as 1.5 cm per month. The removal practices are being continued presently with the funding support from MoEF&CC as a part of conservation and management of coral reefs. The invasion is now under control in Krusadai Island, although the alga is not fully eradicated. In Mulli Island, except off the northeastern side, the corals are not affected by invasion. The reef areas are being regularly monitored by the staff of the Forest Department and researchers of SDMRI-RRT.

Ever since the exotic seaweed *K. alvarezii* was introduced into the GoM, print and television media in both English and the local language (Tamil) have played a leading role in making policy makers, administrators, researchers and fisher folk aware of its impact on coral reefs, and the associated biodiversity and livelihoods.

**Conclusion**

Regular manual removal and monitoring has helped to control the invasion of *K. alvarezii* at Krusadai Island, while in Mulli Island most corals have not so far been affected. The removal of the seaweed has also helped to control a further invasion at Shingle Island. In addition, the cessation of *K. alvarezii* cultivation for over 18 months, due to the occurrence of 'ice-ice disease' on the alga, has also helped in controlling the invasion. However, the rapid regrowth of the alga after removal poses a big challenge to conservation managers in protecting the corals in the GoM from the invasion of *K. alvarezii,* because regular removal and monitoring uses a considerable proportion of yearly budgets.

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# Syndepositional cementation in the reef 'Twilight Zone'

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Marine cementation is an essential process for the stabilization of reef framework and resistance to mechanical erosion. It greatly controls carbonate platform geometry and the evolution of porosity in carbonate systems (Marshall 1983; Grammer et al. 1999). Beyond contributing to early coral-reef diagenesis, cementation is believed to encourage reef development both by producing new available substrate for benthic colonization and by maintaining the rigidity of modern and ancient reef structures (Marshall 1983).

Marine cements have been well documented globally in numerous shallow reef habitats (see review by Macintyre and Marshall 1988). Contrastingly, there has been much less research regarding types and rates of syndepositional (geologically "instantaneous") cementation in low-angle shelf mesophotic coral ecosystems (d = 30-150 m) that potentially provide refugia for impacted shallow-water systems as well as new sources of biodiversity (see review by Kahng et al. 2014).

**Methods**

Following a protocol modified by Grammer et al. (1999), in August 2011 4 nylon mesh bags (50 µm) were placed at 3 mesophotic reef habitats, the Primary Bank, the Hillock Basin, and the Deep Patch, as described by Weinstein et al. (2015), and 2 shallow-water reefs, all in the northern U.S. Virgin Islands. At each site, 2 bags were attached to the seafloor and 2 were hung ~1 m above. Bahamian ooids, selected for their uniform carbonate texture, were put into the mesh bags after being examined with a scanning electron microscope (SEM) to confirm the absence of previous cement (Fig. 1a). Half of the mesh bags were collected in May 2012 and the remainder in May 2013. Collected bags were washed with distilled water, dried, and sieved to isolate cemented clumps >1mm. Clumps were split with razorblades, mounted onto stubs, and sputter coated with palladium prior to SEM inspection for marine cement. When present, the dominant cement habit was recorded, and representative images (3-15 per stub) were taken.

For each image in which aragonite fibrous cement occurred, the lengths of 5-10 of the longest "needles" were measured using *Adobe Photoshop*. Selection criteria included: (1) the start and end points of the needle could be estimated (i.e., the view was not obstructed); and (2) the angle between the "needle" length and the two-dimensional photo plane was less than ~45°. These criteria ensured that all reported lengths were underestimated. Based on these measurements and the time since deployment, minimum values were computed for crystal growth.

**Results**

Ooids cemented into clumps after one year at all sites (Fig. 1b). Four distinguishable cement types were identified: (1) fibrous, isopachous (i.e., constant length) aragonite needles (Fig. 1c, d); (2) spheroidal clusters of needles (Fig. 1e, f); (3) stringy, elongated crystals embedded parallel to thick biofilm accumulations (Fig. 1g); and (4) anhedral, semi-equant aragonitic minimicrite (<1µm: Fig. 1h, i). There was no measurable difference in content between seafloor and elevated bags or between bags at shallow and mesophotic reef sites. Fine micrite cement was detected on samples collected after one year at all sites except Deep Patch; the elongated embedded needle cement was only found after two years on seafloor samples from the Primary Bank site. Besides forming between attached grains, cements also formed on unattached ooid surfaces, though only the fibrous needle cement completely covered grains (Fig. 1c). Needle clusters periodically formed atop earlier episodes of cementation (Fig. 1e). Some aragonite needles formed along with organic biofilms (Fig. 2a, b) and microbial cells (Fig. 2c). In cross-section, mini-micrite-sized crystals were often observed (Fig. 2d, e), but it was unclear if these reflected an early cement stage or were part of the ooid interior surface.

Fibrous aragonite needles were the most common cement type overall, though there were no consistent size or abundance trends between sites. The needle lengths for samples within mesh bags elevated above mesophotic reef sites averaged 5.11 ± 0.14 µm and 6.43 ± 0.94 µm (standard deviation) after the first and second collections, respectively. After the first collection, needles from mesh bags on the substrate were found at 1 of the 3 mesophotic reef sites (the Deep Patch); average needle length was 2.34 ± 0.66 µm. Sample bags were collected from the substrate surface at only two of the mesophotic sites during the second collection (the Hillock Basin site sample was not recoverable). Needle length averaged 5.69 ± 0.57 µm. Although needle lengths did not increase significantly between the collection periods, qualitative analysis indicated a higher needle density at all second-collection sites.

**Discussion**

Results show that syndepositional cementation on gently sloping mesophotic coral reef habitats can be similar to that which has been found in other tropical marine carbonate environments (e.g. shallow coral

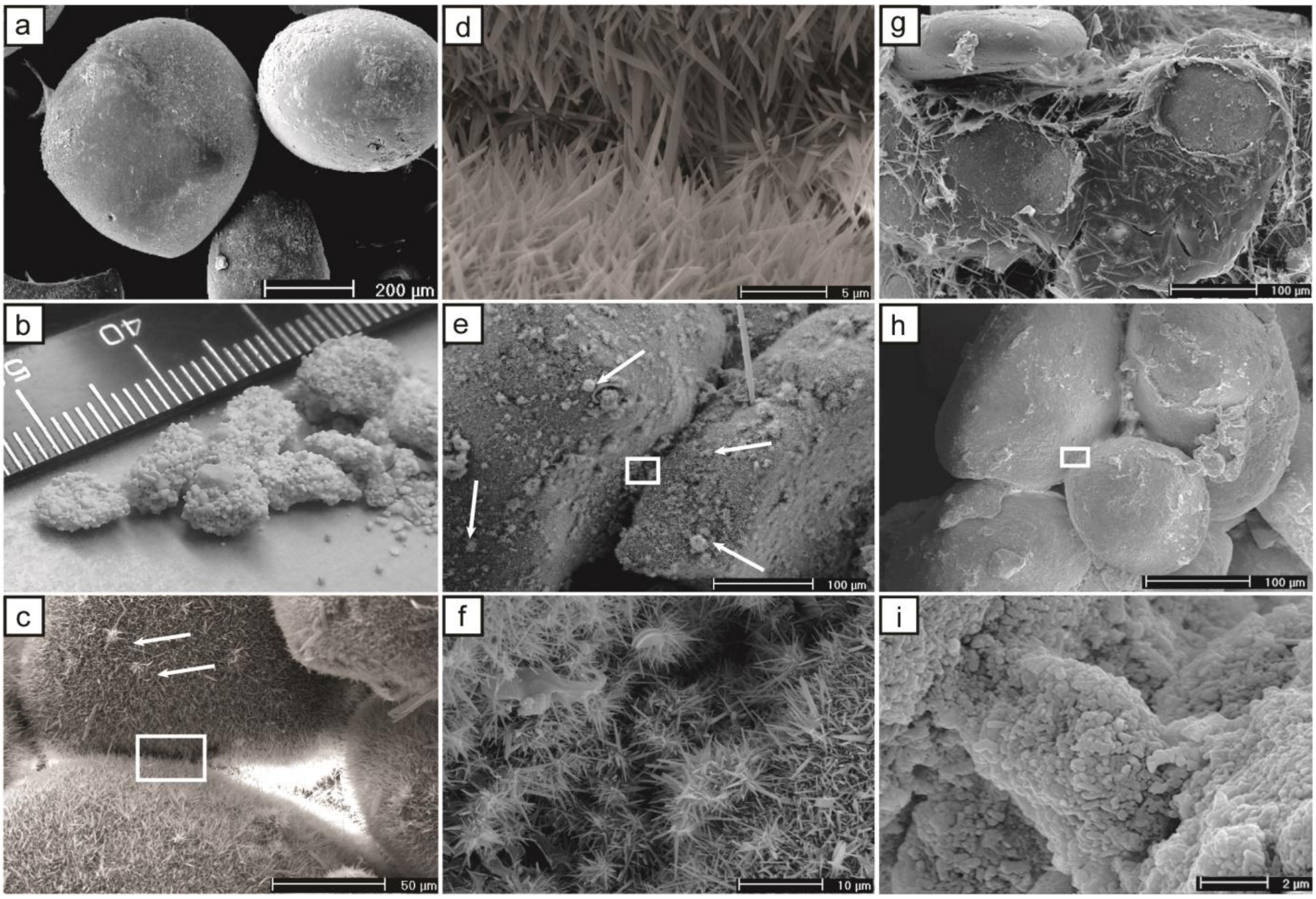

**Figure 1.** Photographs and scanning electron micrographs (SEM) illustrating syndepositional cementation. (a) Smooth Bahamian ooids prior to deployment. (b) Cemented ooid clumps. Scale is in millimeters. (c) SEM of ooid surfaces after 641 days, 1 m above the seafloor at the Hillock Basin site. (d) Inter-fingering fibrous, isopachous aragonite needles between cemented ooids. See white box in c for location. (e) Spheroidal clusters of aragonite needles after 637 days on the seafloor at a shallow-reef site. White arrows indicate secondary cement nodules on top of first generation cement. (f) Fibrous spheroidal cluster cement between attached ooids. See white box in e for location. (g) Elongated cement crystals embedded in biofilm accumulations (parallel to ooid surface) after 625 days on the seafloor at the Primary Bank site. (h) Minimicrite cementation after 277 days on the seafloor at the Primary Bank. (i) Close-up of minimicrite cement between attached ooids. See white box in h for location.

reefs: Friedman et al. 1974, steep mesophotic reefs: James and Ginsburg 1979, deep platform margins: Grammer et al. 1999). Needle lengths were comparable to those reported by Grammer et al. (1999). The depth at which these cements were found confirms that syndepositional cementation is not always influenced by wave conditions, as previously speculated (Marshall 1983; Macintyre and Marshall 1988). Beyond implying the possibility that submarine cementation facilitates the maintenance of structural complexity within mesophotic reefs, the rapid syndepositional cementation described here supports arguments for geologically instantaneous stabilization of depositional carbonate slopes at mesophotic depths prior to the Holocene (Della Porta et al. 2003). Although no recognizable trends were identified within or between shallow and mesophotic reefs, results from this study still imply high potential for the preservation of sedimentary subfacies and subsequently the ability to identify habitat heterogeneity in ancient mesophotic reef deposits (Weinstein et al. 2015).

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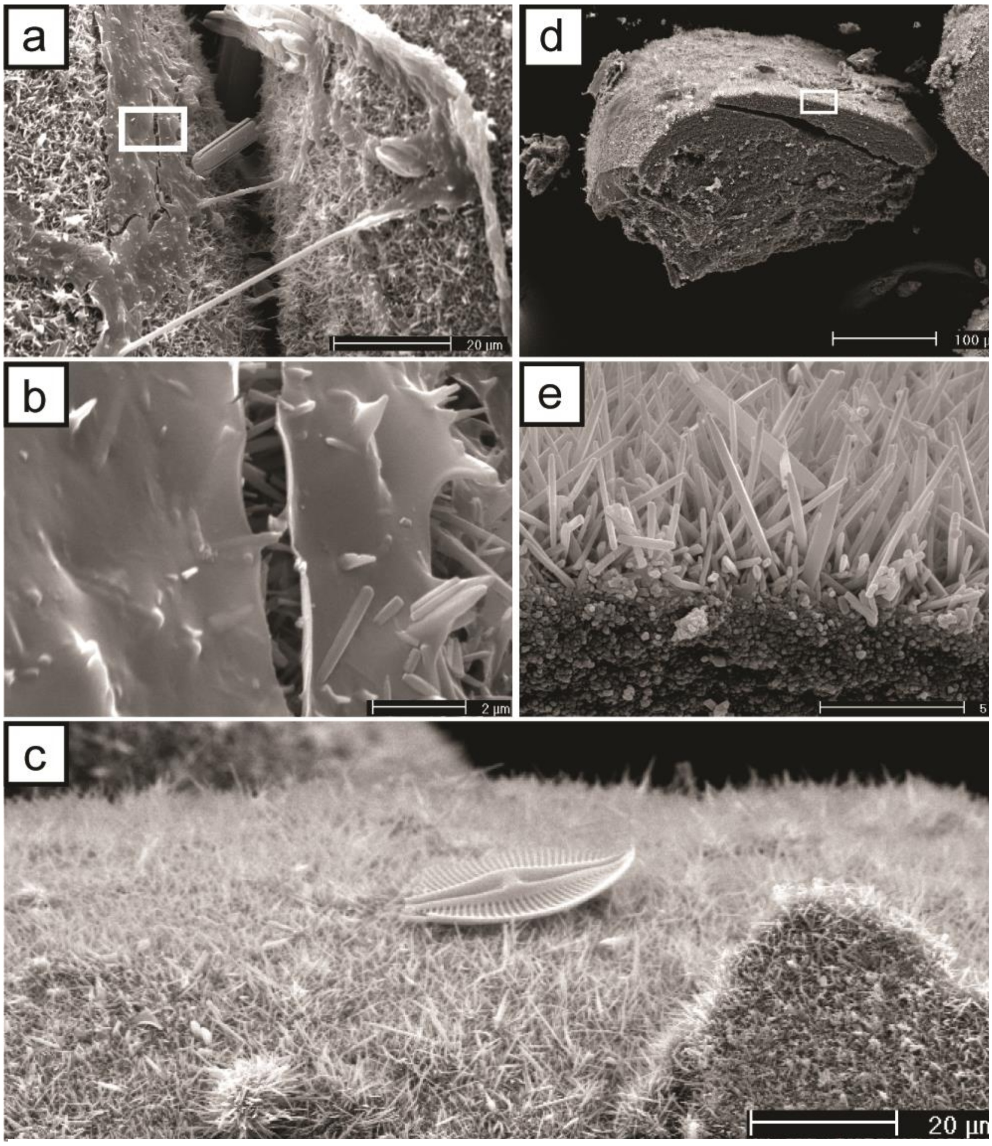

**Figure 2.** Scanning electron micrographs of cement associations. (a) Ooids coated with fibrous aragonite cement and stringy extracellular polymeric substances after 289 days, 1 m above the seafloor at the Hillock Basin site. (b) Close-up of sheet-like biofilms draped over needles. See white box in a for location. (c) Grain exposed 277 days, 1 m above the seafloor at the Primary Bank site shows common association between cements and biological entities such as the diatom near the center of the field of view. (d) Ooid cross section covered with radiating fibrous aragonite cement after 635 days, 1 m above the seafloor at the Deep Patch. (e) Close-up of the basal connection between fibrous cement (above) and minimicritic (below) along the ooid surface. See white box in (d) for location.

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