9-1-2001

Mapping and Monitoring of Coral Communities and Their Spatial Patterns Using a Surface-Based Video Method from a Vessel

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NSUWorks Citation

Bernhard Riegl, Jan L. Korrubel, and Charles Martin. 2001. Mapping and Monitoring of Coral Communities and Their Spatial Patterns Using a Surface-Based Video Method from a Vessel .Bulletin of Marine Science , (2) : 869 -880. https://nsuworks.nova.edu/occ_facarticles/340.

BULLETIN OF MARINE SCIENCE, 69(2): 869–880, 2001

MAPPING AND MONITORING OF CORAL COMMUNITIES AND THEIR SPATIAL PATTERNS USING A SURFACE-BASED VIDEO METHOD FROM A VESSEL

Bernhard Riegl, Jan L. Korrubel and Charles Martin

Maps are useful tools for understanding spatial dynamics and the general distribution of ecosystems, which is of high value to resource managers and scientists (Catt and Hopley, 1988; Mumby et al., 1995; Sheppard et al., 1995), and many management plans rely heavily on maps. Restoration ecologists are aided by maps to be able to assess the severity of impacts and to be able to produce restoration strategies. A variety of approaches exist to mapping the spatial distribution of benthic biota and bedforms, like remote sensing from satellites or planes (Mumby et al., 1995), or geophysical methods like side-scan sonar surveys (Masson et al., 1998; Piper et al., 1999). Most of these methods were developed for specific reasons other than coral reef research and coral-specific applications have only fairly recently been developed (Green et al., 1996; Mumby et al., 1995).

The method described in this paper is an application that was specifically designed for coral research. In order to establish the value and spatial distribution of coral areas that were almost accidentally discovered during a dredging pre-survey in the southern Arabian Gulf (Dubai, United Arab Emirates), a concise method was called for that not only allowed the description of the coral covered area, but also allowed coral species to be differentiated as well as the healthy coral distinguished from the diseased. This called for a visual survey, since other frequently used methods, like airborne imagery or side-scan sonar, allow delineation of coral covered area but give no information on species or health status. Due to the large area involved (37.7 km^2), the time-frame available and the desired level of accuracy (100% visual cover of the area), a diver-based mapping approach (Riegl and Piller, 1997) was not possible. Therefore, rather than have divers undertake large numbers of video transects, we decided to make 'mega-video transects' from a boat that covered the entire coral area. This had the advantage of significantly reducing diver time, speeding up overall survey time, and increasing accuracy by providing 100% recorded visual cover of the coral area. The desired output was a map that specified spatial patterns of coral communities that could be used for management planning. Furthermore, over 1996 a thermal anomaly led to widespread coral mortality in the study area (Riegl, 1999) and it was of interest to map the spatial extent of coral growth lost in this event.

This paper describes (1) the technical details of the vessel-based video survey, (2) shows the product (the maps), and (3) discusses management and monitoring implications of the product.

Material and Methods

The Survey Area.—The area investigated was a shallow subtidal sea-bed, sloping gently offshore to depths of around 9 m. Bottom topography was uniform without major highs or depressions over most of the area, except some low ridges, which rose less than 2 m above the surrounding, flat sea-bed. Corals were found in a belt between 200 and 2000 m offshore (Fig. 1) with a variable density, diversity, and surface cover.

Most of the sea floor was sandy, underlain in wide areas by early diagenetically cemented calcarenites (Shinn, 1969; Evans et al., 1973), also referred to as cap-rock, which provided substra-

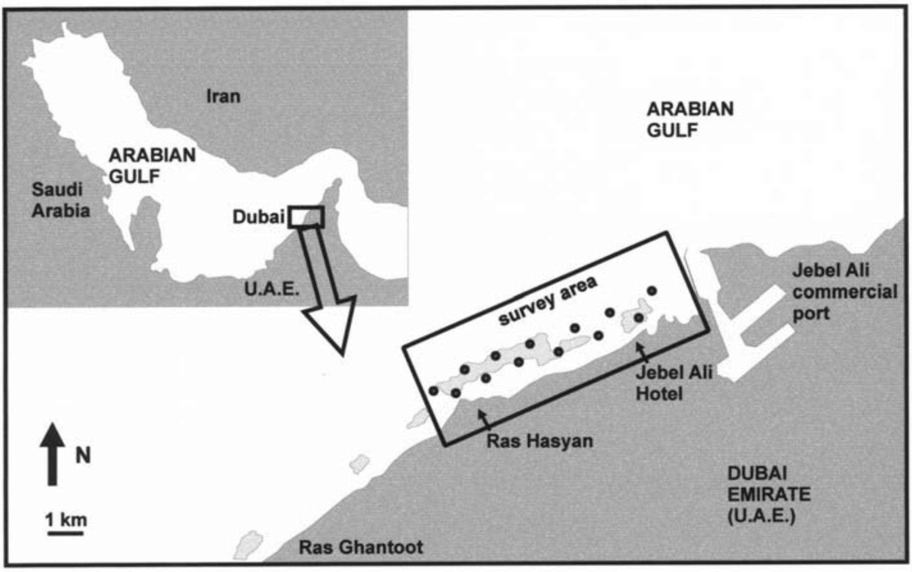

Figure 1. Study area in the southern Arabian Gulf (Dubai, United Arab Emirates). The discontinuous areas of dense coral growth are surrounded by a line. The study area presented in this paper is indicated by a square.

tum for coral settlement. Corals were only found in areas with rocky substratum. They can be best classified as non-framebuilding coral communities sensu Riegl and Piller (1999).

THE VIDEO MAPPING METHOD.—Underwater vertical videography was undertaken from a 41-ft survey vessel fitted with retractable side-booms and six high-resolution video cameras, three cameras (HITACHI VM-H58E) each to port and starboard (Fig. 2). The cameras were fully automatic,

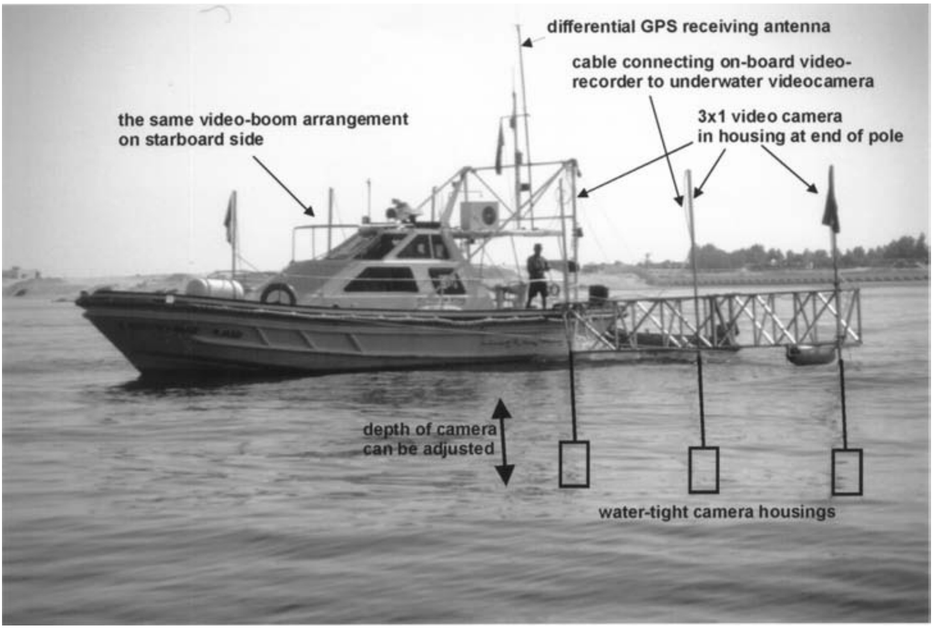

Figure 2. View of the survey vessel.

with auto focus, auto exposure, electronic image stabilizer, and digital zoom (up to ×24) capabilities. Cameras were fitted with HITACHI VM-CL30W wide-conversion lenses, giving each camera a roughly 1:1 height to field-of-view ratio, whereby the field-of-view was 15 cm wider than the height ensuring camera overlap and guaranteeing 100% video coverage. The cameras were fixed at the end of vertical extension tubes that could be lowered or raised between 0.5 and 3.5 m below the sea surface in order to provide a constant distance between the camera-lens and the sea-floor for work in variable water depth. Typically, the cameras filmed sea-floor in approximately 6.4 m of water, giving a 24-m-wide panoramic video swath if lowered to a depth of 2.4 m. The survey vessel sailed along pre-determined survey lines of 20 m spacing, thus ensuring overlap (Fig. 3).

For recording, the video cameras were individually linked to six onboard video recorders which made it possible to leave the cameras underwater when changing video tapes. Via a seventh video deck with karaoke capability, an audio track of way-point information, which correlated to differential GPS fixes that were continuously logged, was simultaneously recorded at regular intervals to geo-reference the video material to the survey map. The audio fixes were correlated to differential GPS fixes by hardcopy printout. For simultaneous onboard viewing of recorded seafloor imagery, three color TV monitors were installed onboard.

To complete the analysis of the seabed features, the panoramic video swath was viewed on six color TV and VCR combination players. The players had a built-in display timer, useful for synchronizing the tapes, and were controlled by a single, wireless remote control unit, thereby controlling all six players simultaneously.

Statistical Description of Coral Communities

In order to be able to map coral communities and associated biota, it was first necessary to describe meaningful associations that could be identified both visually and statistically and that had ecological meaning. Therefore, prior to undertaking video data gathering, a quantitative analysis of benthic biota, in particular of coral communities, was undertaken. Associated biota, such as seagrass meadows and stands of brown algae were investigated qualitatively.

The distribution of the coral covered area was known due to a previous side-scan sonar survey. Thirteen evenly distributed, equidistant sample points were selected within the survey area (Fig. 1). The sample points were located by means of differential GPS fixes. In these localities, diver observations by means of transect sampling with point-intercept recording in 1-m intervals on 50-m line transects was performed. Two transects were taken in each locality due north and due south of the sample point markers; another 14 transects were collected in intermediate areas of special interest (especially dense or sparse coral cover that had not been sampled in the other sites). Variability in ground cover favored the 50-m point count line transect method over alternative transect methods, like the more precise 10-m continuous intercept recording line transects. This was because, in areas of low coverage, in order to avoid undersampling communities of small, widely spaced colonies, the longer point recording transects gave results that were more applicable to the video mapping approach since they recorded larger-scale patterns (Riegl, 1999). The community patterns described by the 10-m transect method were at too small a scale to be practicable for use in conjunction with the video transects.

Direct hits on all underlying coral species, benthic invertebrates and macro-algae were recorded at each 1-m interval along the 50-m transects. Also the type of substratum, classified as either sand, limestone, or rubble, was recorded.

Two multivariate techniques were used to detect patterns within the data-set: agglomerative hierarchical cluster analysis and multidimensional scaling (MDS; Digby and Kempton, 1987; Agard et al., 1993). MDS was preferred over PCA (principal components analysis) as the latter is better suited for the analysis of environmental data (continuous data) than species abundances (James and McCulloch, 1990; Clarke and Warwick, 1994). Furthermore MDS is not limited to the description of patterns within the community but has successfully been used to link community structure to environmental variables (Clarke and Ainsworth, 1993, Agard et al., 1993) and to estimate severity

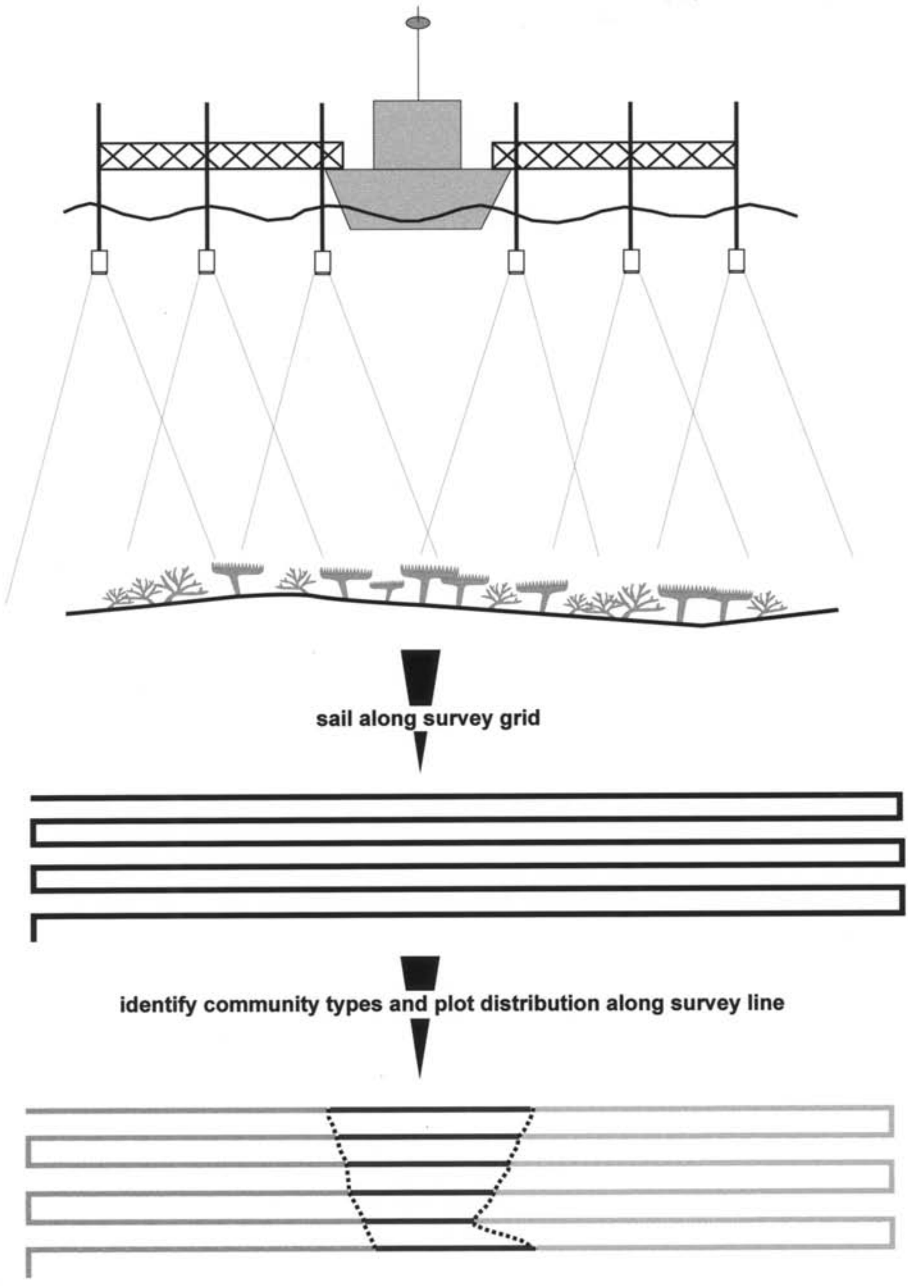

Figure 3. Overview sketch of the survey technology. The vessel is shown with downward facing video cameras. The fields of view overlap, providing a 24-m wide swath of continuous video coverage. The vessel sails along predetermined survey lines of 20 m spacing. Thus the entire surface area of the area of interest is recorded. Videos are then viewed and the spatial distribution (obtained by correlating video frame number with GPS data string) of previously determined bottom types marked along the survey lines printed on the chart. By connecting the contours between the adjacent survey lines, the spatial pattern becomes apparent.

of disturbance (Warwick and Clarke, 1993). Both multivariate methods were used as it was not certain how distinct community structure would be between sites. Each of the above statistical methods has advantages for delineating groups: in a very distinct community setting, cluster analysis separates samples better, while in sample sets with gradations between communites, MDS has more advantages (Field et al., 1982; Kenkel and Orloci, 1986; Warwick et al., 1988). If both analyses provide consistent results, it is likely that they represent natural groupings.

Since these community types were easy to recognize visually, they were used for the video analysis. A series of images was produced of each community type depicting typical species, typical substratum coverage by corals and the typical visual aspect from the surface as recorded in the video transects. The images were placed next to the video-monitors within the field of view of the observers. Therefore, it was easily possible to cross-check community types while watching the video.

After maps were complete, in order to obtain information on spatial coverage of the mapped components, the maps were imported into a ZEISS KS 400 3.0 image analysis program which allowed determination of total space cover of corals in the surveyed area. Thus the total area of framework formation potential could be calculated both in km^2 and percentage of total mapped area.

Results

After data obtained by 50-m point intercept sampling were subjected to cluster analysis using Euclidean Distance as measure, only the clusters formed by the first four dichotomies (of greatest Euclidian Distance) were used for the description of communities. Clusters formed at smaller distances could not be interpreted any more. The MDS ordination mostly supported our interpretation of best cluster size (i.e., best cut-off distance) and the identification of natural transect groups in the classification. Transect groups A and C did not separate as well in the MDS plot as in the cluster analysis (Fig. 4). Biological characteristics of transect groups are given in Table 1.

The analyses of the transects revealed the frequency of each community type on the reefs. Because sampling sites were spread evenly over the reefs, the frequency of each community type was expressed as a percentage of a total number of samples. Therefore, the biggest clusters contain the most widely distributed community (A followed by B and C, Fig. 4).

The most widely distributed community type was represented by group A, which was split by the MDS into two groups, A1 and A2 (Fig. 4). Both groups were dominated by *Porites lutea* (Table 1), but differed in contribution by other species to within cluster similarity (see percentage values in brackets, column 2 of Table 1). However, the differences were hard to tell on the videos, therefore, the two assemblages were amalgamated in the mapping. Coral cover was generally low (Table 1), but individual colonies, particularly massive *P. lutea* and *P. lobata,* reached diameters of up to 4 m. The substratum surrounding the isolated corals had little coral growth and was typically sand. This community was found in most parts of the study area and graded laterally into several other communities, like B or C, or into sand. It was not affected by the 1996 mass mortality event; only the few individual *Acropora* present in this community died, which did not change the community's aspect.

Transect cluster (i.e., community) B (Fig. 4) included the areas of highest coral coverage and diversity, dominated by *Acropora*. The dominant species was *A. downingi*. In peripheral areas, the coral cover was more sparse and dominance shifted to *A. pharaonis*.

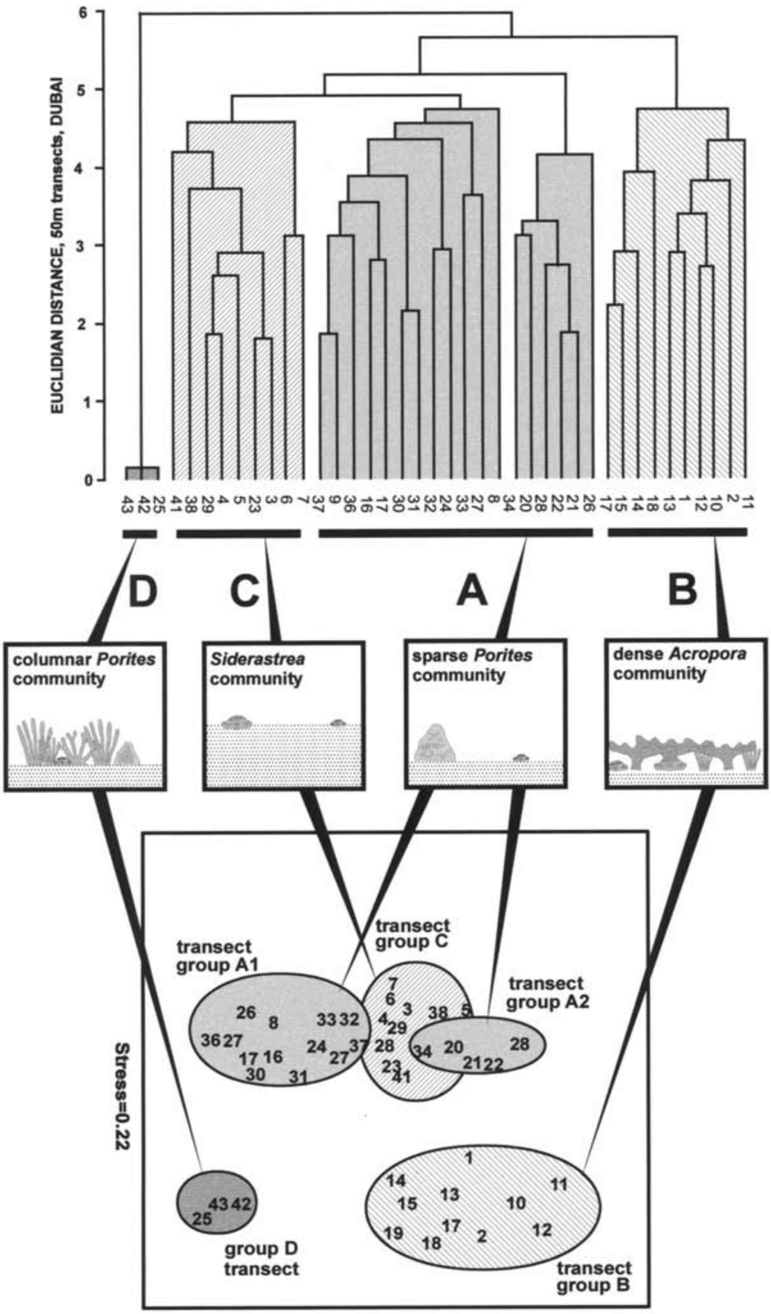

Figure 4. Statistical description of communities. (A) Classification of the 50-m point-intercept line transects. The last five dichotomies of highest Euclidian distance included ecologically and visually interpretable and recognizable clusters. A sketch shows the community's aspect; Table 1 defines biological characteristics. (B) The plot of the same transects produced by multidimensional scaling. Some sample numbers are missing due to superposition of several samples.

Table 1. Biological characteristics of coral communities in the Arabian Gulf study area between Jebel Ali and Ras Hasyan. Community code refers to Figure 4. Dominant species are those that cover the most space within each community (i.e., ecologically and visually dominant). Dominant typology refers to the growth-form type found in most constituent corals of the respective community. 'Big massive' means that corals usually attained sizes up to and over 50–100 cm diameter; 'small massive' means that corals were usually less than 10 cm in diameter. Values are percentages of total transect (sample) area covered by each community (all species).

Community Code	Dominant species (alive) in 1996	Living coral cover (% of sampled area), all species	Dominant typology of corals
A	*Porites lutea*	21 ± 11	Big massive
B	*Acropora downingi*	54 ± 22	Tabular, branching
C	*Siderastrea savignyana*	14 ± 7	Small massive
D	*Porites harrisoni*	51 ± 2	Columnar

Other common species were *A. horrida, A. florida,* and *A. tenuis*. The substratum was cap-rock with a thin cover of coarse sand in some places. Living coverage was between 50 and 70%. On the periphery, this community graded into an increasingly *Porites*-dominated system. During the 1996 mass mortality event, all *Acropora* within this community died. Only the small massive colonies growing underneath the tables, mainly *Porites* spp., survived, which totally changed the ecological and visual aspect of this community.

The community sampled in transect cluster C (Fig. 4) was made up of *Siderastrea savignyana* colonies on cap-rock in flat areas of low sand coverage. The coarse sand covering the cap-rock was usually arranged in ripple trains. *Siderastrea* were found in the valleys between the ripples. They were frequently covered by ripples moving over them, but not killed. Other important coral species in this community were *Pseudosiderastrea tayamai*, *Porites* cf. *mayeri*, and *Coscinarea monile*. Coral cover and diversity were low (Table 1) and the community was not affected by the 1996 mortality event.

A spatially restricted community (Cluster D) which covered little space on the reefs consisted mainly of densely packed colonies of *Porites harrisoni* which built a small reef framework. Space cover within the reef patches was around 80%. Within the *Porites* framework was little loose sediment and it was usually surrounded by cap-rock with thick sand cover. This community was also not affected by the mass mortality event.

This analysis allowed the definition of five visually easily identifiable and mappable coral community and bottom types:

1. Dense *Acropora*-dominated community (mainly *A. downingi*)
2. Sparse massive *Porites* dominated community (mainly *P. lutea*)
3. Columnar *Porites* community (mainly *P. harrisoni*)
4. Seagrass and algae beds
5. Sand (bare sand and sand with *Siderastrea* community)

It was not possible to differentiate the two massive *Porites*-dominated communities on the videos, so they were lumped and mapped as the same. Also, it was not possible to tell the *Siderastrea* community from bare sand. The individual colonies were too small to be picked up. Therefore, this community was not differentiated on maps from areas of bare sand.

The complete video survey yielded some 400 h of video. The videos were viewed simultaneously on six parallel video screens which showed the entire survey swath. The video frame numbers displayed on the video screen could be correlated to the recorded differential GPS position data-string via macros written in MS Access. On a chart, the position of the survey lines was plotted. Video footage corresponding to the survey lines was viewed, and the bottom types were marked onto the chart with different color text markers (for example: bottom type 1 extends from video frame X = GPS position x, to video frame Y = GPS position y; then followed by bottom type 2 from video frame Y = GPS position y to video frame Z = GPS position z, etc.). After the entire video footage was viewed and bottom types marked onto each survey line, the contours between the marked bottom types were connected between the survey lines (Fig. 3). Then the map was digitized and imported into a CAD program for final production of the map. In a last step, the bottom-type map was overlain with depth contours, which had been obtained by multibeam echosounder.

In order to measure the exact areas covered by each bottom type, the finished map was imported as a TIFF image into a ZEISS KS 400 3.0 image-analysis program. The image was converted to black and white, which allowed using the automatic measuring option. The part to be measured was kept in white and the area calculated automatically in pixels. In several subsequent stages, each desired component of the map (i.e., *Acropora* areas, total coral area, seagrass area, etc., Table 2) was marked in white, all surrounding areas converted to black, and the areas measured. Pixel measurements were then converted into square kilometers by measuring the area of a square kilometer in pixels on the screen (Table 2).

Discussion

The approach presented here is a relatively fast, medium-cost, but very accurate method of mapping corals or any other desired benthic biota. The surface-based video method has the advantage that once the underwater work for defining the mappable community types is finished, virtually no further underwater time is necessary and data collection is very fast. Therefore, after the underwater sampling is finished, the vessel-based survey team only needs to consist of a skipper and the data-processing team. This consists usually of a minimum of two people, one responsible for viewing the videos, the other for manipulating data (cross-correlation of video-frame number and GPS position). Once the survey grid is recorded, the main workload is viewing the recorded videos. The time involved can be shortened by having on-board observers record community types on the base chart simultaneously with data collection while the vessel is still under way. This can be achieved by connecting the video cameras to on-board screens for simultaneous viewing and recording and by having real-time differential GPS data available.

The video method has several advantages over other survey methods, like side-scan sonar, for example, which was used for comparison in the present study. Sonar images give good resolution data of the sea-floor, however, resolution is frequently not good enough to allow species identification. Similar limitations apply to the use of aerial photography which additionally cannot be used in turbid areas or if the matter of interest is in deeper waters. Also, the scale of aerial photos is frequently too big to allow the differentiation of small-scale patterns in coral communities (Mumby et al., 1995). Both methods so far have only limited capabilities to differentiate between dead and live corals. Since

Table 2. Areas of the mapped biota as obtained by image analysis using a ZEISS KS 400 3.0 system. Values were first measured in pixels and then converted to square kilometers. Such data can be further used, for example, for the calculation of carbonate budgets or to monitor changes in total coral covered area in response to mass mortality events.

	Area in pixels	Area in km^2
Standard square kilometer	24,000	1
Total sample area	905,824	37.7
Total area covered by seagrass and algae	92,116	3.8
Total area covered by corals	357,586	14.9
Total area covered by *Acropora* framework	187,139	7.8
Total area killed in 1996 mortality event	187,139	7.8
Total area covered by living coral frameworks (*Acropora* and *Porites harrisoni*) in 1996	189,084	7.9
Total area covered by living coral frameworks (*Porites harrisoni*) in 1998	1,945	0.1

the video method provides full visual information, species identifications are possible as well as evaluation of coral health. Also, frame-grabber software can be used for the evaluation of specific sections of the videos, i.e., coral sizes could be measured, frequencies of diseases, etc. The videos can then serve as a monitoring tool.

The video-method requires clear water and a flat seafloor. High rugosity would make area calculations from the individual video frames difficult, since the distance of the seafloor to the lenses would vary constantly. However, determination of community type and health would still be possible. Very turbid waters greatly decrease the depth to which a survey is possible. However, in coral areas this is frequently not the limitation and adjustments can be made by lowering the video booms (Fig. 2) and thus reducing the amount of water between the camera and the sea floor.

Maps of the quality produced by this survey method are valuable for reef management. The maps presented here were used in the original conceptualization of the Jebel Ali marine reserve (Riegl, 1998) since they showed how much dense coral growth there was and how much area was covered by corals. Later the maps were used to determine mortality caused by a thermal anomaly in 1996 which eliminated all *Acropora* in the study area (Riegl, 1999). Figure 5 and Table 2 show the extent of the *Acropora* die-back. Without the map, the severity and extent of the event would have been difficult to estimate spatially. Also, the map allows to select specific sites (for example in the middle of the dead area) that could be used as core areas for transplantation of healthy corals.

Summary

A surface-based video survey and mapping approach was used in the Arabian Gulf (Dubai, U.A.E.) to map the spatial patterns in coral communities and associated biota (seagrasses and brown algae beds). On a 41-ft survey vessel, six downward-facing video cameras were installed on retractable side-booms that recorded a 24-m wide swath. A grid of video transects in 20 m spacing was surveyed over the entire coral covered area (previously determined using side-scan sonar), thus assuring 100% coverage. During the survey, a differential GPS data string that was cross-correlated to frame number on the simultaneous video recording was recorded. Therefore, the determination of each video

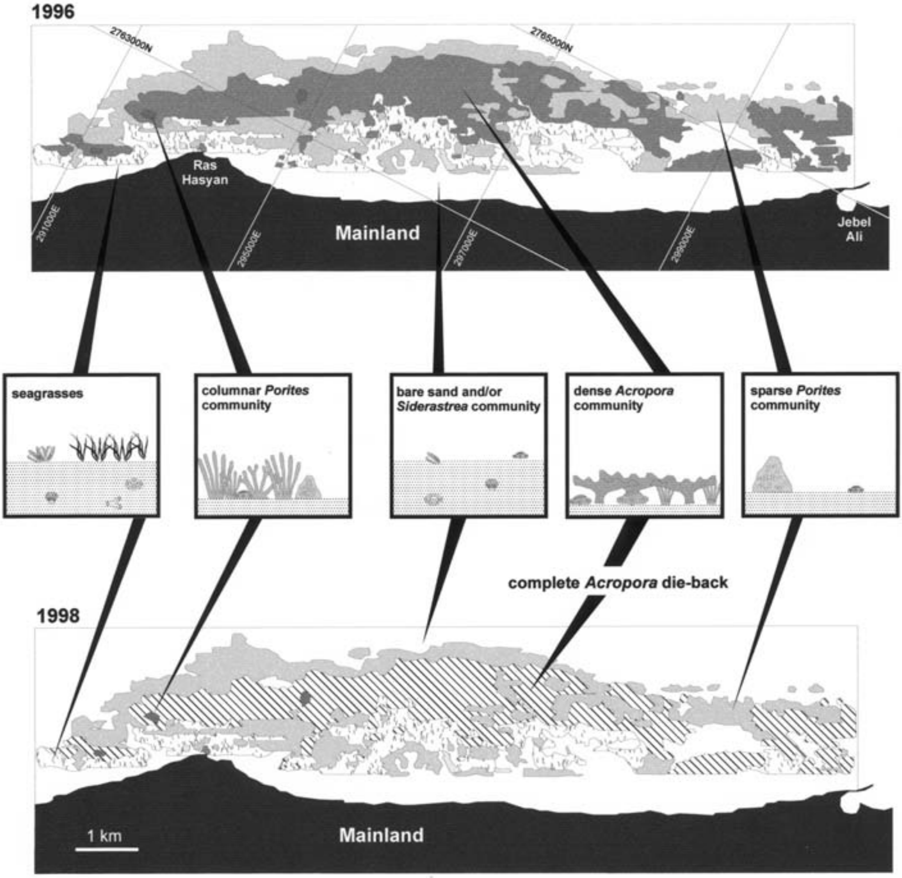

Figure 5. Spatial patterns in coral communities and associated biota in the Jebel Ali area in 1996 and 1998. Over summer 1996, a mass mortality killed all *Acropora* in the area (Riegl, 1999). Using the outlined mapping approach, it was possible to determine the exact damaged area.

frame's exact position was possible. Coral community types were described statistically by using 50-m point-intercept transects. From this analysis, five statistically and visually discernible community and bottom types were determined (dense *Acropora*; sparse massive *Porites*; dense columnar *Porites*; seagrass and brown algae; sand). The distribution of these community types along the survey lines was then determined visually, by watching the videos and calculating the distance traveled by the survey vessel over each community type by cross-correlating video frame number and differential GPS data. The maps produced were used for management planning of a marine reserve and for monitoring.

Acknowledgments

This study was supported by the Austrian Science Foundation (FWF) under grant number P-13165-GEO. The method was originally conceptualized while the authors worked at Martin Mid East Ltd., Abu Dhabi. Hydrographic survey and vessel design by C. Martin. Financial and logistic support was also granted by Dubai Municipality and Martin Mid East Ltd. Post-processing of maps and image analysis was done at KFUG.

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