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Short communication

Developing a two-step fishery-independent design to estimate the relative abundance of deepwater reef fish: Application to a marine protected area off the southeastern United States coast

P.J. Rudershausen[a,*], W.A. Mitchell[a], J.A. Buckel[a], E.H. Williams[b], E. Hazen[c]

[a] Center for Marine Science and Technology, Department of Biology, North Carolina State University, Morehead City, NC 28557, USA
[b] Southeast Fisheries Science Center, Beaufort Laboratory, National Oceanic and Atmospheric Administration, 101 Pivers Island Road, Beaufort, NC 28516, USA
[c] Duke University Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516, USA

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ABSTRACT

Reliable data on reef fishes inhabiting the southeastern United States (North Carolina to Florida) continental shelf large marine ecosystem are difficult to obtain; catch quotas and time and area closures limit the collection of fishery-dependent samples. Further, unbiased fishery-independent samples are expensive to collect with conventional fishing gear. Consequently, stock assessments are often data-limited, especially for deepwater reef species. We estimated the relative abundance of deepwater reef fish with a double sampling approach using fisheries acoustics and conventional fishing gear (hook and line and chevron traps). Double sampling occurred within the newly-created Snowy Wreck Marine Protected Area and a nearby control site. Reef fish concentrations were identified by a single-beam Simrad ES60 transceiver with a transducer operating at 38 kHz. Hook and line samples were collected at 73 acoustic events, and chevron trap samples were collected at 20 acoustic events. The relationship between fisheries acoustic data and catch-per-unit-effort (CPUE) data was examined to develop a model to predict species-generic CPUE at unfished locations. Akaike's Information Criteria (AIC) found equal support for linear, exponential, and power relationships between acoustic backscatter and CPUE for each conventional fishing gear. Further model development would be aided by refining acoustic target information and applying complimentary fish sampling gears (i.e., split-beam fisheries acoustics gear, underwater video). Given further development, a double sampling design should be useful to estimate the relative abundance of important deepwater reef species over a wide area of the shelf break off the southeastern United States, utilizing either survey vessels or vessels-of-opportunity to rapidly collect acoustic samples.

1. Introduction

Most deepwater (80–200 m) reef fishes inhabit hard-bottom habitat along the continental shelf break of the southeastern United States continental shelf large marine ecosystem (SUSLME; North Carolina to Florida). These species are difficult to assess. Intermittent commercial operations, multiple landing sites, variability of species targeted, and dynamic regulations hinder the collection of representative fishery-dependent information. Collection of unbiased fishery-independent information, such as catch-per-unit-effort (CPUE) data, is often cost-prohibitive; the Marine Resource Monitoring Assessment Program (MARMAP) is the only long-term, fishery-independent survey for deepwater reef species of the SUSLME, but occurs over only a fraction of the region, and only regularly from 16 to 91 m deep (McGovern et al., 1998). Estimates of abundance using conventional fishing gears are plagued by high variability (Hanselman and Quinn, 2004); this is especially challenging in the SUSLME because reef fish aggregations over hard-bottom habitat are patchily distributed.

The current stock status of many deepwater reef species in the SUSLME underscores the importance of developing new methods to estimate their abundance. The commercially-important deepwater reef species, snowy grouper (*Epinephelus niveatus*), is overfished and speckled hind (*Epinephelus drummondhayi*) and warsaw grouper (*Epinephelus nigritus*) are species of concern. Depleted or inherently low fish stock sizes hinder the ability to develop reliable indices of relative abundance (Ressler et al., 2009).

Development of effective approaches for sampling deepwater reef fish habitat is needed across a wider area of the continental shelf break of the SUSLME. Eight marine protected areas (MPAs) have recently been designated in the SUSLME. The intent

* Corresponding author. Tel.: +1 252 222 6342; fax: +1 252 222 6311.
E-mail address: pjruders@ncsu.edu (P.J. Rudershausen).

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of these MPAs is to reduce overfishing of common deepwater species and establish refugia for rare species. However, available fishery resource data streams are currently inadequate to evaluate MPA efficacy. Additional coast-wide time closures have recently been instituted and broad area closures are being considered which may further limit fishery-dependent samples. For these reasons, novel fishery-independent sampling techniques and analytical approaches need to be examined to measure the relative abundance of reef species in deepwater and protected areas.

The purpose of double sampling (Thompson, 2002) in fishery surveys is to improve the precision of CPUE estimates. This approach uses a statistical relationship between traditional, relatively expensive CPUE data (e.g., trawling, trapping, hook and line) and inexpensive fisheries acoustics data collected on mobile surveys; this improves sampling efficiency (Thompson, 2002; Hanselman and Quinn, 2004; von Szalay et al., 2007). This relationship can then be used to predict CPUE of the traditional fishing gear when only data from the fisheries acoustics gear are available. Additionally, the expanded use of mobile fisheries acoustics locates patchily distributed reef fish associated with unknown or ephemeral habitat. This co-product may rapidly expand or verify potential sampling sites.

Advances in fisheries acoustics gear, such as improvements in quality, portability, and affordability, also make double sampling more appealing. Commercial-grade acoustic gear have been used in combination with conventional sampling to improve fishery surveys worldwide. For example, Honkalehto and Ryan (2003) used a single-beam Simrad ES60 and trawling to determine the first “quantitative biomass estimate” for a stock of orange roughy (*Hoplostethus atlanticus*) near Tasmania. Hanselman and Quinn (2004) used a Simrad ES60 to increase the precision of abundance estimates for Pacific ocean perch (*Sebastes alutus*). Variance reduction around CPUE estimates were possible for walleye Pollock (*Theragra chalcogramma*) in the Bering Sea using a relationship between estimates of trawl CPUE and acoustic backscatter data from a Simrad ES60 (von Szalay et al., 2007). Approaches that pair conventional sampling and acoustic observations have been used to resolve target species from within mixed-species fish aggregations (Honkalehto and Ryan, 2003; Ressler et al., 2009).

In contrast, fisheries acoustic gears have received less attention in sampling fishes in the SUSLME. In a Gulf of Mexico study on a similar reef fish assemblage, Gledhill et al. (1996) related fisheries acoustics with video observations in an attempt to develop more robust techniques to estimate reef fish abundance; a significant but weak correlation was found between the two fishing gears. In this study, we investigated the utility of hook and line and trap sampling, coupled with fisheries acoustics gear, to rapidly identify reef fish aggregations and predict CPUE of deepwater reef fish species assemblages. We evaluated the relationship between CPUE (dependent variable) and the strength of acoustic backscatter (independent variable) in continental shelf break waters off North Carolina, USA. Finally, we calculated a combined CPUE from the observed and predicted estimates of CPUE.

2. Materials and methods

2.1. Study area, fishing gear, equipment settings, and operational procedures

The Snowy Wreck Marine Protected Area (SWMPA) is approximately 80 nm south of Beaufort Inlet, North Carolina (Fig. 1). Water depths in SWMPA range from 61–290 m. In February 2009, this MPA was given ‘Type 2’ protection where harvest and possession of reef species are prohibited. The MPA was named after a sunken ship inside its boundaries known to harbor aggregations of snowy grouper and other reef species.

Sampling occurred in 2007 (June–October), 2008 (June–September) and 2009 (January–February) before SWMPA closure. Data collection occurred during daylight hours. In 2007,

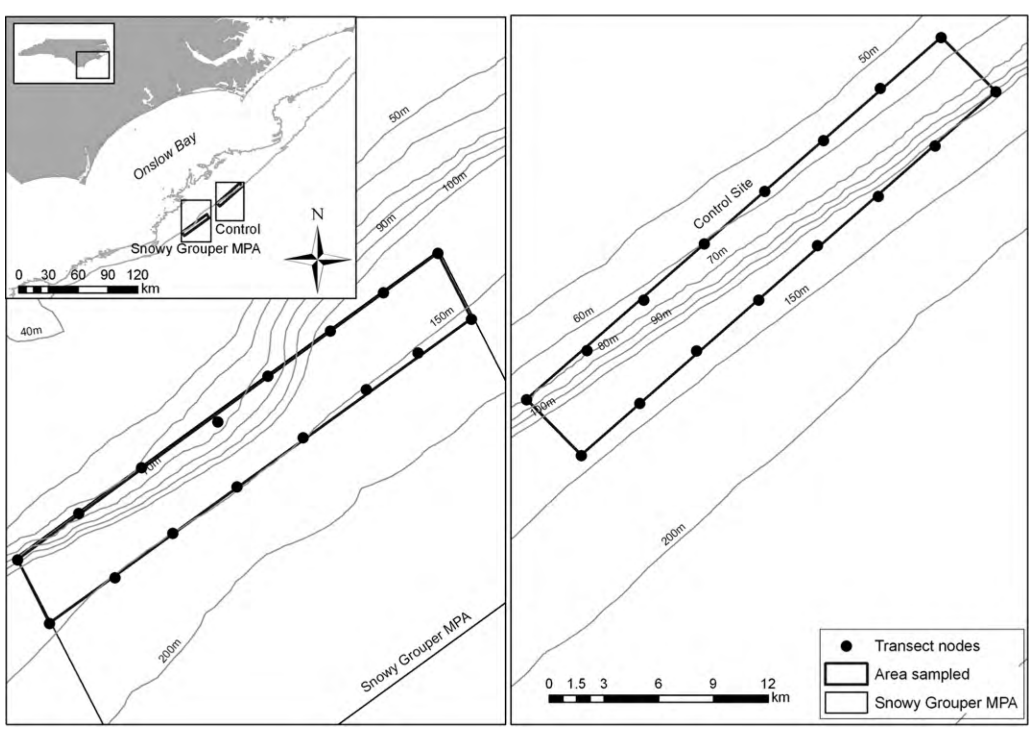

Fig. 1. Map showing the location of Snowy Wreck Marine Protected Area (SWMPA) and a nearby control area off the coast of North Carolina, USA (see inset). The left panel divides SWMPA into an inshore (shelf break) area (4.63 × 27.78 km) and a total area. Sampling occurred throughout SWMPA in 2007. Only the shelf break portion of SWMPA was sampled in 2008. The right panel displays a control shelf break area (4.63 × 27.78 km) that was only sampled in 2008.

acoustic backscatter and hook and line data were collected inside the SWMPA. Acoustic backscatter data were collected over 12 days between 7 June and 16 October 2007 aboard the *F/V Barbara Lynne*, a 13-m diesel-powered fishing vessel. Hook and line data were collected over the same time interval aboard the *F/V Barbara Lynne* on eight out of the 12 days and the *F/V Slow Poke* (a 9-m center-console vessel) on the remaining four. In 2008–2009, acoustic backscatter, hook and line, and chevron trap data were collected on the *F/V Barbara Lynne* in the shelf break region of the SWMPA and a nearby control area of similar dimension and depth (Fig. 1). In both years hook and line and trap data were collected on the day of or day after acoustic sampling. Each trip was attended by a minimum of two personnel with at least one scientific observer.

The original design for this study was to randomly sample linear transects oriented perpendicular to the long axis of the MPA. Following six randomly selected transects in 2007, we found no substantive fish aggregations in >120 m of water with the exception of the actual Snowy Wreck itself. The inshore edge of the SWMPA is considered to be the most biologically productive; thus, sampling efforts were concentrated in that area (4.63 × 27.78 km; Fig. 1) for the remainder of the 2007 study. This adjustment allowed us to maximize the number of reef fish aggregations identified. Ten additional linear transects were then sampled parallel to the long axis of the MPA in waters <120 m; these transects were spaced 0.463 km apart. In 2008–2009, the shelf break portion of the SWMPA and control area were acoustically sampled in a 'zig-zag' pattern by transecting through alternating points on the inshore and offshore long sides of each box; on each of these long axes, points were spaced 4.63 km apart. In each box, the starting point and direction of travel were varied among survey dates so that new benthic habitat was sampled each day.

Fisheries acoustics gear consisted of a Simrad ES60 transceiver outfitted with two single-beam transducers that operate simultaneously at frequencies of 38 and 200 kHz. We elected to use this acoustic gear because it was inexpensive and has potential for industry use (i.e., study fleet). The 38 kHz transducer emitted an elliptical beam; longitudinal (i.e., bow/stern) and transverse (i.e., port/starboard) beam angles were 13° and 21°, respectively. The 200 kHz transducer emitted a circular 7° beam. The transducer housing was affixed to the base of an aluminum pole and deployed amidship from the vessel's port beam. When deployed, the face of the transducer housing was 1 m below the water surface. Boat speed ranged from three to five knots during acoustic data collection. The transceiver was connected to a Garmin 172C GPS plotter that referenced discrete locations where near-bottom backscatter was observed, referred to as acoustic events. Raw ES60 acoustic files were viewed and saved to a laptop computer. The qualitative size (small, medium, large, extra large) and visual characteristics of backscatter (shape, color intensity, distance from bottom), and associated bottom relief (flat, sloping, or ledges) were noted for each acoustic event.

Acoustic events sampled with hook and line or trap fishing gear were a subset of potential reef fish aggregations identified by fisheries acoustics gear. The first two days of hook and line sampling (7 and 11 June, 2007) involved randomly selecting events to be fished with hook and line. During these 2 days, reef fish were only caught when acoustic backscatter was relatively large. Therefore, subsequent hook and line and trap data were collected by randomly selecting from large and extra large events when available, and small and medium events as time permitted or when large or extra large events were absent. The captain of the *F/V Barbara Lynne* used the Simrad fisheries acoustics equipment and GPS to relocate acoustic events. On days when the second vessel assisted, the coordinates for events were relayed via VHF radio.

Hook and line fishing gear consisted of fiberglass rods, electronic reels, and 130 pound low-stretch fishing line. Terminal tackle was a high-low bottom rig consisting of 200 pound monofilament line, two three-way swivels, two 8/0 J-hooks, and lead weight ranging from 0.68 to 1.36 kg. Bait consisted of cut squid (*Loligo* and *Ilex* spp.). Chevron traps were constructed of 35-mm square vinyl-coated wire, with one funnel entrance and one release panel, and had maximum dimensions of 1.5 × 1.7 × 0.6 m (0.91 m^3). Each trap was baited with 24 whole menhaden (*Brevoortia tyrannus*); 16 were hung on four stringers and eight were scattered inside.

When hook and line fishing, captains were permitted to keep vessels in gear (i.e., hover over events) or out of gear (i.e., drift over events) depending on sea conditions. Given the dimensions of the transducer beam at 38 kHz, conventional gear was deployed within 50 m of an event. Hook and line sampling was terminated when the boat drifted greater than 50 m from the event, whereupon the captain repositioned the boat. Fishing continued at an event until four consecutive drops (2 fishers × 2 drops per fisher) yielded no fish. A trap set on an event was soaked for 90 min. Current speed (km/h) and water depth (m) were recorded with each CPUE sample. Depending on the conventional gear type, CPUE was measured as catch-per-drop for each baited two-hook rig or catch-per-trap; at acoustic events where multiple hook and line or trap drops were made, CPUE observations were averaged.

2.2. Processing of acoustic samples

Data from acoustic events were processed using Myriax Echoview software, v. 4.50. No raw data manipulations were applied to correct the periodic systematic error inherent in ES60 systems (e.g., De Robertis and Wilson, 2006; von Szalay et al., 2007). The research objectives of this study were not compromised by permitting up to 1 dB of artificial measurement variability within a single ping, as biased pings would be averaged with echo-integrations. Volumetric backscatter data were reported in decibels (dB), where signal returns approaching zero are stronger than more negative values. To reduce background noise, data were limited to signal returns stronger than −60 dB. Echo-integration (Brandt, 1996) was used to measure acoustic backscatter from 0.25 to 5.25 m above the bottom and 100 m on either side of the event. We felt that these distances were sufficient to capture the full vertical height of reef fish distributions off the bottom, allow for inherent inaccuracies in GPS relocation, and cover a horizontal distance over which vessels drifted while sampling an on- or off-axis acoustic event with hook and line or trap fishing gear. Data processing yielded a measured acoustic volume backscattering coefficient value (S_v (dB)) for each acoustic event.

2.3. Model fitting and demonstration

The 38 kHz acoustic data were used for analyses (described below). We fit each *y*-axis CPUE metric to *x*-axis data (S_v (dB)) using three different models: linear, exponential, and power. These models were examined because of the appearance of the raw data and relationships from prior studies (Hanselman and Quinn, 2004; von Szalay et al., 2007). To select a model, residual sums-of-squares values were used to compute Akaike Information Criteria (AIC); models differing by <4 ΔAIC were concluded to fit the data equally well (Burnham and Anderson, 2002).

The resulting linear model was used to predict hook and line CPUE data for 54 additional events measured acoustically but unfished; estimates of mean CPUE and associated standard deviation were calculated with and without additional events to test for improvements in precision. Standard deviation for each approach was estimated using residuals of the model fit following the regression approach of Cochran (1977) for double sampling. The low sample size of trap data prevented us from predicting CPUE from the acoustic backscatter-trap CPUE relationship.

Table 1
Mean catch-per-drop (hook and line) and catch-per-trap (chevron trapping) for fishes captured from Snowy Wreck Marine Protected Area (SWMPA) (2007–2009) and a nearby control area (2008–2009). We made 368 hook and line and 21 trap drops inside SWMPA and 143 hook and line and 28 trap drops inside the control area; individual efforts were then averaged. This resulted in 73 data points double-sampled with fisheries acoustics and hook and line, and 20 data points double-sampled with fisheries acoustics and chevron traps.

Species	Hook and line		Traps	
	SWMPA	Control	SWMPA	Control
Red porgy *Pagrus pagrus*	0.076	0.154	0.619	0.143
Snowy grouper *Epinephelus niveatus*	0.073	0.021	0.524	0.071
Scamp *Mycteroperca phenax*	0.033	0	0	0.107
Speckled hind *Epinephelus drummondhayi*	0.022	0	0.095	0.036
Knobbed porgy *Calamus nodosus*	0.019	0.014	0	0
Red Grouper *Epinephelus morio*	0.016	0.014	0.238	0.286
Graysby *Cephalopholis cruentatus*	0.011	0	0	0
Greater amberjack *Seriola dumerili*	0.008	0	0	0.036
Tattler *Serranus phoebe*	0.008	0.007	0.048	0
Almaco jack *Seriola rivoliana*	0.005	0	0	0
Blueline tilefish *Caulolatilus microps*	0.005	0	0	0.036
Gray triggerfish *Balistes capriscus*	0.011	0	0.524	0.036
Rock hind *Epinephelus adscensionis*	0.005	0	0	0
Bigeye *Priacanthus arenatus*	0.005	0	0	0
Gag *Mycteroperca microlepis*	0.003	0	0	0
Lesser amberjack *Seriola fasciata*	0.003	0	0	0
Red cornetfish *Fistularia petimba*	0.003	0	0	0
Hogfish snapper *Lachnolaimus maximus*	0.003	0	0	0
Wreckfish *Polyprion americanus*	0.003	0	0	0
Vermilion snapper *Rhomboplites aurorubens*	0.003	0	0	0.036
Tomtate *Haemulon aurolineatum*	0.003	0	0.381	0
Queen snapper *Etelis oculatus*	0.003	0	0	0
Cuban dogfish *Squalus cubensis*	0.003	0	0	0
Coney *Cephalopholis fulva*	0	0.014	0	0
Scorpionfish *Neomerinthe hemingwayi*	0.003	0	0	0
Whitebone porgy *Calamus leucosteus*	0	0	0.048	0
Lionfish *Pterois volitans*	0	0	0.048	0.071
Moray *Gymnothorax* spp.	0	0	0	0.071

3. Results

Acoustic and CPUE data were collected from 93 events revisited with conventional fishing gear. These revisited events were a subset of the total number of locations where near-bottom backscatter was observed. There were 73 events revisited with hook and line and 20 with chevron traps. Hook and line CPUE ranged from 0 to 1.75 fish per drop; forty-eight percent (35/73) of revisits landed fish. Trap CPUE ranged from 0 to 3.67 fish per trap; sixty percent (12/20) of revisits trapped fish. Mean volume backscattering coefficient ranged from −79.25 to −49.76 dB for sites revisited with hook and line and from −83.90 to −60.85 dB for sites revisited with traps.

A total of 152 fish and 25 species was captured with hook and line and a total of 79 fish and 14 species was captured with chevron traps. Red porgy and snowy grouper were the two most abundant species captured with hook and line and traps (Table 1).

The linear, exponential, and power models fit the hook and line data equally well; this was also the case for trap data (Fig. 2; Table 2). The relationship between acoustic backscatter and hook and line CPUE allowed us to predict CPUE at 54 events sampled with fisheries acoustics gear only (open circles: Fig. 3). When in close proximity or along similar depth contours, predicted and observed CPUE values were often similar in magnitude. Mean hook and line CPUE for fished sites (±standard deviation) was 0.206 (0.304). Predicted mean CPUE for additional (unfished) sites was 0.166 (0.296) for the linear regression model fit. The combined CPUE was 0.189 (0.302) based on the linear regression model fit. This reduced the mean overall estimated CPUE within the study area, but did not significantly improve precision.

4. Discussion

This study demonstrated how advanced fisheries acoustics equipment may be used as a fishery-independent tool to estimate species-generic CPUE of deepwater reef species in the SUSLME. The technique provides spatially expanded CPUE estimates at a less expensive rate than conventional fishing gear alone. Additionally, it is an approach to use in the design phase of a survey when

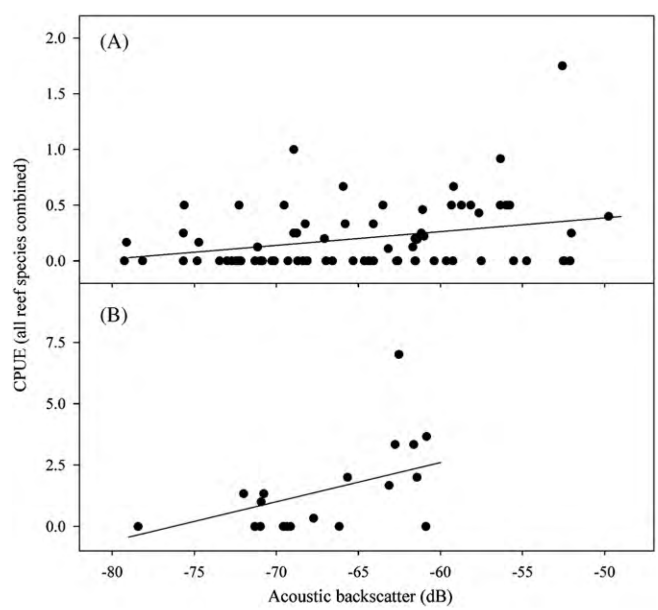

Fig. 2. Scatterplot of potential reef fish aggregations inside Snowy Wreck Marine Protected Area and a nearby control area that were sampled from 2007 to 2009 with a Simrad ES 60 echosounder and subsequently sampled with hook and line (n = 73) (A) and chevron traps (n = 20) (B). Acoustic volumetric backscatter from 0.25 to 5.25 m off the bottom (dB) is the independent (x-axis) variable. Catch-per-unit-effort (CPUE, all reef species combined) is the dependent (y-axis) variable. Each panel displays a linear function fit (see Table 2) through the raw data.

Table 2
Parameter estimates and Akaike's Information Criteria (AIC) calculations for each of three models used to fit CPUE data (*y*-axis) as a function of acoustic backscatter data (*x*-axis) for 73 events revisited with hook and line and 20 events revisited with traps. The AIC values and estimated parameters are provided for each model fit. The lowest AIC score is typically deemed the best fitting model to the data for each metric of CPUE. The ΔAIC is the difference in AIC scores between the best fitting AIC model and other models for each of the respective metrics of CPUE; here model performances differ by <4 ΔAIC and considered equivalent for each conventional fishing gear type.

Fishing gear	Model	Functional form	Residual SS	AIC	ΔAIC	*a*	*b*	*c*
Hook and line	Linear	$Y = a + b \times X$	6.076	−175.14	0.47	1.001	0.012	–
	Exponential	$Y = b \times \exp(-a \times X)$	6.043	−175.54	0.07	−0.060	9.226	–
	Power	$Y = a + b \times X + c \times X^2$	6.037	−175.61	–	2.688	0.065	0.0004
Chevron trap	Linear	$Y = a + b \times X$	45.187	23.80	2.91	12.201	0.160	–
	Exponential	$Y = b \times \exp(-a \times X)$	40.187	21.46	0.57	−0.167	83491.720	–
	Power	$Y = a + b \times X + c \times X^2$	39.074	20.89	–	70.554	1.826	0.0120

reef fish habitats are unmapped. Researchers can identify reef fish aggregations more efficiently than by deploying conventional fishing gear on pre-selected sites of unknown productivity. Finally, modeling a relationship between CPUE and acoustic backscatter allows researchers to estimate CPUE from unfished sites, increasing sample sizes and area sampled.

Estimating abundance is more efficient if the sampling sites are selected based on prior survey information (Wang et al., 2009). This is the case with the technique developed here, as potential habitat is acoustically sampled for the presence of biomass (backscatter) and then a subsample of locations with acoustic backscatter are revisited with conventional fishing gear. Each CPUE is site-specific because acoustic backscatter data (independent variable) are observed. This differs from standard techniques used to develop regional abundance indices, where a global average CPUE is specific only to sites where biological sampling occurred.

Double sampling is most effective if the catch rate and magnitude of integrated acoustic backscatter are highly correlated (von Szalay et al., 2007). von Szalay et al. (2007) reviewed the correlation between trawl gear and acoustic data for studies on the abundance of demersal and pelagic species. They found that the strength of this relationship varied as a function of fish behavior in the vicinity of the boat and the selectivity of the fishing gear. Improvements to our approach are warranted, such as sampling by a remotely operated vehicle outfitted with cameras (Stanley et al., 2000; Ressler et al., 2009), or using split-beam acoustic gear to better estimate reef fish size (Ehrenberg and Torkelson, 1996). Ground-truthing exercises to verify the empirical characteristics of reef fish backscatter would improve this approach, as would theoretical laboratory experiments to model target strengths expected from individual species (Love, 1977) encountered in this study. Refining the model to include data points more confidently thought to be reef fish species will strengthen model-predicted catch rates. Ressler et al. (2009) used a combination of fisher knowledge of historic species distribution, fish school appearance on echograms, and an underwater camera to classify acoustic backscatter to species in a mixed-species *Sebastes* fishery. Incorporating these elements may be useful in refining acoustic relative abundance estimates in the SUSLME.

The combination of single-beam fisheries acoustic gear and conventional fishing gear was not used to predict the CPUE of a single reef fish species; our chief goal was to demonstrate a double sampling technique to estimate the relative abundance of deepwater reef fish. To predict CPUEs of single species, our statistical methodology could be used, but a more technically accu-

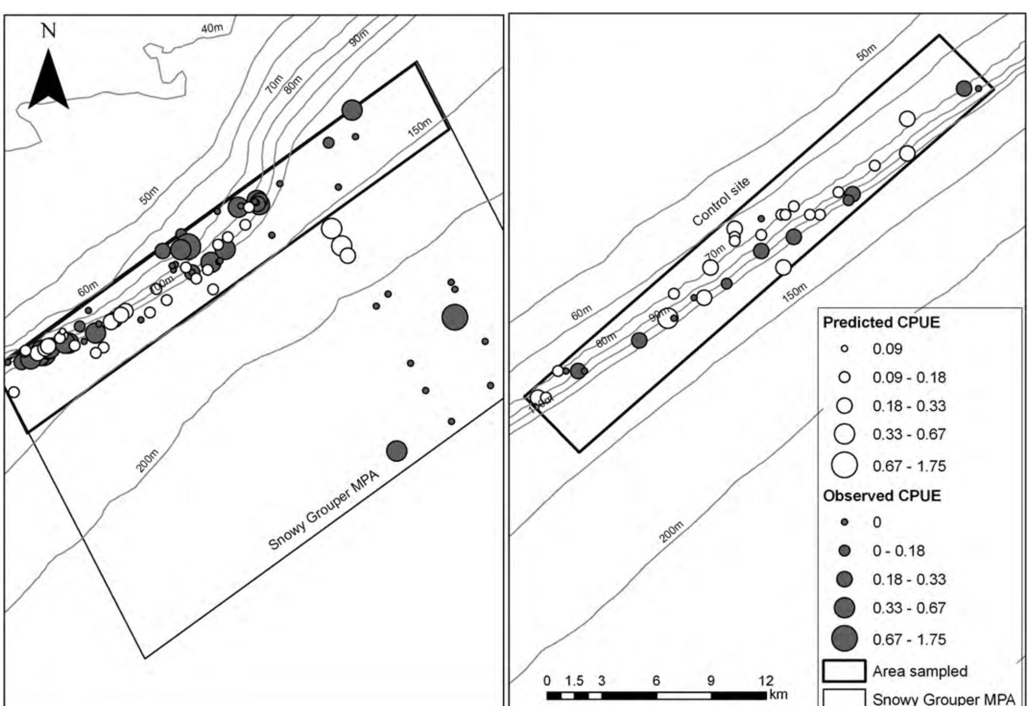

Fig. 3. Bubble plot displaying relative reef fish abundance (hook and line CPUE, catch-per-drop) in Snowy Wreck Marine Protected Area (SWMPA) and nearby control area. The plot is comprised of 73 events hook and line fished and measured for backscatter (closed circles), and 54 additional events (open circles) measured for backscatter, but with hook and line CPUE estimated using the linear model, CPUE = 1.001 + 0.012 × backscatter. The area of each event (circle) is proportional to its CPUE value (see legend).

rate approach would be to use more complex fisheries acoustic gears (e.g., split-beam, multibeam) and a novel deployment (e.g. towed acoustic transducer). The former facilitates the measurement of acoustic backscatter for individual fish targets, and the latter can minimize acoustic dead zone effects. Thus, combining a double sampling statistical approach with the use of more advanced acoustic technology and consistent, high-quality information from CPUE samples (Koslow, 2009) would allow researchers to apportion acoustic backscatter to individual species biomass (e.g., Cyterski et al., 2003). Data processing could be further refined to exclude non-target fishes that fail to meet expected target strength or habitat criteria (e.g., distance target is found above the bottom or away from relief).

The relationships between backscatter and CPUE of the two conventional fishing gears were highly variable. Hook and line and trap sampling could result in biased catches because of fishing gear selectivity, sea conditions (current speed and wave height), or fisher behavior. Where large-scale conventional sampling is not possible, species identification is a major challenge for acoustic research surveys (MacLennan and Holliday, 1996). Some species contributing to integrated backscatter may not be amenable to capture with either of the two conventional fishing gears that we used. Further, the two conventional fishing gears used in this study rely more heavily on fish behavior than other fishing gears; fish have to be willing to feed (hook and line, trap) or seek shelter (trap) to be vulnerable to the two fishing gears. Relatively small acoustic events were difficult to systematically revisit in depths greater than 150 m. We chose to include all 73 hook and line CPUE points and all 20 trap CPUE points in our respective models. As the sample size increases, predictive models may be strengthened by excluding small events, not sampling during poor weather or in strong currents, or not sampling at depths beyond which reef fish occur.

Backscatter integration near the sea floor is prone to bias. Considered vulnerable to an "acoustic dead zone" effect (Ona and Mitson, 1996), near-bottom acoustic backscatter sensed by fisheries acoustics gear such as the Simrad ES60 is especially confounded by the physical properties of a wide beam. Quantitative backscatter integrations cannot completely separate near-bottom fish backscatter from acoustic energy reflected by the ocean floor, yet reef species in this region are closely associated with bottom habitats. We chose a smaller offset (0.25 m) from the bottom (backscatter-integrating from 0.25 to 5.25 m) because we felt that greater offset distances would ignore on-axis reef fish biomass. As a result, there is a positive bias in the backscatter values used to develop the models. This bias should not be detrimental in developing a relationship between variables of interest as long as acoustic survey gear remains consistent and inappropriate conclusions are not made about the acoustic backscatter of single fish targets. Innovations such as deploying transducers on arrays towed at depth would minimize the influence of the dead-zone. Issues hampering the use of fisheries acoustic equipment for single-species stock assessments of demersal fishes include species recognition, near-bottom detection of biomass, and the presence of small, dispersed aggregations of fish (Stanley et al., 2000). Future iterations of the methods advanced here should include the use of more advanced fisheries acoustic gear (such as split-beam technology) and novel methods (video camera) to ground truth species composition.

5. Conclusions and relevance to management

The use of acoustic survey equipment confers several benefits to fishery-independent surveys of deepwater reef fish. First, it rapidly identifies the presence of reef fish habitats that are unmapped or dynamic (e.g., covered with sand 1 year and exposed the next). Second, the sampling is adaptive, improving sampling efficiency where reef fish aggregations are first identified. This differs from the only regular (annual) fishery-independent survey of reef fish in this region, MARMAP. MARMAP uses pre-determined sampling sites that may or may not harbor reef fish, setting conventional fishing gear on some sites where fisheries acoustics gear might have instead pre-determined an absence of biomass. Third, estimates of CPUE from unfished sites are determined from acoustic data. This confers a substantial advantage in precision of CPUE estimates because the acoustic sample allows the researcher to estimate CPUE that is proportional to the intensity of acoustic backscatter at each site, improving sample size. The techniques advanced here should be further considered by management agencies charged with monitoring deepwater reef fishes.

We have demonstrated a means by which deepwater reef fishes in the SUSLME may be sampled in a repeatable, cost-efficient fashion. This survey design could be efficiently conducted if commercial vessels proximal to protected areas are used to census deepwater reef fishes. Industry involvement in data collection may increase their faith in indices of relative abundance of reef fishes and subsequent management actions (Melvin et al., 2002). Additionally, harvest of target species is reduced by employing acoustic methods, and surveys without harvest could be undertaken during closed seasons. A towed video camera system has been used to determine the species composition of demersal fish aggregations sampled acoustically (Ressler et al., 2009); such verification of species composition for robust estimates of relative abundance will be important in developing this method for the reef fishery off the southeastern United States. Fisheries acoustic gear will likely be one of the tools used in the collection of data for ecosystem-based fishery management (Koslow, 2009).

It is not known whether the eight MPAs recently established in the SUSLME will help restore populations of overfished reef species. A before-after-control-impact statistical comparison between the SWMPA and control areas could help answer this question. In 2008, we collected data from the shelf break portion of SWMPA and a similarly sized and configured control area that is open to commercial and recreational fishing. Our pre-closure data collections may be compared to future surveys to determine whether the relative abundance of deepwater reef species has changed.

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