

# Sediment tolerance of two different morphotypes of the deep-sea coral *Lophelia pertusa* from the Gulf of Mexico

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**ABSTRACT:** On the upper slope of the northern Gulf of Mexico, topographic features are often associated with authigenic carbonate, which provides hard substrate for sessile benthic communities. At depths >300 m, large *Lophelia pertusa* colonies frequently occur on these carbonate outcroppings. Surficial sediments at these depths are dominated by fine-grained particulates, which are readily resuspended during the episodic high current events that have been documented for the Gulf of Mexico. Colonies of *L. pertusa* found in the deep Gulf of Mexico exhibit 2 distinct growth forms: the very heavily calcified 'brachycephala' and the more fragile 'gracilis'. The objective of this research was to determine the tolerance of these 2 morphotypes to suspended sediment and to complete burial, using sediment collected from the study region. Results demonstrated that, although both morphotypes of *L. pertusa* can tolerate fairly heavy sediment conditions, mortality increases rapidly with longer burial or higher sediment loads.

**KEY WORDS:** *Lophelia pertusa* · Sediment tolerance · Gulf of Mexico · Deep-water coral · *Lophelia* morphotypes

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## INTRODUCTION

Interest in deep-water corals has increased rapidly over the last decade since deep-water coral systems have been discovered and their significance as habitat for diverse communities of associated fauna has been recognized (Rogers 1999, Freiwald et al. 2004, Freiwald & Roberts 2005, Lumsden et al. 2007). These communities frequently include commercially important fisheries species, which are harvested using large trawls that cause extensive damage to deep-water coral ecosystems. The most well-studied deep-water scleractinian species is *Lophelia pertusa* (Linne, 1758). This colonial coral produces a dendroid branching skeleton with large polyps that are up to 1 cm in diameter. As the branches grow, they frequently anastomose (fuse together) and create a highly complex, large, and stable structure. Colonies typically develop from irregular small bushes to large hemispherical

colonies that eventually coalesce into 'thickets'. Large colonies are composed of an outer layer of live coral surrounding a dead inner core. Dead standing coral is characteristic of deep-water reefs produced by structure-forming scleractinians, and occasionally large tracts of reef are completely or mostly dead.

The distribution of *Lophelia pertusa* is not continuous over the seafloor; rather, it exhibits variation both geographically and bathymetrically (Mortensen 2000). Deep-water coral systems are found on elevated topographic features such as shelf edges, seamounts, canyons, and fjords of most of the world's oceans, exhibiting wide bathymetric distribution to depths of 6200 m (Stanley & Cairns 1988). The documented bathymetric distribution of *L. pertusa* ranges from 39 m (Rapp & Sneli 1999) in Norwegian Fjords to 3600 m (Squires 1959) on the mid-Atlantic Ridge, although this observation has recently been questioned, as the deepest confirmed occurrence of *L. pertusa* in this region

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was 1340 m (Mortensen et al. 2008). This species is most commonly found at intermediate depths on continental shelf features and at temperatures of 4 to 13.8°C (Freiwald et al. 2004).

In 1955, Moore & Bullis (1960) collected large quantities of *Lophelia pertusa* (= *prolifera*) at 420 to 512 m depth from the northeastern continental slope of the Gulf of Mexico, which is ~74 km east of the Mississippi River delta, and there were several additional reports of living *L. pertusa* in the Gulf of Mexico after this discovery (Cairns 1979, Cairns & Viada 1987, MacDonald et al. 1989, Schroeder 2002, Schroeder et al. 2005). Late Pleistocene structures supporting mostly dead colonies of *L. pertusa* have also been documented from the west Florida carbonate ramp slope at a depth of 500 m (Newton et al. 1987, Reed et al. 2006). On the upper slope of the northern Gulf of Mexico, topographic highs are often associated with authigenic carbonate produced as a byproduct of methane oxidation and sulfate reduction by microbial consortia (Aharon & Fu 2000, Boetius et al. 2000). These features often support sessile benthic communities, which include *L. pertusa* colonies. Authigenic carbonate precipitation may therefore explain the observed link between *L. pertusa* distribution and hydrocarbon seepage (Hovland & Thomsen 1997, Hovland et al. 1998), whereby the carbonate provides hard substrata for settlement of coral larvae and other sessile benthic fauna such as sponges, octocorals and antipatharians. In 2004, the Minerals Management Service (MMS) funded a comprehensive study to characterize the coral ecosystems on the continental slope of the northern Gulf of Mexico that included research into the physical, geological and biological features of coral habitats. The results of this research are summarized in the MMS final report (Continental Shelf Associates 2007), and in a NOAA report on the status of deep-sea coral ecosystems of the USA (Lumsden et al. 2007).

Standing dead coral colonies are a characteristic feature of many communities of structure-forming deep-water scleractinians such as *Lophelia pertusa*, including those in the northern Gulf of Mexico; however, the reasons for coral mortality and the ages of the dead corals are largely unknown. Possible causes include changes in environmental variables such as temperature, food supply, sediment load, pathogens, or catastrophic events such as sediment slumping. At depths where *L. pertusa* is known from the Gulf of Mexico, temperatures are ~8°C. Although temperatures can fluctuate by ~2°C between years, they most likely remain below the mortality threshold. There are currently no known pathogens of deep-water corals, but since most deep-water scleractinian reefs are composed of a single foundation species, a disease outbreak could cause widespread mortality. Benthic

storms, periodic strong currents or slumping events could smother large areas of coral, which could subsequently be removed by currents, leaving standing dead colonies and rubble. Periods of high currents have been documented for the deep Gulf of Mexico (Hamilton & Lugo-Fernandez 2001). Alternatively, dead areas may be a result of a natural process of colony growth and senescence; as the colonies develop, the internal core dies and falls apart, leaving an outer layer of live branches. If the process that causes polyp mortality becomes faster than coral growth, the colony could die.

There is abundant evidence of the detrimental effects of high sediment loads on shallow-water corals. These include decreases in primary productivity of algal symbionts in zooxanthellate species (Riegl & Branch 1995, Telesnicki & Goldberg 1995, Anthony & Fabricius 2000), and decreased skeletal growth (Rogers 1983, 1990, Rice & Hunter 1992, Jiménez & Cortes 2003) due to reallocation of energy toward clearing mechanisms (Dallmeyer et al. 1982). High levels of suspended sediment have also been shown to cause death in corals (Riegl 1995, Hillis & Bythell 1998, Wesseling et al. 1999, Kelmo et al. 2003). Death from sedimentation may result from burial and suffocation, but may also result from depletion of energy as corals shed sediment through the energetically costly processes of ciliary action and mucus production. In addition to direct effects, heavy sedimentation has been shown to limit fertilization (Gilmour 1999) and larval settlement (Babcock & Davies 1991, Gilmour 1999), and to influence behavior (Dallmeyer et al. 1982). These studies all focused on shallow coral species; however, similar adverse effects (except those related to photosynthesis) probably also apply to deep-water species. Although the deep sea is more quiescent than nearshore shallow habitats, deep-water coral species may also be exposed to high sediment loads from surface-derived particulates sinking through the water column, from laterally advected material, and from bottom sediments that are resuspended by currents.

Colonies of *Lophelia pertusa* found in the deep Gulf of Mexico exhibit 2 distinct growth forms or 'morphotypes' (Newton et al. 1987). One form is very heavily calcified, has thick branches and very large calices, and was termed 'brachycephala' (Fig. 1A). The other, known as the 'gracilis' form (Fig. 1B), is more fragile and has smaller branches and very prominent septal ridges. This species obviously has high morphological plasticity, an observation which has been documented previously in *L. pertusa* from Norwegian coral mounds (Freiwald et al. 1997) and generally noted by researchers in the field. In the Gulf of Mexico, the skeletal differences are quite profound and have no overlap in distribution (observations to date). It is reasonable to

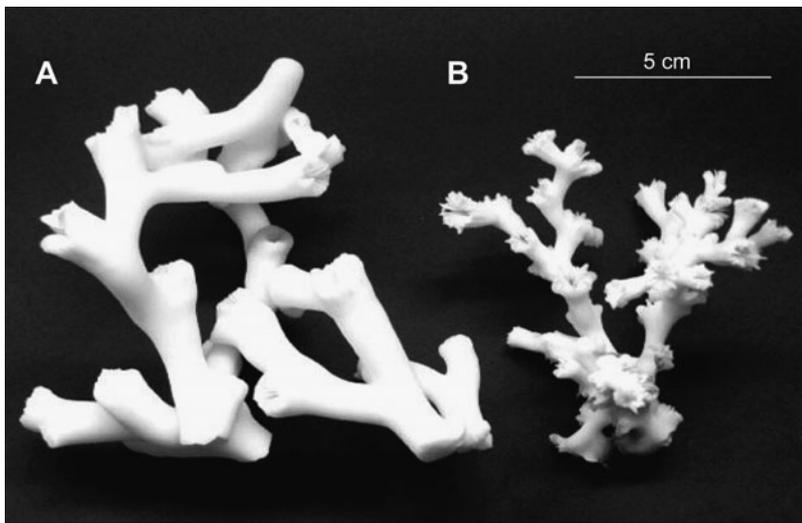


Fig. 1. *Lophelia pertusa*. (A) Heavily calcified 'brachycephala' morphotype, and (B) fragile 'gracilis' morphotype from the Gulf of Mexico

assume that skeletal morphology is influenced by any number of environmental factors including current speed, food availability, aragonite saturation, and temperature. Speculation as to the proximate drivers of these morphological differences is outside the scope of this paper, and requires long-term data on a suite of variables from each coral habitat. The objective of this research was to investigate the tolerance of the 2 different *L. pertusa* morphotypes to a range of suspended sediment concentrations and to complete burial under sediment.

## MATERIALS AND METHODS

Samples of *Lophelia pertusa* were collected from different locations in the northern Gulf of Mexico using a Johnson Sea-Link submersible from Harbor Branch Oceanographic Institution. The heavily calcified brachycephala morphotype was collected at Viosca Knoll lease block 826 (29° 09.63' N, 88° 01.06' W) at depths of 450 to 460 m, while the gracilis form was collected from Green Canyon lease block 354 (27° 35.92' N, 91° 49.60' W) at 528 m. Temperatures at the sites ranged from 6.8 to 8.8°C at Green Canyon and 7.0 to 9.0°C at Viosca Knoll (Continental Shelf Associates 2007). Viosca Knoll is the best-documented coral site in the northern Gulf of Mexico and is also associated with a mature chemosynthetic community, consisting primarily of living tubeworm (mostly *Lamellibrachia luymesii*) aggregations. Coral development is primarily on the crest and flanks of a mound that rises up to 90 m above the surrounding sea floor, to a depth of ~430 m. The mound has carbonate formations in the form of

large plates, slabs, and irregularly shaped blocks, boulders and rubble. Green Canyon lease block 354 lies on a slope descending from 520 to 560 m. The upper portion of the slope contains abundant carbonate mounds supporting scattered *L. pertusa* colonies that are 5 to 10 m in diameter, some of which have coalesced into thickets.

The first experiment investigated the tolerance of *Lophelia pertusa* fragments to a range of sediment loads. Experimental sediments were collected from close to the Green Canyon coral collection sites at 600 m depth, and were sieved (5 mm) to remove large particles. Sediments were autoclaved prior to introduction into the experiments to kill any potential pathogens. Sediment cores were taken from the Green Canyon and Viosca Knoll coral sites for

the characterization of sediment particle size composition. Sediment traps were also deployed adjacent to well-developed coral communities at both sites for 14 mo between July 2004 and September 2005 to measure grain size distribution, deposition rate and organic content of particles falling from the pelagic zone. Each sediment trap was made of PVC pipe (30 cm in length, 4.5 cm inner diameter) that was sealed at the base with an end cap and attached to a 2.3 kg disc weight, and 3 replicate units were deployed at each site.

Small coral fragments (10 to 15 polyps) of each morphotype were exposed to a range of sediment concentrations in individual 19 l experimental systems (Fig. 2). Coral fragments were placed in the experimental aquaria 24 h before the introduction of sediment and when the polyps were all extended. The sediments were gently introduced as concentrated slurries into the bottom of the aquaria, away from the fragments to create 5 suspended sediment concentrations (0, 50, 150, 250, and 350 mg l<sup>-1</sup>). The treatment levels were chosen to represent a continuum between the control (no sediment) and the highest concentration that could be maintained in the experimental system. Treatments were labeled T1, T2, T3, T4, and T5, representing the lowest to the highest suspended sediment concentrations, respectively. Subsamples (50 ml) of suspension were taken daily from each treatment for the duration of the experiment to track any changes in sediment concentration that may have occurred. The average experimental sediment concentrations were 0 (SE: 0.76), 54 (SE: 0.77), 103 (SE: 1.94), 245 (SE: 5.96), and 362 mg l<sup>-1</sup> (SE: 3.67). The SEs in parentheses represent variation among 3 replicate trials. After 14 d

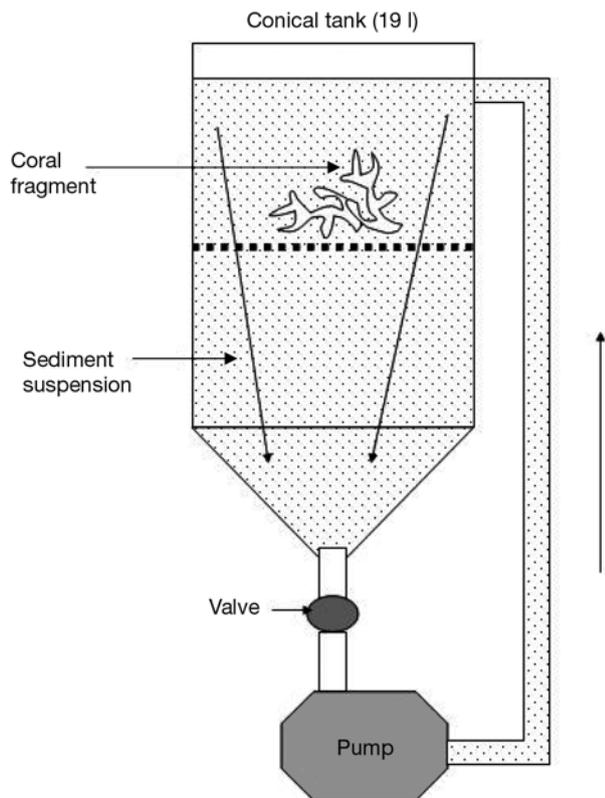


Fig. 2. Experimental apparatus used to investigate sediment tolerance of *Lophelia pertusa* fragments; various concentrations of suspended sediment were maintained in a continuously recirculating system. Coral fragments were placed on a grid in the center of the apparatus as shown, and arrows indicate water flow

under treatment conditions, the fragments were removed and placed into recirculating recovery tanks (8°C) with clean water, and survival was assessed 4 d later. Most of the live polyps extended after 4 d, but those that were retracted were tested by gently squirting a water stream into the calyx using a pipette. If the polyp was alive, further retraction was visible; if not, fragments of dead tissue were flushed from the calyx. This approach was used to ensure accurate assessment of survival since it is difficult to be certain of the status of a retracted polyp immediately after removal from the experiment.

The second experiment tested the response of *Lophelia pertusa* fragments to complete burial over treatment periods of 1, 2, 4, and 7 d. Fragments of each morphotype were placed in individual containers, and assigned a treatment and replicate ( $n = 3$ ) number. The fragments were then loosely buried in sediment from the Gulf of Mexico to depths of  $>1$  cm so the coral could not shed the sediment, and remained buried for the duration of the experiment. They were then distributed randomly on a grid within a recirculating tank of sea-

water at 8°C for the designated treatment period. After removal, each fragment was left to recover as previously described, and scored for polyp survival.

The objective of the third experiment was to determine whether a correlation exists between the calyx diameter and the ability of the polyp to remove sediment. Several fragments of approximately equal size (10 polyps) were randomly assigned positions in an aquarium with flow-through seawater. Each fragment was tapped at the beginning of the experiment to induce polyp retraction, and sediment was gently deposited on the surface of each calyx with a glass pipette until it poured over the sides. This ensured that each polyp received a similar amount of sediment, relative to the calyx diameter. Sediment removal was monitored every 20 min for 10 h until all of the sediment was removed from the surface of the polyps. The diameter of the calyx and the time taken to shed all the sediment was recorded for each polyp.

## RESULTS

The coral fragments were exposed experimentally to a sediment profile similar to that which they would experience *in situ* from the Green Canyon site. The samples from the sediment cores for Green Canyon and Viosca Knoll were respectively characterized as 'clay' and 'slightly gravelly mud' (Continental Shelf Associates 2007) following the Folk (1954) classification scheme. The clay designation is applied to sediment that is primarily composed of particles  $<4$   $\mu\text{m}$ , while the slightly gravelly mud (mud being a mixture of silt and clay) particle range falls mostly within  $<4$  to 62.5  $\mu\text{m}$  (after Wentworth 1922), with a smaller percentage of larger particles. The proportion of particles  $<20$   $\mu\text{m}$  was ~93% by dry weight for the Green Canyon cores and 45% for the Viosca Knoll cores.

Grain-size distributions from the sediment traps deployed at Green Canyon were dominated by the  $<20$   $\mu\text{m}$  size class (88.1%, SE: 3.1% dry weight). Sediment flux calculations yielded an average of 31.16  $\text{g m}^{-2} \text{d}^{-1}$  (SE: 2.44) by dry-weight and organic content was 19.64% ( $\pm 4.64\%$ ) of the total dry weight. The grain size distribution for the Viosca Knoll traps was not available due to a processing error, but sediment flux was 46.80  $\text{g m}^{-2} \text{d}^{-1}$  (SE: 5.37) with an organic content of 16.95% (SE: 1.19%).

Survival in the control treatment was 100% for both morphotypes, with survival decreasing as the treatment sediment concentration increased. The highest sediment level caused complete mortality of the fragile gracilis morphotype and only an average of 6.67% (SE: 6.67) survival of the heavily calcified brachycephala growth form (Fig. 3). A Bartlett's test showed homo-

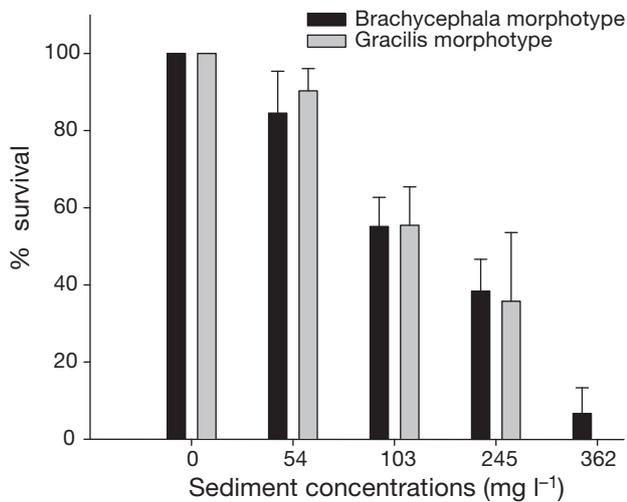


Fig. 3. *Lophelia pertusa*. Mean percent survival ( $\pm$ SE) of 2 morphotypes after exposure to a range of sediment suspensions for 14 d ( $n = 3$ )

scedastic variance ( $p > 0.05$ ), so no data transformation was required. The interaction between treatment and morphology was insignificant ( $F = 0.14$ ,  $p = 0.97$ ) in the 2-factor ANOVA, so a 1-way ANOVA was then performed with the morphotypes being pooled (Table 1). A significant difference was detected across all treatments ( $p < 0.05$ ), but there was no significant difference between 0 and 54 mg l<sup>-1</sup> (T1 and T2) or between 103 and 245 mg l<sup>-1</sup> (T3 and T4) ( $p > 0.05$ ).

Results from the burial experiment show almost complete survival of both morphotypes after 24 h, which dropped to an average of 89.5% (SE: 9.53) after 2 d for the heavily calcified growth form and 73.3% (SE: 15.27) for the fragile morphotype. After 4 d, almost all the polyps had died, and mortality was complete after 7 d (Fig. 4). The survival data showed heteroscedastic variance (Levene's test:  $p = 0.00$ ), even after arcsin transformation. A nonparametric Kruskal-Wallis test showed no significant difference in the responses of the different morphotypes ( $\chi^2$ : 0.24,  $p = 0.62$ ). However, there was a significant treatment effect ( $\chi^2$ : 19.98,  $p = 0.00$ ). The greatest differences occurred between the effects of 1 and 2 d of burial versus 4 and 7 d, indicating a critical survival–mortality point between 2 and 4 d of burial.

Table 1. ANOVA of the effects of suspended sediment concentration (sediment) on survival of *Lophelia pertusa* fragments after 14 d of experimental treatment. \*\* $p < 0.001$

Source	df	MS	F
Sediment	4	9081.16	49.83**
Error	25	182.00	
Total	29		

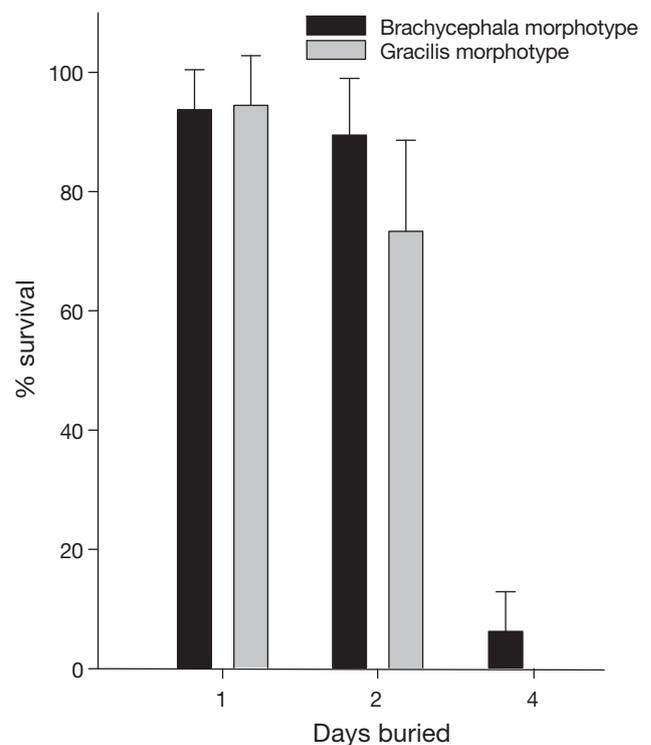


Fig. 4. *Lophelia pertusa*. Mean percent survival ( $\pm$ SE) of 2 morphotypes after burial for different periods of time in Gulf of Mexico sediment ( $n = 3$ )

Results from the sediment-shedding experiment show that complete removal ranged from 46 min to over 9 h after the sediment was placed on the calices (Fig. 5). There was no significant correlation between sediment removal time and calyx diameter ( $r^2 = 0.02$ ). The average time for complete removal was 242.6 min

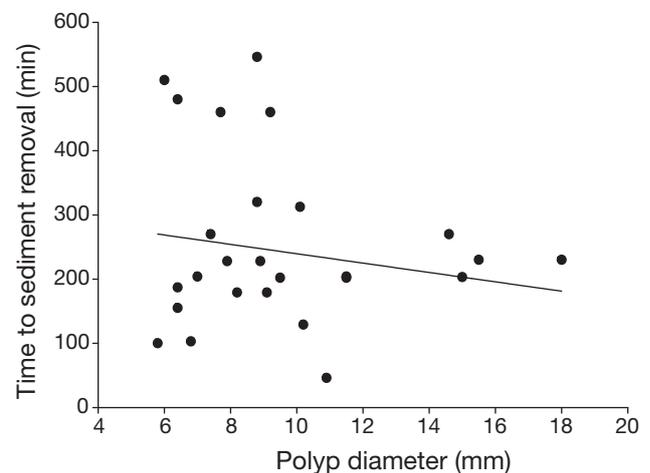


Fig. 5. *Lophelia pertusa*. Regression of time required to shed sediment against polyp diameter. The regression is not significant ( $r^2 = 0.02$ ,  $p > 0.05$ ,  $n = 25$ )

( $\pm 51.0$  min). An interesting observation made during this experiment was that most of the sediment was moved towards the lower edge of the calyx. This occurred in polyps whose calices were only slightly angled to the horizontal, as well as in those that were more inclined, suggesting manipulation by the polyp rather than simply being the result of sediment slipping from the polyp surface.

## DISCUSSION

The results of these sediment tolerance experiments demonstrated that although *Lophelia pertusa* can tolerate fairly heavy sediment conditions, survival seems to decrease in steps rather than showing a continuous linear decline; this may mean that the corals have physiological thresholds beyond which they cannot compensate, at which point some mortality occurs. The experiment probably exposed the coral to higher sediment concentrations than they would normally experience *in situ*, and for a longer duration, indicating that extreme and/or long-term sediment loads would be required to cause significant *L. pertusa* mortality. The burial experiment was designed to investigate whether colonies could survive a catastrophic event such as a sediment slump or a benthic storm wherein portions of the reef may be temporarily covered. Survival for the first 2 d was surprisingly high, but since the sediment was placed loosely over the polyps, and the experiment was maintained in cold, well-oxygenated water, there may have been sufficient oxygen to support metabolism for a limited time. It has been shown experimentally that *L. pertusa* can compensate for low oxygen levels by reducing its metabolic rate (Dodds et al. 2007); however, the almost total mortality at 4 d implies that a physiological threshold was crossed between 2 and 4 d of burial. Despite the mitigating factors mentioned above, the most likely cause of mortality was oxygen deficiency. Corals were scored after 4 d in the recovery tank to make sure the scoring was accurate and there was no post-treatment mortality. Although there was no subsequent data collection, the surviving fragments remained alive indefinitely in the holding tanks.

Since calcification is an energetically expensive metabolic process, we assume that there is some advantage to a heavily calcified morphology. Although this is more likely a response to different current speeds, or food availability rather than to sediment loads, we were expecting the larger polyps to have a greater ability to remove sediment simply due to increased surface area; however, these experiments show that the 2 morphotypes have similar responses to sedimentation and burial. This may be demonstrated

in the context of the sediment shedding experiment, which showed no correlation between polyp diameter and ability to remove sediment. When exposed to small doses of suspended graphite, *Lophelia pertusa* from the northeast Atlantic Ocean were able to effectively clear the particles from the tentacular surface within about 30 s (Shelton 1980). Mortensen (2001) found that particles up to 3 mm in diameter were removed from polyp surfaces within 5 min, while particles up to 5 mm in diameter were cleared in ~15 min. These studies have used artificial particles or grains that are much larger than the sediment to which *L. pertusa* colonies are exposed in the Gulf of Mexico. Shelton (1980) found that each polyp contains 2 types of cilia: oral disc cilia and pharyngeal cilia. When sediment was deposited on the polyps, it collected in a ring around the oral disc and was transported to the edge of the tentacles via oral disc cilia. Sediment may also fall off passively or be washed away by currents. When presented with a combination of small amounts of sediment and food particles, *L. pertusa* have been observed to ingest the sediment, although cleaning and feeding do not appear to occur concurrently (Mortensen 2001). However, turbid conditions may require constant sediment shedding, thus restricting or preventing feeding; it is therefore possible that under prolonged periods of suspended sediment exposure, *L. pertusa* may experience starvation even if food items are present.

Deep-water habitats on the continental slope in the northern Gulf of Mexico are influenced by the high-energy Loop Current, which enters the Gulf through the Yucatan Channel and exits through the Straits of Florida. Eddies from the Loop Current have current speeds of ~1 to 2 m s<sup>-1</sup>, which is comparable to the Loop Current itself, and can exist for many months before decaying in the western Gulf. Loop Current and mesoscale eddies in the Gulf can influence the circulation over the continental slope to depths of several hundred meters, and can be accelerated over topographic features. Below 300 m depth in the Gulf of Mexico, the surficial sediments are dominated by fine-grained pelagic and hemipelagic material (Coleman et al. 1991). This fine sediment may be resuspended during anomalous high current events. Bottom sediments from both study sites were composed mainly of particles <20  $\mu\text{m}$ , which can be eroded at speeds of 20 cm s<sup>-1</sup> and transported at <1 cm s<sup>-1</sup> (Hjulström 1935, 1939). Information from acoustic doppler current meters (Falmouth Scientific 2D-ACM) deployed for several months near the coral sites (Continental Shelf Associates 2007) show that flow speeds above 20 cm s<sup>-1</sup> occurred 3.3% of the time.

Increased terrestrial sediment and nutrient input to continental shelf and slope habitats may occur during

large storms or flooding episodes; estuarine water in the shallow Atchafalaya Bay, Louisiana, reached suspended sediment concentrations of  $1700 \text{ mg l}^{-1}$  during Hurricane Claudette in 2003 (Sheremet et al. 2005). *In situ* measurements of sediment concentrations were taken using 20 l niskin bottles at 3 locations (1 at Green Canyon and 2 at Viosca Knoll) during a cruise in 2005. Although the data are not statistically rigorous, the visibility conditions were 'normal' for the sites (authors' pers. obs.), so these sediment levels are probably representative of average ambient conditions. Sediment concentration at Green Canyon was  $9.24 \text{ mg l}^{-1}$  and the average of the 2 measurements at Viosca Knoll 826 was  $9.62 \text{ mg l}^{-1}$ . The experimental sediment concentrations were much higher than would normally be encountered at the coral study sites. However, in 2005, our first dive in the Gulf of Mexico at Viosca Knoll was cancelled due to poor visibility; this was 1 wk after hurricane Katrina made landfall on the Gulf Coast. The origins of the turbidity were not investigated; they could have been resuspended benthic sediments or could be of terrestrial origin, but this one observation demonstrates that hurricanes can result in an increase in sediment load, even at depths  $>500 \text{ m}$ .

Similar studies have investigated the response of shallow-water coral species to suspended sediment concentrations and burial. In one study (Rice & Hunter 1992), fragments of 7 species of corals from the near-shore west Florida shelf showed no mortality after exposure to suspended sediment concentrations of up to  $199 \text{ mg l}^{-1}$  for 10 d, and the time to 50% mortality after burial ranged from 7 to 16 d. The collection site for these corals was a turbid area with low coral diversity, and the results show that, like *Lophelia pertusa*, these corals can tolerate moderate suspended sediment and complete burial for several days. During a field experiment in the Philippines (Wesseling et al. 1999), 4 species of shallow reef corals were buried under littoral sediment (16% silt, 46% fine sand and 38% coarse sand) for 6 to 68 h. Increasing burial time had increasingly more serious effects; after 68 h of burial, up to 90% of the tissue bleached and 50% of this tissue subsequently died. After a few weeks, however, the bare areas were recolonized by surrounding surviving tissue. The experiment concluded that complete burial can cause considerable whole-colony mortality in sensitive species (e.g. *Acropora* sp.), and may thus result in permanent absence of coral taxa from reefs that are subject to intense sedimentation events. Less sensitive taxa (e.g. *Porites* sp.) may incur substantial damage but significant recovery was observed after a month. These studies both concluded that although species differed in their tolerance to sediment, some species can survive and recover from severe sediment conditions, particularly those that are found in turbid

conditions. This study shows that *Lophelia pertusa* can survive high suspended sediment conditions and complete burial with fine particulate sediments, but since we know very little about the sediment conditions in deep-water reefs, we cannot yet place these results in an environmental context.

In addition to natural high-sediment events, human activities such as bottom trawling can also locally and temporarily increase sediment load; studies by Palanques et al. (2001) documented a 3-fold increase in the amount of suspended sediment that lasted for up to 5 d after trawling on a soft-sediment continental shelf. Deep-sea coral ecosystems have sustained extensive damage from bottom trawls in search of deep-sea species (e.g. orange roughy), but in addition to the direct destruction of coral colonies, sediment plumes generated by the trawls could also cause further mortality or sublethal stress. It is also possible that deep-sea corals will be exposed to high sediment conditions with the projected increase in the frequency of major storms due to anthropogenic climate change.

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