for space with other sessile epi-benthic organisms in this region (Culbertson and Harper 2002; Lambert, 2002; Sammarco 2007).

There are very few reports of successful introductions of corals into the Atlantic. The most striking example and that of greatest concern has been the Indo-Pacific species *Tubastraea coccinea* Lesson, 1829. It was first recorded in 1943 in Puerto Rico and then in 1948 in Curacao, Netherlands Antilles, where they were collected on ship's hulls (Cairns 2000). By the late 1990s and early 2000s, the species was reported to occur off Belize and Mexico (Fenner 1999); Venezuela, northern Gulf of Mexico, and the Florida Keys (Fenner 1999; Fenner and Banks 2004; Sammarco et al. 2004); Brazil (Figueira and Creed 2004); Colombia, Panama, the Bahamas, and throughout the Lesser and Greater Antilles (Humann and DeLoach 2002). *Tubastraea coccinea* is now a highly successful invasive species in the western Atlantic, being the single most abundant scleractinian coral, hermatypic or ahermatypic, in the northern Gulf of Mexico on artificial substrata – by orders of magnitude (Sammarco et al. 2004, 2007). Hundreds of thousands of colonies occur on individual oil and gas platforms there, in densities up to 36 m^{-2} (Sammarco 2008). It does occur on deep banks in the northern Gulf of Mexico but has not been observed to be abundant there (Schmahl 2003; Hickerson et al. 2006; Schmahl and Hickerson 2006). No studies have yet been conducted to investigate whether or not *T. coccinea* has expanded its populations at the expense of other species. The lack of such an active competitive exclusion in the wake of such a dramatic population explosion would presume that the ecosystem had one or more open niches. This is also not known.

A second incident regarding the accidental introduction of a coral to the Atlantic is that of *Fungia scutaria* (Lamarck; Vaughan 1907) to Discovery Bay, Jamaica, W.I., observed as early as 1973 (P.W. Sammarco pers. obs; J. Lang pers. comm.; LaJeunesse et al. 2005). In this case, it is likely that this species will remain "non-invasive". This is because it is a vagile, epibenthic coral and has probably invaded the open niche of soft bottom in that environment, where there is no previously existing coral species with similar habitat requirements.

Together and individually, we (Sammarco and Porter) conducted surveys on the distribution and abundance of scleractinian corals on numerous platforms throughout the northern Gulf of Mexico – from the waters off Corpus Christi, Texas to those off Mobile, Alabama. We encountered numerous coral species during these surveys (see Sammarco et al. 2004; Sammarco 2008); additional results from those surveys will be published elsewhere. Here, however, we report for the first time the introduction of a new species to the Gulf of Mexico, and to the Atlantic Ocean – the Indo-Pacific species *Tubastraea micranthus* (Ehrenberg 1834) (Cnidaria, Dendrophylliidae, Cairns, 2001). *T. micranthus* is a close congener of *T. coccinea*, occurring in shallow water. *T. micranthus* is considered to be unique among the 1500 scleractinian species because, although it is azooxanthellate, it is a hermatypic coral, being capable of building reef-like structures in the Pacific (Roberts et al. 2009). It is also known to have exhibited population expansion characteristics in new environments elsewhere in the world (Loch et al. 2004).

Here we define "invasive species" as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (US Exec. Ord. 13112, 1999), or alternately "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (Invasive Species Advisory Comm. 2005). Such species often spread, encroach upon, or take over the habitat of native species. An "alien species", on the other hand, is "any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem" (ibid.). Not all introduced or alien species are necessarily invasive. Carlton and Eldredge (2009) present evidence that out of the > 400 introduced or cryptogenic species now reported to exist in Hawaii, < 10% may be considered invasive. Our studies show that *Tubastraea micranthus* is an introduced species that has the potential of becoming an invasive species. This is because of its likelihood of exhibiting population expansion characteristics similar to its close Indo-Pacific congener, *Tubastraea coccinea*, which has experienced a remarkable spread throughout the western Atlantic in recent decades.

We report the results of surveys in both shallow and deep water, via SCUBA and ROV reconnaissance, regarding the occurrence of *Tubastraea micranthus* on oil and gas platforms. We also consider the ecological implications of this recent species introduction to the Gulf of Mexico.

Materials and methods

Study sites

Eighty-two (82) oil and gas platforms were surveyed for the presence of scleractinian corals in four sectors across the continental shelf of the northern Gulf of Mexico, from Corpus Christi, TX to Mobile, AL (Annex 1; Cairns and Zibrowius 1997; Sammarco 2005, 2006, 2007, 2008, in prep.; Sammarco et al. 2006, 2008, 2009). Most were standing production platforms; some were toppled platforms within the federal/state "Rigs-to-Reefs" artificial reef program (see Dauterive 2000). One series of surveys covered the offshore lease areas entitled High Island (HI), West Cameron (WC), and East Cameron (EC) to a depth of 10-30 m via SCUBA between 2000 and 2003. A second broader series of four (4) cross-continental shelf transects were performed in the Matagorda Island (MI), Brazos (BA), High Island (HI), West Cameron (WC), Garden Banks (GB), South Timbalier (ST), Ship Shoals (SS), and Main Pass (MP) sectors. These were done between 2003 and 2007, covering 10-37 m depth. A third survey was performed within the Grand Isle (GI) and South Timbalier (ST) lease areas to a depth of 30m (Porter) from 2004-2009. A final survey was done in the South Timbalier (ST) and East Cameron (EC) sectors in depths of 33-117 m. Additional deep surveys were performed on "Rigs-to-Reefs" structures via Remotely Operated Vehicles (ROVs) in the High Island (HI), West Cameron (WC), and East Cameron (EC) lease areas in 2007-2008. (See Annex 1 for a listing of all sites and their locations.) Most sites were surveyed only once.

Survey techniques

A total of 41 SCUBA divers spent ~1,120 person-hours underwater surveying the submerged jackets of these platforms. Techniques of recording and assessing coral species distribution, abundance, density, diversity, etc. are reported in detail in Sammarco et al. (2004); the reader is referred there for further information. In summary, personal visual surveys were implemented using visual belt transects. The transects covered the width of the cylindrical steel platform supports (horizontal, vertical, and diagonal), and, a $\log_5$ scale was used to estimate coral abundance. The area surveyed was calculated from architectural schematics of the platforms provided by the oil and gas companies and used to estimate coral densities.

Continuous belt-transects were also recorded on digital video tape via a diver-held underwater digital video camera. In addition, we used two Remotely Operated Vehicles (ROVs) to conduct our deeper surveys – a SeaBotix LBV-300 and a Phantom 2. Each was fitted with vertical and horizontal propulsion units, site-to-surface video units with a topside monitor, lights, and a sample-retrieval unit (manipulator arm) for collection purposes. Representative coral specimens were collected, returned to the laboratory, cleaned, sun-bleached and dried for purposes of a more detailed examination and verification of species identification. Live specimens of the target species were also collected by Porter.

Several other deeper, toppled platforms that had been decommissioned, extricated, placed on a barge, and transported to shore for salvage, were also examined onshore (Porter); (the sites of origin of these platforms were uncertain).

Video images were captured on mini-DV or DVD via several types of units. A SONY FX-7 HD camera was used in conjunction with an HP 6130 laptop computer possessing a duo-core processor and Pinnacle-12 HD software. A high-resolution 3-chip color SONY camera was also used to record images received from the ROV, in conjunction with a Dell XPS laptop fitted with a duo-core processor using MicroSoft video imaging software.

Processing of visual information on the DVDs was performed with the assistance of a Dell Precision 340 desktop computer with a Pentium 4 processor, fitted with several pieces of image analysis software - Nero 7.0, VideoLAN, and MicroSoft Windows Media Player, capable of zoom and still-image capture. Data were logged in EXCEL files.

Species identification was verified by one of us (Cairns) using reference specimens held at the Museum of Natural History, Smithsonian Institution, Washington, D.C.

Results

Of the 82 structures surveyed, only one was found to possess *Tubastraea micranthus* - the standing production platform GI-93-B (28°32.96'N, 90°40.11'W; Figure 1). The first observation was made in 2006 (Porter). The first way in which these corals were distinguished from *Tubastraea coccinea* was by color. The colonies were dark green or black in tissue pigmentation, as opposed to the bright orange-yellow pigmentation of *T. coccinea* (the origin of its common name "orange cup coral", "sun polyp", or "sun coral"; Humann and DeLoach 2002; Figure 2). The tentacles of *T. micranthus* were sometimes grey in color. (The pigmentation is derived from the tissue, because this species, like its congeners, is azoo-xanthellate.)

The second distinguishing character was its colony morphology. The stalk of the colony sometimes extended vertically > 0.5 m above the substratum. In addition, the corallites were often 20 mm longer than those of *T. coccinea* (Figures 2 and 3). Some colonies possessed 30 cm-long branches, with a pattern of alternating corallites (see Cairns and Zibrowius 1997 for a complete taxonomic description of this species). Calices of *T. micranthus* are smaller than those of *T. coccinea*, the former being 6-8 mm in diameter, and the latter 10-11 mm. The calical structure also varied slightly between the two species, with the tertiary septa of *T. coccinea* sometimes being well developed and having laciniate axial edges (Figure 4).

The colonies were found *in situ* on GI-93-B at depths ranging from 18-22m (Figure 1). In all cases, the colonies were alive. In some cases, colonies were returned to shore and kept alive in aquaria for up to 3 years and, at the time of writing, are still being held successfully in captivity. Some variation in colony morphology was observed, although it was not beyond that described to occur in Indo-Pacific specimens (Sammarco et al. 2008). An examination of dried and bleached specimens of both *Tubastraea coccinea* and *T. micranthus* confirmed morphological differences between the skeletons of each species.

High abundances of this species were found on GI-93-B. Initially, a small patch of scattered colonies was observed in 2006 to extend ~3 m in length along a horizontal support. In 2009, this same patch was observed to have extended over 30 m on the same support, with ~80% live cover in some areas. *Tubastraea micranthus* was clearly expanding its cover in this benthic community, apparently at the expense of other sessile epibenthic organisms, but not necessarily to their total exclusion. No quantitative data are yet available upon which to draw conclusions on this species' differential interspecific competitive capabilities. No massive coverage similar to that of *T. coccinea* has yet been observed on platforms in this region.

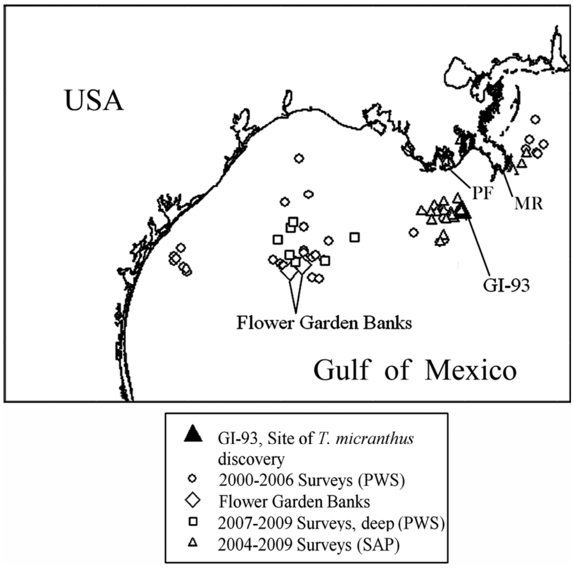

Figure 1. Map of the northern Gulf of Mexico, depicting survey sites for scleractinian corals (see Annex 1 for list of survey sites and geographic coordinates). Surveys conducted in several sets – from 2000 to 2006 across the shelf by SCUBA by Sammarco's research team, from 2004 to 2009 in the central and near-eastern sector by Porter's team, and deep-water surveys from 2007-2009 in the near-western and central sectors by SCUBA and ROV by Sammarco's team. *Tubastraea micranthus* found only on GI-93. MR – Mississippi River mouth, PF - Port Fourchon.

Discussion

The fact that *Tubastraea micranthus* was observed at only one site within the entire survey area covering the northern Gulf of Mexico suggests that this is a very recent introduction. Also, this species is known to grow to a height of 1.0 m. The maximum colony height observed here was 0.5 m, indicating that these colonies might be relatively young. It is known from parallel studies that *T. coccinea* is a species that is capable of successfully dispersing its larvae over large distances and recruiting there (Sammarco 2005, 2006, 2007, 2008, 2009, in prep.; Fenner 1999, 2001; Fenner and Banks 2004; Figueira and Creed 2004; Humann and DeLoach 2002; Sammarco et al. 2006, 2009).

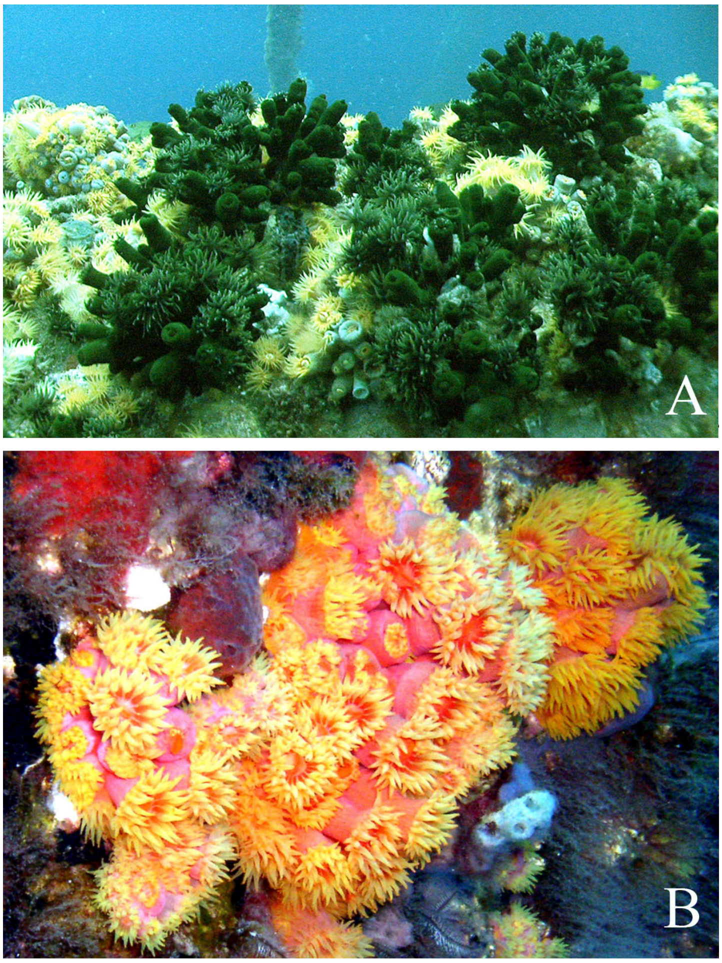

Figure 2. (A) *Tubastraea micranthus* colonies, identified by their dark tissue coloration and extended vertical growth, shown at 20m depth on a horizontal support of the oil platform GI-93 in the northern Gulf of Mexico. The coral species surrounding these colonies are *T. coccinea* (photo by SAP); (B) *Tubastraea coccinea* colonies observed on an oil platform in the High Island (HI) lease area. Note the more compressed habit and lighter, brighter tissue color (photo by PWS).

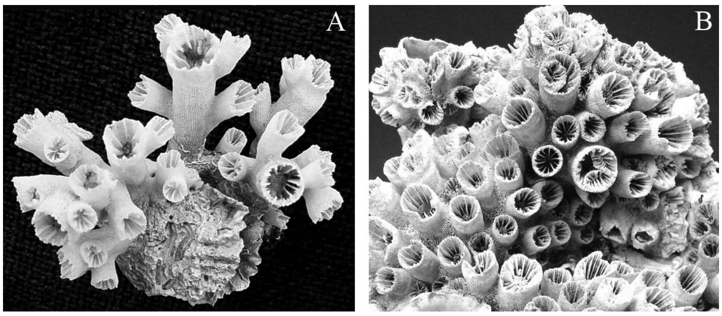

Figure 3. (A) Colony of *Tubastraea micranthus* that has been cleaned of its tissue, dried, and bleached. Note the extended corallites and distinct sparse branching pattern. (B) Colony of *T. coccinea,* similarly prepared. Note the compressed habit and density of short corallites (photos by SAP).

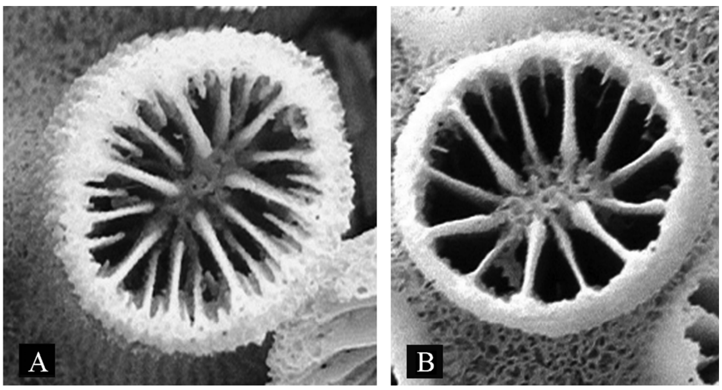

Figure 4. (A) Single corallite of *Tubastraea micranthus*, showing details of the calice structure. Note extensive development of the secondary and tertiary septa. (B) Single corallite of *Tubastraea coccinea*, showing comparative details. Note extensive development of the secondary septa, but only nominal development of the tertiary ones (photos by SAP).

We believe that, because the site at which *T. micranthus* was observed is in relatively close proximity to the mouth of the Mississippi River (near New Orleans, Louisiana) and Port Fourchon, a major deep-water port for the northern Gulf of Mexico, it is quite possible that the vector for this introduction was a vessel traveling from the Indo-Pacific.

If this species has been observed on this (or other) platform(s) before, it is possible that it may have been mistaken for a color morph of *Tubastraea coccinea* by SCUBA divers and other underwater surveyors and collectors, whether observing personally or *via* ROV. Until now, apparently no specimens of *T. micranthus* have been reported or submitted to taxonomic experts for formal identification from this region.

Since *Tubastraea coccinea* was introduced into the western Atlantic in 1943, 56 yrs from the time of writing, it has become the single, most abundant scleractinian coral in the northern GOM. This raises concern over the introduction of its congener – *T. micranthus*. It is possible that *Tubastraea micranthus* may represent the same threat of spread in the GOM and the western Atlantic as *T. coccinea*. It will be critical to monitor its population dynamics in this region to determine whether it has the same capability to expand its population as its congener. *T. coccinea* is known to reproduce asexually via asexual planula production (Ayre and Resing 1986; Shearer 2008) and the highly effective production of runners to produce new colonies (Vermeij 2005; Pagad 2007). It also produces planulae sexually (Glynn et al. 2008a, b). If the reproductive capacity and larval dispersal capabilities of *T. micranthus* are similar to those of *T. coccinea*, *T. micranthus* could potentially reach similar high abundances in the western Atlantic with time (Sammarco et al. 2004; Shearer 2008). Indeed, we predict that if its reproductive, dispersal, and colonization capabilities are similar, there could be a massive biogeographic expansion of this species throughout the Gulf and into the western Atlantic over the next 20-40 years. Our preliminary observations suggest that *T. micranthus* may be competitively dominant over its predecessor, *T. coccinea*, and *T. coccinea* is already known to be a competitive dominant in its benthic community. This implies that *T. micranthus* could represent a threat to other sessile, epibenthic marine fauna and flora in western Atlantic tropical and subtropical waters.

The appearance of *Tubastraea micranthus* represents the third documented case of a scleractinian coral which has been introduced to the western Atlantic. The first was *Fungia scutaria*, introduced to Discovery Bay, Jamaica during the late 1960s (Sammarco pers. obs; J.C. Lang, pers. obs; see LaJeunesse et al. 2005). Specimens of this Indo-Pacific species were apparently transported to Jamaica and kept in seawater aquaria at the Discovery Bay Marine Laboratory. These, however, were open-system running seawater aquaria, and most likely allowed planula larvae to be carried out to the lagoon through the effluent discharge pipes. Adults may also have been introduced into the lagoon directly. The second successful introduction of a scleractinian coral was that of *Tubastraea coccinea*. That introduction has been described in detail by Fenner (2001), Cairns (2000), and Fenner and Banks (2004; see above).

The question arises as to whether a rapid-response is called for on the part of government to eradicate this potential invasive in its early stages of colonization, rather than waiting too long. In the early stages of colonization, successful complete eradication of an invasive species is possible, as has been successfully effected with the sabellid polychaete *Terebrasabella heterouncinata* (Fitzhugh and Rouse 1999). This species was an ectocommensal of South African abalone, which was imported to a central coastal town in California for mariculture purposes (Culver and Kuris 2000). Eradication was effected by removing all of their preferred hosts (a turban snail) and screening the release of potentially contaminated materials from the mariculture unit. A similar rapid response to the infestation of *Caulerpa taxifolia* shortly after its introduction to southern California has also resulted in the near-elimination of this species (Anderson 2005; Woodfield and Merkel 2006). Delay of eradication of invasive species, however, is much more difficult to achieve (Simberloff 2000; Hewitt et al. 2005) and potentially problematic. A community may have reached a new stable equilibrium, integrating the new species. Under such conditions, if the species is removed, the community can become destabilized and rapidly thrown into disequilibrium. This has been documented to occur in the terrestrial environment (Bergstrom et al. 2009; Casey 2009) and could potentially occur in marine or freshwater environments.

Additional surveys within the Gulf of Mexico, including greater depths, should be performed. In addition, investigators conducting similar surveys in other parts of the Atlantic are encouraged to familiarize themselves with *Tubastraea micranthus*, its morphological features, and how they vary from those of *Tubastraea coccinea*, and be aware that this species might appear in their study sites. If *Tubastraea micranthus* is to be eradicated from the Gulf of Mexico, such action should be taken soon.

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References

Anderson LWJ (2005) California's reaction to *Caulerpa Taxifolia*: A model for invasive species rapid response. *Biological Invasions* 7: 1003-1016, doi:10.1007/s10530-004-3123-z

Ayre DJ, Resing JM (1986) Sexual and asexual production of planulae in reef corals. *Marine Biology* 90: 187-190, doi:10.1007/BF00569126

Bergstrom DM, Lucieer A, Kiefer K, Wasley J, Belbin L, Pedersen TK, Shown SL (2009) Indirect effects of invasive species removal devastate World Heritage Island. *Journal of Applied Ecology* 46: 73-81, doi:10.1111/j.1365-2664.2008.01601.x

Cairns SD (2000) Revision of the shallow-water azooxanthellate Scleractinia of the western Atlantic. Studies of the Natural History of the Caribbean Region 75: 1-240, 215 figs.

Cairns SD (2001) A generic revision and phylogenetic analysis of the Dendrophylliidae (Cnidaria: Scleractinia). Smithsonian Contributions to Zoology 615, 75 pp

Cairns SD, Zibrowius H (1997) Cnidaria Anthozoa: Azooxanthellate Scleractinia from the Philippine and Indonesian regions. *Mémoires du Muséum national d'histoire naturelle* 172: 27-243

Carlton JT, Eldredge LG (2009) Marine bioinvasions of Hawai'i: The introduced and cryptogenic marine and estuarine animals and plants of the Hawaiian archipelago. *Bishop Museum Bulletin in Cultural and Environmental Studies* 4: 1-202

Casey M (2009) Species eradication backfires big time. CBS News, Jan. 13, 2009, http://www.cbsnews.com/stories/2009/01/13/tech/main4719190.shtml

Chapman AS (1999) From introduced species to invader: What determines variation in the success of *Codium fragile* ssp. *tomentosoides* (Chlorophyta) in the North Atlantic Ocean? *Helgoländer Meeresuntersuchungen* 52: 77-289

Chesapeake Bay Commission (1995) The introduction of non-indigenous species to the Chesapeake Bay via ballast water. Strategies to decrease the risks of future introductions through ballast water management. Chesapeake Bay Commission, Annapolis, MD, USA.

Christmas J, Eades R, Cincotta D, Shiels A, Miller R, Siemien J, Sinnott T, Fuller P (2001) History, management, and status of introduced fishes in the Chesapeake Bay basin. Proceedings of conservation of biological diversity: A key to the restoration of the Chesapeake Bay ecosystem and beyond, pp 97-116

Culbertson J, Harper DE (2002) Settlement of a colonial ascidian on an artificial reef in the Gulf of Mexico. In: McKay M, Nides J, Vigil D (eds), Proc. Gulf of Mexico fish and fisheries: Bringing together new and recent research, OCS Reports, US Minerals Management Service, no. 2002-004, pp 614-630 (available at http://www.gomr.mms.gov/PI/PDFImages/ESPIS/2/3055.pdf)

Culver SC, Kuris AM (2000) The apparent eradication of a locally established introduced marine pest. *Biological Invasions* 2: 245-253, doi:10.1023/A:1010082407254

Dauterive L (2000) Rigs-to-Reefs policy, progress, and perspective. U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 2000-073, 8 p

Fenner D (1999) New observations on the stony coral (Scleractinia, Milleporidae, and Stylasteridae) species of Belize (Central America) and Cozumel (Mexico). *Bulletin of Marine Science* 64: 143-154

Fenner D (2001) Biogeography of three Caribbean corals (Scleractinia) and the invasion of *Tubastraea coccinea* into the Gulf of Mexico. *Bulletin of Marine Science* 69: 1175-1189

Fenner D, Banks K (2004) Orange cup coral *Tubastraea coccinea* invades Florida and the Flower Garden Banks, northwestern Gulf of Mexico. *Coral Reefs* 23: 505-507

Figueira de Paula A, Creed JC (2004) Two species of the coral *Tubastraea* (Cnidaria, Scleractinia) in Brazil: A case of accidental introduction. *Bulletin of Marine Science* 74: 175-183

Glynn PW, Colley SB, Mate JL, Cortes J, Guzman HM, Bailey RL, Feingold JS, Enochs IC (2008a) Reproductive ecology of the azooxanthellate coral *Tubastraea coccinea* in the equatorial eastern Pacific: Part V. Dendrophylliidae. *Marine Biology* 153: 529-544, doi:10.1007/s00227-007-0827-5

Glynn PW, Colley SB, J.L. Mate JL, Cortes J, Guzman HM, Bailey RL, Feingold JS, Enochs IC (2008b) Reproductive ecology of the azooxanthellate coral *Tubastraea coccinea* in the equatorial eastern Pacific: Part V. Dendrophylliidae (erratum). *Marine Biology* 154: 199, doi:10.1007/s00227-008-0926-y

Graham WM, Bayha KM (2008) Assessing oil and gas platforms for settlement of jellyfish polyps in the northern Gulf of Mexico. Proc. 24th Gulf of Mexico Information Transfer Meeting, US Dept. Interior, Minerals Management Service, New Orleans, LA, USA, OCS Report No. 2008-012, p 348

Graham WM, Martin DL, Felder DL, Asper VL, Perry HM (2003) Ecological and economic implications of a tropical jellyfish invader in the Gulf of Mexico. *Biological Invasions* 5: 53-69, doi:10.1023/A:1024046707234

Griffiths RW (1991) Spatial distribution and dispersal mechanisms of zebra mussels in the Great Lakes basin. *Journal of Shellfish Research* 10: 1-248

Hamner RM, Freshwater DW, Whitfield PE (2007) Mitochondrial cytochrome b analysis reveals two invasive lionfish species with strong founder effects in the western Atlantic. *Journal of Fish Biology* 71: 214-222, doi:10.1111/j.1095-8649.2007.01575.x

Hewitt CL, Campbell ML, McEnnulty F, Moore KM, Murfet NB, Robertson B, Schaffelke B (2005) Efficacy of physical removal of a marine pest: The introduced kelp *Undaria pinnatifida* in a Tasmanian marine reserve, *Biological Invasions* 7: 251-263, doi:10.1007/s10530-004-0739-y

Hickerson EL, Schmahl GP, Weaver DC (2006) Patterns of deep coral communities on reefs and banks in the northwestern Gulf of Mexico. *Eos, Transactions, American Geophysical Union* 87 (36) (suppl.)

Hicks DW, Tunnell JW Jr (1993) Invasion of the south Texas coast by the edible brown mussel *Perna perna* (Linnaeus, 1758). *Veliger* 63: 92-94

Hindar K, Fleming IA, McGinnity P, Diserud O (2006) Genetic and ecological effects of salmon farming on wild salmon: Modeling from experimental results. *ICES Journal of Marine Science* 63: 1234-1247, doi:10.1016/j.icesjms.2006.04.025

Humann P, DeLoach N (2002) Reef coral identification: Florida, Caribbean, Bahamas, including marine plants. New World Publs., Jacksonville, Florida, USA, 278+ pp

ICES (2002) Report of the ICES/IOC/IMO study group on ballast and other ship vectors - Gothenburg, Sweden, 18-19 March 2002. ICES Council Meeting Documents, ICES, Copenhagen, Denmark.

Invasive Species Advisory Committee (2005) Progress Report on Meeting the Invasive Species Challenge: National Invasive Species Management Plan, FY 2004. 30 pp (available at http://www.invasivespeciesinfo.gov/docs/council/progressrpt2005.pdf)

Johnson LE, Carlton LT (1996) Post-establishment spread in large-scale invasions: Dispersal mechanisms of the zebra mussel *Dreissena polymorpha*. *Ecology* 77: 1686-1690, doi:10.2307/2265774

Kerr SJ, Brousseau CS, Muschett M (2005) Invasive aquatic species in Ontario: A review and analysis of potential pathways for introduction. *Fisheries* 30: 21-30, doi:10.1577/1548-8446(2005)30[21:IASIO]2.0.CO;2

LaJeunesse TC, Lee S, Bush S, Bruno JF (2005) Persistence of non-Caribbean algal symbionts in Indo-Pacific mushroom corals released to Jamaica 35 years ago. *Coral Reefs* 24: 157-159, doi:10.1007/s00338-004-0436-4

Lambert G (2002) Non-indigenous ascidians in tropical waters. *Pacific Science* 56: 291-298, doi:10.1353/psc.2002.0026

Loch K, Loch W, Schuhmacher H, Wolf R (2004) Coral recruitment and regeneration on a Maldivian reef four years after the coral bleaching event of 1998. Part 2: 2001-2002. *Marine Ecology* 25: 145-154, doi:10.1111/j.1439-0485.2004.00021.x

Minchin D, Gollasch S (2003) Fouling and ships' hulls: How changing circumstances and spawning events may result in the spread of exotic species. *Biofouling* 19: 111-122, doi:10.1080/0892701021000057891

Osman R, Shirley T (eds) (2007) The Gulf of Mexico and Caribbean marine invasive species workshop: Proceedings and final report. Harte Res. Inst., Texas A&M Univ. – Corpus Christi, TX, 47 pp

Pagad S (2007) *Tubastraea coccinea* (corail). Global Invasive Species Database, Invasive Species Specialist Group, IUCN Species Survival Commission. http://www.issg.org/database/species/ecology.asp?si=1096&fr=1&sts=&lang=FR (accessed on March 15, 2010)

Pederson J (2000) Marine bioinvasions: Proceedings of the first national conference. Proc. 1st Nat. Conf. on Marine Bioinvasions, Cambridge, MA, USA, January 24-27, 2000, 427 pp

Perry HM, Graham M (2000) The spotted jellyfish: Alien invader. Report to NOAA Mississippi-Alabama Sea Grant, Hattiesburg, Mississippi, USA, 2000

Roberts JM, Wheeler AJ, Friewald A, Cairns SD (2009) Cold-water corals. Cambridge University Press, Cambridge, 334 pp

Roberts PD, Pullin AS (2008) The effectiveness of management interventions for the control of *Spartina* species: A systematic review and meta-analysis. *Aquatic Conservation* 18: 592-618, doi:10.1002/aqc.889

Sammarco PW (2005) Gulf drilling platforms as an environmental asset: Long-term artificial reefs and sites for coral recruitment/Determining the geographical distribution, max. depth, and genetic affinities of corals on offshore platforms, northern Gulf of Mexico. US Dept. Interior, Minerals Management Service, Environmental Section, New Orleans, LA, Ann. Rep., 2005

Sammarco PW (2006) Gulf drilling platforms as an environmental asset: Long-term artificial reefs and sites for coral recruitment. Determining the geographical distribution, max. depth, and genetic affinities of corals on offshore platforms, northern Gulf of Mexico. US Dept. Interior, Minerals Management Service, Environmental Section, New Orleans, LA, Ann. Rep., 2006

Sammarco PW (2007) Invasive species on oil and gas platforms in the N. Gulf of Mexico: Island-hopping and biogeographic expansion. In: Osman R, Shirley T (eds), The Gulf of Mexico and Caribbean Marine Invasive

Species Workshop, Harte Research Inst., Texas A&M Univ. – Corpus Christi, Corpus Christi, TX, pp 15-16

Sammarco PW (2008) Gulf drilling platforms as an environmental asset: Long-term artificial reefs and sites for coral recruitment. Determining the geographical distribution, max. depth, and genetic affinities of corals on offshore platforms, northern Gulf of Mexico. US Dept. Interior, Minerals Management Service, Environmental Section New Orleans, LA, Ann. Rep., 2008

Sammarco PW (2009) Determining the geographical distribution, max. depth, and genetic affinities of corals on offshore platforms, northern Gulf of Mexico. Deep-water coral distribution and abundance on active offshore oil and gas platforms vs. decommissioned "Rigs-to-Reefs" platforms. US Dept. Interior, Minerals Management Service, Environmental Section, New Orleans, LA, Ann. Rep., 2009

Sammarco PW, Atchison AD, Boland GS (2004) Expansion of coral communities within the northern Gulf of Mexico via offshore oil and gas platforms. *Marine Ecology Progress Series* 280: 129-143, doi:10.3354/meps280129

Sammarco PW, Atchison AD, Boland GS (2006) Distribution of corals colonizing oil and gas platforms in the northwestern Gulf of Mexico: A preliminary report. US Dept. Interior, Minerals Management Service Information Transfer Meeting, New Orleans, LA, Jan. 2005

Sammarco PW, Atchison AD, Brazeau DA, Boland GS, Lirette A (2007) Coral distribution, abundance, and genetic affinities on oil/gas platforms in the N. Gulf of Mexico: A preliminary look at the Big Picture. Proc. US Dept. Interior, Minerals Management Service Information Transfer Meeting, New Orleans, Jan. 2007

Sammarco PW, Atchison AD, Brazeau DA, Boland GS, Hartley SB, Lirette A (2008) Distribution, abundance, and genetics of corals throughout the N. Gulf of Mexico: The world's largest coral settlement experiment. Proc. 11th Int. Coral Reef Symposium, Fort Lauderdale, FL, July 2008. Abstract

Sammarco PW, Atchison AD, Brazeau DA, Boland GS, Lirette A (2009) Coral distribution, abundance, and genetics in the N. Gulf of Mexico: Role of the Flower Garden Banks and Oil/Gas Platforms. Proc. US-Dept. Interior, Minerals Management Service Information Transfer Meeting, New Orleans, LA, Jan. 2009

Sapota MR (2004) The round goby (*Neogobius melanostomus*) in the Gulf of Gdansk - a species introduction into the Baltic Sea. *Hydrobiologia* 514: 219-224, doi:10.1023/B:hydr.0000018221.28439.ae

Schmahl GP (2003) Biodiversity associated with topographic features in the northwestern Gulf of Mexico. Proc US Dept. Interior, Minerals Management Service Information Transfer Meeting, Gulf of Mexico, OCS Region, Kenner, La.

Schmahl GP, Hickerson EL (2006) Ecosystem approaches to the identification and characterization of a network of reefs and banks in the northwestern Gulf of Mexico. *Eos, Transactions of the American Geophysical Union* 87, (36), suppl.

Secord D (2003) Biological control of marine invasive species: Cautionary tales and land-based lessons. *Biological Invasions* 5: 117-131, doi:10.1023/A:1024054909052

Shearer TL (2008) Range expansion of an introduced coral: Investigating the source and ecological impact of the invasion. 2008 Ocean Sciences Meeting: From the Watershed to the Global Ocean, Orlando, FL (USA), 2-7 Mar 2008

Simberloff D (2000) No reserve is an island: Marine reserves and non-indigenous species. *Bulletin of Marine Science* 66: 567-580

Trowbridge CD (1998) Ecology of the green macroalga *Codium fragile* (Suringar) Hariot 1889: Invasive and non-invasive subspecies. *Oceanography and Marine Biology Annual Review* 36: 1-64

U.S. Executive Order 13112 (1999) Invasive species. Fed. Reg. 64: 6183-6186

Vermeij MJA (2005) A novel growth strategy allows *Tubastraea coccinea* to escape small-scale adverse conditions and start over again. *Coral Reefs* 24: 442, doi:10.1007/s00338-005-0489-z

Weidema IR (ed) (2000) Introduced species in the Nordic countries Nord 13, 242 pp

Whitfield PE, Gardner T, Vives SP, Gilligann MR, Courtenay WR Jr, Ray GC, Hare JA (2002) Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic coast of North America. *Marine Ecology Progress Series* 235: 289-297, doi:10.3354/meps235289

Williams SL (2007) Introduced species in seagrass ecosystems: Status and concerns. *Journal of Experimental Marine Biology and Ecology* 350: 89-110, doi:10.1016/j.jembe.2007.05.032

Wonham MJ, Carlton JT, Ruiz GM, Smith LD (2000) Fish and ships: Relating dispersal frequency to success in biological invasions. *Marine Biology* 136: 1111-1121, doi:10.1007/s002270000303

Woodfield R, Merkel K (2006) Eradication and surveillance of *Caulerpa taxifolia* within Agua Hedionda Lagoon, Carlsbad, California: Fifth year status report. Merkel & Associates, San Diego, California, USA, 13 pp

Annex 1. List of the 82 oil and gas platforms surveyed for scleractinian corals between 2000 and 2009. Most were standing production platforms. Some were toppled platforms within the "Rigs-to-Reefs" Program. Most were surveyed by SCUBA, between 7 and 37 m depth. Several were surveyed by ROV to a maximum depth of 117 m. Platforms divided into transect survey sectors within the northern Gulf of Mexico, covering the western, near-western, central, and near-eastern regions. Latitudes and longitudes of survey sites also shown. PWS = Sammarco; SAP = Porter.

Platform	lat.	long.	Platform	lat.	long.	Platform	lat.	long.
Far Western Sector			**Central Sector**			**Near-Eastern Sector**		
(2003-2006, PWS)			(2003-2006, PWS)			(2003-2006, PWS)		
BA-104-A	27.8669	-96.0334	SS-277-A	28.2993	-91.0876	MP-144-A	29.2924	-88.6691
BA-A-133-A	27.8545	-96.0364	ST-163-A	28.5720	-90.4996	MP-159-1	29.6491	-88.4647
BA-133-D	27.8388	-96.0282	ST-165-A	28.5767	-90.5769	MP-236-B	29.4054	-88.5844
MI-A-4A	27.9042	-96.0892	ST-188-CA	28.5010	-90.3808	MP-265-A	29.3467	-88.2816
MI-618-A	28.0222	-96.3071	ST-190-A	28.4663	-90.4461	MP-288-A	29.2398	-88.4095
MI-651-A	28.0222	-96.3071	ST-292-A	28.2141	-90.4203	MP-289-B	29.2585	-88.4415
MI-672-A	27.9942	-96.2596	ST-295-A	28.1963	-90.5413			
MI-672-B	27.9688	-96.2909						
			(2004-2009, SAP)			(2004-2009, SAP)		
Western Sector			GI-90	28.5850	-90.2383	MC-387	28.5583	-90.9317
(2000-2003, PWS)			GI-93**	28.5583	-90.0800	MP 296	29.2483	-88.6650
EC-317B	28.2084	-92.9519	GI-94	28.5400	-90.2750	MP 306	29.195	-88.5550
HIA -30A	28.0962	-93.4784	GI-95	28.5250	-90.1317	MP-313-B	29.115	-88.7683
HI-A-349B	28.0703	-93.4691	GI-106	29.3983	-90.0967	SP-62	29.0583	-88.9650
HI-A-368B	27.9620	-93.6709	ST-131	28.7083	-90.1467	SP-72	29.0433	-88.9450
HI-A-370A	27.9855	-93.4584	ST-138	28.6300	-90.4100			
HI-A-376A	27.9620	-93.6709	ST-139	28.6667	-90.4550			
HI-A-382	27.9132	-93.9351	ST-146	28.6233	-90.6483			
HI-A-385C	27.9168	-93.9168	ST-150	28.6250	-90.2567			
HI-A-386B	27.9717	-93.5178	ST-156	28.5750	-90.1950			
HI-A-568B	27.9763	-94.1439	ST-162	28.5567	-90.4450			
HI-A-571	27.9556	-94.0271	ST-171	28.5483	-90.6217			
WC-618	28.0367	-93.2312	ST-172	28.5300	-90.5750			
WC-630A	28.0034	-93.2941	ST-178	28.5433	-90.2883			
WC-643A	27.9814	-93.0342	ST-179	28.5183	-90.2967			
			ST-185	28.4817	-90.2367			
(2003-2006, PWS)			ST-186	28.5017	-90.2817			
GB-189-A	27.7786	-93.3095	ST-195	28.5300	-90.6850			
GB-236-A	27.7611	-93.1377	ST-196	28.5417	-90.7317			
HI-A-237-A	28.6678	-93.8857	ST-198	28.4553	-90.7050			
HI-A-287-A	28.3610	-93.7690	ST-204	28.4617	-90.3983			
WC-312-1	29.1872	-93.5822	ST-265	28.2733	-90.4633			
WC-414-A	28.7579	-93.3878	ST-295	28.1963	-90.5413			
WC-522-A	28.3759	-93.4912						
(2007-2008, PWS)								
(Shallow - < 33m - and deep ROV surveys)								
HI-A-376	27.9620	93.6709						
WC-643-A	27.9814	93.0342						
EC-273AP R2R*	28.2550	-92.3930						
HI-A-271 R2R*	28.4395	-93.7169						
HI-A-281 R2R*	28.3642	-93.7853						
HI-A-355R2R*	28.3642	-93.7853						
HI-A-492 R2R*	28.2266	94.0583						

*Toppled Rigs-to-Reefs platforms; all others are standing productions platforms.
**Site of observation of *Tubastraea micranthus*.