Gulf of Mexico Science

Volume 30
Number 1 *Number 1/2 (Combined Issue)*

Article 6

2012

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DOI: 10.18785/goms.3001.06

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Recommended Citation

Grace, M. A., W. Ingram, W. B. Driggers III and T. Henwood. 2012. Assessing Adequate Sampling Levels with Time-Series Resampling of Fishery-Independent Bottom Longline Surveys of the U.S. Gulf of Mexico. Gulf of Mexico Science 30 (1).
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SHORT PAPERS AND NOTES

Gulf of Mexico Science, 2012(1–2), pp. 39–44

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ASSESSING ADEQUATE SAMPLING LEVELS WITH TIME-SERIES RESAMPLING OF FISHERY-INDEPENDENT BOTTOM LONGLINE SURVEYS OF THE U.S. GULF OF MEXICO—For researchers conducting time-series surveys, establishing adequate species-specific sampling levels for achieving statistically useful results (a priori power analysis) can help identify realistic research expectations (Gerrodette, 1987; Fairweather, 1991). Additionally, if the probable impacts of research logistics that affect temporal, spatial, and effort issues can be assessed in advance, it is possible to design more efficient surveys when considering logistic parameters coupled with adequate sampling levels.

Fishery-research projects conducted with bottom longline gear are examples of scientific surveys that routinely encounter a wide variety of species, habitats, and environmental conditions, especially if these surveys have broad spatial coverage. Time-series seasonality issues can be controlled with uniform periodicity for conducting surveys, but it is often more difficult to define and control other factors that can create catch variability (e.g., gear saturation by target and nontarget species; Rothschild, 1967; Somerton and Kikkawa, 1995).

Considering the potentially highly variable results from bottom longline surveys, a prerequisite for determining adequate sampling levels from a time series is standardizing survey gear and developing effective and repeatable survey designs (Hubert, 1996; Grace and Henwood, 1997). While many fishery-independent surveys likely sample at adequate levels, for broad-based Gulf of Mexico fishery-independent bottom longline surveys there is a lack of published literature specifically addressing the vital importance of using power analysis for assessing survey effectiveness.

Methods.—Beginning in 1995, the National Marine Fisheries Service, Southeast Fisheries Science Center, Mississippi Laboratories (MSL) initiated bottom longline surveys to assess the relative abundance and distribution of species distributed in the U.S. western North Atlantic Ocean. The MSL surveys have not targeted a particular species, and because of vessel availability were conducted from late July through Sept. The MSL surveys have attempted to control potential sources of survey bias by conducting fishery-independent surveys that follow five basic objectives: stock-wide surveys, synopticity, a well-defined sampling universe, controlling biases (e.g., standardizing gear and bait), and useful precision by achieving a coefficient of variation <0.5 for as many species as possible (Grace and Henwood, 1997).

For establishing adequate sampling levels through power analysis, the 2001–2005 MSL time series from the U.S. Gulf of Mexico (GOM) was used for defining species distributions. This period was the most consistent for area coverage and annual survey effort (Fig. 1). The 2001–2005 time-series survey design employed random site selection within depths 9–366 m (5–200 fm), and effort was generally 100 hooks (no. 15/0 circle hooks) fished for 1 hr. The mainline was 4 mm diameter monofilament 1.85 km length (1 n. mi), 3 mm diameter monofilament gangions 4 m length; bait was Atlantic mackerel (*Scomber scombrus* (Linnaeus, 1758)). Stations sampled were proportionally allocated based on continental shelf width within 21 statistical zones of 1 degree of latitude (for north to south shorelines) or longitude (for east to west shorelines) and within depth strata 9–55 m (50% allocation), 55–183 m (40% allocation), and 183–366 m (10% allocation or at least two survey sites per statistical zone). Stations were conducted day and night and were not predesignated day or night sites but were occupied in the most time efficient manner possible. Biological (e.g., length, weight, sex, mortality) and environmental (e.g., temperature, dissolved oxygen, salinity) data were collected at each survey site.

Based on GOM distributions, habitat preference, and importance to management, four coastal shark species from the 2001–2005 time series were selected as examples for determining adequate sampling levels; nurse sharks [*Ginglymostoma cirratum* (Bonnaterre, 1788)], blacktip sharks [*Carcharhinus limbatus* (Valenciennes, 1841)], Atlantic sharpnose sharks [*Rhizoprionodon terraenovae* (Richardson, 1836)], and scalloped hammerheads [*Sphyrna lewini* (Griffith and Smith, 1834)]. East and west GOM geographic divisions (88°W longitude demarcation) are based on Hannan et al. (2011), which addresses nurse shark GOM distributions in association with bottom sediment type and abiotic factors [for the purposes of creating GOM east and west treatment groups the west and central GOM

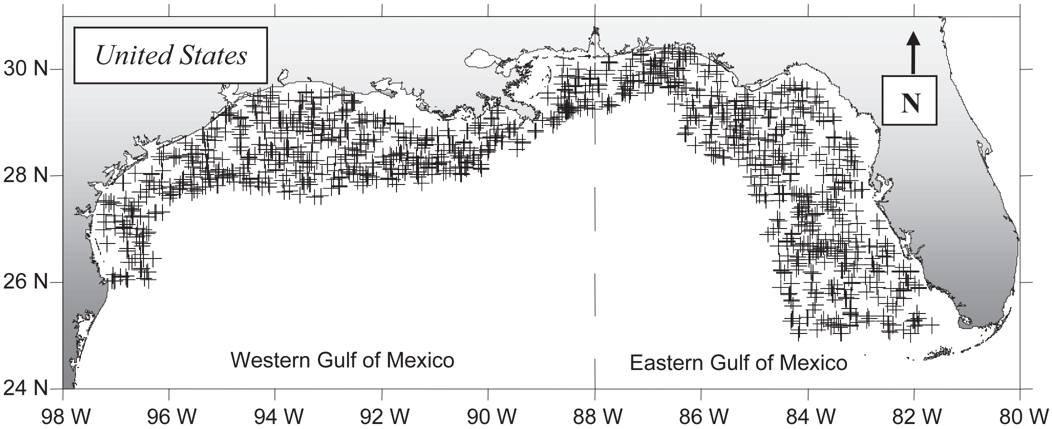

Fig. 1. 2001–2005 MSL bottom longline sampling locations (9–366 m); 552 locations in the eastern GOM, 1,076 locations in the western GOM.

designations from Hannan et al. (2011) are treated together as the west GOM, Fig. 1]. Nurse sharks were primarily distributed in the east GOM (134 captures in the eastern GOM, 5 captures in the western GOM), and their distributions are often localized and associated with bottom features or irregular bottom (Carrier and Pratt, 1998). Blacktip sharks are one of the most commercially important GOM sharks and consequently are a species of concern for the National Marine Fisheries Service large coastal shark management (NOAA/NMFS, 2006); they were the most frequently captured large coastal shark, and their distribution was both in the eastern (97 captures) and western (687 captures) GOM. Atlantic sharpnose sharks were the most numerous of any captures (finfish and elasmobranchs) and were distributed along the entire GOM coast (657 captures in the eastern GOM, 5,102 captures in the western GOM). Scalloped hammerheads (19 captures in the eastern GOM; 93 captures in the western GOM) are a species of management concern because of their declining populations and are impacted by a number of fisheries in the western North Atlantic Ocean (Baum et al., 2007).

Owing to the highly variable nature of the time series (described as zero inflated with an abundance of zero catches), a delta lognormal estimator (Pennington, 1983) was used to calculate mean catch per unit effort (CPUE) by species. By using a priori power analysis, adequate sampling levels were considered sufficient when the sample size (the allocation of sampling sites, n) decreased the coefficient of variation (CV) to <0.5. If a CV > 0.5 was used as a threshold for determining adequate sampling, it would be statistically unlikely that the CPUE for a certain year would be different than zero; therefore, it would be difficult to determine CPUE trends in the time series (if any trends exist).

Time-series resampling (a posteriori power analysis) was conducted from years 2001 to 2004 to test adequate sampling levels; year 2005 was not used in the resampling since for that year the GOM was not completely sampled. Combinations of three of four time-series years were used to calculate adequate sampling levels by species. The result was then compared to the adequate sampling level calculated for the year not used for the 4-yr adequate sampling test group calculations. One thousand resampling calculations were repeated for each test group. This was done for each time-series year for each species in each test group, and the mean result from those calculations was used as the adequate sampling value. The resampling comparison was for the half of the GOM where a test group species was most abundant or gulf-wide for widely distributed species (32 resampling scenarios).

If the MSL surveys were species specific, spatial correlation analysis would better define the potential effects of increasing n as it affects CVs for individual species. However, considering the multitude of factors that characterize the time series and survey areas (e.g., bottom types and environmental conditions) and that the indexes of relative abundance are used in assessments for several species (the surveys do not target specific species), n for the various precision levels was calculated without conducting the additional analysis. Since the MSL time-series annual station allocation does not factor in site-specific com-

DOI: 10.18785/goms.3001.06

Table 1. Adequate sampling levels (n = bottom longline site allocation) for the eastern and western GOM by species (based on CVs < 0.5); 2001–2005 MSL bottom longline time series. Catch rates were not adequate for establishing adequate sampling for nurse sharks in the western GOM.

	Eastern Gulf of Mexico			Western Gulf of Mexico		
Sharks	n	CV	SE	n	CV	SE
Nurse	27	0.495	0.160	200	0.935	0.011
Blacktip	57	0.499	0.097	25	0.497	0.652
Atlantic sharpnose	22	0.492	0.730	16	0.488	5.602
Scalloped hammerhead	147	0.499	0.019	31	0.496	0.083

plexities, including the additional analysis would potentially invalidate the associated time-series resampling.

Results.—Adequate sampling levels varied by species and area (Table 1) and were dependent on relative abundance and species distributions. Adequate sample levels ranged from n = 16 for Atlantic sharpnose sharks in the western Gulf of Mexico, to n > 200 in the western Gulf of Mexico for nurse sharks. From the time-series resampling results for the four shark species used for test group comparisons (Table 2), 71.8% of adequate sampling levels were below the resampling median sample size required for CV < 0.5 (23 resampling scenarios). An additional 15.6% of adequate sampling levels fell between the resampling median optimum sample size and the resampling 95th percentile; therefore, 87.4% of adequate sampling levels were at or below the resampling 95th percentile. For the balance of the species-specific optimum sample levels that exceeded the resampling 95th percentile (four resampling scenarios or 12.5%; 2001 western GOM blacktip sharks, 2001 gulf-wide Atlantic sharpnose sharks, 2001 western GOM Atlantic sharpnose sharks, and 2004 GOM scalloped hammerhead sharks), those scenarios were not only zero inflated, as is typical for the time series in general, but more importantly they reflected extremely high catch rates from differing locations.

Discussion.—For practical adequate sampling in situ applications, it is essential that adequate sampling is allocated using the same survey design criteria as the time series used for calculating adequate sampling levels, and it is also important to use recently collected data, since sampled populations can change over time (Miller et al., 2007). In addition to survey design considerations, catchability should be held constant (since it relates to maintaining consistent materials and methods), so relative abundance estimates can be accurately assessed across a time series (Kimura and Somerton, 2006). In this case, catchability was assumed to be constant because of the consistent use and deployment of similar gear throughout the time series.

A disadvantage to allocating sampling sites based on adequate sampling is it may not account for potential changes in species distributions. For example, if a species range expanded or contracted it would be possible to oversample areas that no longer include distributions or undersample or omit areas that extend beyond distributions reflected by a time series. To prevent a time series used for establishing adequate sampling levels from becoming statistically conservative or noninclusive of changing species distributions, random allocation of survey site locations outside of the distribution of locations used for calculating adequate sampling can test for potential changes in species distributions and help identify potential sources of survey design bias (Warren, 1994). Since MSL surveys typically encompass continental shelf-wide sampling along entire coastlines (e.g., the GOM), the risk of spatially noninclusive survey designs is minimized within logistically defined survey areas. However, since the MSL surveys are temporally confined to July through Sept., the surveys provide synoptic results that may not be similar to survey results from a time series developed from monthly or seasonal surveys. Additionally, species-specific differences in catch rates throughout the day can affect adequate sampling level derivation and application if there is a consistent peak capture period.

With a priori and a posteriori power analysis there are a variety of factors that potentially affect interpretation of results (Steidl et al., 1997; Hoenig and Heisey, 2001; Ortiz, 2002); however, with time-series resampling based on a posteriori power analysis it is possible to test adequate sampling level effectiveness without undertaking additional fishery-independent surveys. By using a fishery-independent bottom longline time series to determine adequate sampling levels it is possible to develop useful sampling strategies for achieving various levels of statistical precision by species, and time-series resampling provides test group scenarios for assessing the effectiveness

TABLE 2. 2001–2004 MSL bottom longline time-series resampling results. The number of stations was those within the minimum and maximum capture depth ranges by species.

Shark species	Area	Comparison year	No. stations	No. stations with captures	Mean CPUE	Sample size required for CV < 0.5	Resampling median sample required for CV < 0.5	Resampling sample size required for the 95th percentile
Nurse	GOM	2001	132	15	0.124	35	39	56
		2002	100	9	0.087	41	34	52
		2003	134	26	0.571	29	36	54
		2004	114	21	0.249	22	35	59
Nurse	Eastern GOM	2001	68	15	0.241	16	16	24
		2002	24	9	0.362	7	18	38
		2003	74	25	0.993	15	15	22
		2004	57	19	0.464	11	16	27
Blacktip	GOM	2001	226	44	0.598	44	34	47
		2002	179	53	0.961	22	33	43
		2003	233	60	1.138	31	33	40
		2004	198	47	0.809	32	33	44
Blacktip	Western GOM	2001	125	33	0.985	32	22	30
		2002	146	48	1.153	20	23	31
		2003	106	45	2.133	18	22	29
		2004	94	36	1.530	20	22	31
Atlantic Sharpnose	GOM	2001	229	103	5.260	27	21	25
		2002	183	116	9.074	16	21	25
		2003	235	131	6.375	15	21	26
		2004	204	114	7.383	22	21	25
Atlantic Sharpnose	Western GOM	2001	127	73	8.616	21	15	17
		2002	150	107	10.673	13	15	18
		2003	107	86	13.167	11	14	18
		2004	97	73	14.784	16	14	19
Scalloped hammerhead	GOM	2001	257	25	0.121	45	51	72
		2002	213	22	0.118	38	51	75
		2003	265	27	0.133	42	51	75
		2004	237	12	0.067	90	48	68
Scalloped hammerhead	Western GOM	2001	137	20	0.191	30	32	50
		2002	172	22	0.146	30	31	47
		2003	114	18	0.199	25	35	52

DOI: 10.18785/goms.3001.06

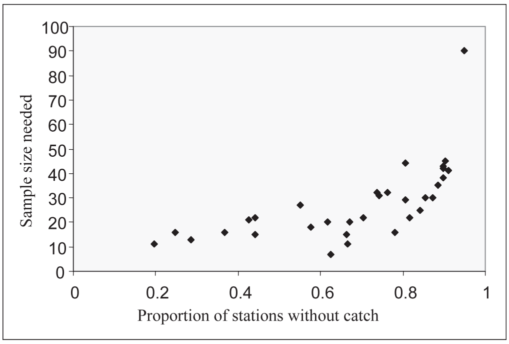

Fig. 2. Sample size requirements (bottom longline site allocation) in proportion to stations without catch.

of adequate sampling levels. Even though the survey design was adequate for building a precise index for several species, the analysis demonstrates that there are inherent logistic constraints that will prevent a single survey from incorporating enough effort to adequately sample each species it encounters throughout their entire range, as evidenced by nurse shark distributions in the western GOM. Additionally, an important factor affecting adequate sampling is that n will increase when the time series is zero inflated (Fig. 2) or has an abundance of extreme values (three standard deviations from the mean; Fig. 3). Even though the 2001–2004 time-series resampling did not reflect 100% effectiveness for establishing adequate sampling levels for all test group scenarios (71.8%), including additional time-series years would likely produce more effective adequate sampling levels as n increases by species. For some species, truncating adequate sampling levels by geographic area and time of day can help optimize field-survey options and better define species-specific sampling. In addition, time-series biological data have the potential to be used for developing adequate sampling, addressing a variety of species specifics such as geographic distributions by size groups, sex ratios, or reproductive status.

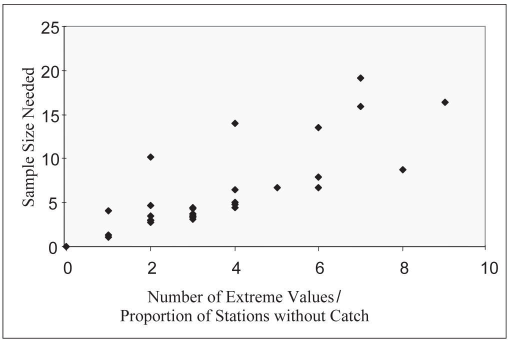

Fig. 3. Sample size requirements (bottom longline site allocation) in proportion to extreme catch values.

Acknowledgments.—Supportive scientists for manuscript development include former MSL director S. Nichols, former MSL acting directors J. Watson and R. Zimmerman, MSL director L. Desfosse, MSL scientists L. Jones and K. Hannan, and Dauphin Island Sea Lab scientist M. Drymon.

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DOI: 10.18785/goms.3001.06