Geospatial Video Monitoring of Benthic Habitats Using the Shallow-Water Positioning System (SWaPS)

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Abstract

In this project, we describe the application of a geospatial video-based survey technique, the Shallow-Water Positioning System (SWaPS), develop by scientists from NOAA's National Geodetic Survey, to document the abundance, distribution, and damage patterns of benthic organisms in shallow marine habitats that have been historically under-represented in monitoring programs due to the difficulties associated with boat access. SWaPS uses a GPS receiver attached to a video camera. The GPS receiver is centered over the digital video camera that is suspended over a glass enclosure that provides a down-looking view of the bottom. SWaPS is presently available in three platforms used for distinct survey requirements: (a) a boat-based system; (b) a remotely-operated system; and (c) a diver-based system. During the surveys, each video frame recorded is stamped with position information, date, depth, heading, and pitch and roll, and the georeferenced digital frames obtained in these surveys can be easily analyzed to document patterns of abundance and distribution of submerged aquatic vegetation (SAV) and other benthic organisms, as well as damage patterns caused by ship groundings and boat propellers in shallow coastal habitats.

The SWaPS methodology provides a fast, spatially precise alternative to diver-based surveys that can be especially useful when: (1) a large number of closely spaced sites need to be surveyed rapidly; (2) field time is limited, as is often the case prior to the onset of an acute disturbance (e.g., hurricane, dredging project); (3) the availability of trained field personnel is limited; (4) resources need to be precisely mapped; (5) a permanent visual archive of the extent and condition of benthic resources is needed; and (6) the same locations need to be surveyed repeatedly without establishing permanent markers. Field surveys using SWaPS can be easily conducted by operators without scientific training, thereby removing the need for specialized field personnel and reducing the cost of field operations.

I. INTRODUCTION

The recent worldwide decline in the condition of coastal resources has highlighted the need to develop innovative, cost effective methodologies to rapidly and accurately document the extent and condition of these important systems. In the present study, we describe the application of a newly developed video-based survey methodology that is especially well suited for conducting georeferenced surveys of shallow benthic habitats, which have been largely neglected primarily because of logistic problems associated with limited boat access.

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II. METHODS

System Description

The shallow-water positioning system (SWaPS), developed by scientists from NOAA's National Geodetic Survey (NGS), uses a GPS receiver centered over a gimbaled digital camcorder that is suspended in a glass dome and provides a clear view of the bottom. A static GPS base station is established in the vicinity of SWaPS operations and serves to track the detectable GPS satellites in synchrony with the mobile GPS receiver onboard the SWaPS survey vessel. Both receivers record the GPS L1 and L2 carrier phases and code ranges every second during operations. After each survey period, both data files are post-processed using the software program KINPOS as described in Mader [1]. The position of the base station is accurately determined using OPUS, a GPS processing service created by the National Geodetic Survey (see http://www.ngs.noaa.gov/ OPUS). The code ranges are used in differential mode to locate the position of the SWaPS platform. The data collected by the base station are relayed via radio modem to the SWaPS platform where the data can be processed in real time as described above. Each video frame recorded is stamped with time, date, water depth, heading, pitch, and roll (Fig. 1). The time code is used to retrieve the precise location of each frame based on the location of the vessel with respect to the base station. Water depth, pitch, roll, camera specifications, and lens specifications can be used to obtain density and size estimates for organisms and/or for other benthic features. Post-processing the GPS data allows the user to recover the same position again with sub-meter accuracy. The video surveys conducted with SWaPS provide a continuous digital video track of the bottom. The data are archived in video format and by grabbing frames at a rate of one frame per second and storing these as digital still images. In 2006, a high-resolution digital SLR camera (10 megapixels) was added to the sampling methodology to provide an additional record of the benthic communities and to aid with species identification in low-visibility conditions.

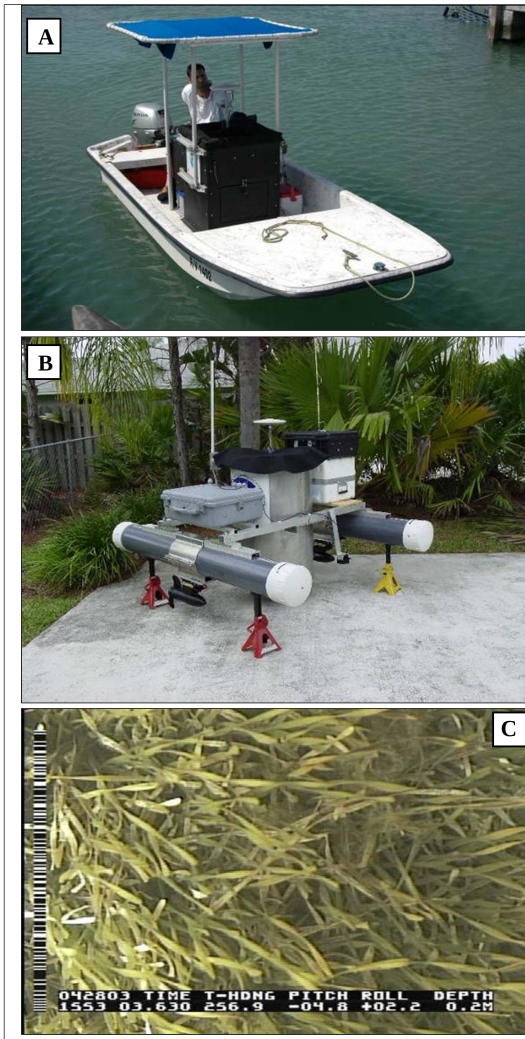

Fig. 1. A) Shallow-Draft SWaPS survey skiff. B) Remotely operated SWaPS platform. C) Video frame image of a seagrass community obtained during a SWaPS survey.

The use of video surveys with accurate spatial stamps provides a rapid and cost-effective method to document the abundance and distribution of benthic organisms in shallow coastal habitats. The most attractive features of the SWaPS system for monitoring and restoration research are: (1) the ability to survey large areas rapidly without the need to deploy divers or specialized field personnel; and (2) the ability to return to precise locations without the need for establishing permanent markers. Moreover, the digital data collected provide a visual archive that can be used for future before-after assessments. At present, SWaPS can be deployed in 3 different platforms designed to survey different types of environments (Fig. 1, 2). The boat-mounted SWaPS provides an effective tool to survey shallow benthic communities over large areas or numerous sites distributed at large distances from ach other [2], [3]. The diver-operated SWaPS provides an ideal platform to survey in detail smaller areas such as coal reefs where the precise maneuvering of the unit by an operator (e.g., diver, snorkeler) is required to document the location and condition of objects such as coral colonies or small injuries. Finally, the remotely operated SWaPS provides an ideal platform in areas where precise maneuvering is required but operators can’t be in the water (e.g., oil spills, crocodile habitat).

Spatial Precision of SWaPS

While high spatial precision can be achieved on land, field conditions on the ocean (e.g., winds, currents, wave action) can often limit the ability to return to the same location using GPS. The spatial precision of SWaPS was tested using ceramic tiles deployed in Biscayne Bay at a depth of 75-100 cm [2]. The location of each tile was determined by maneuvering the SWaPS boat over the tiles, capturing each one in the center of the video frame. The following day, the position of each tile was retrieved and plotted as waypoints using GPS-navigation software. Using the GPS unit as a guide, the boat was repositioned over each waypoint. If the tile could be seen on any portion of the video screen, the tile was counted as a "hit". If the tile was not seen on the screen, the distance between the position of the boat and the position of the tile was measured to determine the extent of the "miss". Out of the 30 tiles deployed, 24 (80%) were relocated within the video frame using the position obtained by post-processing the GPS information recorded during deployment. With a field of view at the bottom of approximately 60 cm, the spatial precision for the relocation of these tiles was < 50 cm. For the tiles that were not relocated within the video screen (20%), the mean distance to the center of the frame was 75 cm (S.D. = ± 12) [2].

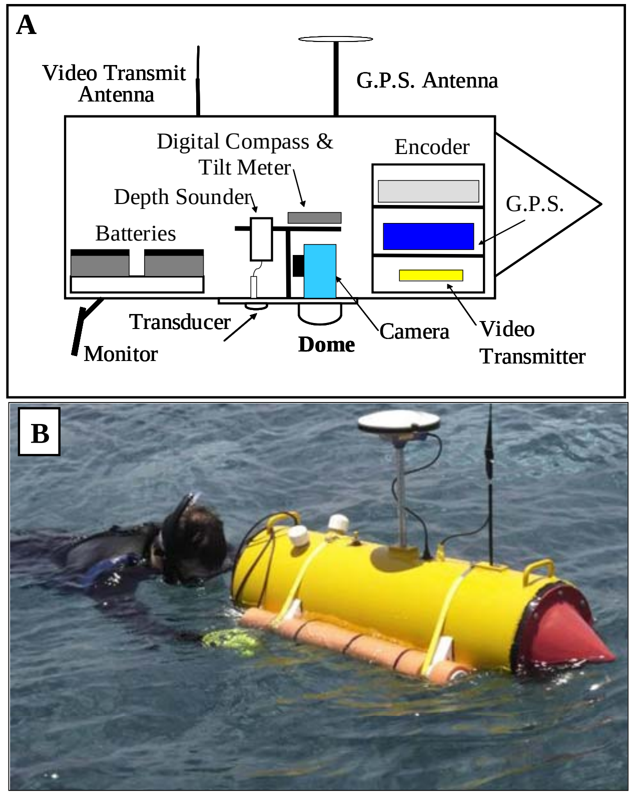

Fig. 2. A) Schematic of the diver-operated SWaPS platform and components. B) Snorkeler conducting a field survey using the diver-operated SWaPS platform.

III. APPLICATIONS

Benthic Monitoring In Biscayne Bay, Florida

The nearshore habitats of Biscayne Bay off the coast of South Florida and adjacent to the city of Miami present a unique area to study benthic habitat patterns. Benthic habitats are dominated by heterogeneous and productive macroalgal, seagrass, hardbottom, and soft sediment communities These benthic communities are both ecologically and socio-economically important by providing essential nursery habitat to popular commercial and recreational species of fishes (e.g., tarpon, snook, snappers, grunts) and macroinvertebrates (e.g., shrimp, lobsters, crabs) as well as providing an ecological bridge between the nearshore mangroves and offshore reef-dwelling communities.

Most of these communities thrive in shallow water (< 1 m) adjacent to urbanized areas of Miami, and experience environmental disturbance from urbanization on the ecosystem such as freshwater runoff, sedimentation, temperature fluctuations, and eutrophication. The location of these habitats makes them highly susceptible to potential changes in freshwater deliveries as proposed in the Everglades Restoration Project, which will likely result in an increase in freshwater inputs into Biscayne Bay. These critical habitats have been under-represented in ongoing environmental monitoring efforts due to the difficult boat access to shallow areas [2], [3], [4].

Over the past four years, the SWaPS program has conducted comprehensive surveys of the shallow, nearshore habitats of Biscayne Bay (< 1 m in depth, < 500 m from shore), providing a unique baseline characterization of the benthic community against which future ecological responses to changes in water quality can be ascertained [2]. The skiff used by SWaPS performs well in shallow environments, and approximately 35 km of littoral habitats at depths < 75 cm were easily surveyed [2]. Depending on the depth of the habitats, survey speeds of ~ 1 knot provide the best image quality during continuous surveys. The average time required to collect georeferenced video along a 25-m transect is 2–3 minutes and, depending on the spacing of the survey locations, a large number of sites can be easily surveyed in a short period of time. In applications where sites are closely spaced, up to 100 sites can be surveyed in a day (Fig. 3).

The results of such a survey can be seen in Fig. 3 where 50 sites were surveyed using SWaPS in Black Point, Biscayne Bay, Florida. The benthic monitoring data for this area were effectively collected in under 3 hrs using the SWaPS shallow-water skiff (Fig. 1). This area is influenced by the periodic release of freshwater from the Black Creek canal, creating a significant salinity gradient in nearshore habitats [2], [3]. In August 2005, the Black Point area was surveyed using a spatial grid with survey points separated by 150 m (Fig. 3). At each survey location, video of the bottom was collected along a 25 m transect. and 10 non-overlapping frames were chosen at random from the image library and analyzed using the methods described in detail by Lirman et al. [2]. For each frame, the percent of the bottom occupied by the different seagrass species was determined. The benthic coverage data obtained were averaged for each site and used to develop surface contours of percentage cover values using ArcView's spatial analyst using an inverse distance weighted interpolation procedure.

The data contours show how species distributions are directly influenced by salinity and freshwater releases. The freshwater released from Black Creek flows generally S of the rock jetty that creates a physical barrier (Fig. 3). Therefore the area S of the jetty experiences lower and more variable salinity compared to the area N of this structure, which is characterized by higher, more stable salinity [3]. The distributions of seagrass species within this area are clearly influenced by their tolerance to salinity patterns. *Thalassia testudinum*, a species commonly dominant in areas with salinity near oceanic values (> 30 psu) is the dominant species in the area N of the Black Point jetty, whereas *Halodule wrightii*, a seagrass species highly tolerant of low and variable salinity, is the dominant species S of the jetty (Fig. 3) [4].

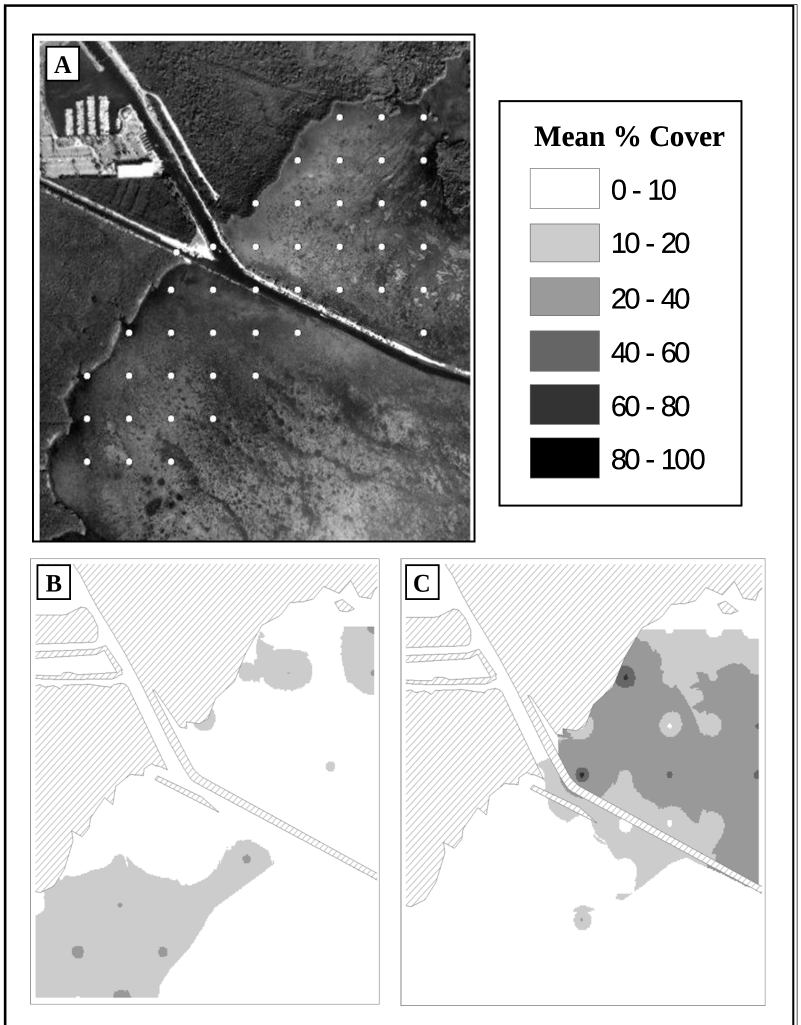

Fig. 3. A) Location of survey sites surveyed with SWaPS in August 2005 in the area around Black Point, Biscayne Bay, Florida. B) Percent cover contours for the seagrass *Halodule wrightii* established from the video frames collected using SWaPS. C) Cover contours for the seagrass *Thalassia testudinum*.

Damage Assessment with SWaPS

Physical damage to shallow coral reefs and seagrass beds by boating activities is a major source of disturbance to these habitats [5], [6]. At present, damage and recovery patterns on coral refs and seagrass beds are determined manually in the field by divers as the scale of these features (0.2 – < 5 m in width) often limits the use of airborne remote sensing instruments. Because of the high spatial precision provided by SWaPS, surveys with this system can also be used effectively to document damage and recovery patterns in shallow habitats. For example, with the aid of SWaPS, individual injuries can be identified unequivocally, and both the area damaged and the rate of recovery over time (e.g., scar closure) can be quantified directly from the images collected. Therefore, SWaPS provides a rapid and inexpensive method to quantify the areal extent of damage that would not require the deployment of trained divers and extensive field time.

In a pilot study, extreme shallow seagrass beds (< 50 cm in depth) were surveyed using the diver-operated SWaPS in Biscayne Bay (Fig. 4). After a seagrass scar was located, the SWaPS unit was swam by a snokeler along its central axis. The data was post-processed to obtain the accurate field position for the video frames. This information was used to evaluate scar length, and the width of the scar was used to evaluate the total area damaged (Fig. 4). This methodology provides a fast and accurate tool to evaluate damage extent that can provide extremely useful in cases were recovery funds are required by federal and state agencies with jurisdiction over the damaged resources.

IV. CONCLUSIONS

The use of georeferenced video surveys with accurate spatial stamps provides a rapid and cost-effective method to document the condition, abundance, and distribution of benthic organisms in shallow coastal habitats. Moreover, the spatial precision of this system (< 1 m) allows for locations to be monitored over time without the need to establish permanent markers. The SWaPS methodology presented here provides a fast, spatially precise, moderate-cost (start-up costs are commonly < $25,000) alternative to diver-based surveys that can be especially useful when: (1) a large number of closely spaced sites need to be surveyed rapidly; (2) field time is limited, as is often the case prior to the onset of an acute disturbance (e.g., hurricane, dredging project); (3) the availability of trained field personnel is limited; (4) resources need to be precisely mapped; (5) a permanent visual archive of the extent and condition of benthic resources is needed; and (6) the same locations require surveying repeatedly without establishing permanent markers. Field surveys using SWaPS can be easily conducted by a single operator without scientific training, thereby removing the need for specialized field personnel and reducing the cost of field operations. Finally, the collection of the benthic information is shifted from the field to the lab, where time and personnel constraints are generally lower.

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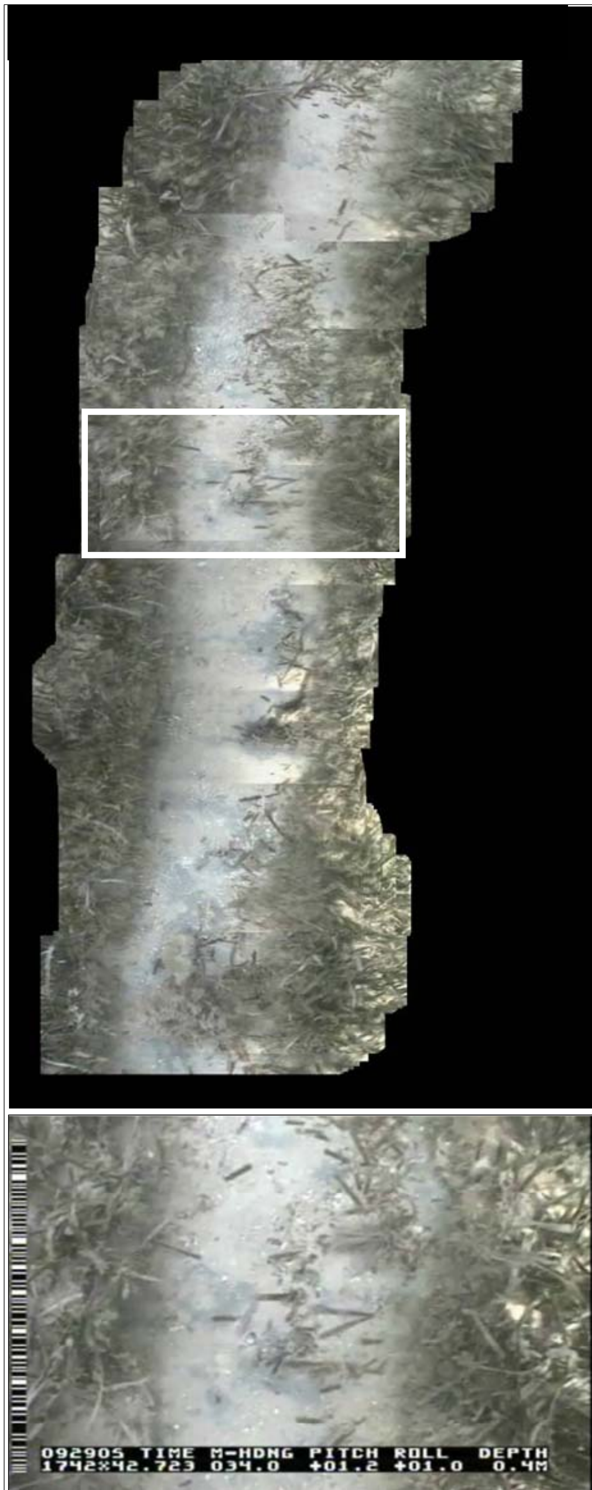

Fig. 4. A) Mosaic of a seagrass scar surveyed with the diver-operated SWaPS platform at a depth of 40 cm. The inset shows one of the video frames with the time, heading, pitch, roll, and depth information collected.