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ScienceDirect
Continental Shelf Research 27 (2007) 2224–2230
CONTINENTAL SHELF RESEARCH
www.elsevier.com/locate/csr

A deep reef in deep trouble

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Received 5 March 2007; received in revised form 9 May 2007; accepted 15 May 2007
Available online 16 June 2007

Abstract

The well-documented degradation of shallower reefs which are often closer to land and more vulnerable to pollution, sewage and other human-related stressors has led to the suggestion that deeper, more remote offshore reefs could possibly serve as sources of coral and fish larvae to replenish the shallower reefs. Yet, the distribution, status, and ecological roles of deep (>30 m) Caribbean reefs are not well known. In this report, an observation of a deep reef which has undergone a recent extensive loss of coral cover is presented. In stark contrast to the typical pattern of coral loss in shallow reefs, the deeper corals were most affected. This report is the first description of such a pattern of coral loss on a deep reef.
Published by Elsevier Ltd.

Keywords: Coral reefs; Deep water; Mortality; Unmanned vehicles; Caribbean

1. Introduction

Most studies on Caribbean coral reefs are based on sites shallower than 30 m (e.g., see studies in Gardner et al., 2003). This concentration on shallow sites provides an incomplete and biased view of coral reefs because many reefs lie entirely or partially below this depth. Photosynthetic reefs, which have zooxanthellae and are the reef-type most studied, have a depth range that extends to at least 119 m (Reed, 1985). Their depth is limited by light penetration. Azooxanthellate reefs which are not limited by light can be found much deeper (Roberts et al., 2006). In this report, 'deep reefs' refers only to photosynthetic reefs.

Shallower coral reefs have been the focus of most studies for two major reasons. First, the principal coral survey methods, basic SCUBA diving and remote sensing, are restricted to shallow waters (<30 m), due to limits of conventional diving and light penetration, respectively. Second, the survey techniques capable of penetrating to greater depths, including drop cameras, advanced SCUBA (e.g., saturation diving, mixed gas diving), remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and submersibles, are expensive and logistically demanding. The costs of these emerging technologies have resulted in a small fraction of studies at deep sites. Information on coral reef systems below 30 m, including where they

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0278-4343/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.csr.2007.05.017

are found, their ecological roles, threats to them, and their status remains poorly understood.

The few studies of deep Caribbean reefs indicate that they may be different from shallow ones. Mapping surveys show deep reefs typically have greater coral cover and lower coral diversity (Jarrett et al., 2005; Armstrong et al., 2006) and monitoring studies have not detected coral declines (Bak and Nieuwland, 1995; Bak et al., 2005) observed among shallow coral systems throughout the Caribbean (Gardner et al., 2003). Such patterns have led to the suggestion that corals on deep reefs could serve as a source of future recruits for shallow reefs during times of stress (Glynn, 1996; Riegl and Piller, 2003). Considering the paucity of data on deep reefs, there is a critical need to map and monitor their condition and investigate possible ecological linkages with shallow reefs. What if the worldwide deterioration of shallower reef systems is already affecting deeper reefs? The answer to this question is becoming more important as coastal populations continue to grow (Hoegh-Guldberg, 1999), global warming continues, and a search for ways to mitigate the decline of shallow reefs remains.

As part of a broader project to map the deep benthic habitats of the US Virgin Islands, an extensive coral mortality event was discovered on a deep reef (depth 40 m). The event was particularly noteworthy in that it was the deeper parts of the reef that were affected; a pattern inverse to that observed in studies on shallow reefs. The extent and pattern of coral mortality and lack of data for deep reefs compelled an account of these observations. In this report the mortality event is described and possible causes are discussed. The goal of this manuscript is to highlight the need for further discussion and surveys of deep reefs, and to show that deep reefs cannot be viewed as categorically invulnerable.

2. Materials and methods

In February 2005, the NOAA ship *Nancy Foster* collected video and still camera images of the seafloor around the US Virgin Islands using a Spectrum Phantom S2 remotely operated vehicle (ROV). The ROV data were collected to ground truth multibeam sonar surveys of the area. One of the mission's exploration targets was a reef, hereafter referred to as Mid-shelf reef #1 (MSR-1), situated among a network of mid-shelf reefs between the island of St. John and the insular shelf edge which is 20 km to the south (18.25°N, 64.77°W) (Fig. 1). The shallowest parts of most near-shore, mid-shelf reefs have been surveyed and described by others including Monaco et al. (2007).

MSR-1 is relatively deep, 30–40 m, and remote. A vast expanse of sand and rhodoliths extends in all directions for a minimum of 5 km. The closest developed area is the town of Cruz Bay (population 3000) on St. John, 8 km to the north. Over half of St. John and much of the surrounding water are within the Virgin Islands National Park. In general, anthropogenic impacts such as pollution and runoff are dramatically less on St. John than on many other Caribbean islands.

The ROV traversed MSR-1 from SE to NW approximately 1 m above the seafloor during daylight hours. Bathymetric survey data (source: National Oceanic and Atmospheric Administration, Satellite and Information Service) were used to direct the ROV along MSR-1's shortest cross-section. This was done to obtain imagery of all the transitions among bottom features (e.g., reef to rhodoliths, reef to sand), along the reef in the shortest amount of time. The transect represented a 1200 m × 1 m swath of MSR-1.

Video was continuously collected along the transect using a forward pointing camera to assist in visualizing three-dimensional benthic structure and to help navigate the ROV. High-resolution still images of the seafloor were systematically collected every 30 s using a downward pointing camera. The speed of the ROV was kept between 0.5 and $1\,m\,s^{-1}$ which resulted in images spaced approximately every 16 m (S.E. 1.7). Each image was estimated to cover $1\,m^2$ area ± 50 cm. An ultra-short baseline system and differential geographic positioning system were used to determine the geographic location of each image within ~5 m. A pressure sensor mounted on the ROV was used to determine the depth.

High-resolution still images (a total of 69) were used to characterize the spatial distribution of benthic cover types. For each image, the relative area of live coral, dead coral with algal turf (DCA), fleshy macroalgae, other biological cover types (e.g., sponges, coralline algae) and bare substrate was estimated visually with the aid of a 10 × 10 grid superimposed on each image.

Following analysis of the images, the transect was divided into six broad-scale reef zones based on macroscale reef morphology (Fig. 2). Zone divisions were positioned at points of inflexion in depth and divided reef valleys from ridges. Zone A, where the transect began and which was the farthest offshore