Artificial Reef Fish Survey Methods: Counts vs. Log-Categories Yield Different Diversity Estimates

Censos de Peces en Arrecifes Artificiales: Conteos y Categorías-Logarítmicas Resultan en Diferentes Estimaciones de Diversidad

Recensements de Poissons de Récifs Artificiels: Décompte et Catégories Logarithmiques Produisent Différents Estimés de Diversité

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ABSTRACT

Texas Parks and Wildlife Department's (TPWD) Artificial Reef Program (ARP) has utilized the roving diver technique (RDT) recording abundances as order of magnitude counts [REEF-type: Single (1); Few (2-10), Many (11-100), and Abundant (> 100), SFMA hereafter] for many years. However, because SFMA counts do not provide numerical abundances in catch per unit effort (CPUE) or density, these data cannot be integrated with other state coastal survey data for stock assessment (e.g., trawl fisheries, gill net, vertical long line). Accordingly, a comparison of exact and order-of-magnitude counts (SFMA) from paired divers was conducted during five consecutive sampling quarters at the USTS Texas Clipper Reef located 17 nm offshore of South Padre Island, Texas, USA. SFMA data were converted to numerical abundances and compared to exact counts via rank correlations of their similarity matrices on the assertion that if both survey methods capture similar species richness and relative abundance, their correlation should be high. In this study, which eliminated roving bias, biodiversity was greatest for the order-of-magnitude count method compared to exact counting which tended to underrepresent small cryptic reef fish as well as pelagic schooling fish. Exact counts by divers were found to underestimate species richness by 15 - 30% compared to the SFMA method. In addition, we found that both enumeration methods produced similar results in capturing relative abundances of large, abundant, and conspicuous species. The results of our survey method comparison indicate that the log-category census method is an effective technique when diversity estimates are a major goal.

KEY WORDS: Artificial reef, visual fish census, Gulf of Mexico, roving diver survey

INTRODUCTION

Artificial reefs are commonly deployed in coastal waters for a variety of purposes, including mitigating loss of hard-bottom habitat, enhancing production of reef-dependent invertebrates and fishes, and creating opportunities for diving and fishing (Broughton 2012). In the northwestern Gulf of Mexico (GOM), natural hard bottom habitats occur as a sparse resource intermittently distributed on the largely unconsolidated seafloor of the continental shelf. Consequently, artificial reefs constitute "islands of opportunity" by providing attachment substrate for habitat-limited sessile invertebrates and algae (Dokken et al. 2000). This resultant biofouling community in turn supports trophically-related motile invertebrate and fish species eventually creating a dynamic environment that increases biomass at the site (Gallaway and Lewbel 1982). Recognizing the potential to enhance recreational fisheries production, diving, and tourism, the Texas legislature past the Artificial Reef Act in 1989, which directed the Texas Parks and Wildlife Department (TPWD) to promote, develop, maintain, monitor, and enhance the artificial reef potential in state waters and federal waters adjacent to Texas (Stephan et al. 1990). In 2015, Texas has established 66 artificial reef sites ranging from 8 to 161 km from shore in the GOM.

Detecting and quantifying artificial reef community dynamics is essential for management. Periodic monitoring provides a record of existing fisheries resources and can facilitate understanding of artificial reef ecosystem processes relevant to artificial reef management. The monitoring of fish communities is considered one of the most difficult tasks in reef management due to the inherent challenges of high individual mobility and widely varying population abundances in space and time (Hill and Wilkinson 2004, Kimmel 1985). Further, attempting to detect changes at the community level requires that all species are monitored (Pattengill-Semmens and Semmens 1998); an impractical approach in most instances. Thus, artificial reef managers look to fisheries science for cost effective, standardized reef data acquisition methods (Steimle and Meier 1997). Underwater visual survey methods have been used extensively for ecological and fisheries-based scientific field surveys of reef fishes (Colvocoresses and Acosta 2007, Schmitt and Sullivan 1996). Among visual census methods applied to reef fish communities, quantitative transect (strip, belt, and line), quantitative point counts, and semi-quantitative rapid visual techniques are most common (Holt et al. 2013, Thresher and Gunn 1986). Transect-based surveys are most widely used in ecological studies as they allow for estimating fish densities in two dimensions by a diver swimming or being towed through a rectangular area of known or estimated length and width (Edgar et al. 2004, Thresher and Gunn 1986). However, even transect methods give widely varying results when applied to the same fish community due to varying transect dimensions and observer speed (Edgar et al. 2004). Transect methods however, are of limited use in quantifying fish populations across the wide range of materials and configurations of artificial reefs particularly as many of these reef structures are oriented vertically rather than horizontally.

The roving diver technique (RDT) is a widely used rapid visual census method for surveying reef fish communities (Holt et al. 2013, Schmitt et al. 2002, Schmitt and Sullivan 1996). During RDT surveys, divers freely roam reef environments and record all fish species that can be positively identified in logarithmic abundance categories:

i) Single (1 fish),
ii) Few (2-10),
iii) Many (11-100), or
iv) Abundant (>100); hereafter referred to as SFMA data (www.REEF.org).

Many governmental management agencies and other non-profit organizations have adopted use of RDT data and methods including Reef Education and Environmental Foundation (REEF), Atlantic and Gulf Rapid Reef Assessment (AGRRA); Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS SMP); Caribbean Coastal Marine Productivity Program (CARICOMP), National Marine Sanctuary programs and state natural resources management (TPWD) (Hill & Wilkinson 2004, Pattengill-Semmens and Semmens 1998, REEF.org, Schmitt and Sullivan 1996). The major critique of fish census with the RDT and collecting order-of-magnitude SFMA data is that it cannot be used in density estimates as the abundance estimates constitute an index and surveys are often conducted over large areas of undetermined size (Holt et al. 2004). Nonetheless, the RDT is noted for detecting a substantially larger number of species than more quantitative transect methods presumably due to factors such as reduced time spent actually counting fish and higher detectability from less stringent survey method (Holt et al. 2004, Schmitt et al. 2002).

The TPWD-Artificial Reef Program (ARP) program has utilized the RDT with abundances reported as SFMA for many years. The RDT has several advantages when applied to surveying artificial reef fish communities including being non-destructive, easily applied to the varying types of materials deployed at artificial reef sites (e.g., high-relief platforms and ships, low-relief concrete structures, etc.), and lack of dependency expensive sampling equipment (except dive gear). Divers participating in TPWD-ARP reef surveys are scientific divers with a good knowledge of local fish populations. Dives extend over 30 - 40 minutes, often allowing survey of entire discrete structures within sport diving depths (18 - 35 m). Thus TPWD-ARP survey conditions are relatively standardized thereby allowing for comparisons within (α-diversity) and among (β-diversity) artificial reef installations they monitor. However, because SFMA counts do not provide numerical abundances in catch per unit effort (CPUE) or density, these data cannot be integrated with other state coastal survey data for stock assessment (e.g., trawl fisheries, gill net, vertical long line). The latter was the motivation for this study as the TPWD-ARP is considering incorporating exact counts into its survey methodology for better integration with state coastal survey data. The purpose of this study is to compare exact counts and order of magnitude SFMA counts within the survey framework of the RDT in terms of equality of species richness and relative abundances. We hypothesize that the order-of-magnitude SFMA count method will capture greater numbers of species and that abundances will be similar for those correspondingly recorded species for exact count methodology.

METHODS

Study Site

The study was conducted 17 nm (31.5 km) offshore of South Padre Island, Texas, USA in the Gulf of Mexico at the site of the reefed USTS Texas Clipper (Texas Clipper hereafter) (26.18°N, 96.98°W). The Texas Clipper was reefed on November 17, 2007 by TPWD-ARP at a regional depth of 40.8 m and a clearance depth of 18.9 m. At 145 m long and 22 m wide, the Texas Clipper is the United States' fourth-largest ship sunk for the purpose of creating an artificial reef. An ecological monitoring program of water quality, and macroinvertebrate and fish diversity commenced soon after (February 2008) has continued approximately quarterly through November 2015. To date, a total of 68 fish species have been documented.

Survey Methods

Paired RTD-type fish surveys were conducted wherein one member of the diver pair performed exact counts of all species encountered while the other diver recorded abundances in order-of-magnitude counts (SFMA). Thus, sampling effort was identical for exact count and SFMA survey methods. Surveyor roles (exact count vs. SFMA) were alternated between two consecutive dives separated by a 2 hour surface interval during each site visit. Replicate visual surveys are preferred to more fully characterize fish biodiversity (Schmitt & Sullivan 1996). Abundances for both SFMA counts and exact counts were logged during each 30-40 min dive in contrast to the post-dive reporting often cited for RDT (Edgar et al. 2004). Surveys were conducted approximately quarterly from May 2012 through June 2013 (total of five surveys). In addition to fish species observations, divers also recorded maximum depth, temperature, dive time, and estimated visibility.

The survey data from each site visit were pooled taking the highest observed category (or exact count) for each species recorded based upon the assertion that if a single individual was observed by one member of the diver pair and two individuals were observed by the second diver, the higher value was more likely correct. Pooled samples were considered replicates in the analyses. Pooling in this study was preferred to averaging as abundance estimation errors will have greater affects in the lower SFMA categories (e.g., Single, 1 and Few, 2 - 10) given the log-based scale of estimation. Further, averaging of observations in each abundance category could potentially give similar abundance index values (Schmitt and Sullivan 1996).

Analysis of Survey Methods

Order-of-magnitude data such as the log-based SFMA categories are genuinely grouped numerical data that could have been collected in a continuous form (de Vaus 2002). Indeed, it is very likely that individual fish in the lower order-of-magnitude intervals (e.g., Single and Few) were counted exactly, then binned by divers. For the purpose of comparing SFMA counts to exact counts in this study, the categorical data were converted to numerical abundances. Converting the SFMA data to numerical abundances first required defining an end point for the open-ended, >100 individuals 'Abundant' category which was set at 1,000 individuals (e.g., Abundant = 101 - 1,000 individuals). Although higher counts are possible, TPWD surveyor counts rarely if ever exceed 1,000 individuals during a diving survey for any one species. Next, interval midpoints were assigned to each SFMA bin according to the log-normal distribution as exact count data (sightings) for fish populations follow a log-normal distribution (Wolfe & Pattengill 2013A). For example, the midpoint (median) of the log-transformed bounds of the Few category, ln(1.5) and ln (10.5), is 3.97 individuals ($e^{\mu} = e^{(\ln(1.5) + \ln(10.5)/2)} = 3.97$) because the sightings in the integer sub-bins (e.g., 2, 3…9, 10) within the range are expected to decline exponentially (Wolfe and Pattengill 2013A). Finally, a zero category was added to the data matrix for the case in which no individuals of a given species were observed in a given sampling interval. Exact count and SFMA count survey data were compared via rank correlations of their Bray-Curtis similarity matrices (PRIMER+; RELATE, Spearman's ρ) on the assertion that if both survey methods capture similar species richness and relative abundance, their correlation should be high (null hypothesis). The analysis was conducted for both untransformed and natural log transformed data to compare method performance across abundant and rarer species, respectively. A modified natural log transformation, ln(X+1), was used to emphasize the presence-absence structure (species richness) in the community data and applied to the counts or midpoints of each species-by-sample matrix. Comparing survey methodology based on presence-absence structure was desired as characterizing fish communities by SFMA counts is often cited as capturing greater numbers of species compared to characterizations by more quantitative exact count methods (Holt et al. 2004, Schmitt et al. 2002). For convenience and simplicity, the ln(X+1) transformed values of SFMA midpoints were rounded to the nearest whole number resulting in log-normal abundances of 0, 1, 2, 4, and 6, for the zero (0 fish), Single (1 fish), Few (2-10), Many (11-100), and Abundant (101-1,000) categories, respectively. While the whole number log-normal abundance values derived from the SFMA counts might seem crude, the typical transformations applied to species-by-sample matrices (forth-root, Log10 = log, and natural log = ln) essentially reduce the abundance values up to 1,000 individuals to a maximum 3 to 7 point scale and make little difference to multivariate ordinations (Clarke et al. 2015).

To determine if the relationship between species richness and survey effort varied across survey methods, the cumulative number of species was plotted against cumulative samples for each of the two survey methods. The similarity percentages routine (SIMPER) was used to identify the taxa most commonly identified by the two survey methods as well as those primarily responsible for driving dissimilarities between survey methods. All multivariate analyses were conducted in PRIMER (ver. 7).

RESULTS

Prior to comparing the results of the two survey methods, a null model was tested by comparing two species-by-samples data matrices derived from the exact count data. The first data matrix consisted of the exact count data that were converted order-of-magnitude SFMA counts represented by whole number log-normal midpoint values (0, 1, 2, 4, or 6). The second data matrix consisted of modified ln-transformed exact count data (ln[x+1]). Bray-Curtis similarity matrices were calculated for each data matrix and compared via their rank correlations (PRIMER+; RELATE) and found to be highly correlated as expected (Spearman's ρ = 0.952, p = 0.013) (note p-value can be ignored as the two data matrices were derived from the same dataset and thus not independent) supporting the null hypothesis that if survey methods capture similar species richness and relative abundances, their resemblance matrices should be highly correlated. Note that further reducing the data matrices in the above example to presence-absence would result in perfect correlation.

SIMPER analyses based on Bray-Curtis similarity matrices of the log-normal exact and SFMA count data indicated that the species documented within each method were fairly consistent across the five sampling intervals with average within survey method similarities of 58.8% and 64.2% for the exact and SFMA count methods, respectively. Ten and 11 species contributed ~70% of the average similarity in exact and SFMA count methods, respectively (Table 1). Eight species (70%) were consistently recorded by both survey methods. These were primarily large conspicuous species that were reported at high abundances by both methods (e.g., Lutjanids, Grunts, Spadefish, and Triggerfish) (Table 1). To compare the two survey methods in terms of capturing similar relative abundances of these more conspicuous species, the untransformed exact counts were compared with the raw SFMA midpoints via their ranked correlation matrices (PRIMER+; RELATE) and found to be marginally correlated (ρ = 0.552, p = 0.069), indicating similar performance of the two survey methods. To weight the comparison of two survey methods more towards the species presence-absence structure, the ln-transformed exact counts were compared to simultaneously collected log-normal SFMA midpoints and found to be uncorrelated (ρ = 0.188, p = 0.703). Thus, the two methods did not similarly assess relative abundance, species richness, or both when rarer species contributed to the analysis. To further negate the effects of varying abundances, the two datasets were reduced to presence/absence and the resulting similarity matrices compared via RELATE and found to be similarly uncorrelated (ρ = 0.337, p = 0.214), indicating variations in the presence-absence structure (species richness) were responsible for the difference. Indeed, exact counts by divers were found to underestimate species richness by 15-30% compared to the SFMA category method (Figure 1).

This difference in species richness was primarily due to the greater detectability of smaller, less abundant Pomacentrids by the SFMA count method. Surprisingly, water-column schoolings Carangids were also better sampled by the SFMA count method (Table 1) and the number of recorded species generally accumulated faster for the SFMA count method (Figure 1). The number of species recorded by the exact count method ranged 21 - 25 across the five sampling intervals with a combined species richness of 39 compared to the SFMA count method, which ranged 20 - 32 species across sampling intervals with a total species richness of 45.

DISCUSSION

Being able to conduct rapid species assessments is becoming increasingly important as a conservation tool in the face of decreasing global diversity (Holt et al. 2013, Schmitt et al. 2002). Despite a large number of comparative studies among underwater fish census methods and several reviews (Sale & Sharp 1983), no standardized methods have emerged (Colvocoresses and Acosta 2007). A majority of comparative visual-census methodology studies have focused on comparing exact-count, fixed-area census methods (e.g., strip transect vs. stationary counts) (Thresher and Gunn 1986, Watson and Quinn 1997) or roving census vs. fixed-area census (Holt et al. 2013, Pattengill 1998, Schmitt et al. 2002, Wolfe & Pattengill-Semmens 2013B). To compare the latter requires simultaneous consideration of two variables; survey design and census method. The traditional REEF RDT (Pattengill-Semmens and Semmens 1998) not only allows roving while surveying but also employs order-of-magnitude counting (SFMA) whereas fixed-area census methods restrict divers to defined areas and employ simultaneous exact counts. So, it is unclear if cited differences are a result of enumeration method (exact counts vs. order-of-magnitude counts) or the survey design itself (roving vs. fixed area). This study compared two methods of recording species abundances for roving surveys, exact counts vs. order-of-magnitude counts (SFMA), while controlling for many confounding factors (e.g., effort, environmental conditions, size of area surveyed, search mode, topography, fish behavior, and fish identification skill level). The REEF RDT, in general, is often cited as better able to synoptically record the full fish species biodiversity in reef ecosystems than exact-count, fixed-area methods because it allows surveyors to range over entire areas and find a greater number of species in a shorter amount of time (Holt et al. 2013, Pattengill-Semmens and Semmens 1998, Schmitt et al. 2002). In this study, roving bias was eliminated and biodiversity estimates were greatest for the order-of-magnitude count method compared to exact counting, which tended to underrepresent small cryptic reef fishes and pelagic schooling fishes. Similar findings are noted in studies comparing roving vs. fixed-area methods, suggesting that focusing on exact counts has as much impact on the biodiversity estimates as whether or not a diver is freely roving or restricted to a defined survey area. Holt et al. (2013) noted that the actual time spent recording species differs considerably when comparing REEF RTD and conventional belt transect surveys and likely influences the observed differences; which for our study can be noted in the faster species accumulation in the log-category method (Figure 1). In our study, we found that both enumeration methods produced

Table 1. Similarity percentages (SIMPER) analyses of natural log-transformed exact counts and order-of-magnitude category midpoints of fish abundances from the Texas Clipper Reef (Texas Parks and Wildlife reef PS-1122) located 31.5 km offshore of South Padre Island, Texas, USA in the Gulf of Mexico. Average within group similarities are 58.8% and 64.2% for exact count and order-of-magnitude counts, respectively. Similarity = Sim, Standard Deviation = SD.

Species	Average Abundance	Average Similarity	Sim/SD	Contribution %	Cumulative %
Exact Counts					
Gray Snapper	3.53	6.29	2.48	10.71	10.71
Atlantic Spadefish	3.27	5.74	2.10	9.76	20.46
Gray Trigger	2.55	4.57	3.82	7.77	28.23
Spanish Hogfish	2.35	4.56	7.17	7.76	35.99
Vermillion Snapper	2.65	4.52	3.42	7.69	43.68
Tomtate	1.89	3.96	5.57	6.74	50.42
Sharpnose Puffer	1.82	3.61	6.12	6.14	56.56
Red Snapper	2.27	3.31	1.08	5.62	62.19
Blue Angelfish	1.43	2.79	6.49	4.74	66.93
Reef Butterfly Fish	1.55	2.75	7.21	4.68	71.61
Order-of Magnitude Counts					
Vermillion Snapper	5.20	5.97	3.53	9.29	9.29
Red Snapper	4.00	5.15	7.98	8.01	17.30
Sharpnose Puffer	4.00	5.15	7.98	8.01	25.32
Gray Snapper	4.80	4.78	2.36	7.44	32.76
Blue Runner	4.80	4.52	1.14	7.04	39.80
Atlantic Spadefish	4.40	4.24	3.14	6.60	46.40
Lookdown	4.00	3.57	1.13	5.56	51.96
Gray Trigger	3.20	3.29	3.06	5.12	57.08
Rock Hind	3.20	3.27	3.29	5.09	62.16
Spanish Hogfish	3.20	3.26	3.42	5.07	67.24
Tomtate	3.00	2.87	1.61	4.46	71.70

similar results in capturing relative abundances of large, abundant, and conspicuous species. This finding is confirmed in studies comparing roving and fixed-area methods (Pattengill-Semmens & Semmens 1998, Schmitt et al. 2002). For example, Pattengill-Semmens & Semmens (1998), reported a high rank correlation (ρ = 0.83) between REEF RDT and quantitative point counts suggesting that the order-of-magnitude abundance score estimates for moderately abundant and frequent species appear to be good approximations of actual abundance.

Clearly it is impossible to completely sample even relatively small and discrete reef ecosystems (e.g., artificial reefs) using any method. Thus, without a full taxonomic list and associated absolute abundances for comparison, it is difficult to relate observed abundance estimates for quantifying the performance of any visual survey method. Even in ideal conditions with well-trained observers, visual census methods routinely record less than 80% of the individuals actually present (Seber 1979, Thresher and Gunn 1986). While estimates of absolute abundance (or density) may be the ideal objective for management, a consistent sampling method combined with adequate sample size will allow detection of relative changes in abundance and meaningful statistical comparisons within (α-diversity) and among (β-diversity) sites (Colvocoresses and Acosta 2007, Thresher and Gunn 1986). When scientific divers participate in fish surveys, variation in abundance estimates between divers is relatively low compared to variation among sites and among sampling intervals (Edgar et al. 2004). As demonstrated in this study, SFMA counts represented by a simple log-scale of relative abundance (log-normal SFMA midpoint values) provide comparable results to exact count methods of the most abundant and conspicuous species and can be used in community analyses to compare spatial and temporal fish biodiversity trends. A majority of studies using log-categories reduce the dataset to presence-absence prior to attempting multivariate analyses as no diversity metrics are currently available to include such abundance categories (Holt et al. 2013). However, in practice, one rarely finds differences between simple categorized scales and more detailed counts provided they are picking up the same presence-absence structure (Clarke et al. 2015). The simple log-scale abundance used in this study (0, 1, 2, 4, 6 for 0, S, F, M, A, respectively) emphasizes presence-absence with some weighting for varying abundance. In practice, a coarse assessment of the abundance of each species is all that is necessary for a stable multivariate analysis. Most multivariate analyses of species-by-sample matrices are performed on transformed abundance values and the simple log-scale representing SFMA used in this study is essentially equivalent to applying commonly used, albeit severe, transformations (forth-root, log, and ln) to exact count data.

Recently, Wolfe and Pattengill (2013a) provided a method of converting SFMA data to numeric means with reasonably small confidence intervals, thereby enhancing its statistical usefulness. If the area surveyed or time duration are known, as is the case for surveying TPWD artificial reef installations, these values can be expressed as density or CPUE. However, expressing these data as density may not provide additional information for comparisons within and among sites beyond the simple log-scale abundance used in this study. If exact counts are desired, the results of this study suggest fewer species should be targeted for quantitative observations as recommended in other studies (Wells 1995). The results of our census method comparison indicate that SFMA counts are an effective technique when diversity estimates are a major goal.

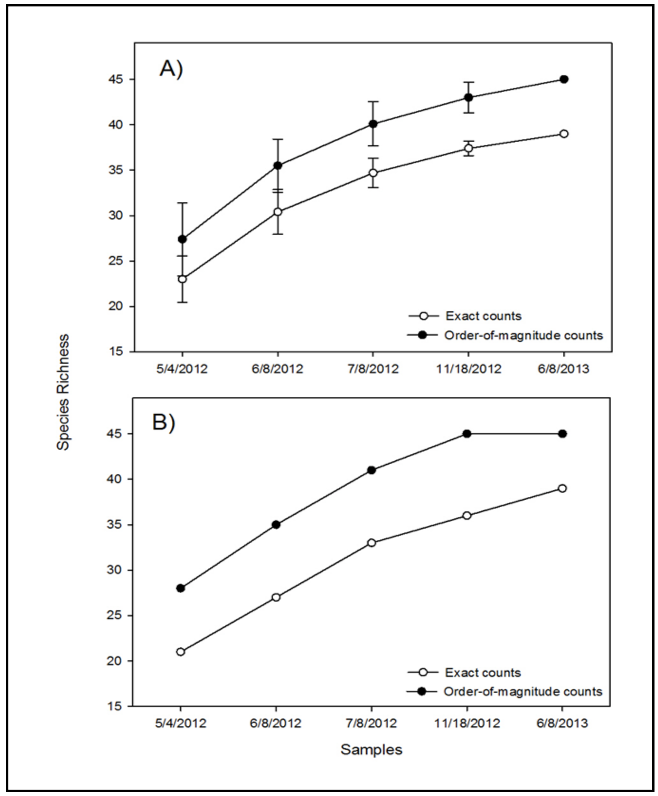

Figure 1. Species accumulation plots for permutated (A) and observed (B) species richness for exact (open circles) and order-of-magnitude (solid circles) count methods of censusing fish biodiversity from the Texas Clipper Reef (Texas Parks and Wildlife artificial reef PS-1122) located 31.5 km offshore of South Padre Island, Texas, USA in the Gulf of Mexico. Bars are 1 standard deviation.

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