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Feasibility of hydroacoustic surveys of spawning aggregations for monitoring Barred Sand Bass populations off southern California

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For fishes that migrate to specific locations to spawn within large aggregations at predictable times, fishery independent surveys of the abundance, distribution, and population structure of adult fish at spawning aggregation sites can provide valuable data for fisheries monitoring and assessments. We tested the feasibility of using high resolution, split-beam sonar to estimate the distribution, abundance, and group sizes of Barred Sand Bass (*Paralabrax nebulifer*) at their primary spawning aggregation site off Huntington Beach, California, in July 2010 and July 2012. We established an *in-situ* target strength distribution for Barred Sand Bass using tethered fish, collected hydroacoustic data opportunistically over the entire spawning grounds, and validated acoustic data with concurrent video surveys and rod and reel sampling of fishes present within the survey area. The modal target strength of Barred Sand Bass was determined to be -35 dB and was distinct from other fish species present. Groups of Barred Sand Bass averaged 30 individuals in abundance and ranged from 2 to 1,711 individuals, with the vast majority of the groups containing less than 10 individuals. Groups of Barred Sand Bass were most abundant in the water column between 5 and 10 m below the surface over bottoms depths of 20 to 30 m, resulting in a negative relationship between group size and depth. Due to the sand bottom habitat of the spawning site, the tendency for fish to aggregate to spawn in the water column during predictable periods, and the low diversity of other fish species present at the spawning site during the peak spawning months, hydroacoustic surveys of primary spawning aggregation sites represent an efficient, practical method for regional population monitoring and fishery assessments of Barred Sand Bass.

Key words: Barred Sand Bass, fishery independent assessment, hydroacoustics, spawning aggregations

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Many marine fishes migrate to form large spawning aggregations that are predictable in time and space, which support very productive commercial and recreational fisheries (Erisman et al. 2017). These aggregations represent a paradox of sorts, as the same aspects that facilitate efficient reproduction make them such ideal targets for fisheries (i.e. large biomass of fishes concentrated at known sites and times) also allow them to be easily and rapidly overfished. For that reason, aggregation fisheries tend to follow a "boom and bust" cycle in which a few years of immense harvest levels are often followed by rapid declines in catch and stock abundance (Sadovy de Mitcheson and Erisman 2012). Widespread declines in spawning aggregations and their fisheries have stimulated increases in targeted efforts to mitigate the negative ecological, social, and economic impacts associated with overfishing them (Nemeth 2005; Aburto-Oropeza et al. 2011; Hamilton et al. 2011; Heppell et al. 2012).

The successful management of aggregation fisheries is predicated on the ability to accurately and rapidly identify changes in the status of the stock or aggregations so that regulatory agencies can respond in a timely manner, which can prove challenging when conventional fisheries monitoring techniques are incongruent with the dynamics of spawning aggregations. Conventional fisheries-dependent (e.g., catch-per-unit effort) and fisheries-independent (e.g., visual censuses) protocols both tend to rely on density-based estimates as proxies for monitoring changes in stock abundance, which can be problematic for assessments of certain spawning aggregations, because the density of fish within aggregations may remain stable even as the total abundance of fish and the aggregation area declines (Erisman et al. 2011). This issue is referred to as hyperstability in fisheries science and can result in the overestimation of population biomass and delayed responses to population declines (Rose and Kulka 1999). Also, while visual censuses work for assessing aggregations located in well-delineated areas of reef in clear, shallow (< 30m) waters of the tropics, they may be less efficient for surveying aggregations in temperate, offshore areas where visibility is poor and fish are widely dispersed across large areas (Colin et al. 2003; Heyman et al. 2017).

Hydroacoustic surveys – here defined as active acoustic surveys with an echosounder – are advantageous for assessing fish populations due to their ability to quickly and efficiently cover large areas, record data instantly over nearly the entire water column, and minimization of the selectivity and observer biases that can be associated with other methods (Trenkel et al. 2011; Yurista et al. 2014). As they are non-invasive and can be conducted over a wide range of depth and visibility conditions, hydroacoustic surveys are suitable for many ecosystems and environments (Murphy and Jenkins 2010). However, hydroacoustic surveys are most commonly used to assess homogenous pelagic fish populations in areas with low diversity, as estimation of target strength (TS) for a given species – a critical step in calculating fish density, abundance, and biomass – is confounded by the presence of other species, size, and position in the water column (Simmonds and MacLennan 2005; Zenone et al. 2017). Thus, rigorous ground truthing with complementary methods is essential for drawing inferences about a given species with hydroacoustics (McClatchie et al. 2000; Simmonds and MacLennan 2005). With ground truthing, hydroacoustic surveys have been established as a useful method of assessing spawning aggregations of fishes (Fudge and Rose 2009; Rose and Leggett 1987; Kloser et al. 1996; Rowell et al. 2017; Egerton et al. 2018; Michaels et al. 2019). Moreover, acoustic surveys may be ideal for robust, quantitative estimates of the density, distribution, and abundance of fishes that aggregate to spawn in the water column, which greatly reduces potential biases associated with the close association of fish with bottom substrate (Egerton et al. 2018).

Barred Sand Bass (*Paralabrax nebulifer*) is a coastal marine fish that ranges from Santa Cruz, California south to Baja California Sur, Mexico, including Guadalupe Island (Kells et al. 2016). Juveniles and adults occupy a variety of different habitats including kelp beds and sand flats on the open coast to inland harbors and bays (Allen et al. 2006). Relatively sedentary and rarely found more than 3 m above the substrate during non-spawning times, Barred Sand Bass form spawning aggregations up in the water column in waters 15 – 40 m deep over soft bottom areas (Turner et al. 1969; Feder et al. 1974; McKinzie et al. 2014; Teesdale et al. 2015). Seasonal patterns in reproduction are consistent across the species' range, with gonadal maturation beginning in April to May and spawning occurring from late June through early September with a clear, strong peak in July and August (Bautista 2014; Jarvis et al. 2014b; Erisman et al. 2017). Based on the collection of ovulated eggs from actively spawning females and vertical movement patterns of tracked fish, spawning is thought to occur in the water column during the mid-day and afternoon hours (Oda et al. 1993; McKinzie et al. 2014). Barred Sand Bass eggs and larvae are pelagic, drifting in open water, and juveniles appear in shallow water from late summer to early winter (Love 1996).

Barred Sand Bass are one of the most commonly caught game fish in southern California, where they have represented a major source of revenue for the local commercial passenger fishing vessel (CPFV) fleet for more than five decades (Schroeder and Love 2002; Dotson and Charter 2003; Jarvis et al. 2014a). The regional recreational fishery for Barred Sand Bass occurs almost exclusively at five sites that collectively represent the main locations of their summer spawning aggregations: Imperial Beach, San Onofre, the Huntington Flats, Santa Monica Bay, and the Ventura Flats (Figure 1). Barred Sand Bass consistently ranked among the top five species in the southern California marine recreational fish catch since the 1970s and represented the most important recreational fishery in the region from the late 1980s to the early 2000s (Oliphant 1990; Jarvis et al. 2014a). However, persistent fishing of their spawning aggregations combined with unfavorable environmental conditions for larval recruitment resulted in severe fishery and population declines in the mid-2000s that have not yet recovered (Erisman et al. 2011; Miller and Erisman 2014; Jarvis et al. 2014a).

The California Department of Fish and Wildlife (CDFW) implemented regulatory changes in 2013 that reduced the daily bag limit from 10 to 5 fish per angler and increased the minimum size limit from 12 to 14 in (30.48 to 35.56 cm) total length (TL) as a means to stimulate recovery of the regional stock and fishery. However, there is a lack of fishery-independent data on the abundance of Barred Sand Bass in southern California and thus a need to create long-term monitoring program to create a fishery independent index of abundance to assess how the stock responds to changes in management regulations, annual variations in environmental conditions, and fishing pressure.

Recently, Davis et al. (2019) compared two fishery-independent survey methods and determined that underwater visual census (UVC) and baited remote underwater videos (BRUVs) were both effective for a long-term monitoring study of Barred Sand Bass at the edges (ecotone) of inshore natural and artificial reefs in southern California where they are known to occur during the non-spawning season. We contend that monitoring of the spawning aggregations that occur away from reefs, over soft bottom habitats, would be the ideal way

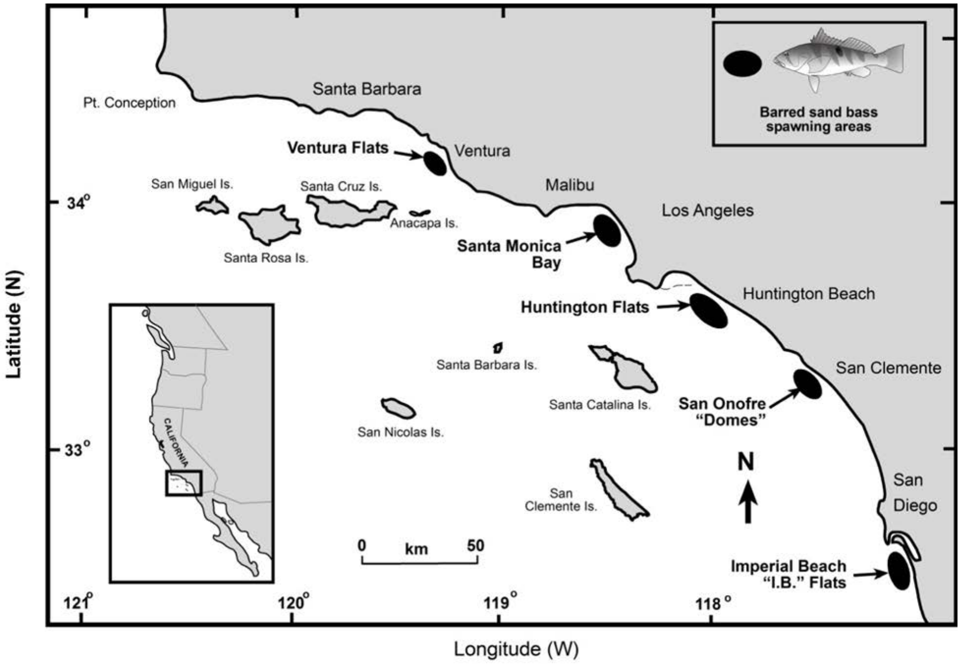

Figure 1. Locations of the five major spawning areas of Barred Sand Bass occupied each year from June to August, historically peaking in July.

to monitor adult abundance and biomass over time. These sites contain the largest numbers of adults and thus are more representative of the regional population of Barred Sand Bass.

For the present study, we explored the feasibility of using active acoustics to survey spawning aggregations of Barred Sand Bass to generate information on adult densities, abundances, and distributions for use in regional monitoring and fishery assessments. Given the spawning behavior of Barred Sand Bass (i.e., aggregate in the water column over sand bottom habitats), the challenging environmental conditions that restrict diver surveys (strong currents, poor visibility, boat traffic) at spawning aggregation sites, and the predictable timing and locations of spawning aggregations, we hypothesized that acoustics would represent an efficient and non-invasive way to survey an entire aggregation site in a systematic, repeatable, and logistically feasible manner. Here we present the results of this preliminary study to test this hypothesis and discuss potential approaches for creating a long-term monitoring protocol for Barred Sand Bass spawning aggregations in the region.

METHODS

Site description

We conducted hydroacoustic surveys on 15, 16, 22, and 23 July 2010 and 18, 19, and 20 July 2012 off Huntington Beach, CA, USA (between 33° 41.0' N, 118° 08.0'W and 33° 39.0' N, 118° 05.0'W) to describe the spatial distribution and group sizes of Barred Sand Bass spawning aggregations. Active acoustic transects were performed across the Huntington Flats area, which is a large, low-relief sandy habitat that occurs between 3-5 km off the coast of Huntington Beach, California (Figure 1) with a depth range of approximately 15-30 m. This area is adjacent to two shallow water oil platforms to the north, with its northwest limit surrounded by a scattered network of artificial reefs, collectively known as Bolsa Chica Artificial Reef. Northwestward of the artificial reef is an area commonly used as an anchorage by large commercial freight vessels, which is just southward of an area known to local anglers as the "Sand Bass Junction." It is well known among the local sport angling community that Barred Sand Bass can be found along the Long Beach and Los Angeles Federal Breakwaters for most of the year, but during the summer months, they are easiest to catch in large numbers on the Huntington Flats in the mid to upper water column (McKinzie et al. 2014).

Acoustic data collection

Data collection employed the use of a BioSonics® DT-X portable split-beam echosounder (206 kHz) integrated with Garmin™ GPS detection. The opening angle of the beam emitted from the circular transducer was 6.8°. We acquired data digitally on VisAcq® acoustic acquisition software on a Panasonic® Toughbook laptop computer. The ping rate was set to 5/s, and the pulse duration was set to 1.0 ms. Calibration of the echosounder was performed on each survey event using a -41.5 dB tungsten carbide sphere according to the standard methods of Foote (1987). We pole-mounted the echosounder on the port side gunwale aboard the R/V Yellowfin, a 24 m research vessel, and transects were conducted opportunistically throughout the Huntington Flats area. Data were recorded over approximately 20 km on each survey day. All surveys were conducted at a speed of 6 knots, and occurred from 0800-1500 h each survey day, as this period was centered on the time of day when Barred Sand Bass are likely to be actively spawning (Oda et al. 1993; Bautista 2014).

Target strength characterization

Based on our rod and reel collections, spawning adult Barred Sand Bass in this region are largely uniform in size (290 ± 29 mm SL), so it was not necessary to develop a target-strength (*TS*) to length relationship. Instead, the target strength distribution of representative individuals was characterized in three principle ways, through 1) rod and reel sampling of specific sonar targets (Figure 2), 2) video confirmation of target species, and 3) tethering of specimens lowered into the sonar cone. We conducted ground truthing of acoustic data on a subset of groups detected by the echosounder. When a school was detected on sonar, video was captured after short time delay, by the Deep Blue Pro Color Underwater Video Camera being towed 10 m directly behind the transducer at the approximated depth of the school.

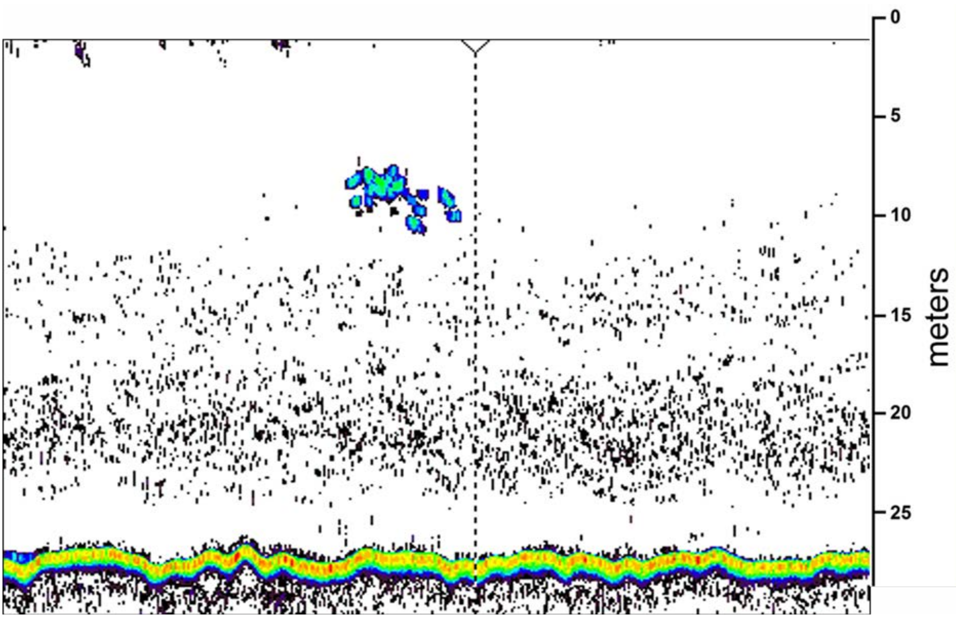

Figure 2. Sonar target verified as Barred Sand Bass aggregation in water column by rod and reel sampling (6–10 m depth); 22 July 2010.

This video was subsequently analyzed to determine the species composition of schooling and surrounding fishes. To account for the influence of gear bias, we also conducted angling as a complementary method of ground truthing. The morphology of these groups was noted to further assist analysts with identification of Barred Sand Bass for the schools that were not ground truthed with camera or angling. *In situ TS* characterizations were performed on 22 and 23 July 2010 and again on 6 August 2012. In separate trials, we collected live Barred Sand Bass and Pacific Mackerel (*Scomber japonicus*) by rod and reel and tethered to a hookless ganion and allowed to swim at different orientations within the acoustic beam.

Acoustic data analysis

We performed all acoustic data analyses in Echoview ® v7.0. Surface noise caused by wave action and bubbles was excluded from the analysis, and a one-meter exclusion zone was created to exclude backscatter from the seabed and the acoustic 'dead zone' that occurs above the seabed. Time varied gain corrections of 40log(R) for *TS* and 20log(R) for s_v, known as the volumetric backscattering coefficient, were applied.

Aggregations were identified manually by analysts, and echo integration was performed to generate estimates of fish density within each school, following this formula:

$$\frac{s_v}{\sigma bs}$$

Where s_v is the volumetric backscattering coefficient (a measure of the total acoustic energy in a volume of water), and *σb* is the cross-sectional backscattering coefficient (a measure of the acoustic energy that can be attributed to a single target). We integrated all schools using a value for *σbs* generated by converting a *TS* of -35 dB, which was the modal *TS* of Barred Sand Bass in the region based on *TS* characterization experiments (Fig. 3). *σbs* is related to *TS* by the following relationship:

$$\sigma bs = 10 log_{10}(TS)$$

Because this species has been suggested to increase vertical activity during spawning events (McKinzie et al. 2014), the average depth was manually recorded for each target. Group size was then determined by extrapolating the number of individual targets in the group.

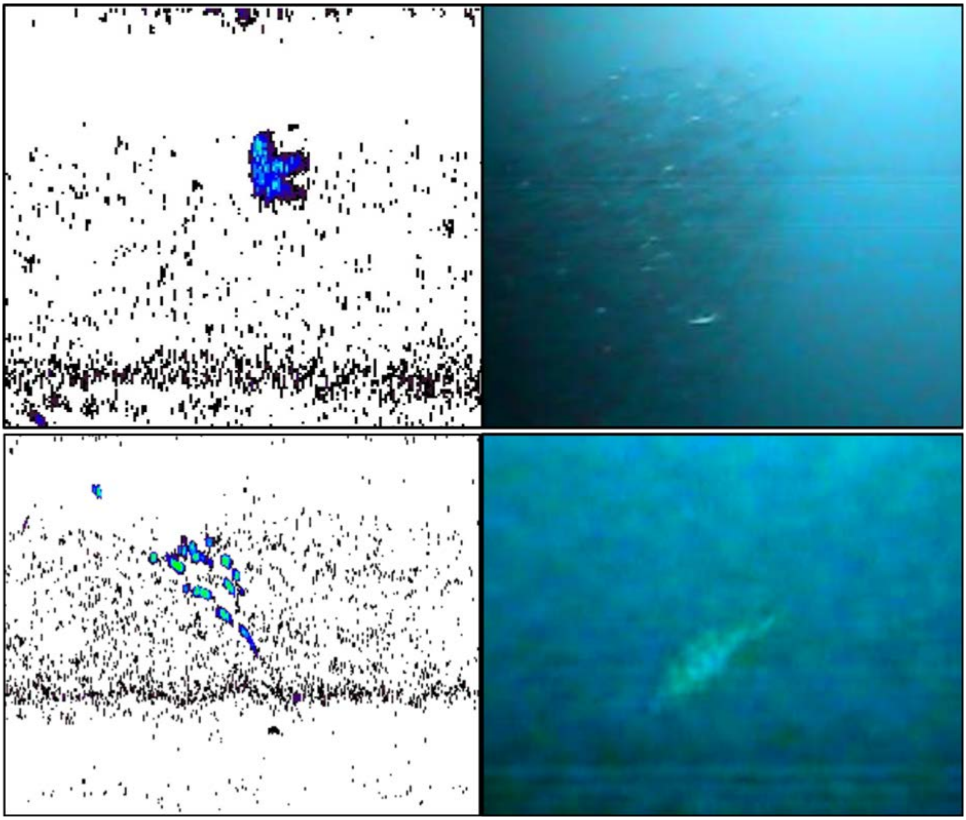

Figure 3. View of sonar record of a school of Northern Anchovy (top) and an aggregation of Barred Sand Bass (bottom) with enlarged still frames from video camera towed 10 m behind the superimposed for both cases; 23 July 2010; 1054–1056 hrs. Video stills of successful verifications were courtesy of Charles Valle, California Department of Fish and Wildlife.

RESULTS

Approximately three hours of video recording conducted on July 23, 2010 yielded four successful video verifications of sonar targets as Barred Sand Bass and one as a school of Northern Anchovy (*Engraulis mordax*). The first successful verification occurred between 1054 and 1056 h when first a school of Northern Anchovy and then a loose aggregation of Barred Sand Bass were detected by both sonar and the video camera which was towed 10 m behind the sonar cone (Figure 3). In this case, video revealed at least 6 individuals in the group where sonar detected 11. The distance of the camera from the sonar transducer, the low visibility, and the escape response of Barred Sand Bass accounted for this difference. Three additional video target verifications of Barred Sand Bass in the water column occurred at 1127, 1132 and 1345 h the same day. On July 22 and 23, 2010, specimens of both Barred Sand Bass and Pacific Mackerel were collected by rod and reel and tethered to a hook-less ganion. This apparatus was lowered into the sonar cone along the port side of the research vessel and staged at several depths while the Biosonics unit continuously recorded (Figure 4). These activities served to accurately calibrate the range, frequencies, and mean target strengths of both species that were numerically dominant in the sampling area. Utilizing sonar recordings of the targets verified by tethering combined with underwater video, the mean *TS* of Barred Sand Bass was determined to be approximately -35 $\pm$ 4 dB (Figure 5). The mean *TS* of Pacific Mackerel was -48 $\pm$ 5 dB and Northern Anchovy, -56 $\pm$ 10 dB with virtually no TS overlap with target species.

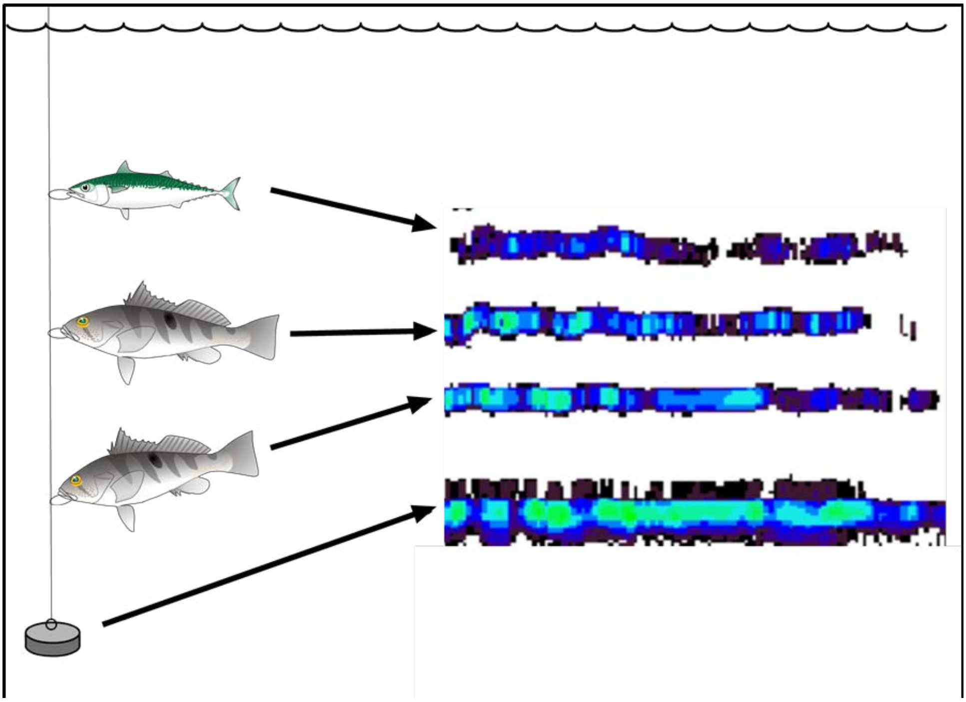

Figure 4. Sonar recording of tether apparatus for ground truthing *TS*; 23 July 2010; (top to bottom) one Pacific Mackerel, two Barred Sand Bass, and 1 kg weight.

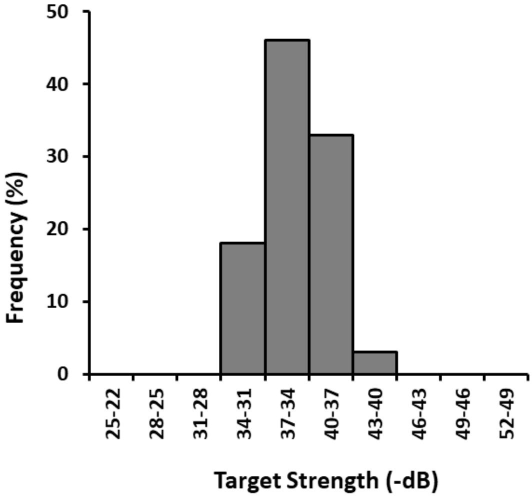

Figure 5. Frequency of occurrence of target strength scores for tethered Barred Sand Bass on August 5, 2012 at a frequency of 206 kHz.

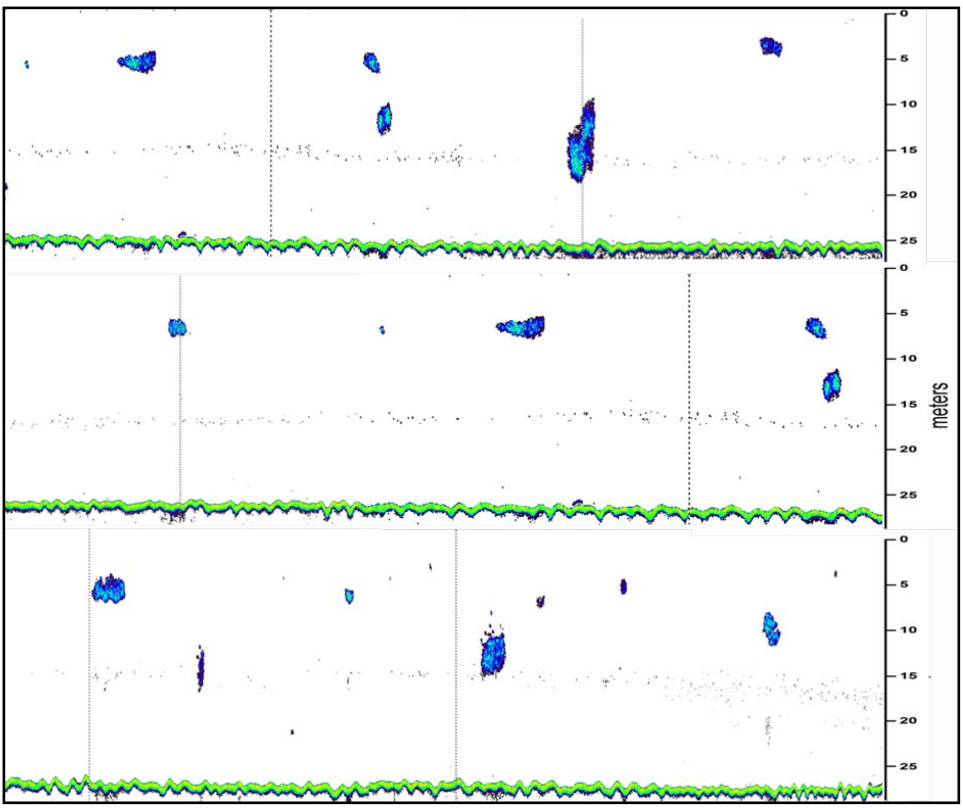

Figure 6. A collage of separate echograms taken from alongshore transects run from July 18 to 19, 2012 showing examples of the various sizes, configurations, and depths of Barred Sand Bass aggregations identified by Echoview ® 5.2 software based on a modal target strength of -35 dB. Depth scale is 1–25 m.

Aggregating groups of Barred Sand Bass were identified in the water column between 0900 and 1500 h during all seven sampling days covering July of both 2010 and 2012. A collage of separate echograms taken from alongshore transects run from July 18-19, 2012 showed examples of the various sizes, configurations, and depths of Barred Sand Bass aggregations. Targets ranged from small through large asymmetrical, globular groups to large, spheroidal aggregations (Figure 6).

During the four-day period of July 2010 sampling, 145 groups of Barred Sand Bass were identified in the water column between 1000 and 1500 h. These groups ranged in relative, estimated size from 2 to just over 1,700 individuals (median = 55). The three-day period of July 2012 sampling yielded a total of 117 groups of Barred Sand Bass were identified in the water column between 1000 and 1500 hrs. Groups ranged in size from 2 to 350 individuals (median = 10) with most of the groups containing less than 10 individuals. Groups of Barred Sand Bass were distributed throughout the water column principally between 5 m depth and the bottom (20 – 25 m) in both summers. However, the largest groups were found almost exclusively between 5 and 10 m depth resulting in significant, negative correlation ($y = -1.582 ln(x) + 17.808$, $R^2 = 0.196$, df = 237, $p << 0.001$) between group size and depth (Figure 7). Based on bathythermograph readings, the depth distribution of the largest groups corresponded closely with the thermocline present most sampling days and indicated that fish were aggregating at temperatures between 16 and 17 °C.

DISCUSSION

Our results indicated that sonar is a feasible and efficient means to assess the distribution and group size of Barred Sand Bass in spawning aggregations. Due to the relatively low diversity of pelagic fishes in the region and behavior of Barred Sand Bass, standardized hydroacoustic surveys would be a viable means to assess the biomass and abundance of spawning Barred Sand Bass in this region.

Barred Sand Bass are known to increase their vertical space usage as they commence spawning activity (McKinzie et al. 2014). However, a major factor to consider when performing active acoustic surveys is that the recorded data are “snapshots” of where fish happened to be at the exact moment when they were insonified. Typically, *Paralabrax* species should be higher in the water column when they are reproductively active, but they should also vary their depths during momentary vertical spawning rushes (Erisman and Allen 2006; Miller and Allen 2006). The Barred Sand Bass is a bottom-associated species rarely found above 3m from the seafloor, primarily inhabiting soft bottom habitats that are associated with ecotone (Love et al. 1996; Mason and Lowe 2010). Therefore, any vertical activity away from structure during the summer months could suggest spawning and/or spawning-related behaviors. However, it could also indicate other behaviors, such as feeding or temperature preferences.

Our findings clearly showed that the largest groups of Barred Sand Bass occurred up in the water column at depths between 5 and 10 m in July of 2010 and 2012. These depths are usually above the prominent thermocline during July off the Huntington Flats. Using acoustic telemetry, McKinzie et al. (2014) described the activity space size and association with seafloor and thermocline were compared for the spawning and non-spawning season Barred Sand Bass at the same location as our study. They found that non-spawning season fish showed affinity with sand/reef ecotone while remaining about 2 m off the seafloor. Spawning season individuals displayed two patterns of behavior, one indicative of spawning and another of resting behavior. Resting individuals tracked during spawning season behaved similarly to fish tracked during the non-spawning season, using smaller activity space areas while associating with reef structures and the seafloor. Presumed spawning individuals utilized sand habitats, using significantly larger activity spaces during the day than at night while associating with the thermocline and making repeated vertical dives toward the seafloor.

The acoustic data processing procedure employed in this study was undertaken to maximize processing efficiency and minimize the influence of confounding factors as much as possible. Integration of schools using a fixed value reduced the influence of multiple

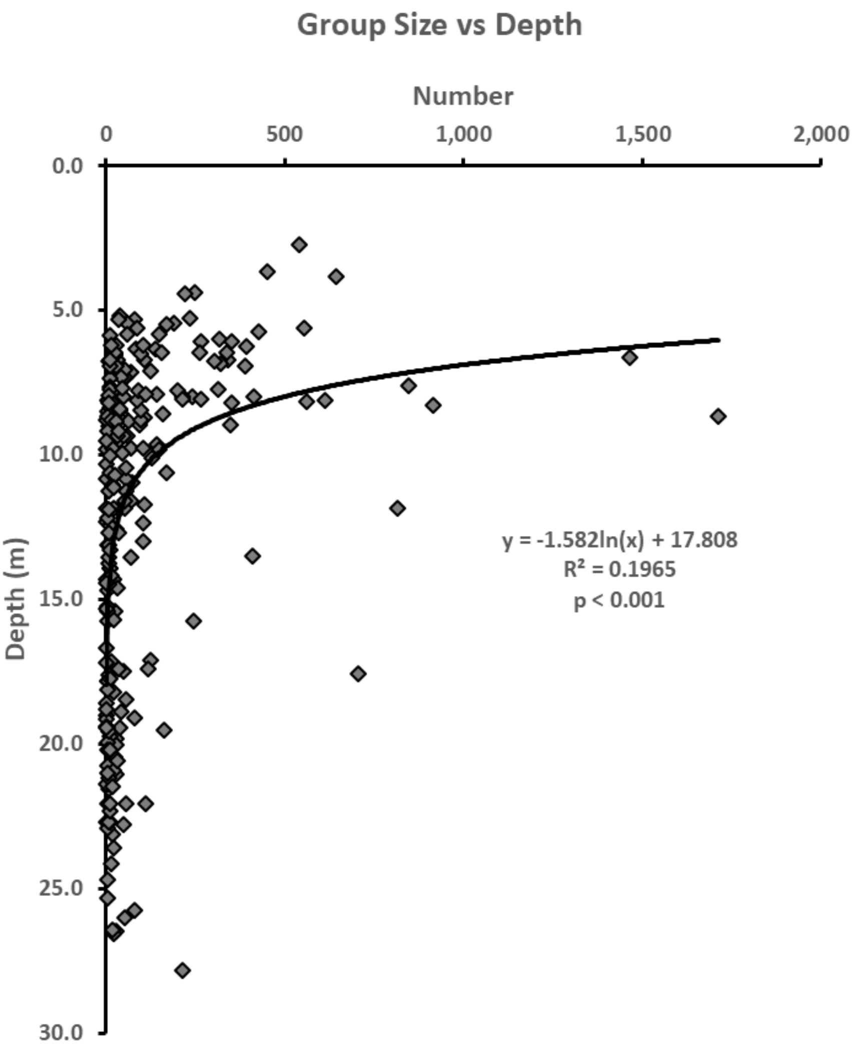

Figure 7. Frequency of group size (# individuals) of Barred Sand Bass aggregations determined from 2010 and 2012 over the Huntington Flats.

echoes (i.e. invalid *in situ TS* estimation due to insufficient separation of targets), which can significantly affect density and biomass estimation (Sawada et al. 1993; Yule et al. 2013). It should be noted that ground truthing was not conducted coincidently with all surveys, and therefore it is possible that individuals or schools of other species with similar *TS* to Barred Sand Bass (e.g., Kelp Bass; *Paralabrax clathratus*) may have been counted as Barred Sand Bass, despite the ecological unlikelihood of this (Young 1963; Mason and Lowe 2010). As the diversity of pelagic fishes in this area is limited, with Barred Sand Bass, Northern Anchovy, and Pacific Mackerel making up 73% of pelagic fishes observed in the present study, we view this as unlikely. Further, we found differences in modal *TS* between Barred Sand Bass, Northern Anchovy, and Pacific Mackerel, which were likely driven by differences in body size and swimbladder morphology (Simmonds and MacLennan 2005). Thus, the likelihood of overlap in *TS* was limited. This conclusion was further supported by the angling, tethering, and video ground truthing surveys, from which Barred Sand Bass were found to form monospecific schools and not to associate with other fishes outside of schools. In future studies, the potential for counting other fishes as Barred Sand Bass could be minimized using coincident ground truthing methods, such as the deployment of a towed camera system adjacent to the transducer on a glider or the deployment of a self-rotating video system (Koenig and Stallings 2015) in locations where large groups or aggregations are detected by the echosounder. Both techniques would allow acoustically-derived estimates of abundance, density, and biomass of Barred Sand Bass to be adjusted based on their relative abundance to other fishes present.

With standardized transects that adequately cover the area in which Barred Sand Bass Spawn (i.e. degree of coverage ≥ 6 based on Aglen 1989) and the addition of the processing of single targets or tracked fish within the *TS* range of Barred Sand Bass, a similar approach could be taken to estimate the biomass and abundance of Barred Sand Bass in the region. There are, however, multiple viable alternatives. For example, after selection of appropriately sized Elementary Distance Sampling Units, echo integration with *in situ TS* could be performed over the entire transect as long as the Nv and/or M% indices are calculated to identify multiple echoes (Sawada et al. 1993; Yule et al. 2013). This approach would require ground truthed knowledge of the relative abundance of species in the area for apportioning of density and biomass, and/or filtering of the data such that only targets within the *TS* range of Barred Sand Bass are integrated. Alternatively, echo counting could be used for single targets, but the integration of schools could have been performed with the distribution of *TS* shown from the *TS* characterization experiments, or with the distribution of *in situ TS* found immediately around the perimeter of the school, instead of the single *TS* value we used. Further, fish tracks (i.e. sequences of single targets belonging to the same fish) could be detected and used for echo counting instead of single targets for more conservative estimates. If cost-effective, systematic hydroacoustic surveys of Barred Sand Bass are to be conducted in this region in the future, it would be beneficial for future studies to compare the results from these alternative methods to facilitate better understanding of the influence of data processing choices on abundance and biomass estimates.

Recommendations for continued studies

Our recommendations for continued studies of Barred Sand Bass aggregations off southern California are as follows. Hydroacoustic assessments of Barred Sand Bass populations should be conducted on a weekly basis during July and August (8 weeks per year) to investigate temporal variations in the distribution, biomass, and abundance of fish at the aggregation site by week, month, and year and in relation to spawning activities, environmental (temperature, thermocline) and fishing (catch, CPUE) data collected on a concurrent basis at the site. However, two additional surveys should be conducted each year (total = 10 survey days per year). The first should be conducted to test and calibrate the equipment in preparation for the surveys, and the second will serve as a contingency day if any of the eight survey days experience technical or other issues that compromise the study design and subsequent analyses. Notably, all survey trips should be divided into a morning segment and an afternoon segment based on the time it takes the research vessel to complete a survey over the entire aggregation area. All surveys should be conducted using a sizeable, stable vessel as a platform. The vessel's on-board sonar must be turned off during the survey runs to avoid acoustic interference with the Biosonics unit. Acoustic surveys should cover depths between 15 and 30m over an approximately 15 km^2 area on the major spawning aggregation site, Huntington Flats, off southern California (Figure 8). For each weekly survey at Huntington Flats, the scientific team should conduct four 5 km sonar transects alongshore in each of two, time segments (0800-1200; 1300-1700 h). Sonar targets, depth, and GPS readings should be recorded continuously over the entire cruise track for each day. Echoview ® 7.0 (or higher) software should be used to estimate abundance, biomass, and

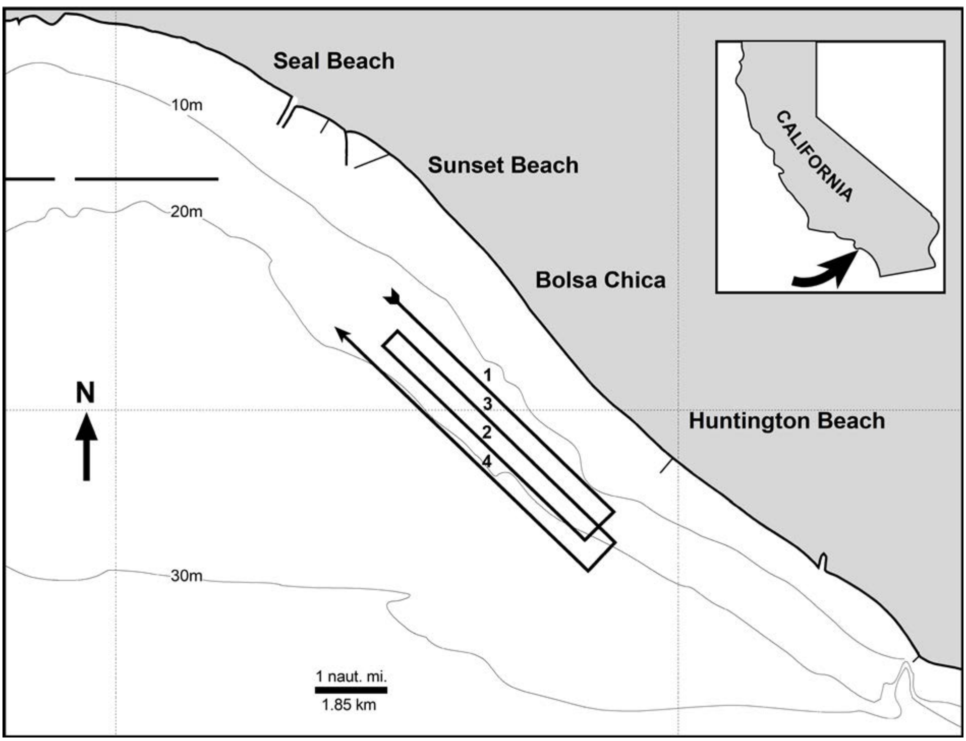

Figure 8. Proposed sampling track for future hydroacoustic surveys off Huntington Beach. Each week of the spawning season, four hydroacoustic transects (4 alongshore segments) should be run each in the morning (0800–1200 h) and afternoon (1200–1600 h) using a BioSonics DT-X sonar unit (centered around the major Barred Sand Bass spawning activity).

the vertical and horizontal distribution (density) of Barred Sand Bass aggregations from each survey. Results from each survey should be compared to characterize variations in the above parameters in relation to time of day, lunar day, month, and location on the survey grid. Moreover, data should then be compared across year to assess inter-annual differences in aggregation dynamics.

Prominent physical and chemical parameters should be closely monitored for each location on each sampling date. Measurements on temperature, salinity, dissolved oxygen, and pH should be taken near the surface and at each 2 m to the bottom using a Hydrolab CTD sensing unit (or equivalent) which should be aboard a smaller, support vessel. A vertical temperature profile should allow the researchers to determine thermocline depth from each survey. Researchers should also record data from various sources on tidal regimes, moon phases, current, wind (speed/direction), wave (height/direction), precipitation, air (barometric) pressure, and upwelling indices. Satellite infrared imagery data should also be obtained in order to examine large-scale temperature and current regimes in the study areas.

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Author Contributions

Conceived and designed the study: LA, BE, CW
Collected the data: LA, CW
Performed the analysis of the data: LA, BE, DB, CW
Authored the manuscript: LA
Provided critical revision of the manuscript: BE, DB, CW

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