AN EVALUATION AND COMPARISON OF TECHNIQUES FOR ESTIMATING FISH SPECIES COMPOSITION, ABUNDANCE AND SIZE STRUCTURE IN MANGROVE AND REEF HABITATS

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ABSTRACT

Underwater visual fish surveys have become the most commonly used method for estimating fish abundance and diversity in coral reef environments, and more recently in adjacent environments such as mangroves. Limitations associated with visual surveys (e.g., restricted to daylight hours and relatively clear-water conditions) have resulted in a potentially incomplete assessment and understanding of fish community composition, structure and dynamics. In the present study, we examine the utility of three techniques for underwater fish community assessment. In mangrove and coral reef habitats, under varying conditions of light and water clarity, we compare and contrast: (1) a dual-frequency, multi-beam sonar system (DIDSON); (2) a stereo-video system; and (3) a standard visual survey. Both DIDSON and stereo-video provided relatively precise and similar length estimates, but stereo-video resulted in underestimates of length in turbid conditions, where DIDSON was not affected. Stereo-video resulted in underestimates of abundance, relative to DIDSON, in clear and turbid mangrove conditions. Importantly, DIDSON enable the quantification and measurement of fish swimming within and behind the prop roots of mangroves that were not visible or detected with stereo-video or visual surveys. DIDSON was also effective in environments in which stereo-video was ineffective (at night and in moving transects). Species composition lists generated by stereo-video and visual census were only somewhat similar, and length-frequency distributions generated by all three methods were similar but differed in degree of spread. We discuss the benefits and limitations of each method for assessing fish community structure, and recommend combined survey approaches to maximize our knowledge of fish utilization of mangrove and reef habitats.

INTRODUCTION

Historically, fish data collection programs have predominantly focused on commercially or recreationally important species, providing data to regulatory agencies tasked with the single-species management of those species. Relatively recently, however, there has been a move towards ecosystem-based management (EBM; Pew Oceans Commission, 2003; Hilborn et al., 2004; Pikitch et al., 2004; Sissenwine and Murawski, 2004; US Commission on Ocean Policy,

2004), under which regulatory agencies are tasked to sustain the health of entire marine ecosystems and the services they provide, including fisheries production (Pikitch et al. 2004). Under EBM, managers need information on the components of the ecosystem and how those components interact. Thus, there exists a growing need for fish data collection programs that include accurate assessment of entire fish communities, including both targeted and non-targeted species, as well as other ecosystem residents (e.g., invertebrates and living benthos).

From a fisheries management and conservation perspective, the importance of coral reef ecosystems as habitat for commercially and recreationally targeted species is well known. Recent work has provided growing evidence for the interconnectivity of mangroves and adjacent coral reef ecosystems. It has long been known that mangrove systems support high densities of juvenile and, in some cases, adult fish (e.g., Odum and Heald, 1972; Thayer et al., 1987; Laegdsgaard and Johnson, 1995). Such observations led to the assumption of mangroves as nursery habitat (defined in the traditional sense of high juvenile abundance; now divided into nursery habitat as defined by Beck et al. (2001) and effective juvenile habitat as defined by Dahlgren et al. (2001)). Increasingly, evidence is being generated to support the "nursery role" of mangroves for fish that later occupy coral reef habitat, both inferentially (e.g., Dorenbosch et al., 2004; Halpern, 2004; Mumby et al., 2004) and explicitly (Chittaro et al. 2004; see Nagelkerken et al. (this issue) for review). As evidence for the interconnectivity of mangrove, coral reef, and other tropical and subtropical environments increases, and as connectivity rates are quantified (Beck et al. 2001; Adams et al. in press), there will be an increasing need for accurate fish community data in mangrove, coral reef, and other interconnected habitats to support ecosystem modeling and management efforts.

Visual census surveys are an established and accepted form of fish community data collection in coral reef systems (e.g., Sale and Douglas, 1981; Bohnsack and Bannerot, 1986; Jennings and Polunin, 1997; Graham et al., 2003; Chittaro, 2004). Increasingly, visual census surveys have been and are being used to assess fish community structure (i.e., species composition, abundance or density, and size distributions) in mangrove systems (Rooker and Dennis, 1991; Serafy et al., 2003; Dorenbosch et al., 2004) and other back reef and coastal habitats (e.g., Nagelkerken et al., 2001; Eggleston et al.; 2004; Lugendo et al. 2005). As with any data collection method, visual census surveys have strengths and weaknesses (e.g., Sale and Douglas, 1981; Edgar et al., 2004). Visual census surveys are most effective under conditions of adequate light levels and clear (non-turbid) waters. As light levels decline and as turbidity increases, visual census surveys become less efficient, with fish becoming increasingly difficult to see and identify. Visual limitations are problematic for mangrove systems, which are often characterized by turbid, low-visibility waters. Regardless of environment, visual surveys cannot effectively be performed at night, when fish community composition and structure may vary significantly from that of the daytime (Rooker and Dennis, 1991; Lin and Shao, 1999; Krumme et al., 2004; Smith and Hindell, 2005 for mangroves; Hodgson, 1972; Galzin, 1987; Rooker et al., 1997 for coral reefs). The limitations of visual census surveys have spurred interest in other survey methods that can provide complementary or potentially more accurate data than can be provided from visual census surveys.

The purpose of this study was to examine the utility of three techniques to generate estimates of fish species composition, abundance, and length in mangrove and coral reef habitats. Under varying conditions of light and water clarity, we compared length and abundance estimates, and variability surrounding those estimates, using a (1) dual-frequency, multi-beam sonar system (DIDSON; hereafter DS); (2) stereo-video system (hereafter SV); and (3) standard

visual census survey (hereafter, VC). We discuss the utility of DS, SV and VC for generating fish community data across a range of environmental conditions in subtropical estuarine and marine habitats, and recommend combined survey approaches to maximize our knowledge of fish utilization of reef and mangrove habitats.

METHODS AND MATERIALS

Data collection occurred during August 2005 in mangrove, canal and coral reef habitats in Biscayne National Park, located adjacent to Miami, Florida, USA (Fig. 1). Data collection occurred at five sites (Keyhole Mangrove, Sandwich Cove Mangrove, Convoy Point Mangrove, Money Reef, and Mowry Canal) using three methods: DIDSON multi-beam sonar (DS), stereo-video (SV), and snorkeler visual census survey (VC).

The DS is a high-definition, multi-beam sonar system developed for the inspection and identification of objects underwater. Our unit was capable of operating at two frequencies (detection mode at 0.7 Mhz and identification mode of 1.2 MHz) and could provide images of objects from 1 meter to over 30 meters in range. All recordings for this study were collected at 1.2 MHz for greatest image resolution. At this frequency setting, the composite sampling beam (~29° in the horizontal and 12° in the vertical) consists of eight sets of 12 transducers (total of 96 beams) arrayed 0.6 degrees from each other in the horizontal plane. In the initialization file for the DS software, we set water temperature at 20-30° C and salinity at the "salt" setting. We adjusted window length based on the orientation of the transducer and the particular sampling environment. We carried out stationary sampling, where the transducer was fixed to the substrate, and mobile sampling, where the transducer was mounted on a plate attached to a pipe fixed to the boat gunwale. During data collection, acoustic signals received at the transducer were processed, viewed in real time, and stored as data files on a field laptop connected via a network cable. Data analysis (i.e., fish length and abundance estimation from data files) occurred on a later date using DIDSON Version 4.54.02 software, available from Sound Metrics Corporation. In the software, images produced by the DS are two-dimensional, with the 12° vertical component compressed. A continuous recording is presented as a series of single frames in a .ddf file format. For post-processing, data files can be viewed as single image snapshots or continuous, near-video quality image streams.

The stereo-video system consists of a STH_MDCS2 stereo-video camera head connected via IEEE 1394 cable to a laptop computer running Small Vision System stereo analysis software. The STH_MDCS2 is an all-digital stereo head for machine vision tasks from Videre Design (www.videre.com). In this study, the cameras were fitted with 12mm lenses. Corrected for water, the viewfield of the camera system expanded from the unit at angles of 22° in the horizontal range and 16° in the vertical range. The camera head and the lenses were fitted with a custom-made underwater housing.   The SV system was calibrated both on land and in water prior to data collection.

The Small Vision System software uses a stereo algorithm to compute range information for a targeted object based on a triangulation method. Side-by-side cameras "see" the target object at different positions within a three-dimensional grid. This difference in position is called disparity. Figure 2 displays a simplified view of stereo geometry. An image of the target object is taken from two different viewpoints. The distance between the viewpoints is called the baseline (*b*). The focal length of the lenses is *f*. The horizontal distance from the image center to the object image is *dl* for the left image, and *dr* for the right image. The stereo cameras were

arranged so that their image planes were embedded within the same plane. Therefore, the difference between dl and dr is the disparity, and is directly related to the distance RF of the object normal to the image plane. The relationship is represented by equation (1):

$$(1) \quad RF = (b*f)/(dl-dr)$$

Using Equation 1, we can plot range as a function of disparity for the stereo video head.

The disparity value can be used to find the relationship between pixels in the two images, which gives the x-y coordinates for any points on the image. Therefore, with a good disparity image of a fish, we can obtain the x-y-z coordinate at the front (nose) of the fish (x_1, y_1, z_1) and at the end (tail) of the fish (x_2, y_2, z_2). Then, the length of the fish (L) is calculated by equation (2):

$$(2) \quad L = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Images collected using SV were viewed in real time, and video files were stored on a connected field laptop computer. Data analysis of fish length and abundance estimation occurred on a later date using SVS 3.0h software, available from SRI International. As with DS, in the SV software continuous recordings were presented as a series of single frames.

For data collection in mangrove and reef habitats, the DS and SV units were placed side by side (mangrove) or stacked (reef) on the benthos, and oriented toward the habitat of interest (Fig. 3a and b). For moving transects, the DS and SV units were stacked and mounted and deployed attached to an adjustable mount on the fore port side of an 8-m research vessel (Fig. 3c)[1]. During data collection, paired DS and SV files were started, recorded, and stopped simultaneously. All data analysis proceeded using data from corresponding DS and SV files.

VC surveys were performed concurrently with DS and SV recordings at two sites: Sandwich Key Mangrove and Money Reef. For each survey, a snorkeler (GTK) entered the water, swam to a point near the DS and SV units, and began and ended data collection concurrently with the beginning and ending of recording of DS and SV files. Based on communication with viewers of the DS and SV live feeds on the adjacent research vessel, the snorkeler attempted to identify the viewfields of the DS and SV units, and to limit the visual survey to that area of habitat. During data collection, the snorkeler recorded on underwater paper the species present, number of individuals per species, and estimated total length per individual, aided by a length reference on the data-collection clipboard.

ENVIRONMENTS

We recorded data in multiple habitats (mangrove, reef and channel) and, in mangrove habitats, under multiple conditions (clear, turbid, and at night). For ease of discussion, hereafter we refer to each habitat or habitat-condition combination as an "environment".

At Keyhole Mangrove, data were first collected under normal conditions, in which water clarity was relatively high. Hereafter, we refer to this environment as Mangrove Clear (MC). Turbid conditions were then artificially created by a snorkeler, who purposefully stirred up bottom sediment, after which additional recordings were made with DS and SV. Hereafter, we

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[1] The SV files from the moving transects were not usable, as the quickly-changing light levels that occurred as the mounted camera moved through the water prohibited necessary exposure adjustment.

refer to this environment as Mangrove Turbid (MT), which was created to simulate high-turbidity, low-visibility conditions common among many mangrove systems. At Convoy Point Mangrove, we recorded data at night solely with DS, as the SV was ineffective without a light source. We refer to this environment as Mangrove Night (MN). Finally, we recorded data in a coral reef habitat (Money Reef (RF)), and in Mowry Canal channel (CH), with the CH data recorded during moving transects. The SV method was ineffective in the CH environment; thus, further discussions of CH involve only DS data. Gear and habitat abbreviations are listed in Table 1.

DATA GENERATION (MEASUREMENT OF LENGTH AND ABUNDANCE)
Length – With the exception of the MC environment, it was exceedingly difficult to "match" the same fish between DS and SV files. Thus, unless otherwise specified, length estimates were not made on fish matched between DS and SV files (i.e., different fish were measured for DS and SV data generation). To generate length estimates for analysis, we randomly chose equal numbers of fish for measurement from corresponding DS and SV files.

As measures of precision, we were interested in determining the variability about repeated length measurements of the same fish "frozen" within a field of view (i.e., within a single DS or SV frame). Additionally, we were interested in determining whether length measurements would vary depending on the position of a fish relative to the DS or SV unit (i.e., whether length estimates would vary across multiple frames). For example, as a fish moved and changed its body angle relative to the DS and SV units, would length measurements change for either measurement method? To address these questions, we randomly chose 10 fish from corresponding DS and SV files recorded from the MC environment (the MT and RF environments were excluded because of a lack of fish that could be measured across multiple frames using SV). For each method (DS and SV), we made three replicate measurements of each fish within a single frame. We then advanced the frame in both DS and SV, resulting in movement of the fish and potentially changing the angle of measurement. We then made three measurements in the second frame, and repeated for a third frame. On one occasion for SV, the target fish had moved partially out of the field of view for the third frame, so replicate measurements were only available for the first and second frame.

We were also interested in comparing mean length measurements and length-frequency distributions between measurement methods (DS and SV). To increase our sample size for each environment, we measured an additional 15 fish with DS and SV in the MC environment, and an additional 10 fish with DS and SV in the MT environment. We also performed length measurements using DS for fish in two additional environments where SV was ineffective: in a mangrove creek at night (MN; n = 10), and a moving transect along a channel (CH; n = 10).

Abundance - We were interested in determining how abundance estimates varied by method and environment. We used abundance as a response variable instead of density (number per unit area or number per unit volume) for two reasons. First, we wanted to assess the ability of DS, relative to SV, to identify fish that were distributed beyond the viewfield of the SV (e.g., within or beyond mangrove prop roots or coral heads). Additional fish identified by DS that were beyond the viewfield of the SV would be apparent from direct comparisons of abundance between DS and SV, but not necessarily with direct comparisons of density, since the extra area or volume viewed by DS would offset the increase in abundance associated with the additional fish, resulting in a minimal or negative change in density. Second, the volumes of the overlapping

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viewfields for DS and SV were nearly identical to the edge of the SV viewfield (e.g., to the edge of mangrove prop roots or coral heads). Thus, any differences in abundance estimates across method or environment would be nearly identical (statistically and graphically) for the overlapping viewfields if density were used as the response variable.

We estimated abundance using DS and SV in three environments (MC, MT and RF) from randomly chosen frames, with n = 30 for each method-environment combination. The far extent of the viewfield for the SV method was the edge of the mangrove prop root mass in the mangrove environment, and several small coral heads in the reef environment (i.e., fish were not observable with SV beyond these structures). Using DS, fish were observable beyond the edge of the mangrove prop root mass (i.e., within the prop roots) and beyond the coral heads. Thus, we made two estimates of abundance using DS: one to the edge of the mangrove prop roots and coral heads (i.e., the same field of view as the SV), and one including fish observed within the prop roots or beyond the coral heads. The former estimate is hereafter referred to as DS-nearfield (DS-NF), and the latter as DS-farfield (DS-FF).

DATA ANALYSIS

Our main interest in data analysis was to compare the utility of method (DS versus SV) within specific environments. Because we were not primarily concerned with comparisons between environments, and because including environment as a factor in analyses increased heteroscedasticity of variance in all cases, we performed separate analyses for each environment.

Length – To assess the variability, by method, of repeated length measurements of the same fish within a frame, we calculated the standard deviation about the mean length for the three within-frame measurements for each fish, by method, in the MC and MT environments. We repeated this step for each of the three replicate frames in which each fish was observed. We then scaled each standard deviation value as a percentage of the mean total length (e.g., scaled value for SD = 5 and TL = 150mm = (5 / 150) x 100 = 3.3%). We randomly chose one of the three replicates for each fish, so that n = 10 scaled standard deviation estimates for each method x environment combination. For both MC and MT, we tested the hypothesis that there was no difference in scaled standard deviation values between methods using a one-way ANOVA with method (DS versus SV) as the factor and the natural log of standard deviation as the response variable (the natural log transformation satisfied parametric assumptions of normality of data and homoscedasticity of variance). We used post-hoc Tukey tests to determine the direction of difference between treatment levels.

To make inferences about whether there were significant differences in length estimates depending on the position of the fish relative to the DS or SV unit (i.e., by frame), we analyzed data separately for each method. For each method, we performed a one-way ANOVA for each replicate fish (N = 10), with mean length as the dependent variable and fish-specific frame (1, 2 or 3) as the treatment, with the square root of length as the response variable. To correct for the increase in probability of committing a Type I error associated with multiple statistical tests, we used a Bonferonni-corrected p-value of .005 for each method (DS and SV). For all analyses, the square root transformation used in the analysis was effective in satisfying the assumption of homoscedasticity, but in some cases not normality of data (in those cases, we were unable to find a transformation that satisfied this assumption). Because parametric tests have been shown to be robust to violations of the assumption of normality of data (Lindman, 1974; Zar, 1984), and because results of the analysis were similar regardless of transformation used, we proceeded with the square root of length as the response variable in all cases. In these analyses, the response of

interest was whether there were significant differences in mean lengths by frames for specific fish, and the number of fish from the 10 examined for each method for which significant differences occurred by frame.

To compare length measurements of specific fish between methods, we utilized data from the MC environment, which was the only environment in which we were able to definitively match the same fish in DS and SV. We calculated a mean length for each of the 10 fish measured for each method, using the nine measurements taken for each fish (three measurements per frame x three frames per fish per gear). For each fish, we then calculated the difference in mean length between method, where difference = $DS_{mean\ length} - SV_{mean\ length}$. We tested the null hypothesis that the difference in means was zero (i.e., that there was no significant difference between means) with a t-test (N = 10).

To compare overall mean length measurements between methods (as a proxy for size-frequency distributions), for both MC (n = 25 per method) and MT (n = 20 per method) we tested the null hypothesis of no differences in measured lengths of different fish, by method, using a one-way ANOVA with method (DS versus SV) as the factor and the square root of total length as the response variable. For both environments, the square root transformation used in the analysis was effective in satisfying the assumption of homoscedasticity, but not normality of data. Again, because parametric tests have been shown to be robust to violations of the assumption of normality of data, and because results of the analysis were similar regardless of transformation used, we proceeded with the square root of length as the response variable. We used post-hoc Tukey tests to determine the direction of difference between treatment levels.

To assess the similarity in length-frequency distributions generated by DS and SV, we generated length-frequency diagrams using the length data described above. To indicate the usefulness of DS in generating presence-absence, abundance, and size-distribution data in environments in which SV was not functional, we also generated length-frequency distributions for data collected with DS in MN and CH environments.

Abundance - To compare abundance estimates between methods, we tested the null hypothesis of no differences in abundance estimates for the MC, MT and RF environments using one-way ANOVAs, with method (DS versus DFF versus SV) as the factor (n = 30 per treatment level for each environment), and the natural log of (abundance + 1), as the response variable. The natural log data transformation used in the analysis was effective in satisfying the assumption of homoscedasticity, but not normality of data. Again, because parametric tests have been shown to be robust to violations of the assumption of normality of data, and because results of the analysis were similar regardless of transformation used, we proceeded with the natural log of abundance as the response variable. We used post-hoc Tukey tests to determine the direction of difference between treatment combinations.

Comparison with Visual Surveys
To determine comparative output between snorkeler VC surveys and the SV and DS systems, we compared species composition, length-frequency distributions, and abundance estimates from the VC surveys with those generated by DS and SV.

RESULTS

Length – In analysis of scaled standard deviations, there was no significant effect of method in the MC environment (ANOVA; $F_{1,18} = 0.17$; $p = .6844$; Fig. 4). For the MT environment, there was a significant effect of method (ANOVA; $F_{1,18} = 16.15$; $p = .0008$), with SV having significantly larger scaled standard deviation values than DS (Fig. 4).

For the comparison of mean length estimates of the same fish across multiple frames, there were significant differences (using a Bonferonni-corrected p-value of .005) in mean lengths across frames for one of the ten fish measured with DS, and for three of the ten fish measured with SV, indicating the potential for length estimates to vary with the position of the fish for both methods.

For the same ten fish compared across methods in the MC environment, the difference in mean lengths was not significantly different than zero (T-test; $T = 1.41$, $n = 10$, $p = .1926$), indicating no significant difference in estimates of mean total lengths between methods. In comparisons of multiple fish, there was no significant effect of method on overall (all fish combined) mean length estimates for MC (ANOVA; $F_{1,48} = 0.11$; $p = .7459$; Fig. 5). In MT, overall (all fish combined) mean length estimates were smaller for SV than for DS (ANOVA; $F_{1,38} = 6.17$; $p = .0175$ for MT; Fig. 5).

Length-frequency distributions generated by DS and SV were relatively similar for MC environments, with SV resulting in a greater range of size estimates than DS (Fig. 6a). Length-frequency estimates generated by DS and SV were also relatively similar for MT environments, but for SV, the distribution shifted to the left (smaller sizes) relative to the MC distribution (Fig. 6b). For DS, the MT distribution was similar to the MC distribution (Fig. 6b). Length-frequency distributions generated by DS in MN and CH environments are presented in Fig. 6c. The CH length-frequency distributions were considerably larger than those from MN, which were similar to MC and MT distributions, with the exception of two large fish > 500 mm TL.

Abundance comparisons
For each environment (MC, MT and RF), there was a significant effect of method (ANOVA, $F_{2,87} = 3.99$, $p = .0220$ for MC; $F_{2,87} = 62.36$, $p < .0001$ for MT; $F_{2,87} = 228.8$, $p < .0001$ for RF) on mean abundance estimates. The direction of effect of method on abundance estimates was dependent on environment. In both the MC and MT environments, the DS-FF method yielded the greatest abundance estimate, followed by DS-NF and SV, respectively (Fig. 7). In the RF environment, SV yielded the greatest abundance estimate, followed by DS-FF and DS-NF, respectively (Fig. 7).

Species Composition and Comparison with Visual Census Surveys
Table 2 contains species lists generated from SV and VC observations (species identification was not possible with DS) for the MC and RF environments. For the MC environment, the VC survey resulted in a much greater species count ($n = 7$) than the SV ($n = 1$). For the RF environment, species counts were similar between the VC survey ($n = 2$) and SV ($n = 3$). Length-frequency estimates for the VC survey, SV and DS for the RF environment are presented in Fig. 8. Length-frequency distributions from all three methods were similar, although length distributions tended to be smallest and narrowest for the VC survey and largest and widest for the SV method. The total fish count from the VC survey in the RF environment ($n = 10$) was moderately greater than the mean abundance estimate generated from the SV method (6.9 +/- .033 fish; Fig. 7), and considerably greater than the mean abundance estimate generated from the DS method (0.4 +/- .140 fish; Fig. 7).

<center>**DISCUSSION**</center>

Lengths – In general, all three methods were effective in generating length estimates. Length estimation was simpler and faster for DS than for SV.

The analysis of scaled standard deviations provided an assessment of the variability associated with length estimation for DS and SV. Both methods were relatively precise in the MC and MT environments, characterized by standard deviations that were < 5% of estimated mean lengths. In the MT environment, scaled standard deviations were similar in precision to those in the MC environment for DS (~2%), and slightly (but significantly) greater for SV (~ 3%). Thus, although both methods were relatively precise, fish surveys in turbid environments may result in less precise and greater ranges of length estimates if SV is utilized, rather than DS.

Results from the comparison of mean length estimates of the same fish across multiple frames indicate that length measurements are somewhat dependent on the position and angle of the fish to be measured relative to the measuring unit (DS or SV). Further research is required to determine how and why mean lengths varied significantly across frames (for 1 of 10 fish measured with DS and 3 of 10 measured with SV). For DS, the orientation of target fish relative to the DS unit did not appear to affect the strength or length of the fish signal in the output data. For SV, fish oriented in the plane perpendicular to the front-to-back camera axis were easiest to measure (i.e., resulted in the greatest contrast when stereo images were created), with fish oriented at increasing angles to this plane becoming increasingly difficult to measure. Thus, SV length measurements will likely be most accurate when fish are oriented in the perpendicular plane. It should be noted that fish oriented at angles greater than ~75° from this plane (i.e., swimming towards or away from the cameras) were not measurable (J. Bohnsack, unpub. data), and thus were not included in this analysis. In such cases, position of a target fish relative to the SV unit definitely affects (inhibits) measurement ability. For both methods, the difference in measured length across frames for some fish suggests that, in general, length measurements for specific fish should be made using measurements made across multiple frames (i.e., such an approach should reduce measurement error).

Comparison of mean length estimates of the same 10 fish and of overall mean length of multiple fish in the MC environment indicate that both DS and SV provide similar length and size-distribution estimates in clear mangrove environments under daylight conditions. Consistent with these results, length-frequency distributions generated by DS and SV were similar in the MC environment (Fig. 6a). The greater range of length frequencies reported from the SV data is expected given the greater variability associated with length measurements using SV relative to DS, as discussed in the analysis of scaled standard deviations.

In turbid conditions (MT), the significant difference in overall mean length estimates between DS and SV indicates that SV length estimates may be reduced considerably when waters are turbid. While the fish measured in the MT environment were not necessarily the same fish measured in the MC environment, the MT data were collected soon after (beginning within minutes) the MC data, and in precisely the same field of view. Estimated overall mean lengths generated by DS were nearly the same in the MT environment as in the MC environment, while estimated lengths for SV were less than length estimates in the MC environment (statistical comparisons were not made between environments; see Fig. 5 for trends), and significantly less than the DS estimates for the MT environment. These results are consistent with the length-frequency distributions generated by DS and SV for the MT environment, in which the SV size-

distribution is shifted to the left (indicating smaller length-frequencies) relative to the DS distribution, and relative to the SV distribution in the MC environment. The potential "undermeasurement" effect occurred because the turbidity generally obscured the caudal margins of subject fish in the disparity image, resulting in measurement from the snout to caudal peduncle of the subject fish. In sum, these results suggest that SV may result in significantly biased underestimates of fish lengths under turbid conditions.

   Lastly, the DS can provide measures of the fish community in turbid channel environments and at night, when SV (and VC) are ineffective. In both the CH and MN environments, the DS system was efficient in enabling generation of length and abundance estimates for fish within its viewfield (Fig. 6c). Conversely, the SV was ineffective in both the CH and MN environments. In the CH environment, the quickly-changing light levels that occurred as the mounted camera moved through the water prohibited necessary exposure adjustment, resulting in unusable video output. This issue could be resolved in future deployments by utilizing wider-angle lenses and a more forward-looking mount. In the MN environment, the camera was ineffective without a light source.

Abundance – In general, all three methods were effective in generating abundance estimates, but effectiveness was dependent on environment. In both the MC and MT environments, DS-NF corresponded to the same area sampled as SV, but provided greater abundance estimates. DS-FF provided even greater abundance estimates than DS-NF. Thus, (1) DS in the far-field enables quantification of fish from areas not visible using video (i.e., within the mangrove prop roots), (2) DS will likely provide more accurate total abundance assessments, and (3) mono or stereo video will likely underestimate true abundance in mangrove habitats.

   It is likely that true abundances were at least somewhat similar between the MC and MT environments, since the MT environment was the same location as MC, and differed solely in that in MT, waters were made turbid by stirring up sediment into the water column. We conclude that abundance estimates in both DS and SV were negatively affected by turbidity, as fish images during analyses were more obscured in the MT environment for both methods. The turbidity effect seemed to be greater for SV than for DS, as the SV abundance estimate was ~ 13% less than the DS-NF estimate and ~ 23% less than the DS-FF estimate in the MC environment, but ~ 45% less than the DS-NF and ~ 62% less than the DS-FF in the MT environment. Thus, using video to generate abundance estimates in turbid mangrove environments may result in even greater underestimates of abundance than in clear mangrove environments.

   Results from the RF environment differed from the MC and MT environments, with SV generating significantly greater abundance estimates than both DS-FF and DS-NF. As in the mangrove environments, the DS method resulted in the far-field quantification of fish not visible in the video screen (in this case, beyond the focal group of coral heads). Nevertheless, fish images near the coral heads in the DS analysis were obscured by signals generated by wave-driven movement of soft corals and macroalgae, resulting in underestimates of fish abundance. In contrast, for the SV system fish in the near-field were easily differentiated from soft corals and macroalgae. Thus, our results indicate that video methods will provide more accurate

assessments of abundance in reef environments[2]. Post-processing methods to remove signals generated by moving benthos in DS should be pursued.

Species Composition and Comparison with Visual Census Surveys – SV and VC were effective in determining species composition. Species could not be identified using DS in this study since many of the species documented using SV and VC (Table 2) are similar morphologically and in their swimming behaviors. In applications where little overlap exists among fish likely to be encountered in terms of body shape, size, and swimming behavior, use of DS has been successful in classifying fish to the species level (P. Johnson, unpublished data).

Our ability to compare VC surveys with DS and SV is limited due to the limited number of concurrent VC surveys that were made (one each in the MC and RF environments). In the MC environment, the visual survey resulted in seven species of fish, while the SV resulted in only one species. The disparity between species observed using VC and SV likely resulted partly from the fact that, despite attempts to match sampling areas between methods, the VC observer was focused on an area different from that of the SV. Nevertheless, it is very likely that at least a portion of the disparity in species observed is due to the fact that the SV has a limited viewfield in the vertical range (as would all video). The top portion of the water column, where the needlefish observed by the VC surveyor swam, was not observable with the camera system. Such limitations of video (and DS) should be taken into account during study design, and remedied, if possible, before sampling / data collection occurs. Additionally, the disparity between VC and SV surveys suggests the potential for considerable variation in fish community composition over very small spatial scales in mangrove habitats. Such variation should be considered when planning protocols for fish community assessment in mangrove habitats, particularly with an immobile recording device such as SV or DS.

In the reef environment, species totals were similar between the VC and SV surveys, with the SV method resulting in the identification of one more species (n = 3) than the VC survey (n = 2). The additional species was the striped parrotfish (several individuals), which were either out of the viewfield of the VC surveyor, or within the viewfield but unobserved during their relatively rapid entry and exit into the area (as observed on SV). The latter situation could have occurred while the VC surveyor was recording species or size estimates on the underwater data sheet. The similarity in species counts between the SV and VC survey methods indicates that video is appropriate for assessing fish species composition over relatively small spatial scales in reef environments. The limited viewfield of the SV system relative to the greater local spatial scale of fish movement limited the ability to make absolute abundance estimates using SV, as fish repeatedly moved out of and in to the SV viewfield. It was impossible to determine whether a fish entering the SV viewfield was a "new" fish, or one that had previously left the viewfield but remained in the general area. Because of the limited viewfield, the SV method resulted in lower abundance estimates (6.9 +/- .033 fish; Fig. 7) than the VC survey. These results indicate that the SV method is appropriate for assessing fish community composition and, with caveats of small spatial scale of observation, abundance in reef environments.

CONCLUSION

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[2] No fish with typically "stationary" behaviors (e.g., flatfish, lizardfish, and searobins) were observed during our surveys. It is likely that such fish would be (1) less visible than motile fish using any of the methods described herein, and (2) more likely to be identified using SV and VC than DS.

All of the methods utilized (DS, SV and VC) were adequate for measuring components of the fish community in mangrove and reef environments. The strengths and weaknesses of each method varied by environment. In general, length estimation was simpler and faster for DS than for SV, while SV allowed determination of species composition, which was not possible using DS. DS was capable of providing size-distribution and abundance data in some environments where SV and VC surveys were limited or incapable of providing data (e.g., highly turbid environments, and night observations in any environment). Table 3 contains a matrix of methods and environments, with the cross-matrix cells providing a summary of the utility of a specific method in a specific environment. Depending on the objectives and logistical constraints of a study, different methods will be optimal. When possible, we recommended using multiple methods to maximize knowledge of fish community structure in subtropical and tropical shallow-water environments.

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Table 1: Acronyms for methods and environments.

Acronym	Method or Environments
DS	DIDSON
DS-NF	DIDSON - nearfield
DS-FF	DIDSON - farfield
SV	Stereo-video
VC	Visual census (snorkeler)
MC	Mangrove clear
MT	Mangrove turbid
RF	Reef
MN	Mangrove Night
CH	Channel (moving transects)

Table 2: Species lists generated from SV versus VC observations for the MC and RF environments.

Mangrove Clear		Reef	
SV	**Visual**	**SV**	**Visual**
Lutjanus apodus	*Lutjanus apodus*	*Haemulon sciurus*	*Haemulon sciurus*
	Lutjanus griseus	*Haemulon plumierii*	*Haemulon plumierii*
	Eucinostomus melanopterus	*Scarus iserti*	
	Strongylura notata		
	Haemulon sciurus		
	Haemulon plumierii		
	Archosargus rhomboidalis		

Table 3: Matrix of methods and environments, with the cross-matrix cells providing a summary of the utility of a specific method in a specific environment. S = species identification, A = abundance, L = length.

	METHOD		
	Stereo-Video	**DIDSON**	**Visual census (diver or snorkeler)**
ENVIRONMENT			
Clear (day)	S, A, L	A, L	S, A, L
Turbid (day)	S, A	A, L	S, A, L (dependent on water clarity; data quality reduced with increasing turbidity)
Prop roots		A, L	
Reef	S, A	L	S, A, L
Night		A, L	
Moving / Channel	Not effective in this study; could be addressed by altering camera components	A, L	S, A, L (dependent on water clarity; data quality reduced with increasing turbidity)

Figure 1: Map depicting study area. The dark outline in the center of the map is the boundary line for Biscayne National Park.

Figure 2: Diagram illustrating disparity as the offset of the image location of an object.

Figure 3: DS and SV deployment methods in (a) mangrove, (b) reef, and (c) channel / moving transect environments. In (a), the DS unit is on the lower left, and the SV unit is on the lower right.

Figure 4: Scaled standard deviations, expressed as a percentage of mean fish length, +/- SE generated by DS (gray bars) and SV (clear bars) in MC and MT environments. Statistical analyses were performed on natural log-transformed data. Letters above columns indicate statistical grouping (no significant difference between treatment combinations in the same letter group).

Figure 5: Mean length estimates +/- SE generated by DS (gray bars) and SV (clear bars) for MC and MT environments. Statistical analyses were performed separately for MC and MT using square root-transformed data. Letters above columns indicate statistical grouping (no significant difference between treatment combinations in the same letter group).

Figure 6: Length-frequency distributions generated by DS (gray bars) and SV (clear bars) for (a) MC, (b) MT, and by DS for (c) MN (striped bars) and CH (hatched bars) environments.

Figure 7: Mean abundance estimates +/- SE generated by DS-NF (gray bars), DFF (striped bars), and SV (clear bars) for MC, MT and RF environments. DS-NF are estimates from the same area sampled by SV; DS-FF are estimates from the entire DS sampling area. Statistical analyses were performed separately for MC, MT and RF using natural log-transformed data. Letters above columns indicate statistical grouping (no significant difference between treatment combinations in the same letter group).

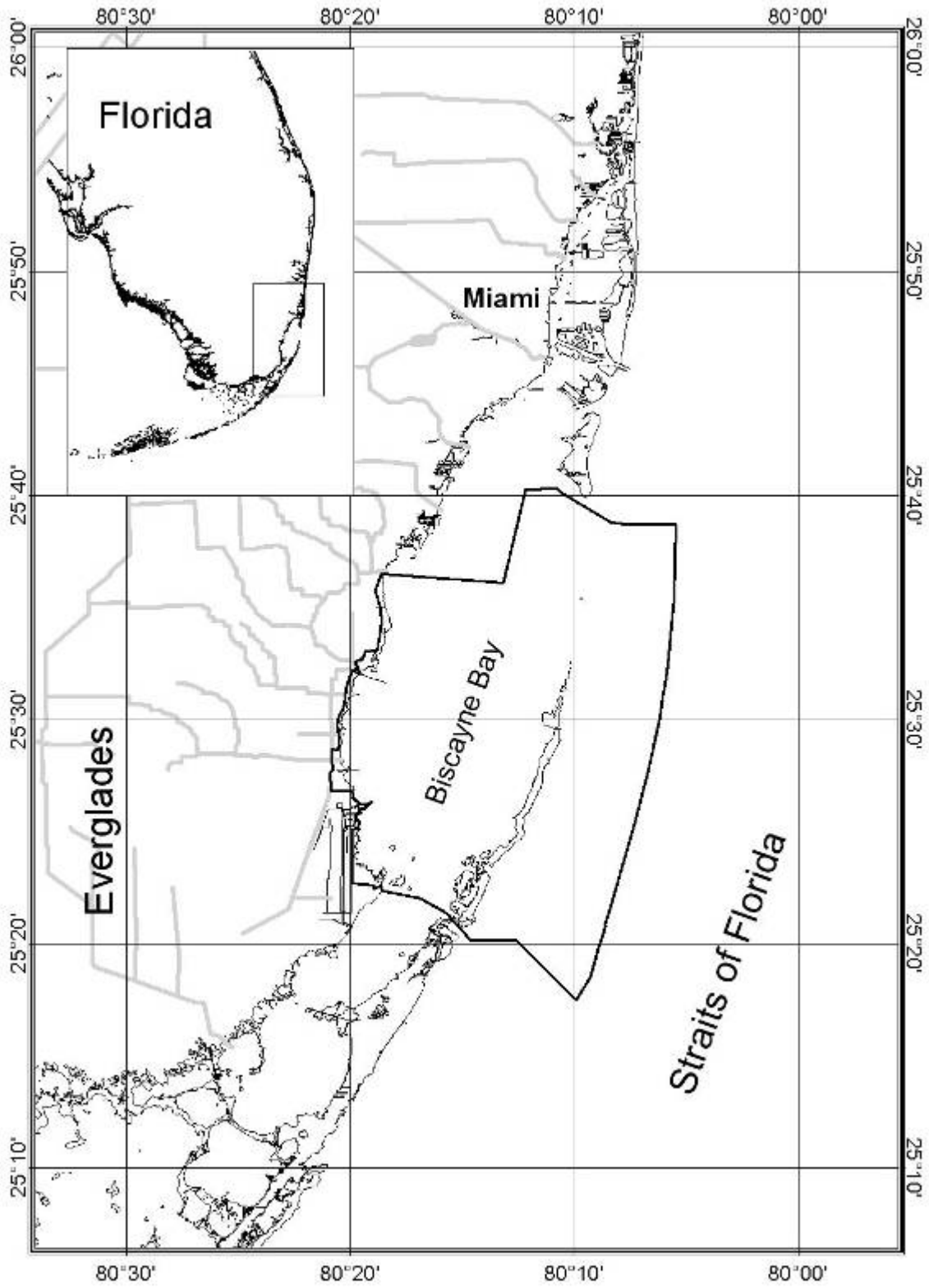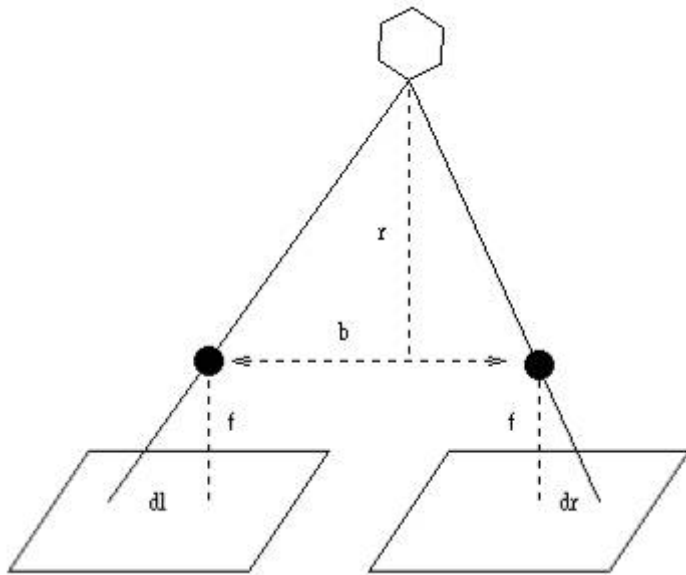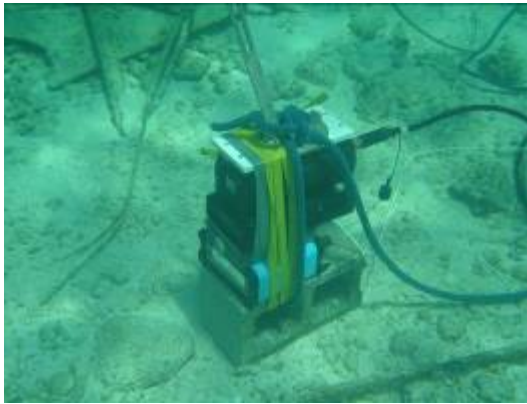**Figure 8:** Length-frequency distributions generated by DS (gray bars), SV (clear bars), and VC (striped bars) in the RF environment.
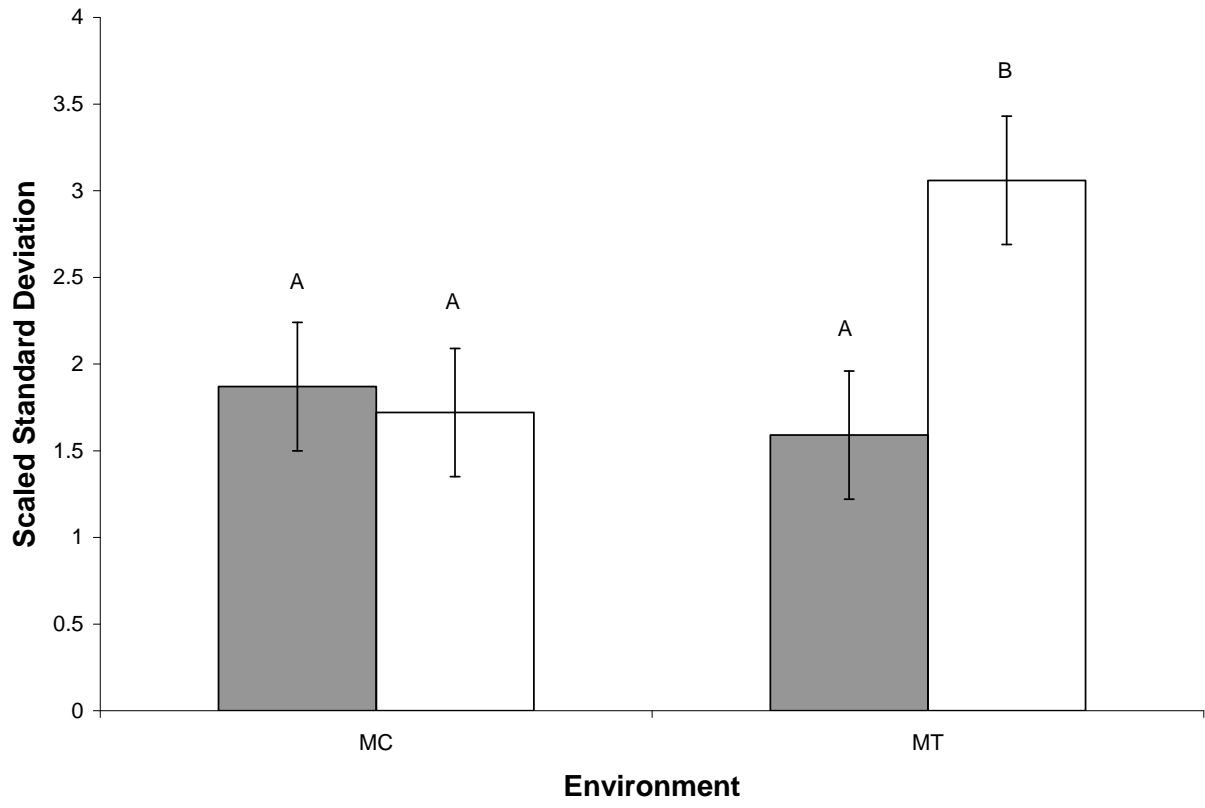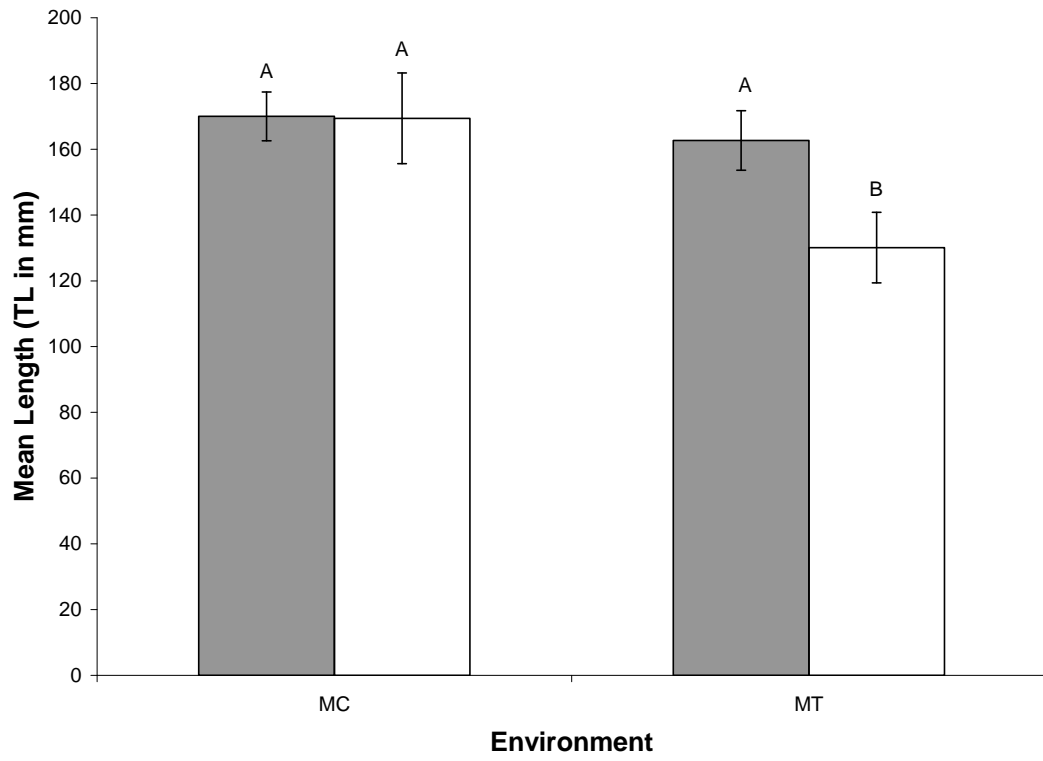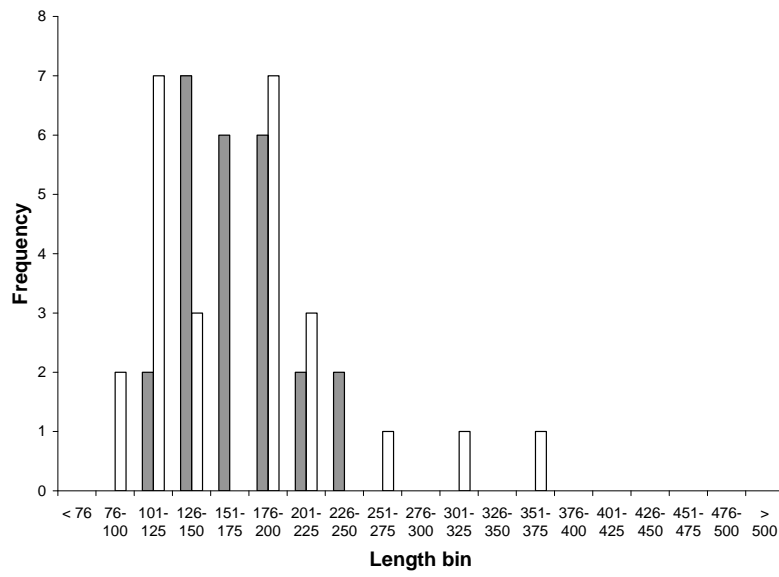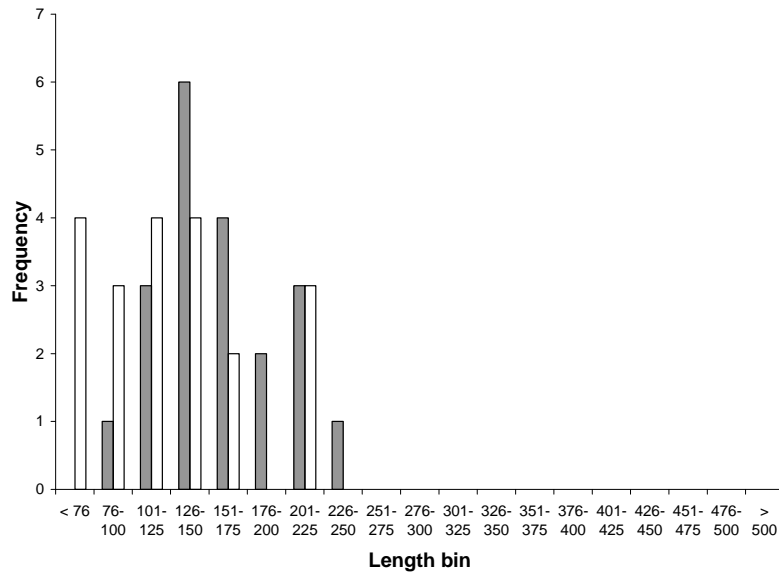
Fig. 1.

Fig. 2

Fig. 3

A.

B.

C.

Fig. 4

Fig. 5

Fig. 6

(a)

(b)

(c)

Fig. 7

Fig. 8