Development of a Remotely Operated Vehicle Based Methodology to Estimate Fish Community Structure at Artificial Reef Sites in the Northern Gulf of Mexico

WILLIAM F. PATTERSON, III, MICHAEL A. DANCE*, and DUSTIN T. ADDIS

University of West Florida, Department of Biology, 11000 University Parkway, Pensacola, Florida 32514 USA

**Current Address: Texas A&M University at Galveston, 5007 Avenue U, Galveston, Texas 77551 USA*

ABSTRACT

A remotely operated vehicle (ROV) based methodology was developed to estimate reef fish community structure at artificial reef sites off Pensacola, Florida in the northern Gulf of Mexico. The method is based on the visual census technique developed by Bohnsack and Bannerot (1986), with a key departure being that sampling was conducted with a micro ROV instead of divers. A VideoRay Pro III ROV equipped with a red laser scale (distance between lasers = 10 cm) was employed to sample fish communities and estimate the size distribution of fishes at study sites. Pool experiments were conducted to examine the effect of distance from target (1, 2.5, and 5 m) and laser angle of incidence (0º, 5º, 10º, 15º, 20º, and 30º from perpendicular) on the accuracy of estimating fish length with the laser scale. Results indicate that fish length estimated with the laser scale was accurate (i.e., mean absolute error < 5%) for distances < 5 m and angles of incidence ≤20º from perpendicular. In the field, the ROV was used to sample a 15-m wide cylinder around artificial reefs from the seafloor through the water column. Two readers independently analyzed video samples (n = 24) in which all fishes were identified to the lowest taxonomic level possible and counted. Average percent error between readers among all samples was 7.4%; the correlation coefficient between taxa-specific counts was 0.997 ($p < 0.001$). Overall, results suggest that micro ROVs can be used to estimate reef fish community structure precisely at artificial reef sites, as well as to estimate size distributions accurately of fishes present.

KEY WORDS: Artificial reef, reef fish, Remotely Operated Vehicle

Desarrollo de un Vehículo Operado Remotamente Basado en la Metodología Para Examinar la Estructura de la Comunidad de Peces en el Arrecife Artificial Sitios en el Norte del Golfo de Mexico

Un vehículo operado remotamente (ROV), con sede metodología fue desarrollada para estimar los peces de los arrecifes la estructura de la comunidad de arrecifes artificiales en zonas de Pensacola, Florida, en el norte del Golfo de Mexico. El método se basa en la técnica de censo visual desarrollado por Bohnsack y Bannerot (1986), con una partida clave es que el muestreo se llevó a cabo con un ROV micro en lugar de los buceadores. A VideoRay ROV III Pro equipado con un láser rojo escala (distancia entre el láser = 10 cm) se utilizó para la muestra las comunidades de peces y estimar la distribución del tamaño de los peces en sitios de estudio. Piscina experimentos se llevaron a cabo para examinar el efecto de la distancia del objetivo (1, 2.5, y 5 m) y láser ángulo de incidencia (0º, 5º, 10º, 15º, 20º y 30º de la perpendicular) sobre la exactitud de la estimación de longitud de los peces con el láser escala. Los resultados indican que la duración estimada de peces con el láser se precisa escala (es decir, con una media de error absoluto <5%) para las distancias <5 m y ángulos de incidencia ≤ 20º. En el campo, el ROV se utilizó una muestra de 15-m de ancho alrededor del cilindro de arrecifes artificiales desde el fondo marino a través de la columna de agua. Dos lectores de vídeo independiente, analizaron muestras (n = 24) en el que todos los peces se identificaron a la menor nivel taxonómico posible y contados. Promedio por ciento de error entre los lectores entre todas las muestras fue de 7,4%, el coeficiente de correlación entre taxa específicos se cuenta con 0,997 ($p < 0,01$). En general, los resultados sugieren que las microempresas ROV se puede utilizar para estimar los peces de los arrecifes con precisión la estructura de la comunidad en sitios de arrecife artificial, así como para estimar la distribución del tamaño de los peces presentes.

PALABRAS CLAVES: Filones artificiales, los peces de los arrecifes, Vehículo Operado a Distancia

INTRODUCTION

Artificial reefs have been constructed of a variety of materials in marine and aquatic habitats around the world for myriad purposes, such as mitigating loss of structurally complex or hardbottom habitat, enhancing production of reef-dependent invertebrates or fishes, providing divers with increased opportunity to view reef-associated organisms, and aggregating fishes to increase fishing efficiency (Abelson 2006, Baine 2001, Oh *et al.* 2008, Okechi and Polovina 1995, Seaman 2008). While resource managers often cite more than one goal for a given artificial reef program, recreational and commercial fishermen generally are among the most vocal proponents of artificial reefs because increased catch rates often follow reef creation (Bohnsack 1989, Bortone 2006, Grossman *et al.* 1997). In turn, increased catch rates have been interpreted by user groups as evidence of increased productivity of targeted species (Lindberg 1997); however, the ecological versus fishery function of artificial reefs remains unresolved (Pitcher and Seaman 2000, Powers *et al.* 2003). Despite early warnings that artificial reefs may serve as net sinks of reef fish production (Bohnsack and Sutherland 1985, Bohnsack 1989, Pitcher *et al.* 2000), a quarter century later we still know much more about how to engineer and deploy artificial reefs than we do about their ecological function (Bortone 2006, Miller 2002, Sayer *et al.* 2005).

We have conducted a study in an artificial reef permit area off Pensacola, Florida since fall 2004 to examine the ecological function of artificial reefs that were deployed in

2003 by the state of Florida's Fish and Wildlife Conservation Commission (FL FWC) but not reported to the fishing public. The overall goal of our research is to examine the ecological function of a subset (n = 27) of the sites built by the FL FWC (Figure 1, Table 1), and to evaluate whether unreported, but not otherwise protected, reef sites can serve as effective no-harvest refugia for reef fishes. A key component of the work is quarterly sampling of reef fish communities at study sites. Prior to beginning the study, we considered utilizing divers to conduct visual sampling of fish populations, but reef depths (27-37 m) would either limit bottom time with conventional SCUBA or necessitate technical diving. Instead, a method was developed that utilizes a micro remotely operated vehicle (ROV) to video sample reef fish communities.

Transect sampling with ROVs has been reported in the literature (e.g., Kelley *et al.* 2008, Moser *et al.* 1998), but the small scale of our study sites make them ill-suited for transect sampling. Therefore, we developed a ROV sampling protocol based on the Bohnsack and Bannerot (1986) diver-based point count method. Sampling was conducted with a VideoRay Pro III micro ROV (dimensions: 30 cm long, 24 cm tall, 22 cm wide; mass = 3.84 kg), which has a depth rating of 170 m, a wide angle (105º) lens on its 570-line color camera, and is equipped with a red laser scale (10 cm between lasers), to estimate fish size (additional ROV specifications available at www.videoray.com). Here, details of the sampling protocol are reported, as well as of tests that were conducted to examine assumptions of the method and reproducibility of results.

METHODS

Laser scales like the one available on VideoRay micro ROVs suffer increasing bias, due to the parallax effect, in estimating fish lengths as the angle between the ROV and the fish target deviates from perpendicular (Parry *et al.* 2002). Although sophisticated laser scales have been engineered for divers and for deployment on larger ROVs to control for issues with parallax (e.g., Pilgrim *et al.* 2000), that level of technology is not yet available for VideoRay micro ROVs. Therefore, the degree of bias that occurs at different angles from perpendicular between the ROV and a fish target with VideoRay's basic laser scale was tested. This was done by conducting a pool experiment in which three fish images were printed on waterproof paper and affixed to plastic foam board, which in turn was attached to a 1 m tall metal ring stand (Figure 2A). Three different fish models were created: a 590 mm total length (TL) gag, *Mycteroperca microlepis*, a 385 mm fork length (FL) red snapper, *Lutjanus campechanus*, and a 185 mm FL vermilion snapper, *Rhomboplites aurorubens*. Models were sequentially deployed in the University of West Florida's (UWF) indoor swimming pool as the focal point of an array that was established on the pool's bottom with distances of 1, 2.5, and 5 m from the targeted fish model and angles of 0º, 5º, 10º, 15º, 20º, and 30º from perpendicular. The ROV was positioned by hand in the pool at the various angle/distance combinations; video of the experiment was recorded on digital video tape with a Sony GVD1000 digital VCR.

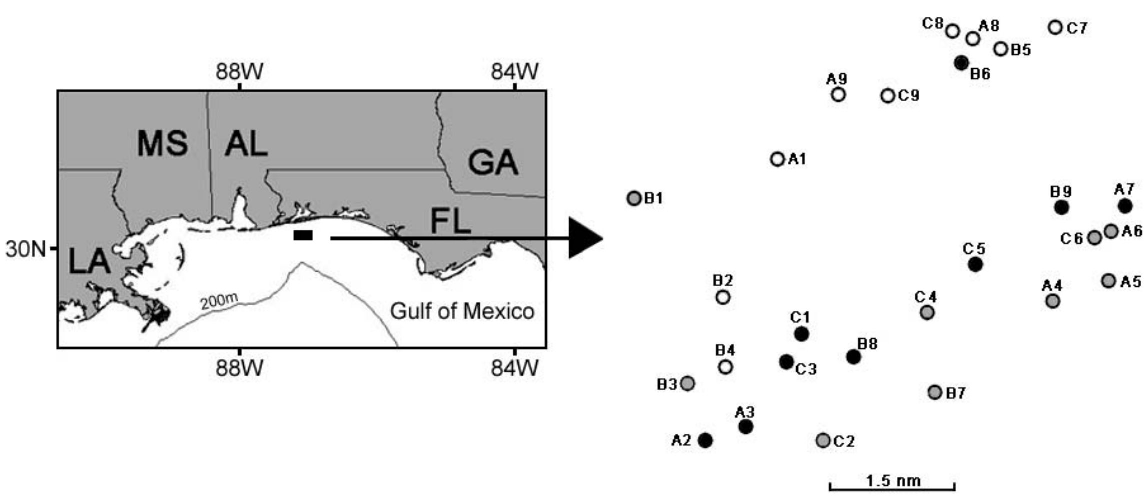


Figure 1. Map of the northern Gulf of Mexico indicating the position of the Escambia East Large Area Artificial Reef Site (EE-LAARS) where study reefs were located. Study sites were located in the southwest corner of the EE-LAARS. Their relative positions are indicated. Letter indicates reef type. Symbol color indicates depth stratum: white = shallow stratum sites (<31 m), black indicates mid-depth sites (31-35 m), and gray indicates deep stratum sites (>35 m).

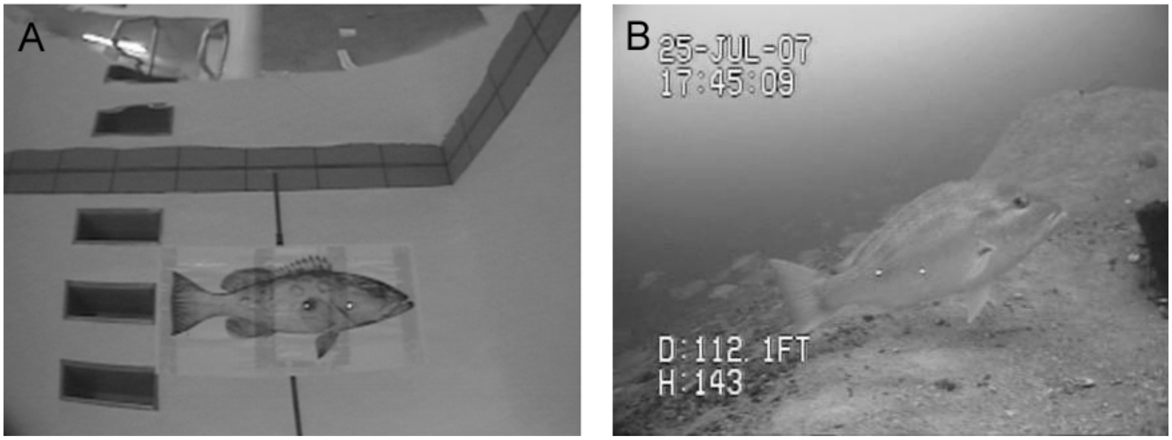
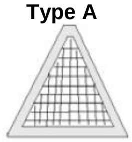
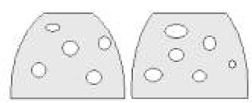


Figure 2. Digital images of A) a 590 mm TL gag model positioned 1 m directly in front of the Pro III micro ROV during the pool experiment designed to test the accuracy of estimating fish length with the ROV's laser scale, and B) a red snapper estimated to be 672 mm FL that was observed at a sampling reef in July 2007. Lasers striking both the gag model (A) and the red snapper (B) are visible in the images. In panel B, the depth (D in ft) and heading (H in degrees) of the ROV, as well as the sampling date and time, have been electronically overlain on the video image.

Table 1. Dimensions of study artificial reef types in the Escambia East Large Area Artificial Reef Site off Pensacola, Florida.

Reef Type: / Reef Properties	Type A	Type B	Type C
			
modules per site	1	2	2
module height m	3.05	1.83	1.45
module base m	3.05	3.05	1.83
module volume m^3	4.09	4.90	2.84
construction	welded rebar sides; concrete base and corner supports	concrete; smaller insert on the inside of outer module	concrete

Ten individual frames were captured from the digital video recorded at each angle/distance combination for each fish model. Digital images were either viewed on a 53.3-cm Sony LMD-170 high resolution LCD monitor and measured with digital calipers or were uploaded into an Image Pro image analysis system to extract length information electronically. Length was estimated for the respective model in each video frame by multiplying the measured of the model by the known distance between lasers (100 mm), and then dividing that product by the distance measured between lasers striking the model in the image. The same methodology was utilized to estimate fish length from video samples taken at artificial reef study sites (Fig. 2B). For example, if a fish's FL in a digital image was measured to be 219.0 mm FL and the distance between the laser points in the image measured 32.6 mm, then the fish's actual FL would be estimated to be 672 mm {[(224.4 mm*100 mm)/33.4 mm)] = 672 mm}.

Mean estimated fish length was plotted versus laser angle of incidence (angular deviance from 90º) for both the 1 m and 2.5 m distances from the pool experiment. The lighting in the UWF pool house was too bright to see the lasers consistently at 5 m so that distance was dropped from the analysis. Dropping the 5 m distance ended up being inconsequential in the field based on estimates of fish distance from the ROV when struck by the laser scale (see below). Non-linear regressions were computed in SAS (SAS Institute Inc., Cary, NC) for each ROV distance to model the bias associated with increasing angular deviance from 90º that lasers strike fish. Non-linear regressions also were computed to predict the distance between the ROV and a target from the measured distance between lasers striking a fish model.

Video sampling in the field also was performed with a VideoRay Pro III ROV. The ROV was controlled with an integrated control box via the ROV's tether. Real-time ROV movement was observed on a high resolution monitor with a live feed from the ROV's 570-line resolution video camera; the camera is capable of 160^o vertical tilt, and has a wide focus range and a wide viewing angle (105º). Depth and heading of the ROV were electronically overlaid on the video image (Figure 2B). Lighting, when needed, was provided by twin 20-watt high efficiency halogen lights mounted on the ROV. As in the pool experiment, video output from the ROV was recorded on digital video tape with a Sony GVD1000 digital VCR.

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Video sampling of fishes at study sites occurred quarterly from fall 2004 through summer 2008, although data presented here only were collected through summer 2006. Video sampling with the ROV required modification of the established, diver-based point count method described by Bohnsack and Bannerot (1986). In their method, a diver identifies and counts all fishes within a 15-m diameter cylinder from the seafloor (or reef) to the surface. In the modified ROV method, the ROV first is positioned 1 m above the seafloor and approximately 5.5 m away from a given artificial reef. The ROV is pivoted in a 360º spin for approximately 30 seconds and then moved to the opposite side of the reef. Once there, the ROV is again positioned 1 m above the seafloor and 5.5 m away from the reef and pivoted 360º. The ROV then is flown to 1 m directly above the reef and pivoted 360º to video sample fishes in the water column above the reef. Next, the ROV is flown to 10 m above the reef and pivoted 360º. Once spins are completed, the ROV is flown back down to the

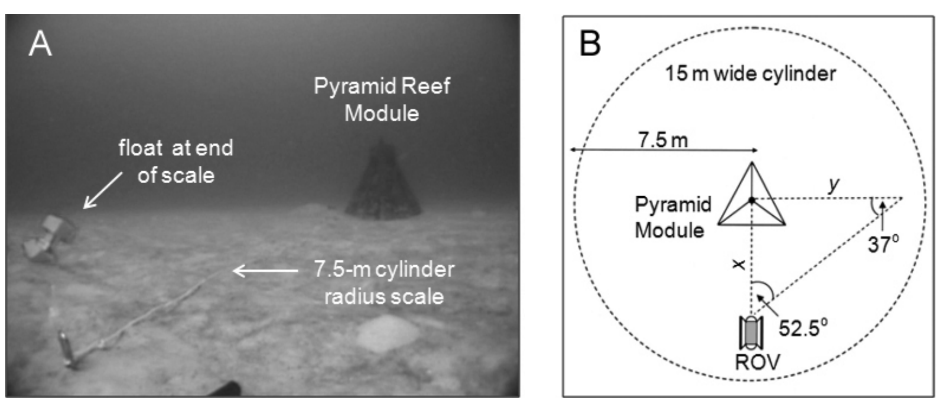

Figure 3. A) A 7.5 m scale deployed on the seafloor to indicate sampling cylinder radius, and B) an example of how geometry is employed to estimate width of camera view and the distance the ROV is from an artificial reef. A pyramid reef module's base is 3.1 m; thus, the distance y ≈ 7.2 m and the distance x ≈ 5.5 m when the pyramid's base fills approximately 20% of the camera's view.

reef and positioned such that fishes inside the reef structure or within the reef's invertebrate fouling community are video sampled. The entire video sampling procedure can be accomplished in < 5 minutes. Following video sampling, the ROV is positioned among the fishes present in an attempt to increase the sample size of fish struck with the laser scale.

It is apparent that for the ROV based cylinder sampling method to be successful one must be able to estimate accurately the diameter of the cylinder being sampled. Therefore, three techniques have been developed to allow one to estimate a sample cylinder's radius. The first is deployment of a 7.5 m scale to indicate cylinder radius. The scale is weighted with 238 g of lead on each end, and the end away from the reef has an orange float that is easily seen underwater (Figure 3A). The second method, and the one predominantly used, is based on the known dimensions of modules and the geometry implied by the camera's 105º view (Figure 3B). For example, the base of an A-type module is 3.05 m in width (Table 1). Therefore, the distance *y* in Figure 5B is 7.2 m when the ROV is 5.5 m from the module. This is true because the angles of the right triangle depicted in Figure 5B are known to be 90º, 52.5º, and 37.5º; thus, the tangent of 37.5º equals the distance *x* between the ROV and the reef center divided by distance *y*. If the ROV is 5.5 m away from the reef center, then *y* would be 7.2 m. Multiplying 7.2 by 2 yields the total distance in the reef's plane that is in view when the ROV is 5.5 m away from it. Therefore, when the ROV is 5.5 m away from the center of the reef, the distance across the field of view is 14.4 m. Since the base of the reef is 3.05 m wide, it will fill approximately 20% of the distance across the field of view when the ROV is 5.5 m from it. Therefore, the pilot can position the ROV approximately 5.5 m from the reef in the above example by ensuring the reef base is approximately 20% of distance across the field of view in the plane of the reef. Lastly, the distance the ROV is from the reef can be estimated from the measured distance in video captures between lasers striking the reef (see below).

A primary concern about any sampling method is reproducibility of results. To examine agreement in fish counts between video readers, independent fish counts made by two readers (combinations of the authors) from samples collected during 24 sampling events (i.e., three randomly selected study sites from each of the first eight quarters of sampling) were compared. Analysis of video samples was performed in the Fisheries Laboratory at UWF with a Sony DVCAM DSR-11 digital VCR and a Sony LMD-170 high resolution LCD monitor. For a given video sample, fish were identified to the lowest taxon possible (typically to species) and enumerated for five separate video segments: 1st 360º spin 1 m above seafloor, 2nd spin 1 m above seafloor on the opposite side of the reef as the 1st spin, the spin 1 m above reef, the spin 10 m above the reef, and inside the reef. To avoid double counting individuals, fish observed during the 1st and 2nd spins were counted as part of the respective spin's sampling segment only if they occurred on the side of the reef on which the ROV was located, and fish observed during the 3rd spin were only counted above the height of the reef. Fish numbers were summed across all five sampling segments for a total count. Reader counts were correlated between initial and second readers. Differences between reader estimates were evaluated by computing the average percent error (APE) for each taxon in a given sample. Average percent error between reader counts for a given taxon was computed as:

$$\mathbf{APE = 100 \times ((1/n) \times (((ABS(R_1 - mean))/mean) + ((ABS(R_2 - mean))/mean)))}$$

Where:

n = number of readers
ABS = absolute value
R_1 = count from reader 1
R_2 = count from reader 2
mean = average count between readers.

Average percent error among all samples was computed as the mean of all taxa-specific APEs.

RESULTS

Bias in fish model length estimates from the pool experiment typically was less than 5% for distances of 1 and 2.5 m between the ROV and models if the angular deviance from 90º was 20º or less (Figure 4). Non-linear regressions were highly significant ($p < 0.001$) for both those distances and regression coefficients indicated predicted lines fit the data well. Regression coefficients were even higher for models computed to predict the distance between the ROV and a target from the measured distance between lasers in digital images of fish models (Figure 5). Those regressions also were highly significant ($p < 0.001$).

A total of 177 paired taxa-specific (98.3% to the level of species) fish counts was made by two readers among the 24 samples selected for reader comparisons (Figure 6). Numbers of individuals ranged from 1 to 265 fish in initial reads. The correlation between readers was high ($p < 0.001$, Pearson's $r = 0.997$) and all reader comparisons fell close to the line of 1:1 agreement. The APE between readers was 7.4%; however, 61% of species had counts of < 5 individuals in initial reads and APE can be inflated when even minor differences exist in counts of uncommon species. For example, a difference of only one fish for species for which the initial read produced a count of five would yield a count-specific error of 20%.

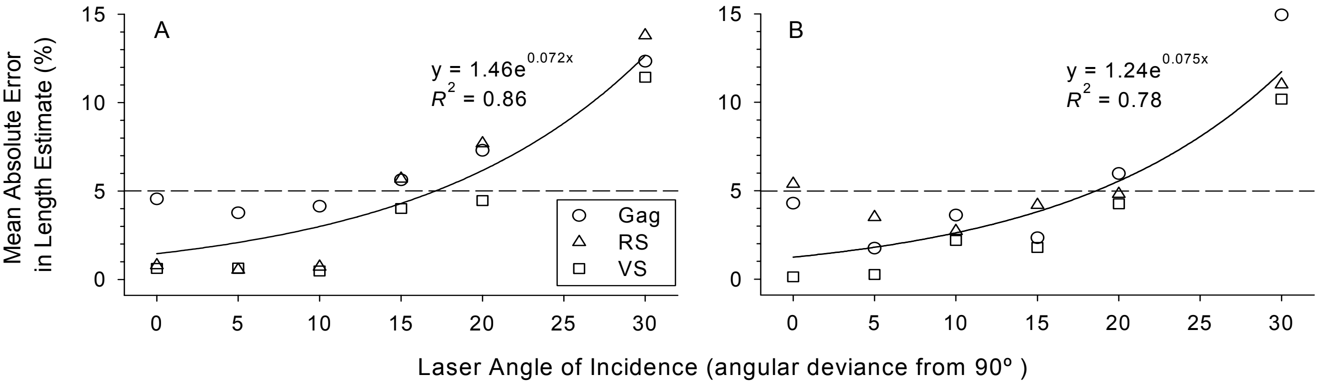

Figure 4. Mean absolute percent error in fish length estimates versus laser angle of incidence for gag, red snapper (RS) and vermilion snapper (VS) models deployed in pool experiments with the ROV positioned A) 1 m from models and B) 2.5 m from models. Equations are for the fitted lines (non-linear regression), which predict percent error from laser angle of incidence.

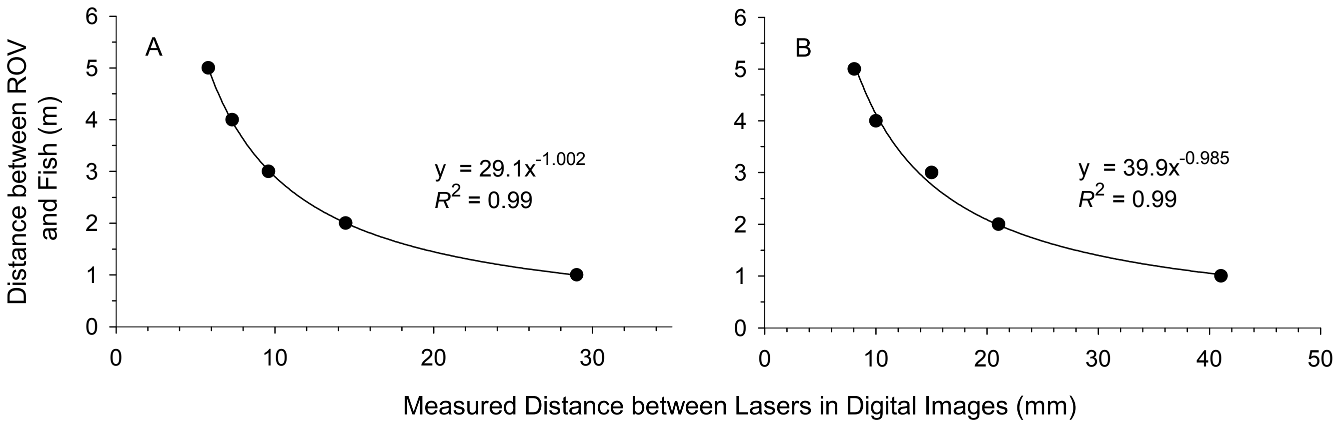

Figure 5. The relationship between the measured distance between lasers striking the 590 mm TL gag model and the known distance between the model and the ROV positioned directly in front of it for A) laser measurements made on a 25 inch high resolution video monitor with digital calipers and B) those made electronically with an Image Pro image analysis system. Fitted lines are non-linear regressions computed to predict the distance between a target and the ROV at study reefs from the measured distance between lasers striking the target.

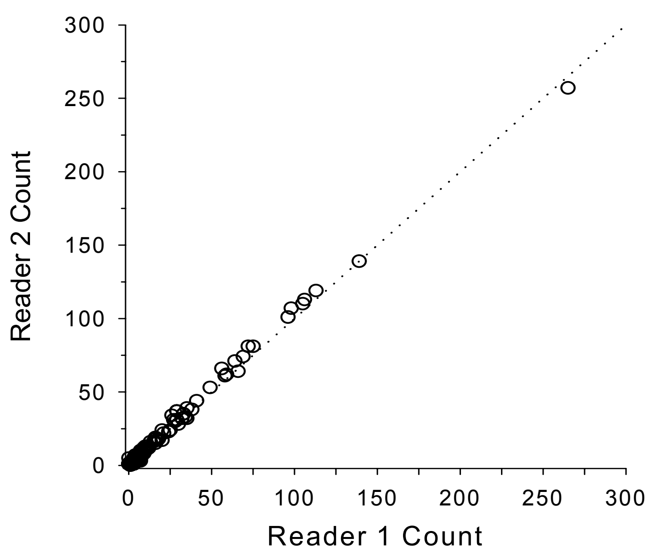

Figure 6. Comparison of reader counts (n = 177) for fish taxa observed in ROV video from 24 sampling events at artificial reef sites in the northern Gulf of Mexico. Each symbol represents a count comparison for an individual taxon. The diagonal line represents the line of 1:1 agreement between readers.

CONCLUSIONS

Overall, study results suggest that micro ROVs can be used to estimate size distributions of fishes present at artificial reef sites accurately and that estimates of reef fish community structure are precise. The degree of accuracy in estimating fish size with the laser scale is particularly promising given that fish size can be estimated accurately (i.e., < 5% absolute error) as far as 2.5 m from the ROV. While we have no means to estimate the angle at which lasers strike fish *in situ*, we do have some confidence that measurements have not been attempted for fish which have angles of incidence that are greater than 20º from perpendicular. It may be that accuracy decreases at distances greater than 2.5 m, but lighting conditions in UWF's pool house precluded testing that hypothesis. However, when the regressions in Figure 5 were applied to data from fish (n = 6,977) that were struck by lasers during ROV sampling at study sites, the mean distance (± SE) between fish and the ROV was predicted to be 1.03 m (± 0.01), and less than 0.1% of fish (n = 59) struck with lasers were estimated to be more than 2.5 m from the ROV (W.F.P., Unpublished data).

In the field, the ROV's presence did not appear to alter fish behavior significantly, and *in situ* laser data indicate that fish often swim very closely to the ROV. Red snapper did appear agitated when the ROV's light array was powered on. However, lights were only rarely needed to conduct video sampling, and even then were only used to sample small fishes associated with a reef's fouling community after water column sampling was completed. We did experience a few instances when gray triggerfish, *Balistes capriscus*, nipped at the ROV from behind or at its tether, as well as a single instance in which a loggerhead turtle, *Caretta caretta*, nudged the ROV with its head. Several sharks seemed to circle around the ROV, perhaps attracted by the machine's electrical signals, but none inspected it closely or appeared aggressive toward it.

The behavior of fish with respect to the presence divers or a ROV is an important aspect of sampling reef fish communities. Stanley and Wilson (1995) reported that the presence of divers at petroleum platforms off Louisiana affected the distribution of reef fish biomass perceived by a hydroacoustic array. While fish clearly avoided divers, a similar pattern was not observed when groundtruthing fish species composition with a ROV. When avoidance is not an issue, diver and ROV counts of marine fauna have been shown to be comparable (Parry *et al*. 2002). However, a clear advantage that sampling with a ROV has is that depth is much less of a factor than it is with divers (Kelley *et al*. 2008, Morris 2007). Even at the modest depths of artificial reefs in the current study, the logistics of using divers to conduct fish counts would have been far more complicated than using the micro ROV with which we sampled fish communities.

Another advantage of using a ROV to video sample reef communities is that a digital record exists of fishes encountered. That is especially beneficial at high diversity sites in that the tape can be viewed repeatedly to conduct species-specific counts, and the tape can be forwarded a single frame at a time to confirm species identifications and counts. This property of our sampling approach likely aided the high precision of fish community estimates. While that should not be confused with accuracy, reproducibility of results clearly is an important sampling consideration. Diver comparisons may be beneficial to examine the accuracy of counts, but others have shown that diver avoidance may make comparisons problematic (Rutecki, T.L. *et al*. 1983, Schmidt and Gassner 2006, Stanley and Wilson 1995).

Results of tests reported here indicate that sampling small scale artificial reef sites with a micro ROV is effective for estimating fish community structure and size distribution. When one considers the cost of sampling, further advantages of sampling with a micro ROV become apparent. The initial expense of UWF's VideoRay Pro III system (~$23,000 US for the ROV and laser scale and another $5,000 in electronics equipment) may be cost prohibitive for some research programs, but when one considers the expense of maintaining dive equipment, employing divers, and covering the liability of diver safety, the initial investment in the ROV system actually is cost effective. For example, 405 ROV dives have been conducted in the broader study to sample the 27 study sites over the course of four years. Contracting technical divers to conduct that level of sampling would have cost in excess of $50,000 US.

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