Efficacy of TIP length composition for use in length-based mortality estimation

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Efficacy of TIP length composition for use in length-based mortality estimation

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Executive summary

We examine statistical properties of TIP length composition data for spiny lobster including the spatial distribution of sampling effort relative to fishing activity and the apparent reliability of mean length estimates based on sample size. Our analysis evaluates the information content in TIP length compositions, prior to the use of these data in stock assessment. Correspondence between fishery activity (catches and trips taken) and sampling of those fishing events via TIP was reasonable for Puerto Rico, St. Thomas, and St. Croix. Analysis of effective sample sizes needed to estimate mean length from TIP datasets were reasonable for Puerto Rico and St. Croix, while ESS for St. Thomas was more concerning. Simulation modeling also reasonably supported the reliability of TIP length composition datasets for use in data-limited assessment methods.

Introduction

Some data-limited stock assessment methods rely on the observation of mean length to estimate total mortality and related measures of a stock's reproductive state (Beverton and Holt, 1957; Ehrhardt and Ault, 1992; Gedamke and Hoenig, 2006). The reliability of mean length observations will influence the corresponding reliability of total mortality estimates. Accordingly, we examined the statistical properties of TIP length composition data for spiny lobster prior to considering whether to use these data in stock assessment. We approached the question of length composition efficacy for data-limited stock assessment by first graphically comparing fishery catches to TIP sampling intensity, by both gear and spatial region. We then evaluated the effective sample size (ESS) of TIP data, both spatially and temporally. ESS reveals the extent to which the observed sample size, *n*, is consistent with a random sample of the statistical population, *ESS*. Thus, ESS is a measure of the information content in sample of length observations. Finally, we conducted simulation of length composition data according to specified ESSs to reveal the correspondence between ESS and accuracy of mean length observations.

Graphical representation of TIP sampling by gear and coast

Methods

We examined the gears associated with spiny lobster sampled by the TIP datasets for Puerto Rico, St. Thomas, and St. Croix. Percentages of samples by island and gear types in the TIP data were compared to the percentages of pounds reported by island and gear types in the logbook data (Figure 1). For Puerto Rico, we also looked at the percentages by gear type and coast (Figure 2). Because of the two different units used to develop annual percentages (pounds from the logbook data and individuals sampled by TIP), caution when interpreting these plots is warranted. However, they can be used to get a preliminary sense of the representativeness of the TIP data for spiny lobster.

Results

In Puerto Rico and in St. Thomas, the predominant gears associated with the majority of spiny lobster landings were also associated with the majority of spiny lobsters sampled by TIP. In Puerto Rico, some minor differences exist between the two data sources. Compared to the percentages of landings, TIP samples from diving are slightly underrepresented and the TIP samples from pots and traps are slightly overrepresented. However, these differences are not of particular concern for using the length data.

In St. Croix, a disproportionately large percentage of spiny lobster TIP samples are associated with the pot and trap gear type compared to the percentages of landings for the same gear. However, this difference is not of particular concern since the analysis will focus on the predominant gear (Diving).

Effective sample size

Methods

We examined the precision of length-frequency distributions of spiny lobster obtained from TIP datasets for Puerto Rico, St. Thomas, and St. Croix. Given complications of field sampling, including those related to the use of fishery-dependent sampling, length samples collected from n sampling events are not necessarily a random sample from the entire population, but instead may be subject to errors attributable to data collection methods (Hulson et al., 2012). This circumstance can lead to less information about the population being contained in the M total length observations than would have been obtained from sampling M fish randomly from the population (Pennington et al., 2002). The quantity known as effective sample size (ESS) is an estimate of the sample size obtained through random sampling that would contain the equivalent information contained in the observed sample, M. The ESS is less than or equal to M. Steps necessary to estimate ESS are found in Pennington et al. (2002), where in our application to the TIP datasets, each fishing trip was treated as sampling event, n. ESS was calculated separately for each of the three island platforms and for each year. For Puerto Rico, we also estimated ESS for four spatial areas.

Simulation was carried out to evaluate the effect of ESS on precision and bias of mean length estimates arising from sampling of length composition datasets. Length composition datasets were generated from a population simulation representative of spiny lobster. The simulated population was used to generate equilibrium length composition, binned using 2 mm intervals. Length-structured population dynamics were simulated, which is an approach well-suited for modeling marine invertebrates (Haddon, 2011). Length-based models account for survival, growth, and reproduction through time by assigning individuals to length classes or length bins. Numbers-at-length matrices differ from numbers-at-age matrices because the latter tracks specific cohorts as they transition between age classes, while the former probabilistically tracks transitions between length classes where individuals from several cohorts are likely to be found in any given length bin (Haddon, 2011). The simulated spiny lobster population had life history characteristics representative of US Caribbean stocks: segmented growth obtained through analysis of mark-recapture data from St. Thomas, natural mortality of 0.34 $year^{-1}$ (FAO, 2001), maturity-at-length obtained from TIP data (Die, 2005), length-weight from TIP data (SEDAR, 2018), and Beverton-Holt stock-recruitment relationship with assumed steepness of 0.95. This population simulation was used to generate binned equilibrium length composition at depletion levels of 0.8 and 0.2.

Given simulated 'true' length compositions, a sample of these lengths was drawn from numbers-at-lengths above the minimum harvest size of 89 mm using a multinomial sampling distribution, with a specified sample size (which is equivalent to ESS). The mean of the length sample was calculated, along with standard deviation of mean estimator (i.e., $SD_i/\sqrt{ESS_i}$, where SD is standard deviation of the sample, and ESS is number of length samples). Percent bias between the estimated mean and true mean of the simulated length composition was calculated: (estimated mean – true mean) / true mean x 100. This process was repeated for 1,000 independent replicates at a given ESS. We then repeated this sampling exercise for ESSs ranging from 10 to 500. Results were summarized according to mean and centered 95% distributions in bias in mean length versus ESS. We similarly summarized the precision of the mean estimator as coefficient of variation versus ESS.

Results

Effective sample sizes (ESS) for all of the island platforms vary considerably through time (Tables 1 & 2). For Puerto Rico, East, West, and South regions tended to have substantially higher ESS than the North region, as the former three regions represent the vast majority of the area where fishing takes place. By pooling length samples across all four regions, each year had ESS > 50, with the exception of 1988. Temporal trends in ESS were similarly stable for St. Croix, with all years having ESS > 50 with the exception of 2011. St. Thomas length sampling had similar consistency. Note that for each island platform, missing values reflect a lack of data availability in those respective years.

Simulations highlight that bias in estimation of mean length can exceed 10% at very low ESS (Fig. 3). However, exponential reduction in bias occurs as ESS increases, and bias tends to be less than 5% at ESSs exceeding 50. Similarly, imprecision of the mean estimator is, on average, 2% or less when ESS exceeds 50. These results are encouraging, given the observed ESS estimates from TIP sampling for Puerto Rico and St. Croix.

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Table 1. Effective sample size (ESS) for St. Croix (STX) and St. Thomas (STT) TIP length composition datasets. n is number of length observations.

Year	STX		STT	
	n	ESS	n	ESS
1980			301	61
1981	260	62	916	311
1982	408	201		
1983	399	247	103	49
1984	867	237	755	102
1985	1631	991	1114	294
1986	1329	1017	299	111
1987	1621	713	415	71
1988	761	695	701	492
1989	54	135		
1990	552	407		
1991	625	223		
1992	798	297	193	51
1993	824	487	212	142
1994	790	441	76	226
1995	547	154	29	6
1996	400	258	117	291
1997	634	245		
1998	517	257		
1999	542	257		
2000	320	61		
2001	295	212		
2002	598	252	318	60
2003	564	269	354	48
2004	433	188	162	65
2005	526	435	203	181
2006	366	330	799	179
2007	647	548		
2008	404	124	90	21
2009	388	231	738	114
2010	717	411	933	235
2011	33	17	619	252
2012			444	659
2013			286	150
2014				
2015			110	8
2016	169	77	722	262
2017	273	140	619	207

Table 2. Effective sample size (ESS) for Puerto Rico TIP length composition datasets. n is number of length observations.

Year	East		West		North		South		All	
	n	ESS	n	ESS	n	ESS	n	ESS	n	ESS
1980	131	108	126	55	11	17	59	64	337	170
1981										
1982										
1983	11	6	114	62			8	12	133	79
1984	304	237	642	392			104	130	1272	840
1985	148	53	298	235	5	NA	491	420	970	475
1986	84	36	157	57	13	3	221	290	551	248
1987	75	35	104	62			313	261	603	424
1988							4	NA	38	18
1989	62	65	51	14	26	23	393	301	545	220
1990	14	17	25	1	33	12	477	457	549	109
1991	185	47	24	25	25	19	691	296	925	344
1992	88	43	175	107	3	3	495	341	779	540
1993	91	25	71	32	8	2	393	186	563	234
1994	62	27	132	93			19	12	217	125
1995	92	54	131	60	1	NA	300	198	624	158
1996	204	84	58	36	1	NA	249	176	512	280
1997	13	164	20	8			197	122	230	147
1998	258	181	192	115			188	87	638	344
1999	314	118	291	44	50	9	366	198	1021	252
2000	212	62	234	134	12	38	328	213	795	283
2001	506	237	308	226	72	47	392	363	1278	755
2002	81	23	227	100	46	16	239	123	606	181
2003	687	377	373	199	131	39	256	200	1447	758
2004	598	196	760	438	104	16	159	132	1621	416
2005	169	89	974	558	29	11	260	161	1432	775
2006	181	18	1041	132	143	62	416	163	1781	248
2007	262	100	1014	298	50	36	384	192	1710	507
2008	131	11	488	309	57	12	201	78	877	173
2009	185	68	873	449	72	50	456	187	1586	673
2010	147	82	770	386	21	319	399	232	1337	705
2011	221	104	1704	985	173	128	495	365	2593	1344
2012	318	169	1867	1120	299	204	492	296	2976	1442
2013	713	244	2123	1159	86	28	333	262	3255	1537
2014	1079	682	1549	870	2	2	972	397	3615	1808
2015	854	523	1349	845	25	5	782	602	3010	1749
2016	1030	296	1631	931			753	448	3435	1481

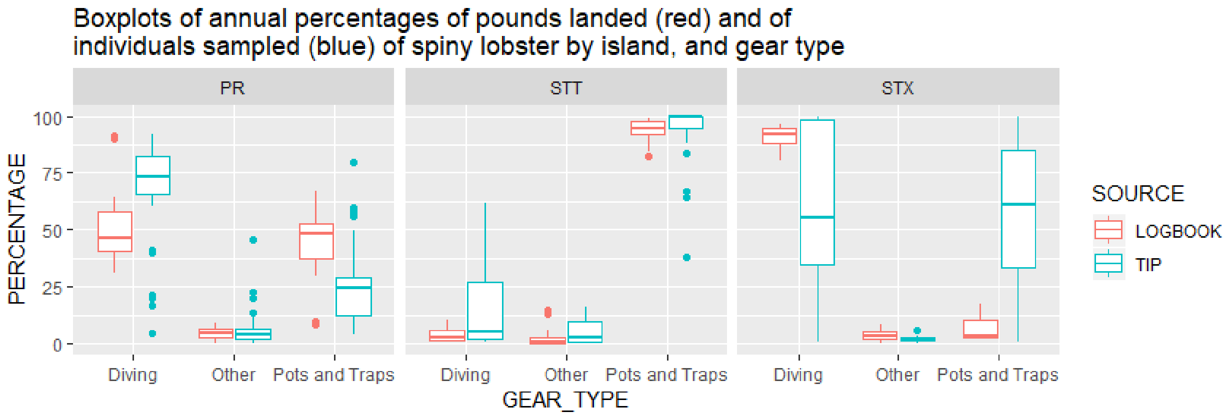

Figure 1. Boxplots of annual percentages of pounds landed (red) and of individuals sampled (blue) of spiny lobster by island and gear type.

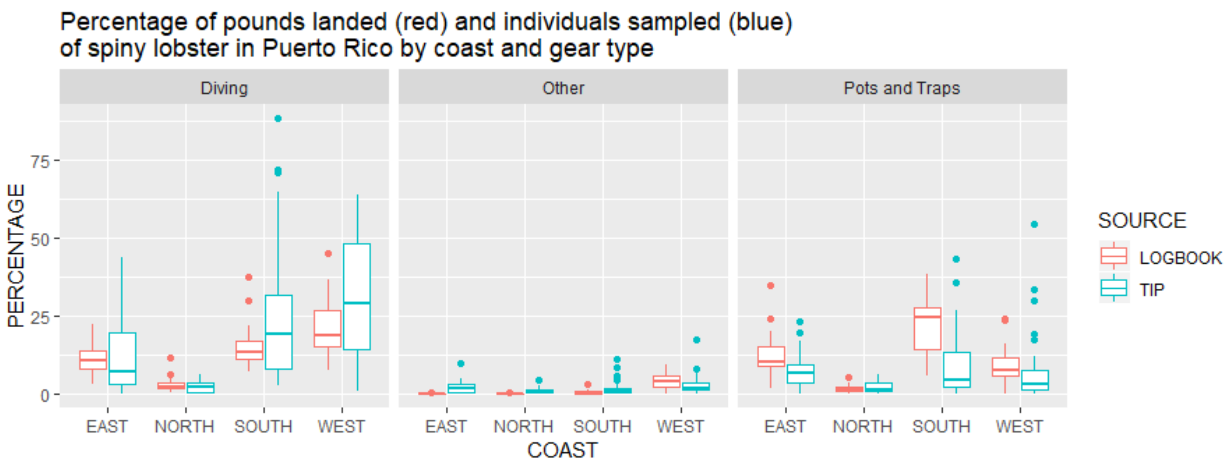

Figure 2. Boxplots of annual percentages of pounds landed (red) and of individuals sampled (blue) of spiny lobster in Puerto Rico by coast and gear type.

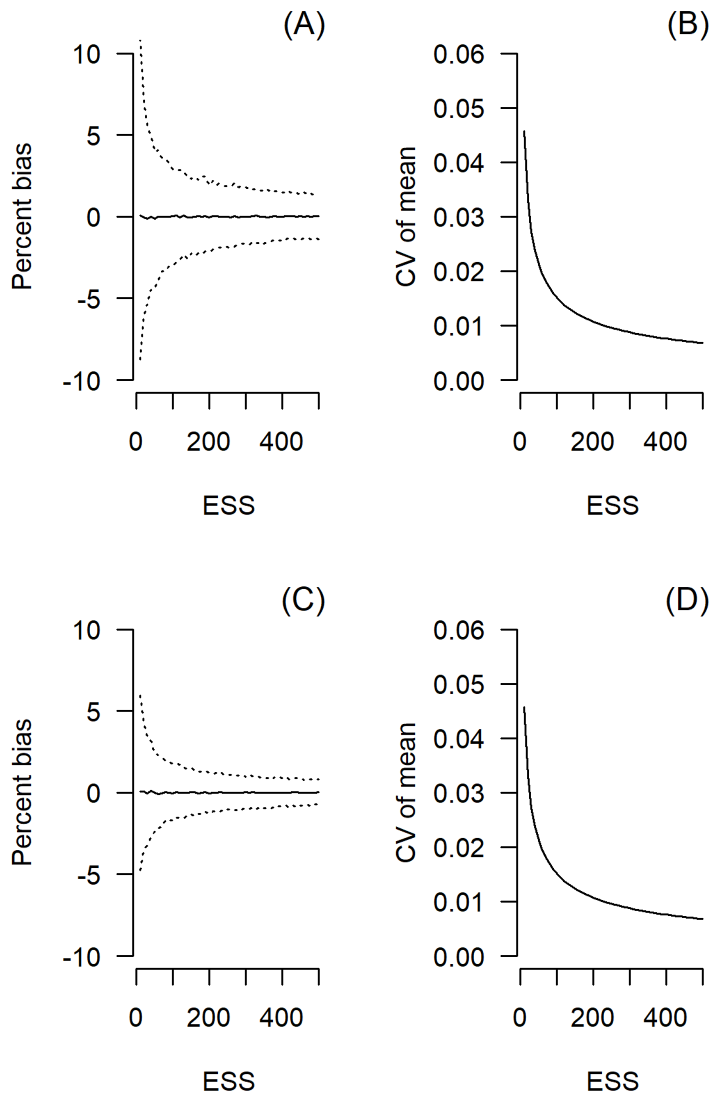

Figure 3. Simulated effects of effective sample size (ESS) on corresponding bias in estimating mean length (A & C) and precision of the estimated mean (B & D). Simulations consisted of generated equilibrium length composition at depletion levels of 0.8 (A & B) and 0.2 (C & D) for a population with life history characteristics representative of spiny lobster. Length observations were sampled according to a multinomial sampling distribution with ESSs ranging from 10 to 500 (x-axes in all plots).