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Diver Depth-Gauge Profiling beyond Wading Depths: A New Simple Method for Underwater Surveying

Jennifer L. Rahn[†]*, **Heidi J.L. Lannon**[‡], **and Joann Mossa**[§]

[†]Department of Geography
Samford University
Birmingham, AL 35229, U.S.A.

[‡]Department of Social and Behavioral Science
Santa Fe College
Gainesville, FL 32606, U.S.A.

[§]Department of Geography
University of Florida
Gainesville, FL 32611, U.S.A.

ABSTRACT

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Surveying subaqueous beach profiles and features beyond wading depths can be a costly process, requiring use of expensive equipment and boats. This paper describes the materials and methods of a simple, low-cost technique for underwater bathymetric surveying, herein named the diver depth-gauge profiling (DDGP) method. Although accuracy of depth data depends on the quality of the depth gauges used, it is commonly within 0.3 m. Data collection reliability was evaluated by repeated underwater beach profile surveys, and an example of its use in the Caribbean is provided.

ADDITIONAL INDEX WORDS: *Low-cost surveying, bathymetry, shoreline change, beach width change, volume change, Caribbean, Saba.*

INTRODUCTION

The shape of the beach, above and below water, sheds light on the coastal processes that are at work at on the shoreline (U.S. Army Corps of Engineers, 2012). Beach profiling has long been the simplest tool for monitoring beach morphology and shoreline changes for coastal planning and research (Morton *et al*., 1993; Smith and Bryan, 2007). Many methods of simple, easy-to-use subaerial beach profiling have been described in the literature (Andrade and Ferreira, 2006; Delgado and Lloyd, 2004; Emery, 1961; Krause, 2005; Mossa, 1998; Namikas *et al*., 2007; Pueleo *et al*., 2008). However, most of these low-cost beach profile methods can only be used to survey to the low water mark or wading depth. Although low-cost land surveying techniques are now common, surveying an underwater beach is still challenging and often uses high-tech equipment. Thus, there is a need for more low-cost methods of underwater surveying. Extending the beach profile from wading depth to wave base or depth of closure is important to document changes to the entire beach, including winter bar formation and detailed sediment transport (Nordstrom and Inman, 1975).

Amphibious Survey Techniques

The most expensive, highest-resolution methods of surveying the underwater portion of the beach profile include hydrographic surveying using laser measurements (LIDAR) or single-beam and multibeam sounding technologies; they provide very detailed bathymetric information but require lengthy postprocessing (Kenny *et al*., 2003; Robertson, Zhanga, and Whitman, 2007). Side-scan sonar can also be used with a boat or with a remotely operated vehicle (Ballard, Coleman, and Rosenberg, 2000; Spiers *et al*., 2009.

Less expensive (but less accurate) methods include using a sonar depth finder fixed on a boat and a global positioning system (GPS) used to calculate location, or using two stakes in surveyed locations on the beach, which provide a defined line for the boat to follow, and a laser range finder to measure the distance to one of the stakes (Millard, 2003; SACPB, 2000; Tortell and Awosika, 1996). Also, a boat can be used with a GPS or survey equipment and a fathometer (Browder and Dean, 2000; SACPB, 2000).

Other methods include carrying a survey prism further seaward past wading depth in an underwater vehicle, such as a coastal research amphibious buggy (CRAB) (Birkemeier and Mason, 1994; Larson and Kraus, 1994), the water and beach profiler (Van Rijn, Vermetten, and Schimmel, 2002), and an underwater towed body such as a sea sled (Knezek, 1997; Smith *et al*., 1997).

The main drawbacks of these existing methods are that they are very expensive (side-scan sonar), not very portable (CRAB), or require the use of a boat (fathometers and sonars). These drawbacks can be avoided by simply using SCUBA and some low-cost equipment.

METHODS

Diver Depth-Gauge Profiling Supplies

Field supplies for the diver depth-gauge profiling (DDGP) method include an underwater compass (that is attached to a

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*Corresponding author: jlrahn@gmail.com

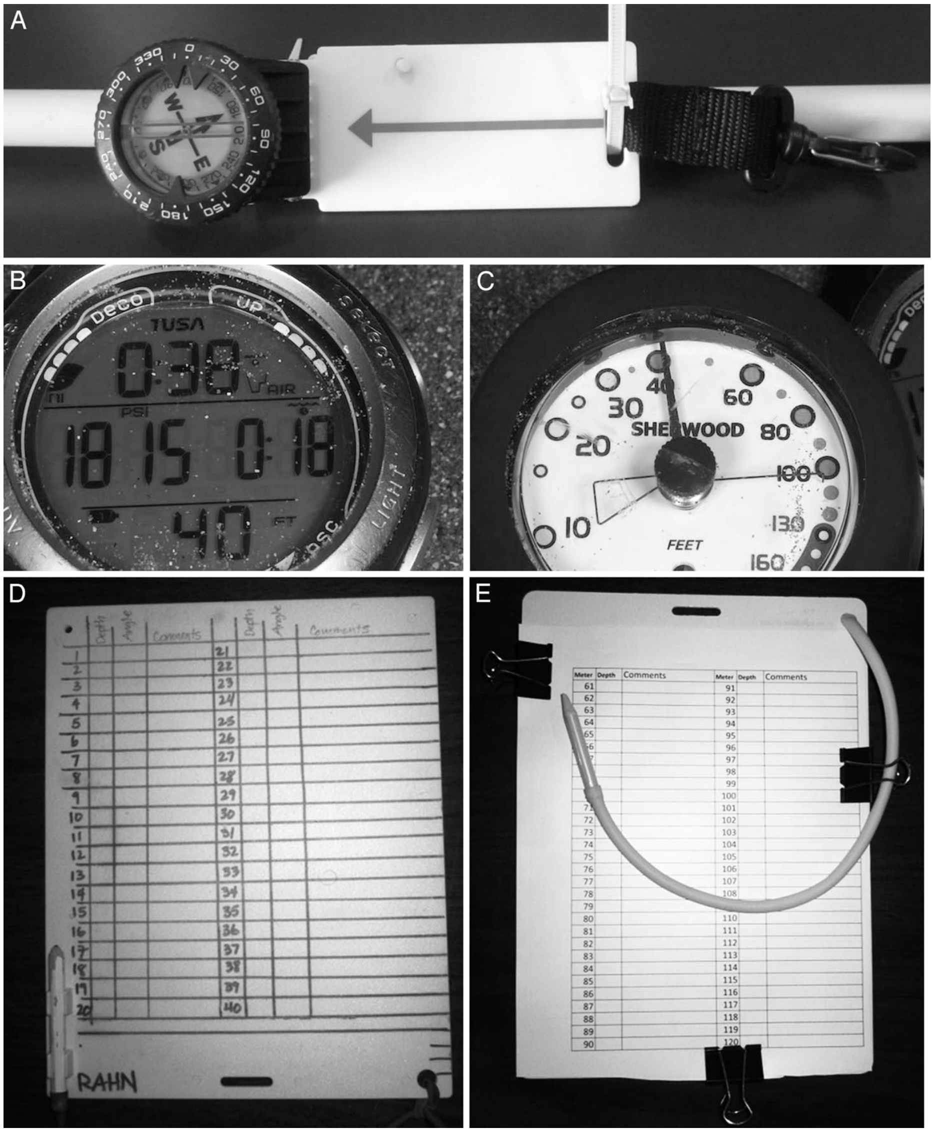

Figure 1. (A) Underwater compass attached to a meter stick with cable ties. (B) Underwater digital dive computer; depth is shown in upper right. (C) Underwater analog dive computer; depth is shown by the needle. (D) Underwater dive slate, with rows and columns in permanent ink. Data can be filled in with a pencil and erased afterwards. (E) Waterproof paper with data categories printed, which attaches easily to the dive slate with binder clips.

polyvinyl chloride [PVC] pipe), dive computer, dive slate, data sheet on waterproof paper, binder clips, pencils, zip/cable ties, and SCUBA dive gear. In order to have a standard measure on the seafloor, a 1-m-long PVC pipe was used (any width will do; we used 1.3 cm [0.5 inch]). We found that a 1-m-long measuring stick provided fine enough resolution to collect data for hundreds of meters along a gently sloping bay. However, the length of the stick can be modified to fit each scenario; a shorter length may be appropriate in areas of steep slope.

An underwater compass is needed to keep the survey on a straight line. It is preferable for the compass to be attached to PVC pipe (Figure 1A). At first, this method was tried with just the meter stick, but later the compass was added because it is very easy to become disoriented on sandy seafloors or in reduced visibility.

In addition to other important SCUBA diving information, dive computers record depth. Many of them state in their specifications that their accuracy from 0 m to 100 m depth is within ±1% of displayed value + 0.3 m. Dive computers can be purchased for $170 and up (Figure 1B), but they can also be rented by the day at dive shop s for US$10–20. A depth gauge can be used instead (Figure 1C), but many of them are analog-based, and thus they will have a lower accuracy (for example, they have a "hand" like an analog clock, and the depths cannot be read with the accuracy of a digital depth gauge).

In order to record the data underwater, we at first used large, 20.3 by 27.9 cm (8.5 by 11 inches) dive slates (Figure 1D)

Figure 2. Photo of diver depth-gauge profiling (DDGP) technique. Person on right orients and moves the meter stick. Person on left reads and records depth at each meter. A video of the process can be seen on YouTube at http://youtu.be/0yMtwU5xGuQ. (Color for this figure is available in the online version of this paper.)

purchased for about US$10. The basic rows and columns were written in permanent ink on the slates; they were filled in with pencil, erased, and reused. However, we preferred having a permanent record of our data, so we began to use waterproof paper (for example, Write In The Rain; http://www.riteintherain.com) that can be printed out ahead of time (Figure 1E). This allows for more flexibility in the design and modification of the data sheets, and they can easily be attached to the dive slate with binder clips. Pencils are the ideal underwater writing instrument for both the dive slate and waterproof paper. When changing data sheets or performing other tasks underwater, the pencils can be pushed into the sand so that they don't float away, or they can be attached to the dive slate with string.

Diver Depth-Gauge Profiling Method

After completing subaerial beach profile measurements, each profile should be marked near the water's edge. The survey can be done by one person, but it is easier and safer with two divers (Figure 2).

(1) The meter stick person sets the compass direction perpendicular to shore (in the direction of the subaerial profile, marked with something visible such as PVC or bright flagging tape) and records the angle. Alternatively, the angle may be known in advance from the beach profile.
(2) Both divers go down to place the meter stick at the starting point (where terrestrial survey left off, *i.e.* wading depth, as marked above).
(3) The meter stick person orients the meter stick to the proper heading offshore and places it on the seafloor.
(4) The recorder places the dive computer at the same spot on the meter stick each time. They read the depth on the dive computer and write it on the slate or data sheet.
(5) The meter stick person moves the stick to the next meter at the proper heading, and the process is repeated until the required depth/distance is reached or dive time elapses.

This method is best illustrated by watching a video of the process; it can be seen on YouTube at http://www.youtube.com/watch?v=0yMtwU5xGuQ&feature=youtu.be. A fast team can record each depth in about 5 seconds; in our surveys, we completed 270 m in 35 minutes.

Application and Data Collection

Data were collected at the 13 km^2 Dutch Caribbean island of Saba (17.6333° N, 63.2333° W) on Wells Bay beach (Figure 3). Wells Bay is bordered on the north and south sides by bedrock headlands; in-between is a relatively sheltered beach. This is

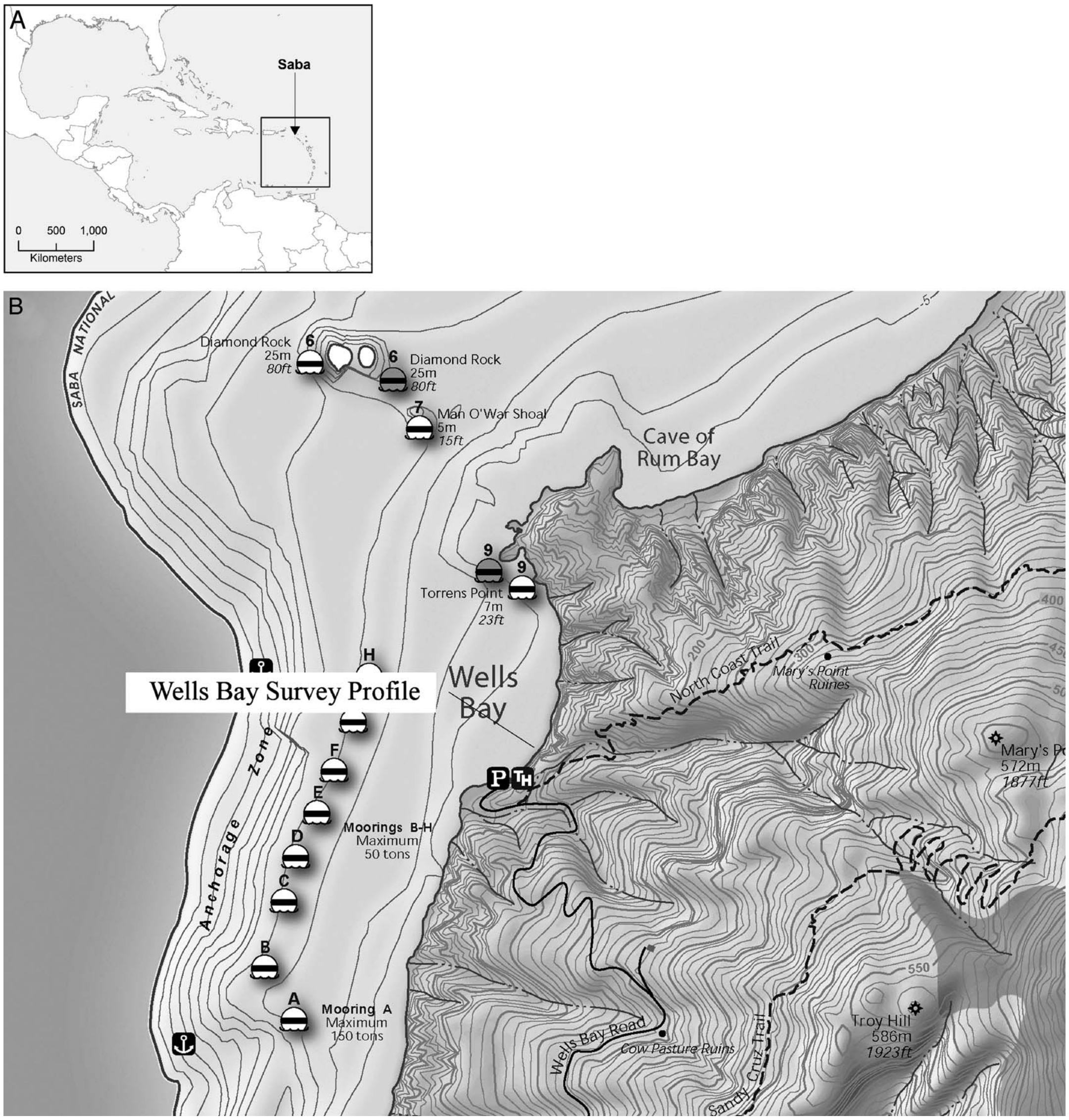

Figure 3. (A) Study area location, Saba, Dutch Caribbean (courtesy of the Dutch Caribbean Nature Alliance). (B). Wells Bay bathymetry from Saba Marine Park map.

the only accessible sandy beach on the island and therefore is a popular place to recreate. The beach is approximately 130 m long and about 13–20 m wide, backed by a 50-m-high cliff. The bathymetry is gently sloping, and the sand in the bay goes out at least 750 m to a depth of 20 m, before the slope abruptly increases and a large steep ledge eventually drops to a depth of 60 m and beyond (Figure 3C). Locals call it "Wandering Beach" because it frequently disappears in the fall and winter and reappears in the spring, unlike many of the white sandy perennial beaches of neighboring islands. For most years, the sandy beach arrives in Wells Bay in March and remains throughout the summer months. With the onset of north swells in the late fall, the sand is removed, and cobbles replace the sand. The profile shape is influenced by waves, water level, and sediment grain size (Kraus, 2005) and varies as a function of time of year, as well as time since a recent storm. During 2009, the sandy beach disappeared and has not returned. Older locals report that this has happened in the past decades, where the beach disappears for a few years at a time. The current hypothesis is that the sand has moved too far away from shore and is unable to be remobilized in normal summer wave conditions to return to the coast. Our underwater survey methodology was used to take seasonal measurements of the subaqueous beach profile to understand the Wells Bay beach sediment dynamics.

Surveys of the bathymetry of Wells Bay were taken over a 12 month period (July 2011, January 2012, March 2012, July 2012) to monitor the sand dynamics of the Wells Bay offshore slope (Figure 4A). The most significant change in the underwater profile was that much of the sand volume from

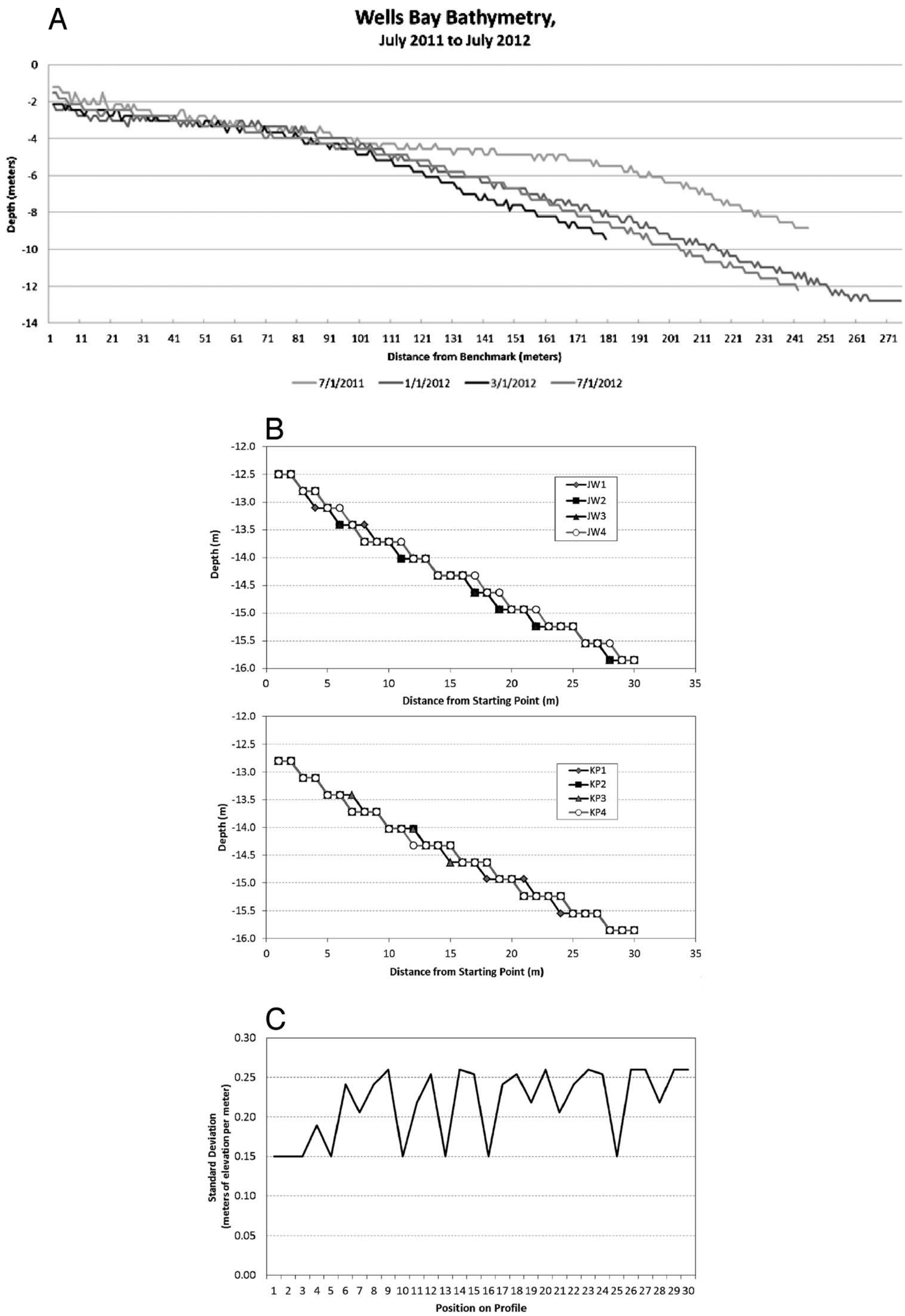

Figure 4. (A) Wells Bay bathymetry collected from 2011 to 2012 using the DDGP method. (B) Graph of comparison profiles by two teams. (C) Standard deviation by reading for comparison profiles from data in part B.

about 100 m from the benchmark and deeper has been lost since July 2011. From 160 m out, the profiles average 2.5 m lower in the 2012 surveys compared to the 2011 survey. From these data, it can be seen that the DDGP methodology was extremely useful to monitor offshore changes.

DISCUSSION

Accuracy of a measurement system is the degree of closeness of measurements of a quantity to that quantity's actual (true) value. For this methodology, the accuracy of the dive computer depth gauge is important. Underwater computer depth gauges sense pressure, not depth. Most errors are likely due to the way the manufacturer chooses to convert from pressure to depth. For more information on the detail of dive computer errors, see the Navy Department Diving Unit report at http://archive.rubicon-foundation.org/xmlui/handle/123456789/3296.

Accuracy is generally reported in terms of the ratio of a measured value to a (presumed) true value converted into a percentage format (*i.e.* an accuracy of 99% indicates that measured values will be within ±1% of the true value) (Namikas *et al.*, 2007). Because we had no true measure of depth, the accuracy of this method cannot be assessed. However, a small survey was conducted with the help of Saba Divers divemasters to test four different brands of dive computers. The results show that the computers were each consistent in their depth, but that the differences between them ranged from 24.3 m to 24.9 m (a range of 0.6 m) at the same depth (also see Figures 1B and C for comparison). So it is important that the same dive computer be used for all measurements. If more than one dive computer is used, they need to be compared side-by-side ahead of time so that differences between them can be corrected.

While ground-truthed accuracy of the method cannot be evaluated because LIDAR, side-scan, or other depth data are unavailable in this area of the Caribbean, data collection reliability was evaluated. In order to assess the repeatability of this method, eight repeated measurements of a 30 m underwater transect between 12 and 17 m depth were taken by two teams. Each team surveyed two profiles and then switched roles (meter stick person and data recorder). Each survey team had a different brand of dive computer (*i.e.* depth gauge). Differences in depth between the two computers were 0.3 m (1 ft), which was accounted for in the data analysis (the difference between the two computers was checked on previous dives). The data from the two survey teams are shown in Figure 4B, and the measurements never varied more than 0.3 m (1 ft) with the same dive computer. The standard deviation of the eight recorded values for each point on the profile records varied between a minimum of 0.15 m and a maximum of 0.25 m (Figure 4C). The comparisons suggest that there is little variability among successive measurements from a single user. If sites are going to be measured repeatedly, perhaps scour chains, which are used in gravel-bed rivers (*e.g.* Nawa and Frissell, 1993), could be useful at underwater monuments for validation of repeat surveys.

In many cases, the tidal range will have an effect on the beach profile (Masselink, 1993), as well as the depth recorded on a dive computer. Ideally, DDGP surveys should be referenced to a vertical datum. On the island of Saba, near the site surveyed, there is no published vertical datum, and the tides only vary by 10 cm (Kjerfve, 1981). For this scenario, it was not necessary to tie in the DDGP surveys to shore. For research in areas with higher tides, researchers should monitor the tidal changes and make sure any repeat surveys occur during the same part of a tidal range. Tidal data for coastal areas are published by the national hydrographic service of the country concerned. Additionally, DDGP surveys could utilize a submerged benchmark; this could be a large rock or metal pipe that would be measured before/after each survey to compare tides. Alternatively, a second dive computer could be used to take depth at the beginning and end of the surveying to determine tide changes.

The advantages of this method are that one or two SCUBA-certified persons can measure depth for many hundreds of meters offshore, using low-budget supplies. The main disadvantages of this particular method are that SCUBA certification is necessary, and a certain degree of visibility is needed (heavy turbidity may make the data collection difficult). As with other survey techniques, it will be difficult or impossible to collect data during high seas (large waves or swells) or during times with strong currents.

CONCLUSIONS

The DDGP method is a one- or preferably a two-person method for underwater surveying beyond wading depths. It is relatively inexpensive; besides SCUBA dive gear, supplies needed include an underwater compass, PVC pipe, zip/cable ties, dive computer, dive slate, waterproof data sheet, binder clips, and pencils. This method provides a fairly rapid way of extending beach profiles from wading depths to safe SCUBA depths (30 m), with measurements varying 0.3 me (1 ft) or less with the same dive computer, at the same tidal stage, with slightly more variation between differing dive computers. In areas where bathymetric data might be necessary, such as wave refraction studies, and studies of submarine features, this method is a useful addition to the limited low-cost methods of surveying in shallow, complex waters.

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