Elk Statistical Population Reconstruction Modeling:

Preface to the 2019 Update

What's different about this report? The initial report (2018) submitted to Kentucky Department of Fish and Wildlife Resources (KDFWR) by the model developers was a proof of concept used to demonstrate how a statistical population reconstruction (SPR) model could help meet KDFWR's elk population modeling needs. The 2019 SPR report builds on the foundation laid in the 2018 version, and serves as a progressive step from proof of concept to practice. This report reflects the benefits of incorporating two additional years of data in the analyses, which results in increased predictive abilities.

Although the 2018 report provided KDFWR's Elk Program staff with a point-estimate of elk total abundance (population number) that aligned relatively close to our historic life-table model, the previous SPR model was criticized by some stakeholders for its large confidence intervals. A confidence interval, which is a numeric range that takes into account potential sources of error, is important because it provides a range of values in which the actual population number should occur. It is critical to understand that the 2018 report utilized the *bare minimum* amount of data to generate its estimates of abundance and survivability, resulting in the large confidence intervals shown the 2018 report. When the first iterations of the SPR model were run, the required data were only available for 3 years—some of which had to be grouped together due to data availability (i.e., there was significant disparity between the data available for bulls and cows from previous projects). The 2018 report stipulated the need for a minimum of 3-5 years of complete data for the model to be effective, so the inclusion of the 2017 and 2018 data (used for the 2019 report) barely meets these identified requirements. As such, even though the model's confidence intervals appear to be relatively large, they have narrowed considerably, and will continue to narrow further with each additional year of data (Figures 1-3 in the 2019 Report).

How have the population estimates changed? It is important to first explain what appear to be discrepancies involving the point-estimates for elk abundance between the 2018 and 2019 reports. The 2018 report provides estimates of total elk abundance that are different from the point estimates recorded for the same years in the 2019 report. Here's why: as the model receives additional data, it re-analyzes previous annual data in addition to that from the current year. It provides enhanced estimates as it receives new information and its predictive abilities improve, which in turn it improves earlier estimates as well. With this in mind, the old estimates aren't incorrect. Rather, they just become more refined and precise as additional years and data are incorporated into the model.

That said, incorporating additional data have produced these expected results: confidence intervals for estimates are narrower, and the point estimates are more reliable. For example, with fewer data available in the 2018 iteration of the model, the previous point-estimate of total abundance in Kentucky's elk zone for 2016 was 13,157 elk (95% confidence interval of 2,671 - 23,643 animals; Table 9 in the 2018 report). With additional data from 2017 and 2018 incorporated, the SPR model yielded a point-estimate for total elk abundance in 2016 to be 8,621 elk (95% confidence interval of 4,080 – 13,162 animals; Table 9 in the 2019 report).

The 2019 SPR report that follows shows that the SPR model estimated the Kentucky elk population in 2018 to be 10,089 elk (95% confidence interval of 4,827 – 15,351 animals). For reference, the life-table model used historically to estimate Kentucky's elk population produced an estimate of 13,106 animals in 2018.

How has the SPR Model benefitted KDFWR? Realized benefits from the development of an SPR elk model have been numerous. Elk Program staff have streamlined data collection efforts, including the addition of new data sources (e.g., hunter effort or age-at-harvest data). Most importantly, the SPR model has provided KDFWR with a viable model to compare with the existing life-table model.

KDFWR has also recently initiated a multi-year research project aimed at providing additional inputs to strengthen our SPR model. Elk Program staff and University of Kentucky (UK) researchers deployed 72 new collars on adult elk throughout the elk zone in January 2020 to gain additional baseline information in portions of the elk zone we previously knew little about. This complements the 21 elk already collared in the elk zone. KDFWR plans to deploy additional collars in 2020 and continue collaring elk annually through 2022 to further this project.

Complementary to the above project, Elk Program staff and UK researchers have initiated a new study aimed at reassessing the reproductive potential for Kentucky elk. All females were aged at capture, and biologists used ultrasonography and a blood sample to determine pregnancy status. Twenty-five of those females deemed pregnant were fitted with vaginal implant transmitters (VITs) which will facilitate the capture of their calves in the spring. Current funding levels will allow us to deploy an additional 25-50 VITs annually through 2022.

Future work: It is clear to Elk Program staff the great value that a Kentucky-specific SPR model holds for the future management of our elk population. However, KDFWR also recognizes that it is just another tool and that it cannot solely rely on a single method of estimating our elk population. In addition to our continued use of the life-table model, staff will seek to take full advantage of the increased number of collars in the elk zone by using additional population survey techniques. These include camera traps and designated flying/driving routes to conduct a mark-resight analysis as a means of "ground truthing" estimates yielded by both the SPR and life-table models. The high number of marked individuals distributed throughout the elk zone will provide useful context to these two methods of surveying the population. During this mark-resight project, we hope to capitalize on the knowledge of landowners, outfitters, and hunters to collaborate and maximize the effectiveness of the project.

Kentucky Elk Statistical Population Reconstruction Modeling Project Update

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Final Report

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Overview

The Kentucky Department of Fish and Wildlife Resources requested we update a Statistical Population Reconstruction (SPR) model for their elk population which we developed in 2016. We updated the 2016 Kentucky elk SPR model with total harvest, hunter effort, and auxiliary data from 2017 and 2018 (Tables 1-4). All of the same data preparation procedures and assumptions outlined in the previous report were used here including the observed age distributions from tooth submissions, used to estimate expected age-at-harvest distributions for each season type. The model begins in 2011, following permit differentiation for rifle and archery hunters. There are 3 age-classes in the model, calf, yearling and adult. The adult age-class encompasses all ages older than a yearling. There are 3 periods in which antlered males (yearling and adult age-classes) are harvested, Bull Archery, Bull Rifle and Either Sex Archery. There are two periods when antlerless males (calves) and females (all age-classes) can be harvested, Either Sex Archery and Cow Rifle.

We ran the models with just the addition of the 2017 data, then again with the 2017 and 2018 data to get an idea of how each year of data contributed to the precision and point estimates resulting from the model. No additional auxiliary data for males was included because of the low sample sizes and widely disparate estimates of harvest mortality.

Table 1. Male total harvest and hunter effort data 2011-2018.

Year	Bull Archery		Bull Firearm		Either Sex Archery		Cow Rifle	
	Number of Permits Purchased	Total Male Harvest	Number of Permits Purchased	Total Male Harvest	Number of Permits Purchased	Total Male Harvest	Number of Permits Purchased	Total Male Harvest (Calf Only)
2011	79	50	118	136	298	22	328	11
2012	88	58	135	148	322	28	360	10
2013	93	43	147	160	328	38	405	4
2014	93	45	145	146	321	44	400	7
2015	94	38	143	159	285	46	346	5
2016	98	38	139	146	296	58	323	9
2017	93	44	143	122	210	31	255	4
2018	95	48	143	127	208	33	259	10

Table 2. Female total harvest and hunter effort data 2014-2018.

Year	Either Sex Archery		Cow Rifle	
	Number of Permits Purchased	Total Female Harvest	Number of Permits Purchased	Total Female Harvest
2014	321	55	400	183
2015	285	43	346	229
2016	296	42	323	208
2017	210	30	255	119
2018	208	36	259	140

Table 3. Female auxiliary data 2013-2018. 2013 and 2014 were again combined and included in the 2014 model year. Harvest mortality information was only included in the model in 2016-2018. * indicates the years in which collar data were used to inform harvest rate as well as natural survival rate.

Season Year	At Risk	Harvested	Died	Lived
2013	37	8	2	27
2014	78	20	3	55
2015	52	2	1	49
2016*	0	0	0	0
2017*	14	1	4	9
2018*	21	1	1	19
Total	202	32	11	159

Table 4. Male auxiliary data 2011-2015. Additional male auxiliary (8 adults in 2017 and 10 adults in 2018) were not included because of the low sample size and widely disparate harvest estimates of 0% and 40%. Harvest mortality information was only included in the model in 2015. * indicates the years in which collar data were used to inform harvest rate as well as natural survival rate.

Season Year	At Risk	Harvested	Died	Lived
2011	57	8	5	44
2012	104	42	12	50
2013	96	23	16	57
2014	75	17	6	52
2015*	52	3	1	48
Total	384	93	40	251

Results- 2017 (adding only 2017 data)

Table 5. Sex-specific and total annual abundance estimates 95% confidence interval (CI) bounds for an elk population in Kentucky 2011-2017.

Year	Male Abundance	Standard Error	CV of Male Abundance	Upper 95% CI bound	Lower 95% CI bound
2011	10,907	3346.7	0.307	17467	4347
2012	11,011	3666.8	0.333	18198	3824
2013	7,994	2600.1	0.325	13090	2898
2014	6,408	2032.5	0.317	10391	2424
2015	5,104	1629.1	0.319	8297	1911
2016	6,518	2167.8	0.333	10767	2269
2017	6,495	2223.7	0.342	10854	2137
Year	Female Abundance	Standard Error	CV of Female Abundance	Upper 95% CI bound	Lower 95% CI bound
2014	3,832	2135.5	0.557	8,017	0
2015	3,494	1981.6	0.567	7,378	0
2016	4,431	1849.4	0.417	8,056	806
2017	4,013	1688.8	0.421	7,323	703
Year	Total Abundance	Standard Error	CV of Total Abundance	Upper 95% CI bound	Lower 95% CI bound
2014	10,240	3476.3	0.339	17,054	3,426
2015	8,597	2976.7	0.346	14,431	2,763
2016	10,949	3574.1	0.326	17,954	3,944
2017	10,508	3515.0	0.335	17,397	3,619

Table 6. Age-specific abundance estimates for male (2011-2017) and female (2014-2017) elk in Kentucky.

	Male				
	Year	Calf	Yearling	2 years old	3+ years old
Age-Specific Abundance	2011	1,406	606	570	8,325
	2012	1,295	552	242	8,921
	2013	984	634	499	5,878
	2014	1,222	537	453	4,196
	2015	888	459	679	3,078
	2016	1,680	900	651	3,288
	2017	1,027	1,473	928	3,068
	Female				
	Year	Calf	Yearling	2 years old	3+ years old
	2014	1,197	729	428	1,477
	2015	870	666	647	1,311
	2016	1,646	826	634	1,324
	2017	1,008	1,361	514	1,130

Table 7. Total annual survival estimates for by sex and age class for the elk population in Kentucky 2011-2017.

Total Survival Estimates							
Male				Female			
Year	Calf	Yearling	2+ years old	Year	Calf	Yearling	2+ years old
2011	0.832	0.832	0.820	2011			
2012	0.829	0.829	0.815	2012			
2013	0.831	0.831	0.809	2013			
2014	0.831	0.831	0.798	2014	0.901	0.872	0.807
2015	0.832	0.832	0.785	2015	0.902	0.855	0.798
2016	0.832	0.832	0.790	2016	0.902	0.864	0.809
2017	0.834	0.832	0.803	2017	0.904	0.888	0.846

Table 8. Period specific and total annual harvest probability estimates for male and female elk in Kentucky 2011-2017.

Harvest Probability Estimates

Male

Bull Archery

Year	Calf	Yearling	2+ years old
2011	0	0.0013	0.0054
2012	0	0.0015	0.0059
2013	0	0.0016	0.0072
2014	0	0.0016	0.0083
2015	0	0.0016	0.0096
2016	0	0.0017	0.0096
2017	0	0.0016	0.0080

Bull Rifle

Year	Calf	Yearling	2+ years old
2011	0	0.0020	0.0149
2012	0	0.0023	0.0164
2013	0	0.0025	0.0241
2014	0	0.0025	0.0320
2015	0	0.0024	0.0413
2016	0	0.0024	0.0374
2017	0	0.0024	0.0294

Either Sex Archery

Year	Calf	Yearling	2+ years old
2011	0.0038	0.0050	0.0029
2012	0.0041	0.0054	0.0029
2013	0.0042	0.0055	0.0053
2014	0.0041	0.0054	0.0093
2015	0.0037	0.0048	0.0141
2016	0.0038	0.0050	0.0127
2017	0.0027	0.0035	0.0053

Cow Rifle

Year	Calf	Yearling	2+ years old
2011	0.004	0	0
2012	0.005	0	0
2013	0.005	0	0
2014	0.005	0	0
2015	0.005	0	0
2016	0.004	0	0
2017	0.003	0	0

Total Annual

Year	Calf	Yearling	2+ years old
2011	0.0078	0.0082	0.0228
2012	0.0085	0.0091	0.0248
2013	0.0091	0.0095	0.0361
2014	0.0090	0.0093	0.0486
2015	0.0079	0.0087	0.0634
2016	0.0077	0.0089	0.0584
2017	0.006	0.007	0.0420

Female

Either Sex Archery

Year	Calf	Yearling	2+ years old
2014	0.0042	0.0109	0.0218
2015	0.0037	0.0096	0.0194
2016	0.0038	0.0100	0.0202
2017	0.0027	0.0071	0.0144

Cow Rifle

Year	Calf	Yearling	2+ years old
2014	0.0052	0.0301	0.0926
2015	0.0045	0.0509	0.1047
2016	0.0042	0.0399	0.0916
2017	0.0033	0.0162	0.0560

Total Annual

Year	Calf	Yearling	2+ years old
2014	0.0092	0.0398	0.1097
2015	0.0080	0.0585	0.1190
2016	0.0079	0.0484	0.1072
2017	0.0060	0.0228	0.0681

Results- 2018 (including both 2017 and 2018 data)

Table 9. Sex-specific and total annual abundance estimates with 95% confidence interval (CI) bounds for the elk population in Kentucky 2011-2018.

Year	Male Abundance	Standard Error	CV of Male Abundance	Upper 95% CI bound	Lower 95% CI bound
2011	9,006	2353.3	0.261	13,619	4,394
2012	9,240	2697.6	0.292	14,527	3,953
2013	6,611	1837.8	0.278	10,213	3,009
2014	5,132	1356.8	0.264	7,791	2,473
2015	4,138	1090.8	0.264	6,276	2,000
2016	5,160	1426.9	0.277	7,957	2,363
2017	4,838	1367.3	0.283	7,518	2,158
2018	5,793	1686.3	0.291	9,098	2,488
Year	**Female Abundance**	**Standard Error**	**CV of Female Abundance**	**Upper 95% CI bound**	**Lower 95% CI bound**
2014	3,057	1394.4	0.456	5,789	0
2015	2,783	1310.6	0.471	5,351	0
2016	3,461	1226.5	0.354	5,865	1,057
2017	2,869	1074.1	0.374	4,975	764
2018	4,296	1141.0	0.266	6,532	2,059
Year	**Total Abundance**	**Standard Error**	**CV of Total Abundance**	**Upper 95% CI bound**	**Lower 95% CI bound**
2014	8,189	2263.8	0.276	12,626	3,751
2015	6,920	1952.6	0.282	10,748	3,093
2016	8,621	2316.9	0.269	13,162	4,080
2017	7,708	2124.0	0.276	11,871	3,545
2018	10,089	2684.7	0.266	15,351	4,827

Table 10. Age-specific abundance estimates for male (2011-2018) and female (2014-2018) elk in Kentucky.

	Male				
	Year	Calf	Yearling	2 years old	3+ years old
Age-Specific Abundance	2011	1,064	449	480	7,014
	2012	981	409	207	7,643
	2013	744	470	422	4,975
	2014	925	398	371	3,439
	2015	672	340	565	2,561
	2016	1,271	666	532	2,690
	2017	776	1,090	690	2,282
	2018	1,418	495	414	3,465
	Female				
	Year	Calf	Yearling	2 years old	3+ years old
	2014	902	518	368	1,268
	2015	655	507	535	1,085
	2016	1,240	604	524	1,094
	2017	759	814	405	892
	2018	1,386	979	490	1,441

Table 11. Total annual survival estimates for by sex and age class for the elk population in Kentucky 2011-2018.

Total Survival Estimates							
Male				Female			
Year	Calf	Yearling	2+ years old	Year	Calf	Yearling	2+ years old
2011	0.816	0.815	0.802	2011			
2012	0.812	0.811	0.798	2012			
2013	0.814	0.814	0.789	2013			
2014	0.814	0.814	0.775	2014	0.898	0.857	0.790
2015	0.816	0.815	0.761	2015	0.900	0.838	0.775
2016	0.816	0.815	0.765	2016	0.900	0.848	0.788
2017	0.818	0.816	0.777	2017	0.902	0.874	0.829
2018	0.82	0.8158	0.78601	2018	0.902	0.884	0.843

Table 12. Period specific and total annual harvest probability estimates for male and female elk in Kentucky 2011-2017.

Harvest Probability Estimates

Male

Bull Archery

Year	Calf	Yearling	2+ years old
2011	0	0.0018	0.0062
2012	0	0.0020	0.0067
2013	0	0.0021	0.0083
2014	0	0.0021	0.0097
2015	0	0.0022	0.0112
2016	0	0.0023	0.0113
2017	0	0.0021	0.0098
2018	0	0.0022	0.0091

Bull Rifle

Year	Calf	Yearling	2+ years old
2011	0	0.0027	0.0177
2012	0	0.0031	0.0192
2013	0	0.0034	0.0286
2014	0	0.0033	0.0391
2015	0	0.0033	0.0498
2016	0	0.0032	0.0458
2017	0	0.0033	0.0396
2018	0	0.0033	0.0322

Either Sex Archery

Year	Calf	Yearling	2+ years old
2011	0.0051	0.0067	0.0036
2012	0.0055	0.0073	0.0035
2013	0.0056	0.0074	0.0065
2014	0.0055	0.0073	0.0119
2015	0.0049	0.0065	0.0174
2016	0.0050	0.0067	0.0162
2017	0.0036	0.0048	0.0083
2018	0.0036	0.0047	0.0055

Cow Rifle

Year	Calf	Yearling	2+ years old
2011	0.006	0	0
2012	0.006	0	0
2013	0.007	0	0
2014	0.007	0	0
2015	0.006	0	0
2016	0.006	0	0
2017	0.004	0	0
2018	0.004	0	0

Total Annual

Year	Calf	Yearling	2+ years old
2011	0.0103	0.0111	0.0271
2012	0.0112	0.0122	0.0289
2013	0.0121	0.0128	0.0426
2014	0.0119	0.0126	0.0593
2015	0.0104	0.0118	0.0761
2016	0.0102	0.0120	0.0714
2017	0.008	0.010	0.0565
2018	0.008	0.010	0.046

Female

Either Sex Archery

Year	Calf	Yearling	2+ years old
2014	0.0055	0.0151	0.0257
2015	0.0049	0.0134	0.0228
2016	0.0051	0.0139	0.0237
2017	0.0036	0.0099	0.0169
2018	0.0036	0.0098	0.0167

Cow Rifle

Year	Calf	Yearling	2+ years old
2014	0.0069	0.0429	0.1080
2015	0.0060	0.0663	0.1276
2016	0.0056	0.0547	0.1120
2017	0.0044	0.0293	0.0726
2018	0.0045	0.0185	0.0572

Total Annual

Year	Calf	Yearling	2+ years old
2014	0.0122	0.0560	0.1277
2015	0.0107	0.0769	0.1438
2016	0.0105	0.0663	0.1298
2017	0.0079	0.0381	0.0864
2018	0.0079	0.0276	0.0715

Results- Comparison

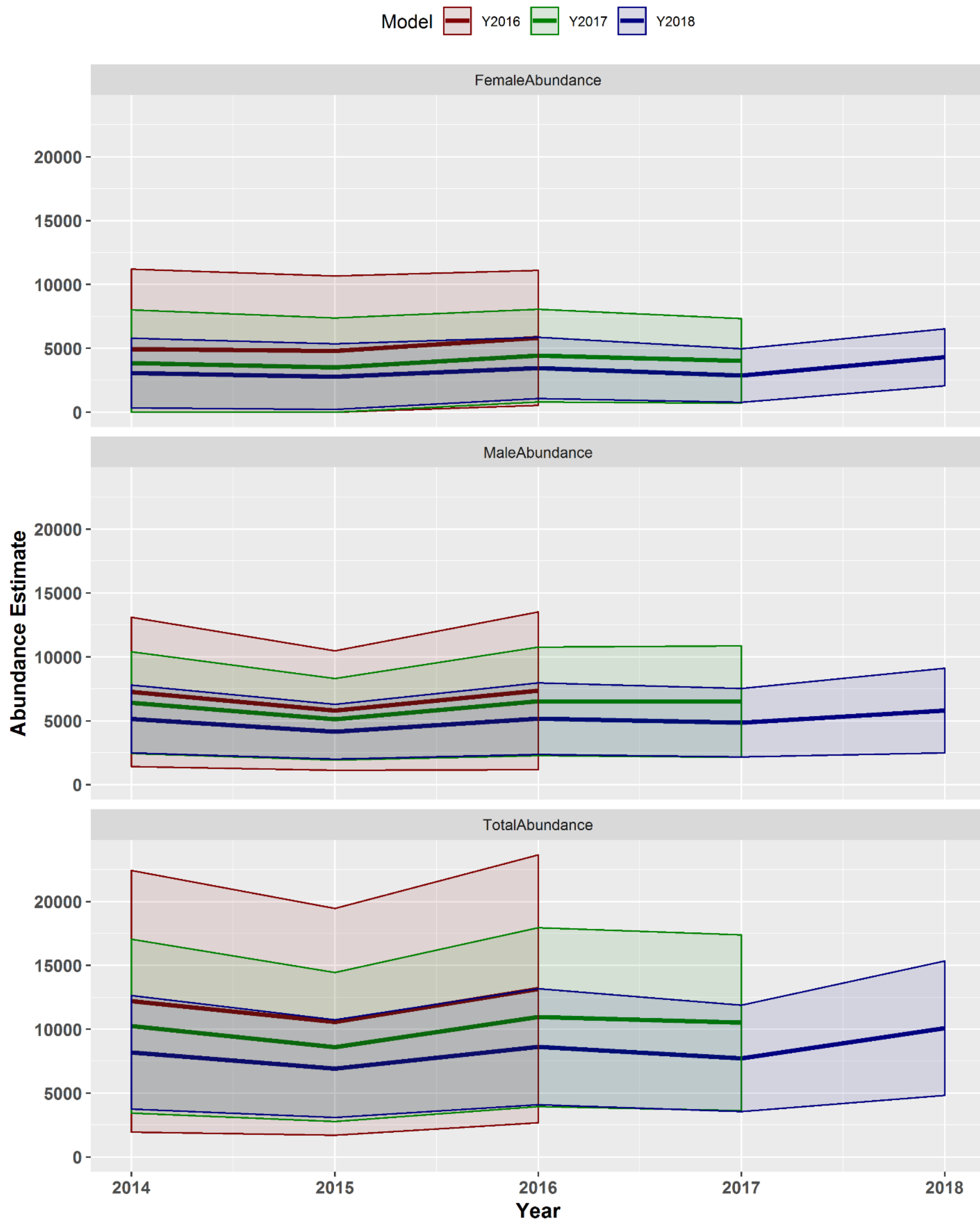

Figure 1. Sex-specific and overall total abundance 2014-2018 and associated 95% confidence intervals, for models with the data outlined above up through 2016 (the original analysis) in red, 2017 in green, and 2018 in blue.

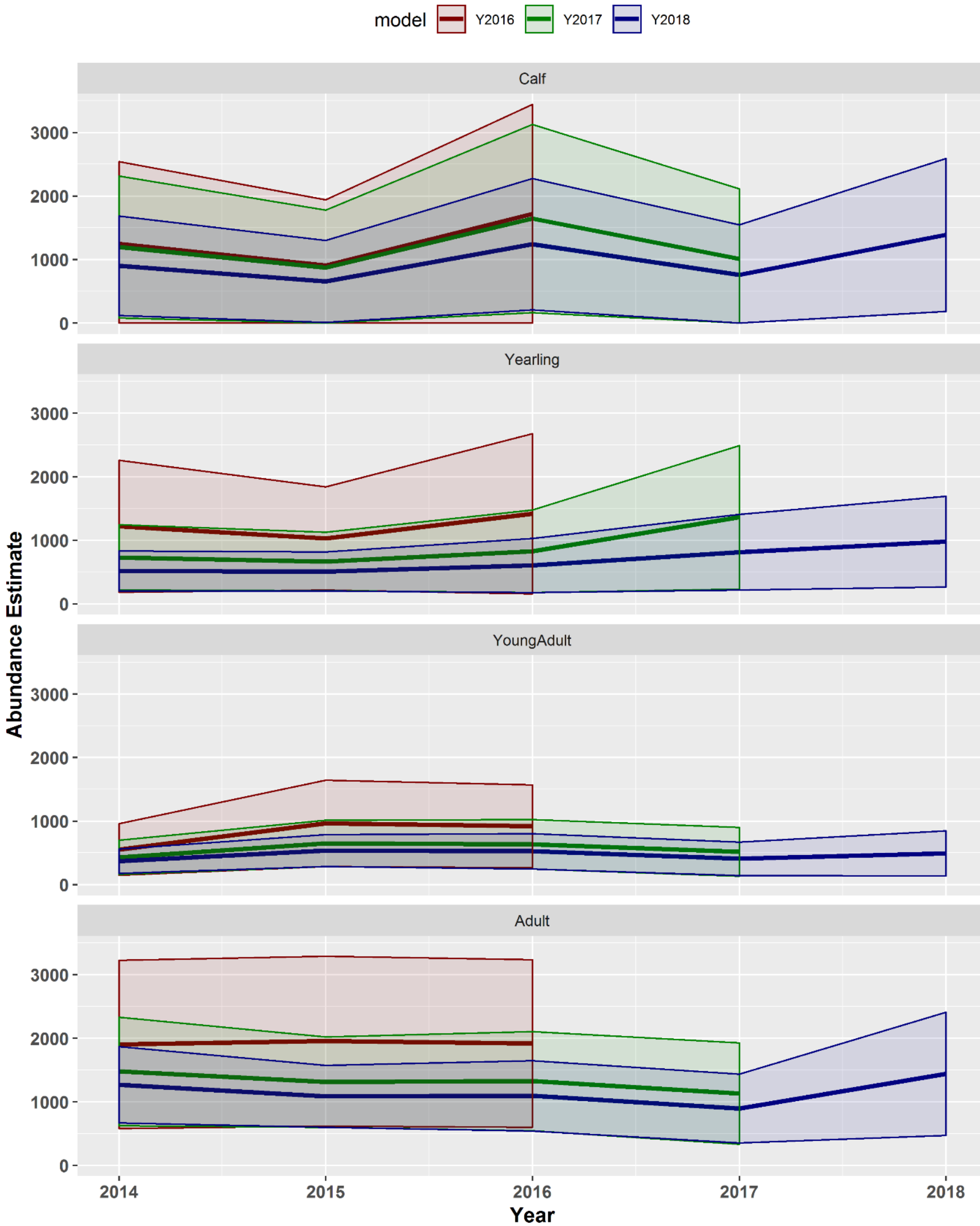

Figure 2. Age-specific female abundance 2014-2018 and associated 95% confidence intervals, for models with the data outlined above up through 2016 (the original analysis) in red, 2017 in green, and 2018 in blue.

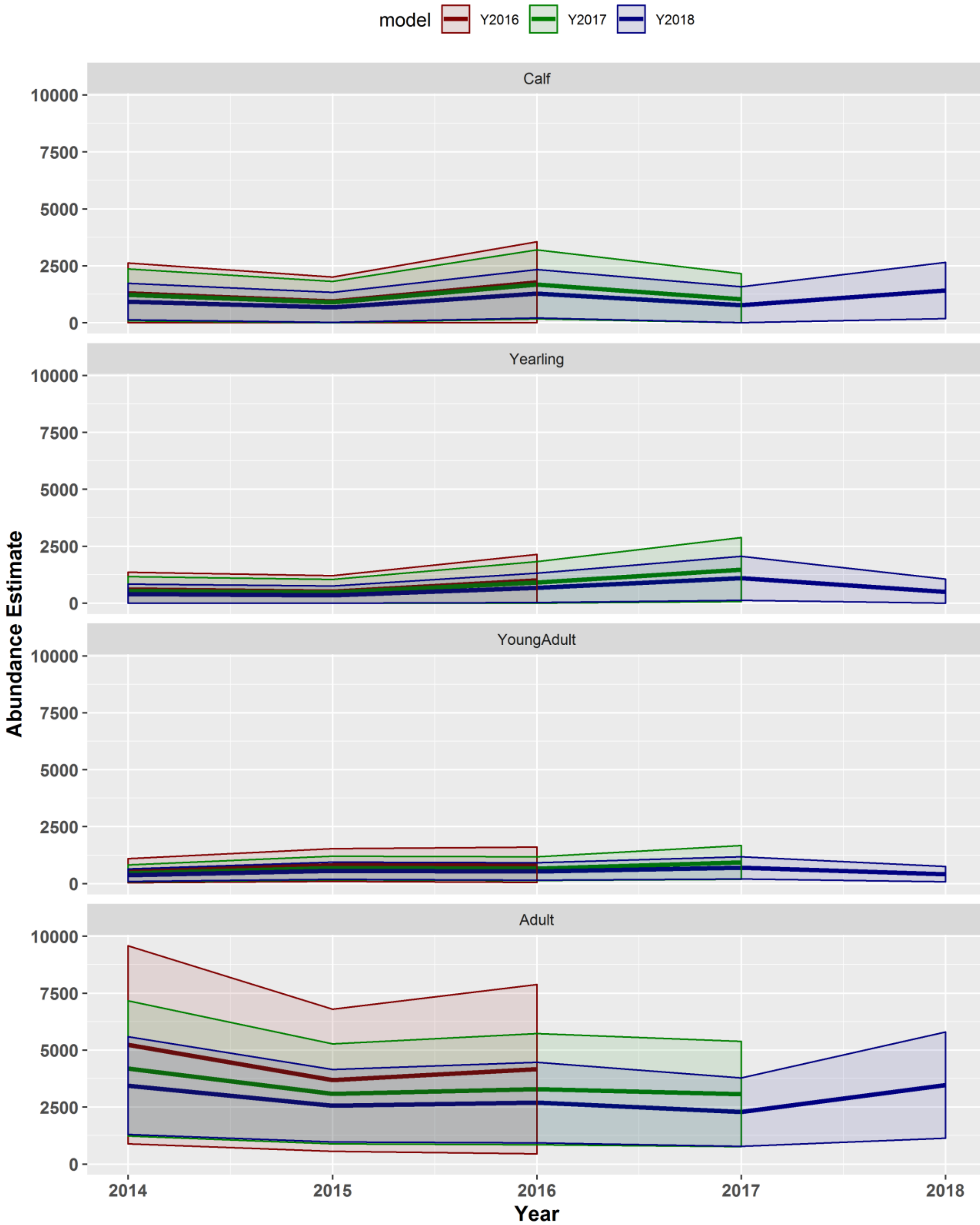

Figure 3. Age-specific male abundance 2014-2018 and associated 95% confidence intervals, models with the data outlined above up through 2016 (the original analysis) in red, 2017 in green, and 2018 in blue.

Discussion

It is important to remember that results presented in 2016 were made from a minimal amount of data and illustrated a proof of concept. As more years of data have been added the parameter estimates have shifted but are still within previously reported confidence intervals (Figure 1). Using the 2015 total abundance estimate to illustrate the change, we can see that in the Y2016 model the estimate was 10,577 (SE=4533.5), in the Y2017 model the estimate was 8,597 (SE=2976.7), and in the Y2018 model the estimate was 6,920 (SE=1952.6). Although this may seem like a substantial change in a parameter point estimate, if we consider the precision of that point estimate we can see that this level of change in point estimate was within one standard error of the original point estimate and thus was reasonably probable. There are no indications in the data that the models have fit drastically differently. The cause of the shift is likely that we have increased the precision of our estimates and thus have a better of idea where in the space of likely abundance estimates from the original model we are more probably in. Over time the point estimates will change less, and we can see the confidence intervals narrowing with just two additional years of data (Figure 3). However, this model update still includes the age-at-harvest information based on collared animals in the first three years for males, and there is a chance that parameter estimates will shift when those are removed.

Recommendations

1. There was no collar data available for 2016. We assume this is an oversight, because very few of the animals alive during the previous analysis were included in the updated collar data we received. Our first recommendation is to take a closer look at the collar data, fully evaluate the time from 2016-2019 and make sure you are getting the most out of the information you have available. This assessment should include an evaluation of why there was a 40% harvest mortality in the 2018 collar data for adult males.
2. In the previous report we recommended collection of an additional three years of data and the revaluation of auxiliary data collection strategy and precision goals. Based on this updated information our recommendation remains the same: collect another year of data and perform a formal evaluation (related to recommendation 1).
3. We recommend a sensitivity analysis removing the collar only age at harvest data, one year at a time and evaluating model stability of these changes. With the 2019 data there will be enough data to run the model without the collar age at harvest data and do a single year of stability analysis.