

# Towed-diver Surveys, A Method for Mesoscale Spatial Assessment of Benthic Reef Habitat: A Case Study at Midway Atoll in the Hawaiian Archipelago

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## ABSTRACT

An integrated method for reef benthic habitat assessment to the depth limits of conventional SCUBA is described, in which divers maneuver boards equipped with digital video, temperature, and depth recorders while being towed behind a small boat. The tow path is concurrently recorded by a Global Positioning System (GPS) receiver onboard the tow boat, to which a layback model is applied to more accurately map the position of the recorded imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-sec intervals. The results of 15 towed-diver surveys conducted at Midway Atoll in the Hawaiian Archipelago during a mass coral bleaching event in 2002 are presented to exemplify the method and are compared to quantitative results derived from more conventional methods of benthic biotic assessment. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale, roving diver assessments, providing a mesoscale spatial assessment of reef habitats. The spatial coverage afforded by towed-diver surveys provides more comprehensive data to managers concerning the extent, intensity, differential taxonomic response, and bathymetric correlates of bleaching than does data derived from conventional, site-specific surveys alone.

**Key words** Benthic assessment, coral bleaching, Midway Atoll, towed diver

## Key learnings:

1. Towed-diver surveys are an effective method for assessing benthic communities over large spatial scales.
2. The value of towed-diver survey results is enhanced when compared with results of more conventional survey methods (e.g., belt transect) at specific sites.
3. Limitations of the method must be balanced with its advantages before implementation.

## INTRODUCTION

The manta tow technique, in which snorkel divers are towed behind a small boat, is a versatile method that has been adapted to census specific benthic targets including crown-of-thorns starfish *Acanthaster planci* (e.g. Chesher 1969, Moran and De'ath 1992), introduced algal species (Rodgers and Cox 1999), and derelict fishing gear (Donohue et al. 2000). Manta tows have also proved useful for broader benthic habitat characterization (e.g. Kenchington 1978, Miller and Müller 1999, Lopez Victoria et al. 2000). A primary advantage of the manta tow technique in habitat characterization is that it enables efficient survey coverage of large areas of reef benthos; a disadvantage is the lack of fine taxonomic resolution that can be observed and recorded compared to surveys conducted by free-swimming divers (Carleton and Done 1995). The technique has not customarily included a photographic or videographic component (Bass and Miller 1996) that provides a permanent record of the benthos and that is suitable for quantitative image analysis.

Technological advances in videography over the past decade have catalyzed the development and evaluation of protocols designed to quantitatively assess reef benthos using computer-assisted image analysis (Vogt et al. 1997, Osborne and Oxley 1997, Page et al. 2001). Most field studies have involved video surveys of multiple, short (10-50 m) transects by free-swimming divers (e.g. Aronson et al. 1994, Lybolt and Eaken 2000, Ninio et al. 2000, Crabbe and Smith 2002), from which randomly or regularly selected frames have been assessed for benthic composition and abundance by the projection of random points on the image (e.g. Carleton and Done 1995, Miller and Müller 1999). While such surveys enable reliable, site-specific habitat description, they generally sample but a single habitat, and they do not capture the transitions by which habitat characteristics change over larger spatial scales.

Carleton and Done (1995) coupled the use of a manta tow with a camcorder mounted on the manta-board in an underwater housing so as to record a portion of the benthic survey area; the observer maneuvering the manta-board was equipped with SCUBA rather than snorkel gear. Though the authors report the potential of the technique for sampling on the scale of kilometers, the actual lengths of reported surveys were confined to 200 meters and, despite the SCUBA capacity of the observer, were conducted to maximum depths of 3 meters. No protocol by which the tow path could be georeferenced was described, an important procedure for linking image to position over large, geomorphic spatial scales.

In 1990, the Honolulu Laboratory of NOAA Fisheries inaugurated the use of SCUBA-diver-controlled towboards equipped with videographic equipment to assess benthic variables deemed important to lobster habitat on three emergent banks in the Northwestern Hawaiian Islands (Parrish and Polovina 1994). Since that time the Honolulu Laboratory has continued to develop an integrated towed-diver survey methodology in response to advances in videographic and georeferencing technology and has adapted the method for mesoscale assessment of coral reef benthic habitats. Our methodology differs from other techniques widely used and reported in that: (a) towed divers regularly survey the reef benthos to the accepted limit of conventional SCUBA, (b) the tow track is mapped through the concurrent recording of GPS positions and depth data, and (c) the data extraction and analysis regime includes percent cover quantification of all identifiable components within sampled frames rather than a point sampling strategy. In this paper we present the main components of our integrated methodology, provide a case study of data collected and processed using this methodology during a mass coral bleaching event at Midway Atoll in the Hawaiian Archipelago (Aeby et al. 2003, Kenyon et al. 2004), and compare results with data derived from more conventional belt-transect surveys.

## **MATERIALS AND METHODS**

### **Personnel allocation**

Four people are utilized to conduct each towed-diver survey: two SCUBA divers, a coxswain to drive the surface boat, and an additional crew member to deploy and retrieve the towboards, operate GPS units, and record the time at which videorecording begins and ends. Efficiency is enhanced by the four people composing two teams of two divers, such that surface personnel and divers switch roles at the end of each tow survey. One member of each dive team maneuvers a towboard dedicated to recording observations concerning the benthic habitat ('habitat' towboard), while the other member of the dive team maneuvers a towboard dedicated to recording observations of ecologically and economically important fish taxa ('fish' towboard). This paper focuses on protocols pertinent to benthic habitat characterization.

### **Towboards and accessory instruments**

Constructed of marine-grade plywood and coated in epoxy resin, towboards are equipped with a digital video camera recorder inside an underwater housing with a wide-angle port and color-

correction filter, mounted to maintain a viewing angle perpendicular to the bottom. The videocamera automatically records the date and time on the imagery. On each side of the camera bracket, a waterproof, battery-operated laser pointer is mounted, with the inter-laser distance calibrated to project two red dots in the field of view that are 20 centimeters apart. A depth gauge, digital watch, and alarm chronograph set to emit an auditory signal every 5 minutes after activation are mounted on a separate bracket. The camera clock and digital watch are synchronized with the clock of the GPS unit used onboard the towboat. Plexiglas strips affixed to the towboard allow insertion of a vinyl data sheet for recording written information pertinent to the overall tow as well as quantitative visual estimates of benthic composition integrated over 5-min periods. An SBE 39 temperature recorder (Sea-Bird Electronics, Inc.) mounted on the towboard electronically records depth, temperature, and time at 5-sec intervals. While conducting the videotaped survey, the diver maneuvers the habitat towboard to maintain an estimated distance of 1 meter above the substrate. A simple telegraph is operated by the diver who maneuvers the fish towboard to maintain communication with the tow boat, using several prearranged acoustic signals based on dots (short tones) and dashes (long tones).

Each towboard is separately connected to the towboat transom by an adjustable-length (typically 60 m long), 3/8' inch low-stretch buoyant line. Rather than being directly attached to the towboard, the tow line connects to a short bridle with a stainless steel swivel shackle that allows the diver to disconnect the towboard from the tow line if the towboard becomes grounded and cannot be quickly freed by the diver. Each towboard has a 5-m-long trailing line for the divers to grab if they become detached from the towboard. Divers receive special training in the risks associated with conducting surveys. A standard video survey (< 21 m depth) is 50 minutes long. At greater depths (21 – 27 m) the time is adjusted according to no-decompression limits.

#### **Coordination with collection of GPS tow track data**

To georeference all data collected during a tow, a GPS receiver is programmed to record longitude and latitude coordinates every 5 seconds onboard the tow boat. When the divers are ready to begin videorecording, a prearranged acoustic signal is sent to the tow boat, where the crew member marks a waypoint indicating the start point of the videotape recording. The coxswain attempts to drive along a predetermined isobath using a bathymetric chart, depth sounder, and shoreline features (when present) as a guide while maintaining a speed of 2.5 - 3.5 km/hour (1.7 - 2.5 knots). At the end of the benthic survey, before beginning an ascent to the safety stop, another coded signal is sent to the tow boat to record the time and place at which the video recording ended.

The primary GPS positioning error is the difference between the location of the GPS unit onboard the tow boat and the divers, typically some 55 meters behind the tow boat. To reduce this source of error, a series of tows were conducted to determine a model that addresses the 'layback' difference between the position of the videocamera and the position of the GPS unit on the tow boat. Normal survey protocols were conducted, with the addition of a surface snorkeler being towed directly above the towboard divers while wearing a backpack containing a GPS unit inside a waterproof bag. The coxswain maneuvered the tow boat over a series of courses that varied in frequency and amplitude of curvature to mimic the most conservative and the most extreme deviations of the divers'/snorkeler's position from the coordinates recorded by the GPS unit on the tow boat during regular surveys.

#### **Tape processing and data extraction**

The quantitative analysis of each benthic videotape begins with the capture of single, still frames as the tape is simultaneously played through a computer and a high-resolution monitor. The high-resolution monitor assists with identification of benthic characters that may be difficult to distinguish on the lower-resolution computer screen. If the frame is too blurry because of momentary excessive speed, or more than an estimated 5% of the benthos cannot be identified due to shadow, the analyst toggles forward frame by frame until the next frame that is suitable for analysis is reached. A sampling

interval of 30 sec was selected as best optimizing the joint interests of reproducible results, inter-frame distance, and time required to complete the analysis.

Each captured still frame is next imported into SigmaScan<sup>®</sup> Pro (SPSS Science<sup>™</sup>) for tracing benthic components using a stylus and graphics tablet. The benthic area (cm<sup>2</sup>) captured within the frame is determined using the projected pair of red laser dots known to be 20 cm apart, and is used as the denominator in the percent cover calculations for benthic components within that frame. For frames in which the dots have not been imprinted because of laser malfunction, the number of pixels composing the still image is used as the denominator in percent cover calculations. The number of benthic categories that can be identified from still frames varies according to the geographic locality surveyed; the variation is attributable to different coral faunas. Categories that are consistent among geographic locality include macroalgae, turf algae, coralline algae, invertebrates other than coral, sand, rubble, carbonate pavement, rock, and unencrusted (recently dead) coral. A spreadsheet called up within the SigmaScan<sup>®</sup> Pro program receives the computed area (in cm<sup>2</sup> or pixels) of each member of each benthic category as the analyst completes its tracing with the stylus. Tracing proceeds until only one category present within the frame remains. These values are then imported into a Microsoft<sup>®</sup> Excel spreadsheet that has been preformatted with formulas for the calculation of percent cover of each category of imported data. The percent cover of the remaining untraced category is computed by subtracting the sum of the other categories from 100. Lastly, the time-stamp for the still frame is manually entered. The percent cover data and time stamp from each frame-specific Excel spreadsheet are then compiled into a master spreadsheet from which the quantitative habitat data can be summarized over whatever time/spatial interval is desired.

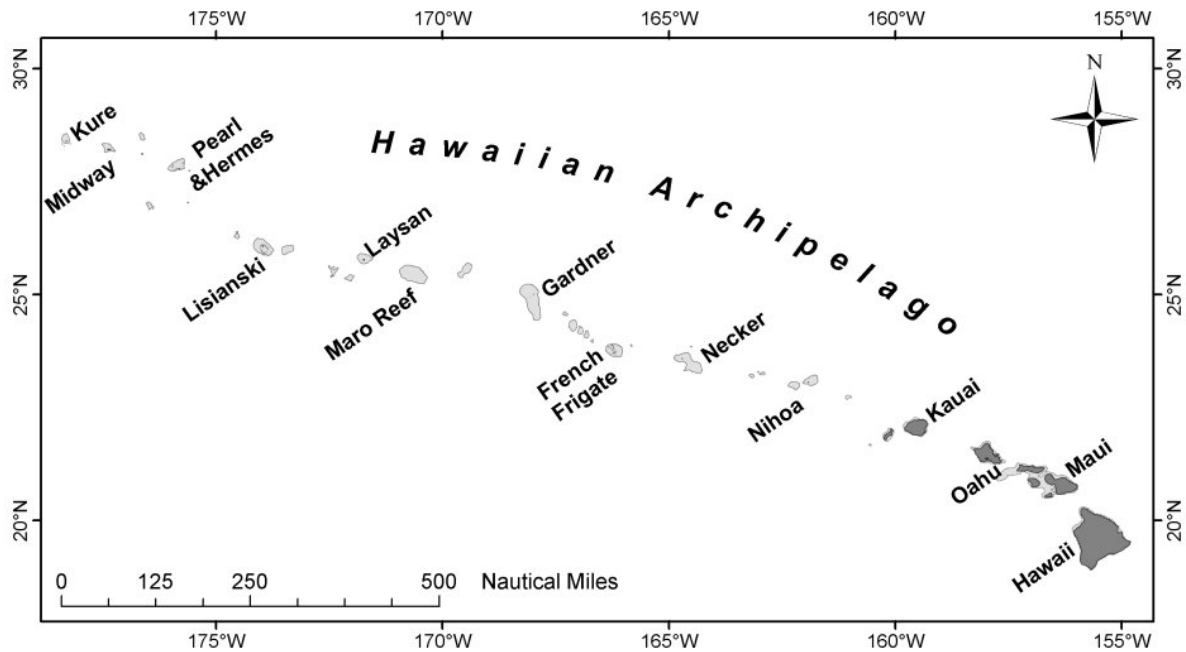
### **GIS data ingestion, processing, and display**

GPS data are downloaded directly into GIS using a custom-designed (Hoeke, unpublished) ArcView<sup>®</sup> extension. Data are downloaded as (1) track data files, containing a position and time stamp every 5 sec, and (2) waypoint data files, defining locations of the start and end of the videotaped survey. The customized extension then performs a number of calculations and allows for editing and quality control of the data including (1) a layback calculation to rectify the position of the towboard, (2) merging all track files for a single day, (3) sorting and trimming track files based on waypoint files, interpolating for lost GPS data if necessary, (4) calculating sequential dive numbers, local time, and other attribute fields, (5) adding temperature and depth data, matching SBE 39 and GPS time stamps, and (6) calculating sequential segments for each tow; using segment lengths of 30 sec and 5 min to correlate with the intervals over which analytical and in situ data are compiled, respectively. The extension then adds video analysis data (30-sec segments) and in situ observational benthic data (5-min segments) as separate files. These separate files are spatially represented as polyline files, where each segment of analysis/observation data is a separate polyline. The nodes of these polylines match the nodes in the track file. The attribute tables (\*.dbf) of the analysis/observation tables are tied to the track file's attributes by the dive number and the respective segment number. The resulting georeferenced observations can be mapped in conjunction with IKONOS-acquired imagery and viewed on spatial scales of resolution varying from 33 m (the average separation between sequential frames) to the entire length of a tow (i.e. several kilometers).

### **Case study, Midway Atoll**

Midway Atoll (28°15'N, 177°20'W) is one of the northwestern-most atolls in the Hawaiian Archipelago (Figure 1). Between 20 and 25 September 2002, 15 towed-diver surveys were conducted at Midway Atoll to assess a mass coral bleaching event (Aeby et al. 2003, Kenyon et al. 2004). Video analysis was conducted by a single analyst. The categories of live coral that could be recognized in recorded videotapes were *Pocillopora*, massive/encrusting *Porites*, *Porites compressa*, *Montipora*, and other live coral (e.g., *Pavona*, *Fungia*). For each category, percent cover of bleached and unbleached coral were separately quantified. Incidence of bleaching was computed as the percentage of coral

cover that was bleached. To examine the correlation between depth and incidence of bleaching, each sampled still frame was paired with its depth using concurrent time stamps on the video and depth recorder.



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### Comparison with belt transect data

Between 19 and 25 September 2002, belt transects enclosing 50 m<sup>2</sup> or 100 m<sup>2</sup> at each of 20 sites were conducted according to the methods of Maragos et al. (2004), in which the number of colonies as well as the number with bleached tissue was tallied by genus. Incidence of bleaching was computed as the percentage of colonies with bleached tissue. To examine the correlation between depth and incidence of bleaching, for each site the percentage of all colonies with bleached tissue was paired with that site's depth.

## RESULTS

### Towed-diver surveys

The distance between sample frames captured at 30-sec intervals depends upon the tow speed; the average distance ranged from 19.2 m to 38.6 m (mean = 33.0,  $n = 20$  tows). The average benthic area captured in

laser-scaled frames was 10,907 cm<sup>2</sup> (SE = 119,  $n = 700$ ). Towed divers surveyed 37.5 km of benthic habitat within 3 atoll zones (forereef, backreef, channel) (Table 1, Figure 2), from which 1129 frames were analyzed, for a total analysis area of 1231 m<sup>2</sup>. The videotape from a standard 50-min tow over a habitat with a diversified benthos (e.g. backreef) requires approximately 16 hours for complete analysis, from capturing still frames to summarization. Coral cover was low (<12%) in all 3 zones (Table 1). Incidence of bleaching was highest on the backreef, lowest on the forereef, and moderate in the broad channel along the northwest exposure (Table 1, Figure 2). Bleaching was most prevalent in *Pocillopora* and *Montipora*, with a low incidence of bleaching in *Porites* (Table 1). There was a significant negative correlation between the incidence of bleaching and depth ( $r_s = 0.50$ ,  $n = 1129$ ,  $p = 0.00$ ).

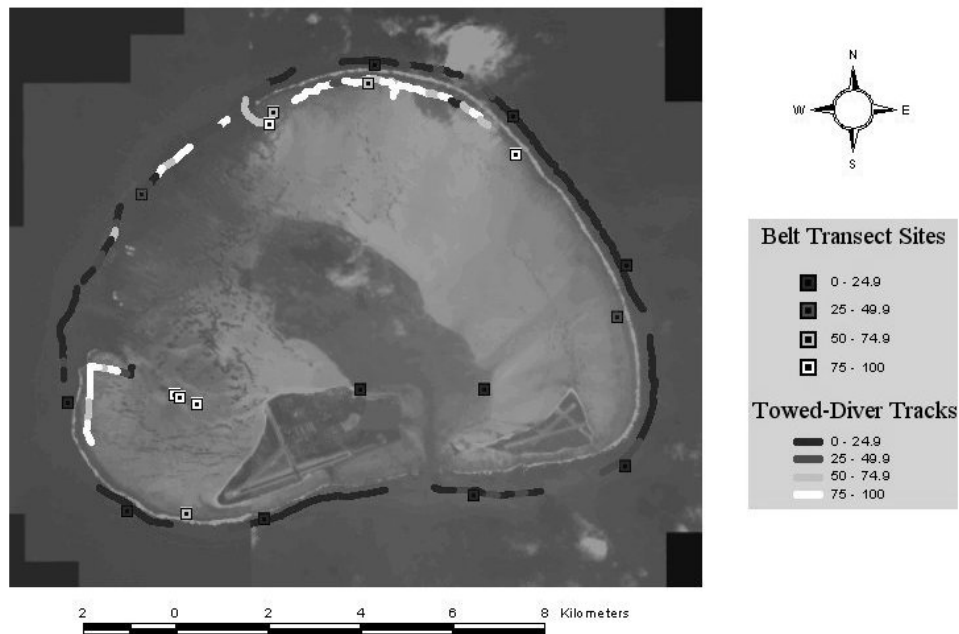
Table 1. Summary of towed-diver and belt-transect surveys conducted at Midway Atoll, Northwestern Hawaiian Islands, in September 2002 to assess coral bleaching. NS = not surveyed

Towed-diver surveys								
Distance surveyed (km)	Average % total coral cover	Average % bleached	Average % of total coral cover / average % cover that is bleached					
			<i>Pocillopora</i>	massive/encrusting <i>Porites</i>	<i>Porites compressa</i>	<i>Montipora</i>	Other coral	
Backreef	8.7	11.3	77.4	19.5 / 89.9	1.5 / 78.4	0.1 / 0.0	79.0 / 80.7	0.0 / 0.0
Forereef	21.9	1.6	15.0	23.1 / 63.7	76.0 / 8.5	0.8 / 0.0	0.0 / 0.0	0.2 / 0.0
Channel	6.9	1.5	32.4	11.2 / 88.6	83.1 / 17.9	0.5 / 35.0	0.4 / 61.8	4.8 / 67.7
Lagoon	NS	-	-	-	-	-	-	-

Belt transect surveys							
Area surveyed (m <sup>2</sup> )	# coral colonies counted	% colonies bleached	Number of colonies / % with bleached tissue				
			<i>Pocillopora</i>	<i>Porites</i> *	<i>Montipora</i>	Other coral	
Backreef	400	408	56.1	74 / 83.8	59 / 0.0	266 / 61.3	9 / 44.4
Forereef	550	1258	3.7	159 / 30.0	1065 / 0.0	2 / 0.0	32 / 0.0
Channel	50	67	32.8	12 / 66.7	26 / 0.0	8 / 0.0	21 / 66.7
Lagoon	450	303	39.0	128 / 92.2	132 / 0.0	0 / 0.0	43 / 0.0

\* Different growth forms/species of *Porites* were not separated using this method



**Figure 2.** Locations of towed-diver and belt transect surveys at Midway Atoll, using IKONOS-acquired imagery as a basemap. Sites and track segments are shaded according to incidence of bleached coral; values presented for towed-diver surveys are averages computed over sequential 5-min intervals.

### Comparison with belt transect data

Belt-transect divers surveyed 1450 m<sup>2</sup> of benthic habitat in 4 zones (Table 1). Incidence of bleaching was highest on the backreef, lowest on the forereef, and moderate in the channel and on lagoon patch reefs (Table 1, Figure 2). Bleaching was most prevalent in *Pocillopora* and *Montipora*, with no bleaching observed in *Porites* (Table 1). There was a significant negative correlation between the incidence of bleaching and depth ( $r_s = 0.73$ ,  $n = 20$ ,  $p = 0.00$ ).

## CONCLUSIONS AND RECOMMENDATIONS

Towed-diver surveys provide an efficient method for recording spatial variability in benthic communities on coral reefs when conducted by experienced divers trained in the safety considerations that pertain to this advanced diving technique. A primary strength of towed-diver surveys is their ability to assess the major benthic components and condition of reef habitats over spatial scales substantially greater than can be observed and documented by free-swimming divers. In the present study at Midway Atoll, belt-transect divers examined more benthic area than was analyzed from towboard videos (1450 m<sup>2</sup> vs. 1231 m<sup>2</sup>, respectively); however, results from towed-divers were derived over a survey length of 37.5 km (Table 1), while results from belt transects were derived over transect lengths totaling 725 m. Because the samples (still frames) from towed-diver surveys are spread over a long curvilinear dimension, whereas belt transect surveys are concentrated at specific sites (Figure 2), towed-diver surveys provide a broader spatial assessment of large reef systems with variable habitats. The primary conclusions generated from both methods are congruent: (1) incidences of bleaching were highest on the backreef, lowest on the forereef, and moderate in other atoll zones; (2) *Pocillopora* and *Montipora* were highly susceptible to bleaching whereas *Porites* evidenced little bleaching; and (3) there was a significant negative correlation between depth and the incidence of bleaching. In receiving corroboration from the similar results generated through belt-transect surveys, towed-diver surveys allow extrapolation to broader spatial scales.

Because they are powered by a surface boat, towed divers are able to survey in sea conditions that are too extreme for roving divers or their support skiff to safely work in, e.g. high swell, strong current, or poor anchorage. They provide a permanent visual record that is amenable to re-sampling by different analysts, or to re-analysis when more automated, image-recognition technologies are developed. Inclusion of a GPS receiver on the towing boat allows georeferencing the survey path, and incorporation of a layback model improves the accuracy of positioning the recorded imagery, thereby providing a basis for ground-truthing satellite and aerial remote sensing imagery (e.g. Andréfouët et al. 2002, Bainbridge and Reichelt 1988). The method is particularly useful for assessing remote areas that can only be visited infrequently and for short durations.

A primary limitation of interpreting visual information from a towed camera is the loss of taxonomic resolution compared to the capacity of roving diver classifications. Field equipment as well as computer equipment needed to analyze imagery is expensive, realistically limiting this method to programs with large budgets. Image analysis is time-consuming. Field and computer personnel require special training, the former to ensure safety and accuracy, the latter to ensure consistency and reproducibility. Interested researchers should weight the advantages and limitations of towed-diver surveys before investing in and implementing the method.

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