Coral reefs: research methods
D.R. Stoddart and R.E. Johannes, eds.
Monographs on oceanographic methodology 5
Unesco 1978

4

Photogrammetry of reef environments by helium balloon

K. Rützler[1]

Present findings show that aerial photography by balloon-suspended camera is an inexpensive and easy-to-use technique with a good potential for hitherto unexplored applications. At remote locations where airplanes or helicopters with sophisticated photogrammetric equipment are not available, the balloon method may be the only means for producing accurate maps with substantial area coverage.

When undertaking an ecological study the initial step is to survey the region to determine the kinds of habitats present, their extent and their location. A coral reef comprises a number of geomorphic and biogenous features, such as the actual reef framework, rock, sand patches, sea grass areas, mangroves, lagoons and islands. An accurate knowledge of this topography and of the water depth distribution enables one to pinpoint localities for collecting and subsequent floristic and faunistic inventory. More imporant, a careful reconnaissance provides the basis for understanding the impact of physical, chemical and biological processes that are connected with water currents, waves and tides, as well as with meteorological and other parameters. Habitat maps are valuable tools for the selection of significant sampling locations and experimental sites and, finally, they serve as a reference for future topographical changes caused by constructive processes or destructive forces.

Ground-level mapping of cays and shallow reefs is routine (Stoddart, 1962; Domm, 1971; Stoddart, Chapter 2) and will continue to produce records of unequalled resolution. The same techniques can also be used by divers underwater where they are aided by the possibility of taking vertical photographs (Johnston *et al.*, 1969; Rützler, 1976). This touches one of the weaknesses of ground-level mapping, the difficulty of copying complex shapes and maintaining correct proportions. The procedures are tedious and frequently subject to error.

Aerial photography has long been used for large-scale mapping and for creating matrices where details can be filled in by other surveying methods

1. Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

(Kumpf and Randall, 1961; Macintyre, 1968; Smith and Anson, 1968; Adey, 1975; Hopley, Chapter 3). The problem of speed, inherent in low-flying airplanes, has been overcome by the use of helicopters, which have been successfully employed for survey of marine habitats (Ellis, 1966; Burton and Buhaut, 1975).

Many ecological studies, on coral reefs in particular, are conducted in remote areas where logistical support in the form of airplanes or helicopters are difficult and expensive to obtain. Although small private airplanes can be chartered at many locations, they usually do not permit good vertical photography at low altitude. Discouraged by similar problems, archaeologists developed a camera system which was suspended from a hydrogen-inflated balloon and which could be used to detect and map Greek temple sites in the Mediterranean (Whittlesey, 1967). This technique was applied with equal success to terrestrial and submarine excavations (Jameson, 1974).

During the Smithsonian Reef Project at Carrie Bow Cay, Belize, the cay and reef flat, including principal community components, were mapped from the ground. A 600 m main transect crossing the barrier reef, from the lagoon to and down the fore-reef slope was the focal point for many efforts to determine

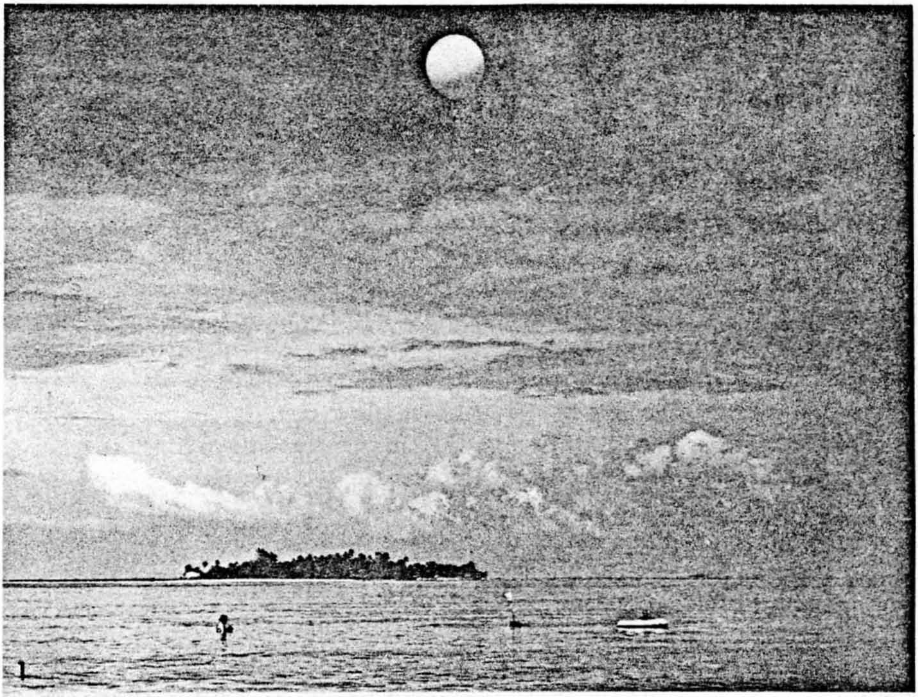

Figure 1
Balloon-supported camera over the barrier reef of Belize. South Water Cay is in the background. The front tether-trigger cable is operated from the small raft. A transect marker is visible in the centre. (photo: E. Kirsteuer).

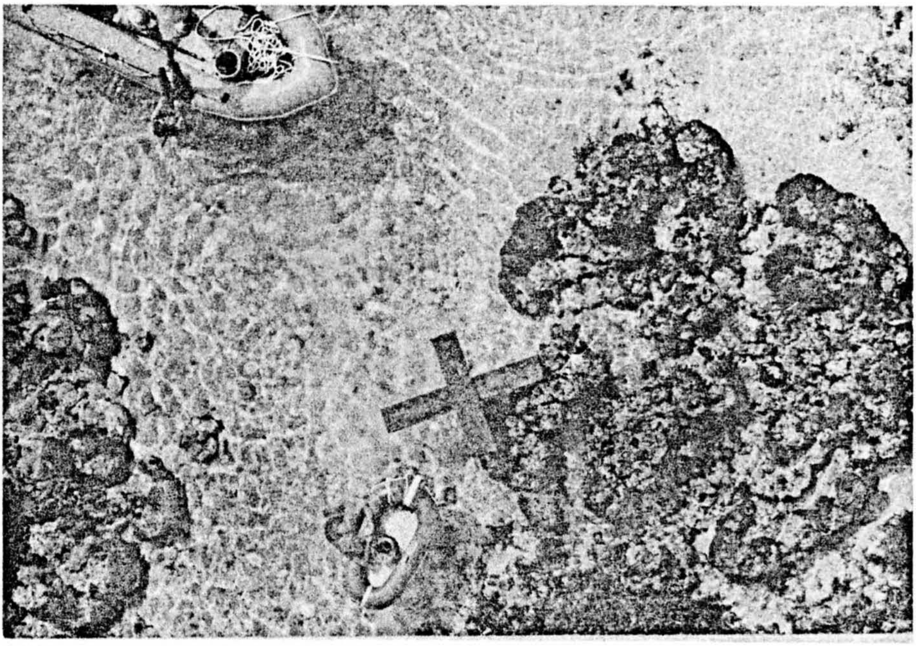

Figure 2
The location of Fig. 1, as it is seen by the balloon camera. The same transect marker is visible to the right of the longer bar of the cross. The cross measures 2 × 1.5 metres.

the distribution pattern of bottom types, framework constituents and associated biota. No great problems were encountered when recording changes along the transect line proper. It is almost impossible, however, to map complicated structures in the right proportions within a 5 m belt on either side of the transect line, covering 6000 m^2. The same is true with areas surveyed outside the transect. These had to be localized in relation to the cay and to the main transect with the help of compass bearings and range-finder measurements. Since only oblique photographs could be obtained from the locally available low-winged aircraft, the balloon technique was used for much of the photogrammetric work (Figs. 1–5).

EQUIPMENT AND SURVEYING METHODS

A standard 35 mm Nikon F Camera was chosen because it was available and could easily be equipped with an electrical motor drive (Nikon F-36). Unnecessary accessories, like viewfinder and exposure meter, were removed to reduce weight, and the mirror locked in the up position to avoid vibrations. The camera was mounted, lens down, on the bottom plane of the tetrahedron built from 1/2 inch (13 mm) angular aluminum moulding, with 50 cm side length (Fig. 3). It was balanced and positioned so that the longer axis of the picture frame would be parallel to one side of the tetrahedron. To the centre of this side, a plastic-coated fishing leader wire (35 kg test strength) was fastened to serve as the rear tether. The opposite corner supported the trigger cable, a two-stranded size 22 (0.6 mm diameter) conductor, which was also used as front tether and to guide the balloon. Maximum tether length used during the tests was 40 m. A manual switch at the end of the conductor cable was used to trigger exposures and subsequent film advance.

The camera, complete with film, motor drive and batteries, weighs 1600 g, the tetrahedron frame, with two 40 m tether lines, weighs 800 g. A balloon had

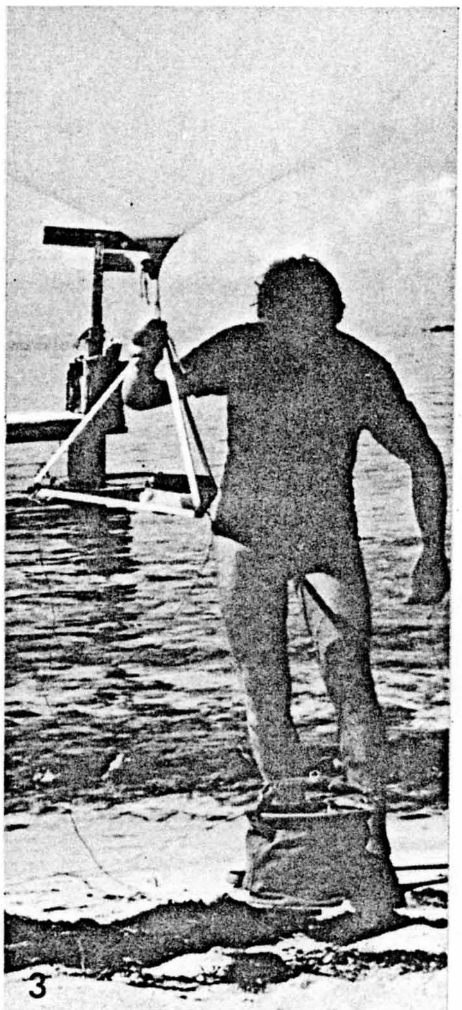

Figure 3
Tetrahedron frame with camera ready for use. A bucket holds the trigger cable and keeps the contact switch dry (photo: E. Kirsteuer).

to be chosen that could lift this weight, with some allowance for extra tether length, but with minimum size to save helium gas and offer small resistance to air currents. The selected 1450 g meteorological balloon (Weathermeasure Corporation, Sacramento, California) has 2665 g free lift. It uses 4 m^3 of helium gas for this performance and inflates to 2 m in diameter. Helium has less lifting capacity (93 per cent) and is not as easily obtained as hydrogen, but it is much safer to use and does not require expensive non-static balloons. Helium is stored in standard 240 cu ft. (6.8 m^3) cylinders. Sixty per cent of this volume is needed to fill one balloon. The rest can be used to compensate for gas losses during storage. Filling is effected through a two-stage helium regulator and a filling adaptor that fits the 32 mm diameter balloon neck and has a 2665 g weight built-in. The neck is tied off after the balloon has lifted its filling device off the ground. The balloon with camera frame attached can easily be handled by one person and can be carried to the survey area on foot, by swimming or by slow-moving boat.

The field to be covered by each exposure is a function of camera height and focal length of the lens used. For 36 × 24 mm film size, lenses with no less than 24 mm focal length should be used to avoid glare and distortion problems. These, however, depend also on water depth and sun angle. Balloon height above 50 m is impractical because camera orientation and movement cannot be seen clearly and handling becomes difficult, particularly for overlapping picture series. Our experience indicates that routine surveys of a given area should be conducted at two levels. For coarse structure and general proportions a 24 mm lens at 50 m altitude covers a field of 75 × 50 m. For high resolution mapping a 50 mm lens at 35 m altitude covers a 24 × 16 m area. On a calm day, however, the only limitation to camera altitude is the resistance of the trigger wire which should not exceed 100 ohms. Trigger control by radio was found to be impractical because of the additional expense and because tether lines have also to be used.

Some variation of balloon height will always occur because of air turbulence and changing angle and pull on the tether lines which are handled by two persons. It is therefore important to have a scale on each picture. A brightly painted wooden cross, 2 × 1.5 m, is used. The longer axis is kept in line with the transect by a swimmer (Fig. 4). The image of the cross permits subsequent corrections of scale and picture orientation and provides a control of the vertical viewing angle (Figs. 3 and 5). In deep water (below 1 m), the scale must be placed on the bottom or a correction factor based on the water depth must be applied.

A negative colour film (Kodak Vericolor II) has been used exclusively to date. Colour or black-and-white prints and transparencies can be produced from this material, it has a greater exposure latitude than reversal colour films, and colour balance and density can be controlled during printing. At a film speed of ASA 100 (20 DIN) common exposure values were 1/1000 sec at f4 for 11.00–14.00 hours time, cloudless sky, 1–2 m water depth off Carrie Bow Cay (16°48′N latitude) in December.

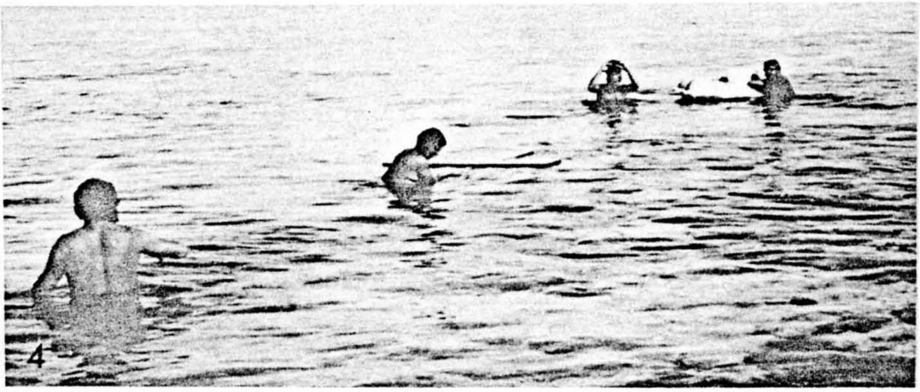

Figure 4
Ground crew during mapping procedure. Two persons are aligning the balloon with its tether lines, a third one is positioning the cross for later orientation and scale reference (photo: E. Kirsteuer).

Figure 5
Vertical view of Carrie Bow Cay reef flat showing sand areas, live *Acropora*, *Diploria* and *Montastrea*, and coral rubble. The area covered by this photograph is 18 × 12 metres.

DISCUSSION

Experiments with remote aerial photogrammetry by helium balloon show that this method combines many advantages of ground-level mapping with those of higher altitude aerial photography. Calm weather conditions are required but will usually be encountered during studies of some duration. A zeppelin-shaped balloon could operate even in moderate winds.

The altitude of the camera can be readily varied to combine general views and close-ups of the same location. On a 12 × 8 m area with 1–2 m water depth, covered by a 36 × 24 mm negative frame, prominent coral species, live versus dead coral, coralline algae coverage, sand, sea grass and even a 6 mm diameter nylon rope that served as transect line could be distinguished. Use of a camera with larger negative format would increase this resolution.

Penetration of water depth by means of the balloon camera equals, in the author's experience, that of a diver's eye swimming at the surface. Noon time with steepest sun angle will ensure optimal results. The condition of the water surface is of course critical. Even small ripples should be avoided as they cause distortions during close-up exposures. High altitude photographs are less affected as long as the ripples or waves are small, compared with the structures be be recorded.

Camera oscillations can occur after positioning the balloon at a new location. These and the horizontal orientation of the camera can both be controlled with the two tether lines. Just before each exposure the tethers should be relaxed to ensure vertical position of the lens axis. Suspension of the camera in gimbals might be an improvement.

When mapping a reef, cay or similar structure, it is important to allow for a generous overlap of exposures in a particular transect series. With a rectangular camera format, especially, even small horizontal deviations can cause undesirable gaps. Some of these can be compensated for by a duplicate picture series on a smaller scale. Clearly visible reference markers installed for the entire survey area ensure proper localization of each exposure. These can be anchored to the bottom and serve as scale reference at the same time.

Experience is restricted to the use of standard colour negative film. The applications of infrared sensitive materials and other remote sensing techniques have not yet been explored. Particularly, films and filters allowing maximum penetration in deep water should be tested.

Although the present arrangement is designed for vertical photogrammetric recording using still pictures, the camera angle could be adjusted for oblique exposures, and motion picture sequences could be produced in a similar manner.

ACKNOWLEDGMENTS

The author thanks E. Kirsteuer, H. Pulpan, C. Ruetzler and K. Sandved for enthusiastic cooperation in the field, as well as I. G. Macintyre and D. L. Pawson for reviewing the manuscript.

This work was supported by the Smithsonian Research Foundation and by a grant from the Exxon Corporation, Contribution no. 29. Investigations of Marine Shallow Water Ecosystems Project, Smithsonian Institution.

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