Population trends and conservation status of elephants in Botswana and the Kavango Zambezi Transfrontier Conservation Area

A review of elephant aerial surveys, 2010 - 2022

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An Elephants Without Borders Technical Report

Scott Schlossberg[1] & Michael Chase[1*]

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[1] Elephants Without Borders, P.O. Box 682, Kasane, Botswana

This report was compiled by Elephants Without Borders.

*Corresponding author email: er@info.bw

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Executive Summary

In 2022, an aerial survey for African savanna elephants (*Loxodonta africana*) was conducted over the Kavango-Zambezi Transfrontier Conservation Area (KAZA) in southern Africa. KAZA is a 520,000-km^2 network of protected areas in Angola, Botswana, Namibia, Zambia, and Zimbabwe. The aerial survey found that KAZA holds ~228,000 elephants, confirming that this is the world's largest population of savanna elephants and a critical stronghold for this endangered species.

In this report, we attempt to place the KAZA results in context by examining trends in elephant populations since the last set of KAZA-wide elephant surveys in 2014-2015. We also report new data on elephant poaching in Botswana.

We were able to compare numbers of elephants on the KAZA survey with 2014-2015 surveys in Angola, Botswana, Namibia, and Zimbabwe. Overall, numbers of elephants did not change significantly between 2014-2015 and 2022, with an estimated growth rate of 1.2% per year. Carcass ratios, an index of elephant mortality rates, did increase significantly over that time period, growing from 8% to 11% and potentially indicating unsustainable mortality rates.

We also examined recent population trends by individual country. In northern Botswana, overall elephant populations have not changed significantly since 2010. Between 2018, the date of the most recent survey prior to the KAZA survey, and 2022, elephant numbers have generally increased in national parks and other protected areas, especially in the Okavango Delta. Numbers have generally decreased in pastoral and agricultural areas. In the Okavango Panhandle, elephant populations have been roughly stable since 2010, in contrast to the Botswana government's claim of 7.6% growth per year[7].

Elephant trophy hunting in Botswana resumed in 2019. Between 2018 and 2022, numbers of elephants decreased by 25% in areas that were open to hunting and increased by 28% in areas where hunting is not allowed. If these trends continue, the ability of Botswana to produce trophy-quality elephants in hunting areas may be in question.

Carcass ratios have been steadily increasing in Botswana since 2010 and were near 12% in 2022, potentially indicating high mortality rates. Fresh/recent carcass ratios in northern Botswana were unchanged between 2018 and 2022. The 2018 survey was conducted during a period of high poaching activity, suggesting that mortality rates at the time of the 2022 survey were still high.

Between October 2023 and February 2024, we located 56 poached elephant carcasses in northern Botswana, mainly west of Chobe NP. Many of these carcasses were in an area that we previously identified as a poaching "hotspot" in 2018-2019. The area monitored for poaching in 2023-2024 is a small fraction of the total elephant range in northern Botswana, so the 56 carcasses found could indicate a wider problem with poaching.

In southeast Angola, the elephant population increased non-significantly between 2015 and 2022. But elephant populations in the western half of the Angola study area essentially disappeared over that time, while estimated numbers increased in the east, near the Kwando River. Carcass ratios have decreased since 2015 but remain very high at 16%. The growing population estimates are contradicted by the high carcass numbers, suggesting that elephant populations are not healthy in Angola. We suspect that elephants are moving into Angola from

the larger populations in Namibia and Botswana but are experiencing high mortality rates in Angola, possibly due to poaching.

In Zimbabwe, elephant numbers did not change significantly between 2014 and 2022 in either the Sebungwe or north-west Matabeleland regions. Patterns of change by stratum were generally heterogeneous. Numbers were roughly unchanged over this time in Hwange NP. Two areas just outside the park saw large increases in numbers. Carcass ratios decreased in Zimbabwe since 2014, significantly in Sebungwe and non-significantly in north-west Matabeleland.

In Namibia, between 2015 and 2022, the elephant population decreased slightly and non-significantly in the Kavango-Zambezi region and increased non-significantly in Khaudum Nyae-Nyae. Notably, numbers of elephants declined along the Angola and Zambia borders in Kavango-Zambezi.

Overall, KAZA's elephants generally have stable or slowly increasing populations. Rising carcass ratios in some parts of KAZA and the fact that populations are no longer growing rapidly, if at all, mean that continued monitoring of KAZA's elephant population is critical. Multi-country surveys of KAZA, like the ones in 2014-2015 and 2022, should be conducted regularly to monitor the population and detect any negative changes before they can advance too far. Specifically, high carcass ratios and reports of poaching in Angola and Botswana mean that these populations should be given high priority for future monitoring.

Introduction

In 2022, the governments of Angola, Botswana, Namibia, Zambia, and Zimbabwe collaborated with non-government partners to conduct an aerial survey for elephants and other wildlife in the Kavango-Zambezi Transfrontier Conservation Area or KAZA[1]. KAZA is a 520,000-km^2 network of protected areas and other lands where the five partner countries have agreed to cooperatively manage and conserve biodiversity and promote economic activity[2].

For the endangered African savanna elephant (*Loxodonta africana*), KAZA is critically important. Elephants freely cross international borders in much of KAZA, making a survey of the entire area an ideal way to estimate populations[3]. The 2022 survey found that 227,900 elephants live in KAZA, meaning that KAZA holds over half of all remaining savanna elephants[1,4].

The KAZA survey came at an opportune moment for elephant conservation. The last large-scale survey of savanna elephants, the Great Elephant Census (GEC), led by Elephants Without Borders, took place in 2014-2015. The GEC revealed that continental elephant numbers had decreased by 30% in just 10 years, largely due to poaching[5].

Since 2015, controversies have arisen regarding management of KAZA's elephants. After a five-year ban on hunting, Botswana resumed elephant trophy hunting in 2019[6]. The government justified this decision, in part, based on purported rapid growth in elephant populations and human-elephant conflict[7]. More recently, drought and bacterial outbreaks have been implicated in mass elephant deaths in Zimbabwe and Botswana[8,9]. Numerous incidents of poaching continue to be reported in some of the KAZA countries. At the same time, the governments of both Zimbabwe and Botswana, claiming that elephants are overpopulated there, have called for exporting elephants to other countries[10,11]. In 2019, Botswana, Namibia, and Zimbabwe unsuccessfully petitioned CITES for permission to sell ivory stocks as well as hides, hair, and other products derived from elephants[12].

Addressing the complicated issues over elephant management requires the best possible data on elephant populations. The 2022 KAZA survey is a good start in this direction, but the report summarizing the survey results did little to address the specific issues noted above. Answering these questions—how and where are populations changing within countries? are large elephant populations in Zimbabwe and Botswana still growing? how are elephant populations faring where hunting is occurring? is poaching affecting elephant populations in KAZA?—will require a detailed analysis of elephant population data in specific regions. The report on the 2022 KAZA survey included only a very cursory analysis of trends, comparing elephant numbers by country or region with previous surveys[1]. For Botswana, Angola, Namibia, and Zambia, the 2022 survey covered a different area than previous surveys, making simple comparisons with previous surveys invalid[13]. Also, region- and country-level summaries are not sufficient to answer most of the questions above. Managers need accurate and detailed information about how and where elephant populations are changing to effectively manage KAZA's 227,900 elephants.

In this report, we use localized data on elephant populations to assess recent changes and trends in KAZA. The report summarizing the KAZA survey described the patterns observed in 2022. Our focus here is on changes in elephant populations. We compared the 2022 KAZA results with previous surveys at the stratum and regional levels to help address some of the growing controversies over elephants in KAZA. In addition, we present our recent observations of poaching in northern Botswana, following up on our 2019 paper on this subject[11].

Methods

Study area

The study area for the report was the area surveyed in 2022 in Angola, Botswana, Namibia, and Zimbabwe (Fig. 1). The Zambia survey area was excluded from analysis, as discussed below.

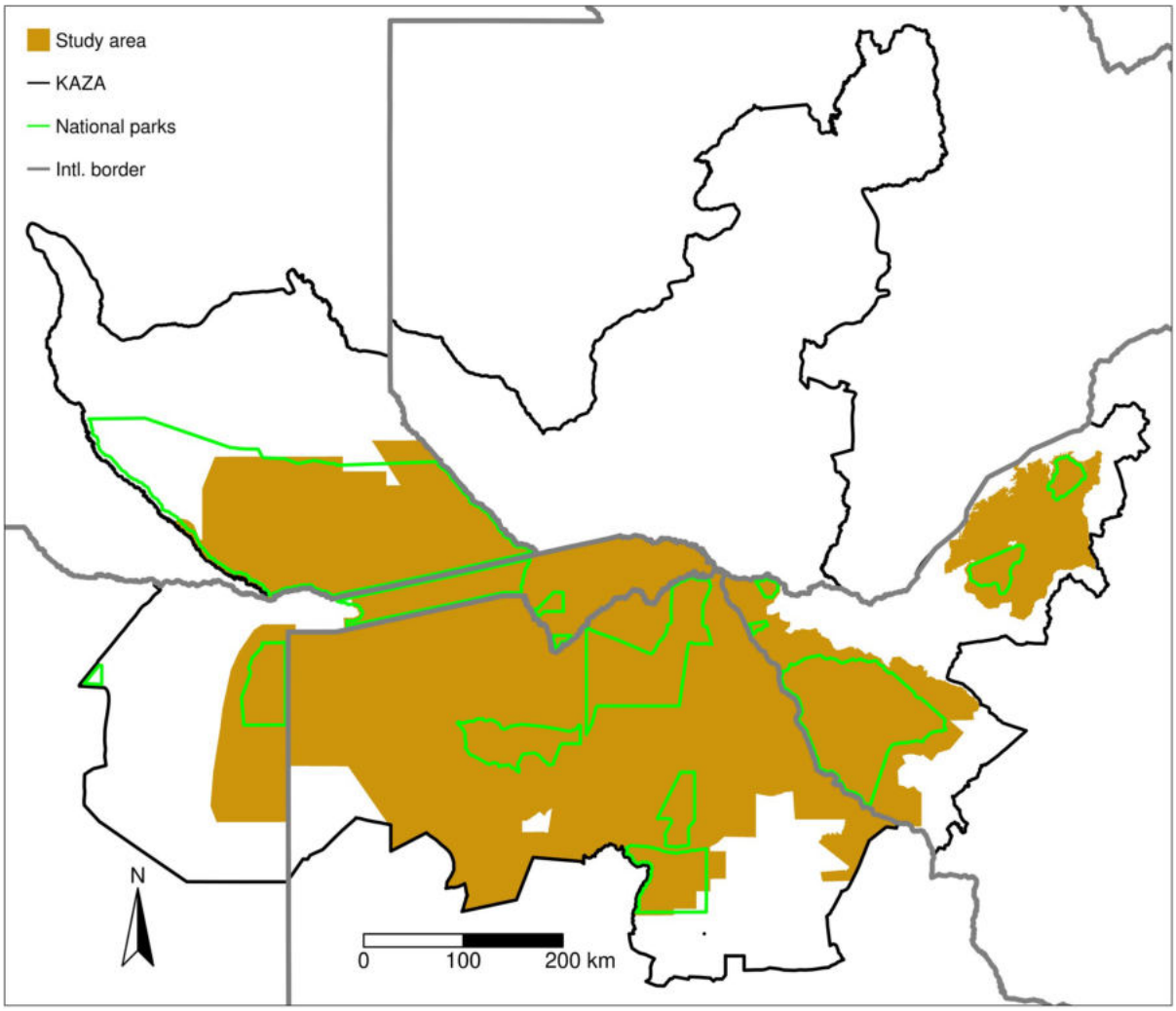

Figure 1. Study area in southern Africa and protected areas (green lines). Zambia sites, not shown, were not included in this report.

To analyze trends and changes in elephant populations, we compared estimates from the 2022 survey with estimates from earlier surveys. For each comparison, we used GIS software to ensure that study areas on previous surveys covered the area surveyed in 2022. Comparisons across years are only valid if the areas surveyed are identical or nearly so. Zimbabwe strata from 2022 were largely unchanged from previous surveys in 2014. For the Khaudum Nyae-Nyae region in Namibia, the Nyae-Nyae Conservancy was stratified differently in 2015 and 2022[10,13]. We merged the seven strata in the conservancy from the 2015 surveys into a single stratum. The 2022 survey divided Nyae-Nyae into five strata. We merged these five strata to

produce identical maps across years. For Angola, we had to recalculate 2015 estimates from the Cuito stratum, in the southwestern part of the study area, because the 2015 survey extended outside the boundaries of KAZA[14].

For Botswana, stratification for the 2022 survey deviated substantially from the 2018[15], 2014[16], and 2010[17] surveys. We requested the raw data from the KAZA survey from the Botswana Department of Wildlife and National Parks (DWNP) multiple times but did not receive a response. To compare the 2022 results against previous surveys, we reanalyzed the older survey data using the 2022 stratum boundaries. Where a 2022 stratum boundary split an earlier stratum, we re-stratified the earlier survey by splitting strata, transects, and observations to match the 2022 boundaries. We then recalculated population estimates using standard sample transect methods[18]. The re-stratification may add some error to the pre-2022 estimates, but the new estimates remain unbiased. See Appendix 1 for Botswana study area boundaries for the 2018-2022 and 2010-2022 analyses.

After examining the changes to the Botswana strata between 2018 and 2022, we are unable to understand why so many stratum boundaries were changed for the 2022 survey. In some cases, areas that we had previously divided because they had strong gradients in elephant density were merged for 2022. These alterations made assessing changes in elephant populations more complicated (see Discussion for more on this topic).

Data sources

Data sources used in this report are listed in Table 1. All surveys were aerial surveys, and the primary unit of analysis was the stratum, a contiguous area averaging 1,671 ± SD of 1,178 km^2 for the 2022 survey (with transfrontier strata split by country). For the surveys in Table 1, the vast majority of strata utilized systematic transect sampling with a range of sampling intensities. A few strata in Botswana prior to 2022 were sampled with total counts, and two strata in Sebungwe utilized randomized block sampling in both 2014 and 2022. All surveys in Table 1 were conducted during the dry season, when animals and carcasses are easiest to see.

Of course, there are numerous surveys from prior to 2014-2015 (or 2010 in the case of Botswana). The paper summarizing the Great Elephant Census in 2014-2015 included a trend analysis for 1995 to 2015[5]. Here, we were more interested in subsequent trends, between 2014-2015 and 2022. For Botswana, we went back to 2010 to incorporate all of the high-intensity surveys that Elephants Without Borders has conducted there.

Because strata in the Kafue region of Zambia were changed substantially between the 2015 and 2022 surveys, we did not analyze change in Kafue populations for this report. Also, we excluded the Sioma Ngwezi region from analyses because the official 2022 survey produced an estimate of 0 while a reconnaissance flight north the survey area found a large herd of 508 elephants[1]. It is unclear what population estimate should be used for this region, so we excluded this small area from the analysis. If included in the study, the 508 elephants would represent just 0.2% of the total KAZA population in 2022.

The 2015 Namibia survey had some inconsistencies in estimated number of carcasses[13], and in the past, Namibia has sometimes removed elephant carcasses from the field[1]. Thus, we did not analyze carcass ratios for Namibia, nor did we include Namibia results when carcass ratios were analyzed for all of KAZA.

Table 1. Survey data used in this report. Area refers to the area of the original survey and not necessarily the area of overlap between the 2022 and earlier study areas as used in this report.

Country	Region	Year	Dates	Area (km^2)	Sampling Intensity	Citation
Angola	Luengue-Luiana	2015	12 Oct. – 12 Nov.	37,929	8%	[14]
		2022	18 Oct. – 24 Oct.	32,869	4%	[1]
Botswana	Northern Botswana	2010	01 July – 13 Dec.	73,478	14%	[17]
		2014	29 July – 22 Oct.	98,425	12%	[16]
		2018	03 July – 03 Oct.	103,662	13%	[15]
		2022	10 Sep. – 11 Oct.	123,664	6%	[1]
Namibia	Kavango Zambezi	2015	Sep. - Oct.	17,474	13%	[13]
		2022	01 Oct. – 10 Oct.	18,057	9%	[1]
	Khaudum Nyae-Nyae	2015	Oct.	12,851	9%	[13]
		2022	11 Oct. – 15 Oct.	18,305	6%	[1]
Zimbabwe	North-west Matabeleland	2014	07 Oct. – 23 Oct.	24,959	8%	[5]
		2022	30 Aug. – 09 Sept.	25,047	9%	[1]
	Sebungwe	2014	12 July – 28 Sept.	15,227	13%	[5]
		2022	22 Aug. – 09 Sept.	15,176	11%	[1]

Analyses

For Angola, Botswana, Namibia, and Zimbabwe, we analyzed elephant population change at the stratum level. For stratum-level comparisons, wherever possible, we used population estimates and their variances from the original survey source in Table 1. As noted above, for some strata we had to recalculate estimates on pre-2022 surveys to fit altered stratum boundaries.

We also analyzed change in elephant populations at the level of region ("superstratum" in the 2022 KAZA survey report; "ecosystem" in the GEC paper) and for all of KAZA, with the exceptions noted above. For these larger-scale comparisons, we calculated the regional population estimate as the sum of the stratum estimates. The variance of a regional estimate was the sum of the stratum variances.

We used Z-tests to compare two population estimates or carcass ratios for a given stratum, region, or larger area between surveys. For Botswana, our time series included four survey estimates going back to 2010. To calculate instantaneous population growth rates (r) over this time period, we used the diffusion method[19].

We calculated carcass ratios as

$$ratio = \frac{[est.\ \ carcasses]}{[est.\ \ carcasses] + [est.\ \ live\ \ elephants]} \cdot 100\%$$

so that the carcass ratio is the percentage of all live and dead elephants that were dead. Carcass ratios are an index of elephant mortality rates. Ratios ≥8% typically indicate a declining elephant population[20]. The variance (V) of a carcass ratio was calculated as:

$$V(y/x)=(\mu_y/\mu_x)^2\left[\sigma_y^2/\mu_y^2+\sigma_x^2/\mu_x^2-2COV(y,x)/(\mu_y\mu_x)\right]$$

where μ_y and μ_x are the estimated numbers of carcasses and carcasses plus live elephants respectively, and σ^2 are variances of those estimates[21]. Because carcass ratios varied widely by stratum in all years and regions, we assumed no covariance between carcass and elephant numbers. If the covariance is positive (more carcasses in areas with more elephants), then this assumption would result in our overestimating variances, making tests of change in carcass ratios conservative.

Because of our interest in Botswana's elephants, we conducted several additional analyses on the Botswana data. To understand how hunting might be affecting elephant populations or how hunting might be affected by elephant population dynamics, we calculated changes in elephant populations between 2018 and 2022 in strata with and without hunting. For this analysis, we excluded 2022 strata that were partly open to hunting. Strata with hunting had to have hunting in at least 90% of their area open to hunting, and likewise for non-hunting strata. We summed the population estimates between the hunting and non-hunting areas and compared totals across years with Z tests.

To look for evidence of recent poaching or other mortality sources in Botswana, we compared estimated numbers of fresh/recent carcasses between 2018 and 2022 by stratum with Z tests.

We conducted a separate trend analysis for the Okavango Panhandle region, including the 2022 NG11, NG12, and NG13 strata. Elephant populations in this area have been controversial due to human-elephant conflict and reported exponential growth in elephant numbers[22]. We note that the strata boundaries used on the 2022 KAZA survey forced us to exclude the northeast portion of the NG13 Controlled Hunting Area (CHA) and the southwestern corner of NG12. So, our overall population estimates may not be an exact match for previous estimates that included the full CHAs. Our study area, however, includes the vast majority of the Okavango Panhandle.

The government of Botswana has claimed that the population is growing at 6% per year[7]. To test whether or not such growth rates are supported by survey data, we used simulations. For the 2010-2022 study area, we took the 2010 population estimate and projected it forward under exponential growth at r values of 0.01-0.06 year^{-1}. We then used Z tests to compare the projected population estimates against the 2022 estimate. For the projected estimate, we assumed a constant coefficient of variation (CV), so the SE for the projected 2010 value was $(1+r)^{12}\cdot SE_{2010}$. We can reject any r value for which the difference, by Z test, between the actual 2022 estimate and the projected value from 2010 is significant at $P \leq 0.05$. We also conducted the same analysis for the 2018-2022 study area, projecting populations for 4 years.

Results

Botswana

Trends, 2010-2022

Overall, elephant numbers were relatively stable in northern Botswana between 2010 and 2022 (Fig. 2). Rates of population growth over this period were not significantly different from 0 for all elephants (r = -0.003 ± 0.02, P = 0.88), breeding herds (-0.003 ± 0.02, P = 0.92), and bulls (0.001 ± 0.06, P = 0.99). In Fig. 2, none of the survey-to-survey changes in total elephant numbers were significant (all P > 0.06 via Z tests). For breeding herds, the decrease from 2010 to 2014 was significant (P < 0.001) but the other changes were not (all P > 0.1). For bulls, the population did not change significantly between 2018 and 2022 (P = 0.63) while the earlier inter-survey changes were significant (P < 0.001).

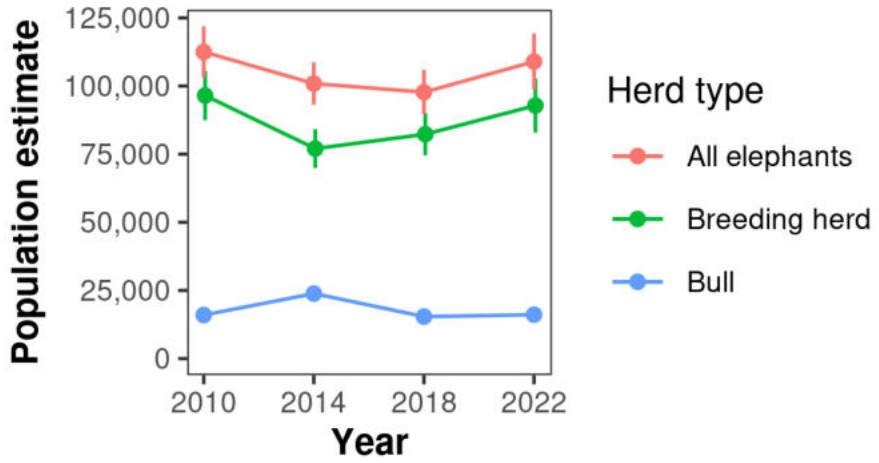

Figure 2. Changes in estimated elephant population size (±1 SE), northern Botswana, 2010-2022.

Carcass ratios increased substantially between 2010 and 2022 in northern Botswana (Fig. 3). Even if we ignore the 2010 estimate, which may have been biased low due to a wider, 500-m survey strip in some strata, the changes between 2014 and 2022 are significant for all carcasses (2014 vs 2018: Z = 3.32, P < 0.001; 2018 vs. 2022: Z = 3.83, P < 0.001). For fresh/recent carcass ratios, the increase between 2014 and 2018 was significant (Z = 6.60, P < 0.001) while fresh/recent ratios were essentially unchanged between 2018 and 2022 (Z = 0.04, P = 0.97).

Recent changes, 2018-2022

To get a more detailed picture of recent changes in elephant populations, we looked at differences between 2018 and 2022. The study area in common for these two surveys is larger than for the 2010-2022 comparison above and includes 96% of the 2022 estimated elephant population in northern Botswana (Appendix 1).

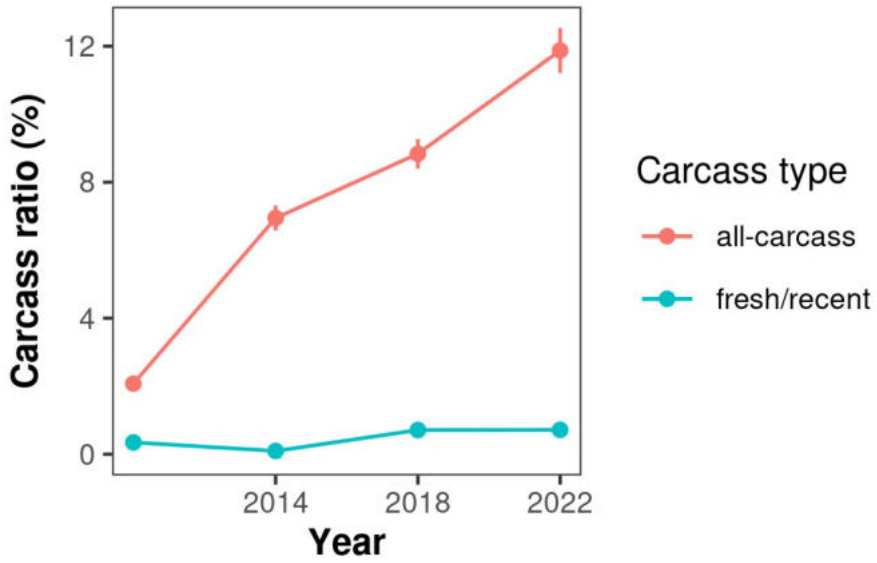

Figure 3. Changes in elephant carcass ratios (±1 SE), northern Botswana, 2010-2022.

Overall, elephant populations increased by 6,357 ± 7,584 elephants between 2018 and 2022, which was not statistically significant (Table 2). This represents a population growth rate of 0.013 ± 0.015 or 1.3% per year. Likewise, numbers of bulls and breeding herds did not change significantly between 2018 and 2022.

Table 2. Change in elephant populations between 2018 and 2022, northern Botswana.

	2022 survey		2018 survey		2018 to 2022 change			
Herd type	**Population estimate**	**SE**	**Population estimate**	**SE**	**Change in estimate**	**SE of change**	**Z**	**P**
Elephant	126,637	5,856	120,280	4,820	6,357	7,584	0.84	0.40
Breeding herd	106,580	5,572	101,118	4,601	5,462	7,227	0.76	0.45
Bull	20,058	1,154	19,162	1,038	896	1,552	0.58	0.56

Though elephant populations changed relatively little overall, mapping changes by stratum revealed substantial geographic variation in population dynamics. Populations were generally stable or increased recently in Chobe NP, protected areas in the Okavango Delta, and in the Chobe Riverfront area (Fig. 4). Elephant numbers declined in the Okavango Panhandle and in southeastern parts of the study area, especially in these CHAs: NG 42, 43, 47 and 49; CT 1, 2, 5, and 6; and CH 7, 8, 11, and 12. In the southeast, numbers increased in CH4 and CH7. Changes in artificial waterholes may have influenced these dry-season results. New waterholes have recently been placed in CH4 and CH7. Older waterholes formerly used by elephants are no longer functioning in CT 1, 2, and 3. Given the magnitudes of the changes in population over a 4-year period, the changes in Fig. 4 are almost certainly due to movements of elephants.

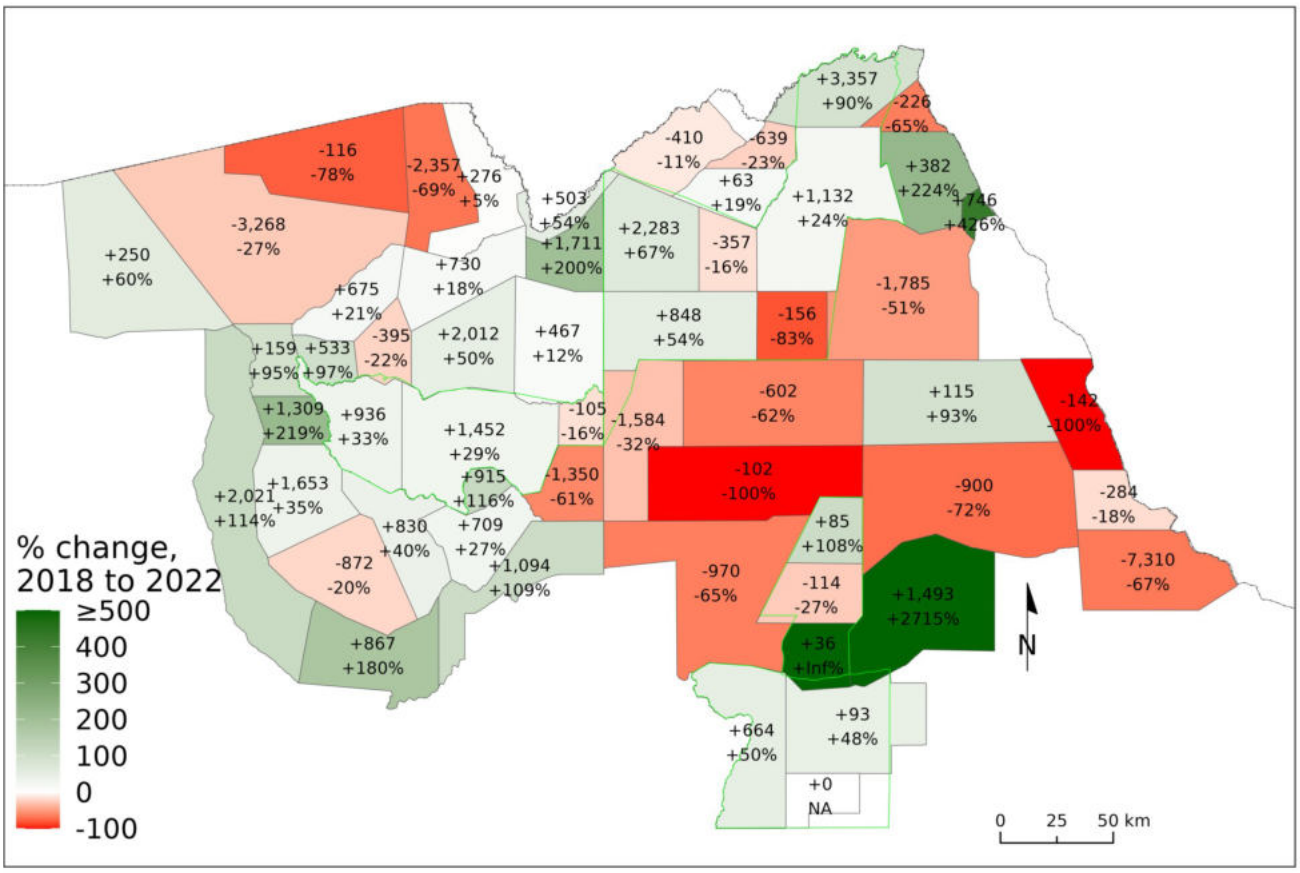

Figure 4. Change in elephant populations between 2018 and 2022, northern Botswana. Upper number in each stratum is the net change in estimates. Lower number and shading indicate percentage change.

For the 2018-2022 study area, carcass ratios for all carcass types combined increased significantly between 2018 and 2022, while fresh-carcass ratios were similar between years (Table 3). One possible explanation for the change is higher detection probability in 2022 due to that survey using a smaller strip width than the 2018 study. The changes in ratio by stratum, however, show geographic patterns suggesting that these changes are meaningful (Fig. 5). Carcass ratios and carcass numbers (not shown) increased the most in the southeastern part of the study area where elephant numbers had also decreased (Fig. 5). Ratios were generally lower or unchanged in Chobe NP, Moremi Game Reserve (GR), and the wildlife areas used for non-consumptive tourism.

Table 3. Carcass ratios in 2018 and 2022, northern Botswana.

	2022 ratios		2018 ratios		2018 to 2022 change			
Ratio type	**Ratio (%)**	**SE (%)**	**Ratio (%)**	**SE (%)**	**Diff. (%)**	**SE (%)**	**Z**	**P**
Fresh/recent	0.70	0.09	0.68	0.08	+0.01	0.12	0.11	0.91
All carcasses	12.4	0.7	8.2	0.4	+4.3	0.8	5.66	<0.001

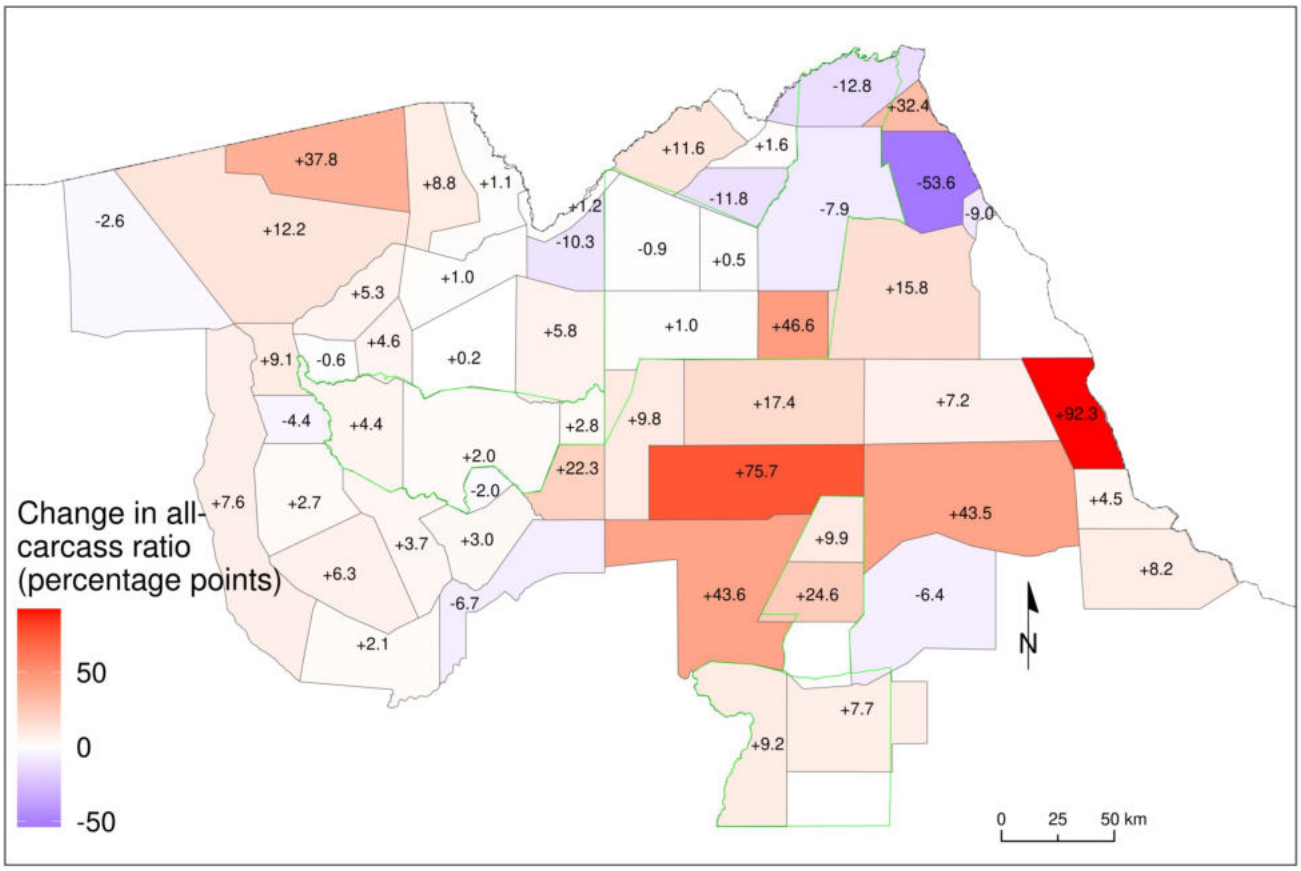

Figure 5. Change in all-carcass ratios (carcass estimates as a percentage of live elephant + carcass estimates), northern Botswana, 2018-2022.

As a general rule, carcass ratios >8% are a sign of an elephant population where mortality may be higher than birth rates, putting a population at risk[20]. Using the 2022 survey, 63% of the Botswana elephant population is living in strata where the carcass ratio exceeds 8% (Fig. 6: the two darkest shades of red indicate ratios >8%). This includes many of the outlying portions of the study area, including the Ngamiland strata west and north of the Okavango Delta, and most of the southeastern part of the study area.

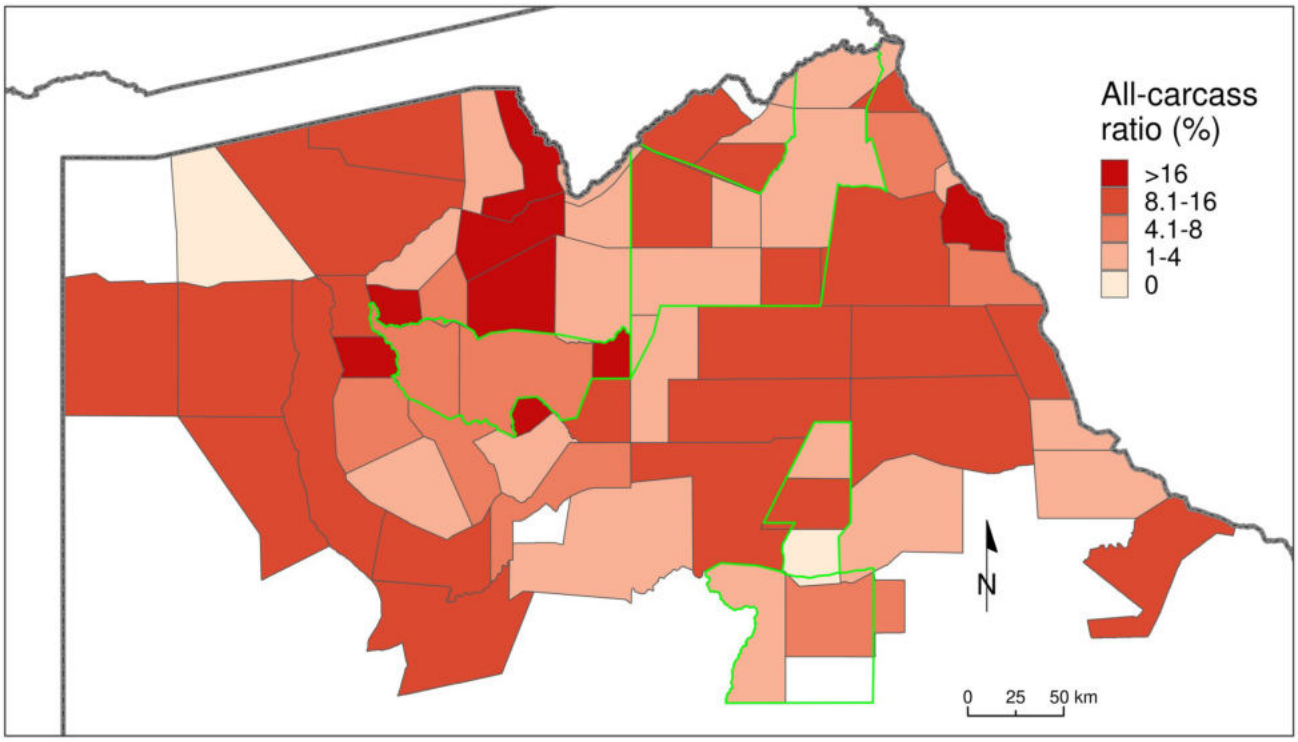

Figure 6. Carcass ratios (for all carcasses) in Botswana on the 2022 aerial survey.

As another way to gauge the health of Botswana's elephant population, we looked at changes in numbers of fresh/recent carcasses. In 2018, we found high numbers of fresh carcasses in several strata. Further ground examination of these carcasses revealed that most had been poached, and we identified several poaching "hotspots" across northern Botswana[11,15]. Comparing the 2018 and 2022 surveys, we found a mix of increases and decreases in numbers of fresh/recent carcasses (Fig. 7). In several areas where we found poaching in 2018, including the Okavango Panhandle and the Khwai area, numbers of fresh/recent carcasses were lower in 2022. At the same time, 2022 saw large increases in fresh carcass numbers along the Namibia Border near the Kwando and Chobe Rivers and in the Savuti region of Chobe NP. According to the KAZA survey report, carcasses found in this area in 2022 were examined by the Botswana Department of Wildlife and National Parks and found to have their tusks intact. As discussed below, however, we have found dozens of poached elephant carcasses recently in some of these areas (see *Poaching*, below).

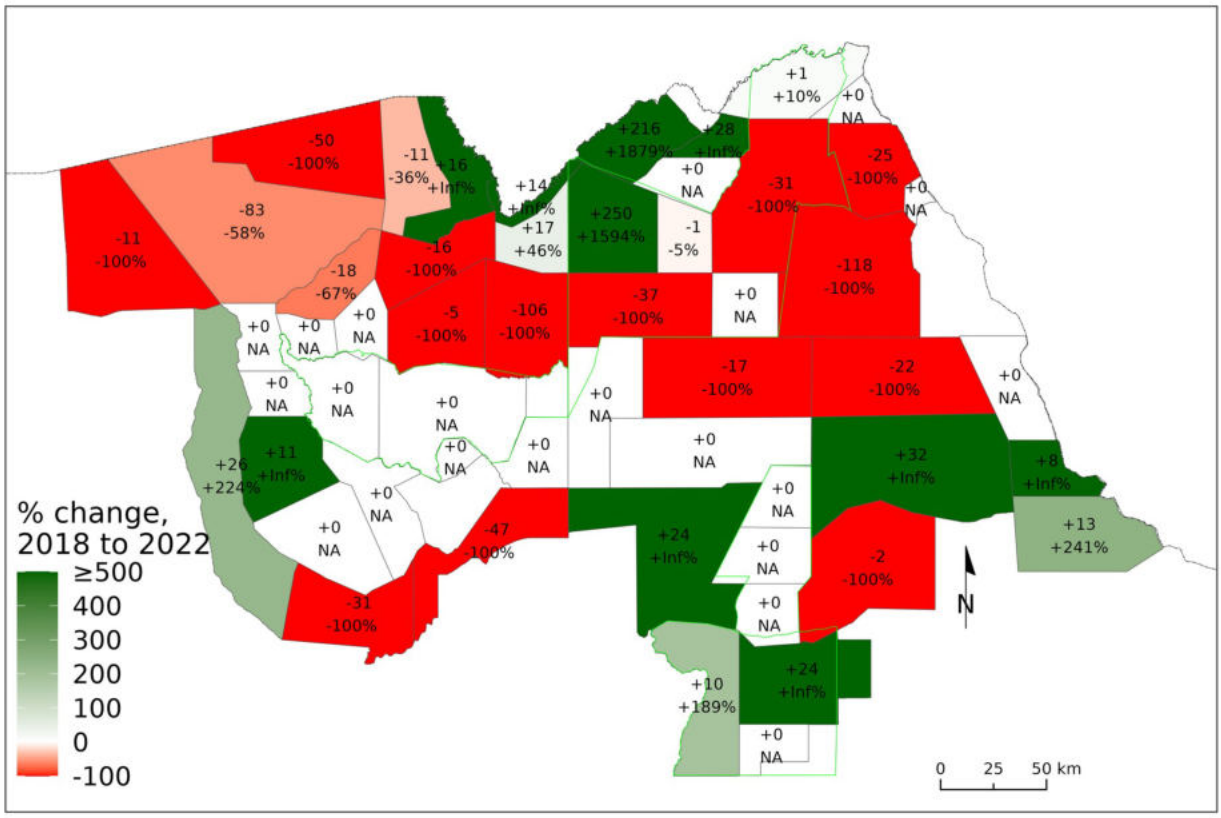

Figure 7. Change in fresh/recent carcass ratios between 2018 and 2022, northern Botswana. Upper number is change in estimate. Lower number is percentage change.

Hunting

In 2019, elephant trophy hunting resumed in Botswana after a five-year moratorium. Hunting occurs in numerous CHAs throughout the elephant's range in northern Botswana (Fig. 8). Hunting is not permitted in national parks, game reserves, and wildlife management areas designated primarily for eco-tourism.

To better understand the impact and sustainability of elephant hunting in Botswana, we looked at recent population changes in strata that were open or closed to hunting. Between 2018 and 2022, overall elephant numbers increased significantly in areas without hunting (Fig. 9; $Z = 3.19$, $P = 0.001$) and decreased significantly in areas with hunting ($Z = -2.07$, $P = 0.04$). Patterns were similar for breeding herds and bulls separately, though the changes between surveys were not significant for bulls. As in Fig. 4 above, the changes in Fig. 9 were most likely due to movements between strata.

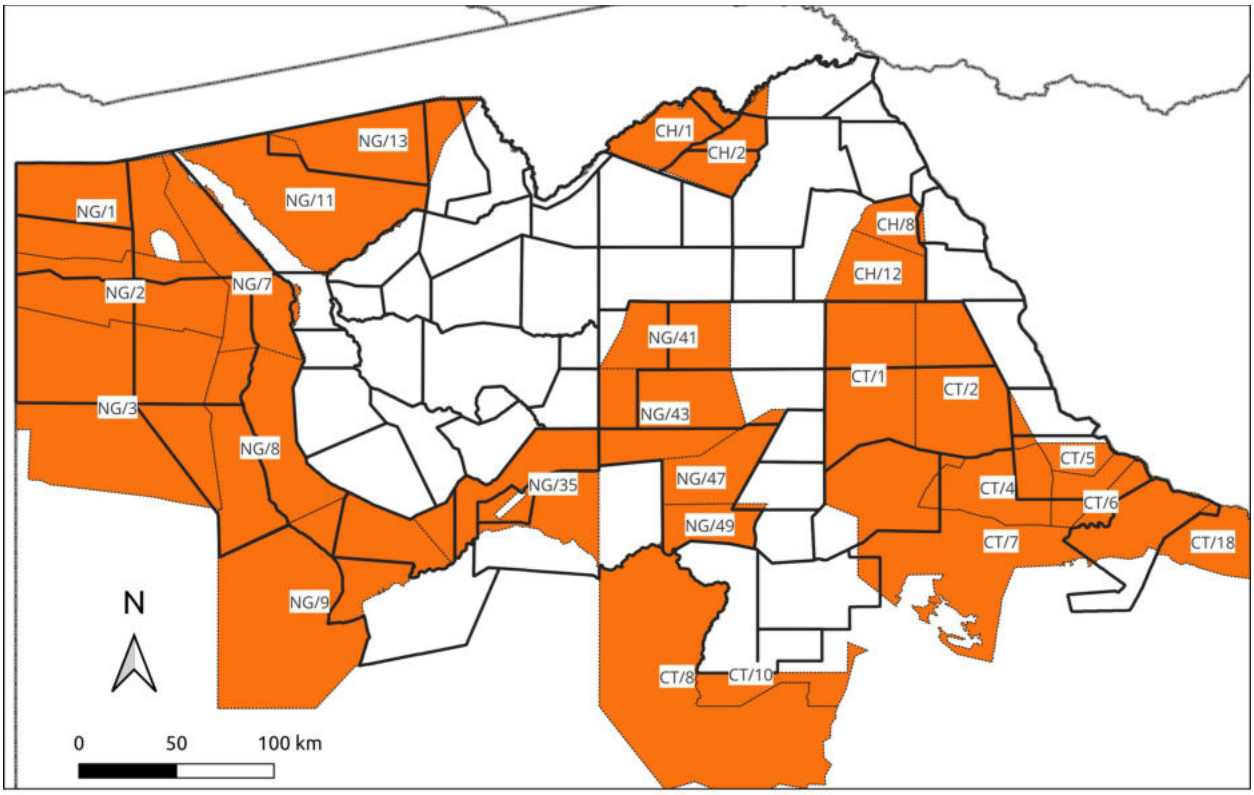

Figure 8. CHAs with hunting (orange with gray border, labeled) and stratum boundaries on the 2022 KAZA survey (thicker black lines).

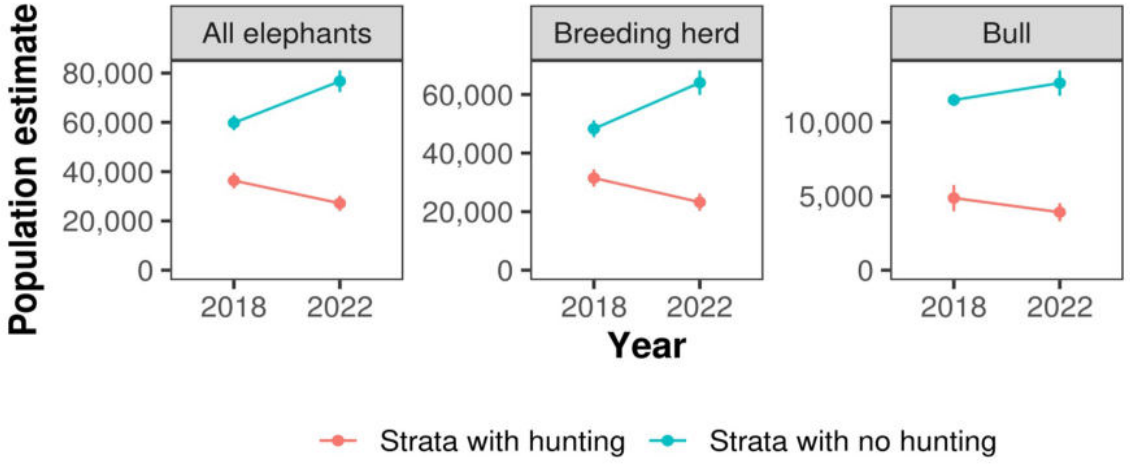

Figure 9. Population change in elephants, 2018-2022, in areas with and without elephant hunting in northern Botswana.

Poaching

In 2023 and 2024, we have been conducting occasional reconnaissance flights for elephants and illegal activity in northern Botswana. On these flights, we have observed and photographed

a total of 56 poached elephants, as determined by evidence of tusk removal typical of poachers. Most poached carcasses were in NG15 and NG18, with a few found in NG13 and Chobe National Park (Fig. 10). The poached carcasses found in NG15 in 2023 were in a poaching hotspot that we reported in 2018 and published about in 2019[11]. The carcasses in NG18, found in 2024, were in an area where we had not previously documented ivory poaching.

These carcasses were all fresh or recent on the four-category scale as of the date originally found, between October 2023 and February 2024. Thus, it is highly unlikely that any of these were present on the 2022 KAZA survey.

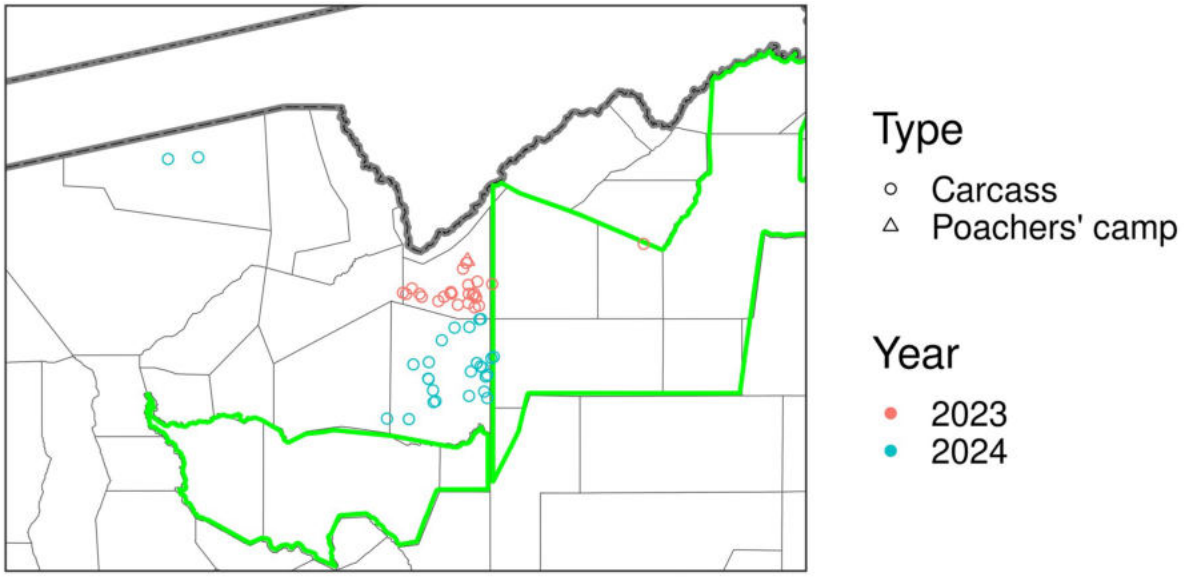

Figure 10. Locations of poached elephants and a poachers' camp, northern Botswana, 2023-2024. Thick gray lines indicate international borders, thin black lines are stratum boundaries for the 2022 KAZA survey. Moremi GR and Chobe NP are outlined in green.

Okavango Panhandle populations

In the Okavango Panhandle, overall elephant populations decreased by 18% between the 2018 and 2022 surveys (Fig. 4). For the 2010-2022 period, the overall elephant population growth rate was 0.002 ± 0.03 (Fig. 11). The 2018 survey had a higher estimate than the other three surveys. Breeding herd numbers were flat as well, with r = 0.004 ± 0.03. For bulls, the population declined at r = -0.07 ± 0.07. None of these growth rates are significantly different from 0.

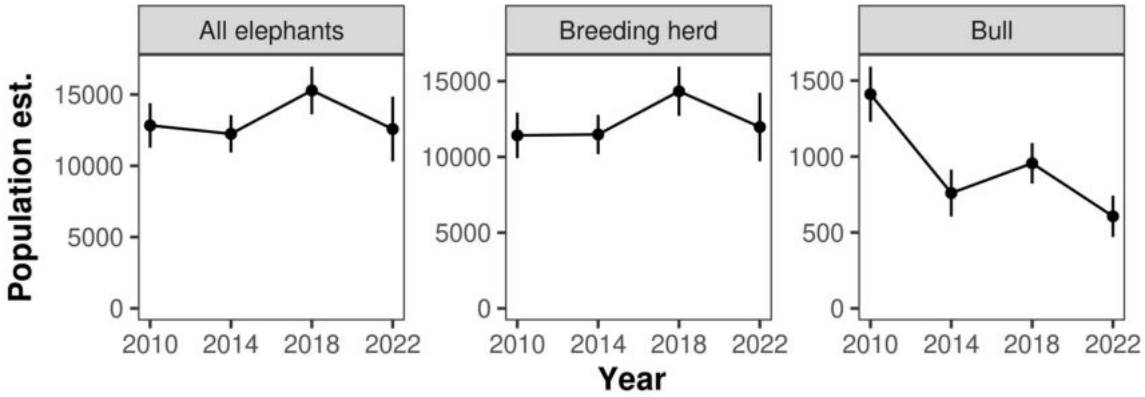

Figure 11. Elephant population estimates for the Okavango Panhandle strata, northern Botswana.

Potential elephant population growth rates

Using simulations, we compared populations beginning in 2010 with given growth rates against the 2022 estimates to determine what *r* values were consistent with the results of the KAZA survey. For the smaller 2010-2022 area, we can reject any population growth rate ≥ 0.02 (Fig. 12). For the larger 2018-2022 area, we can reject population growth rates ≥ 0.046.

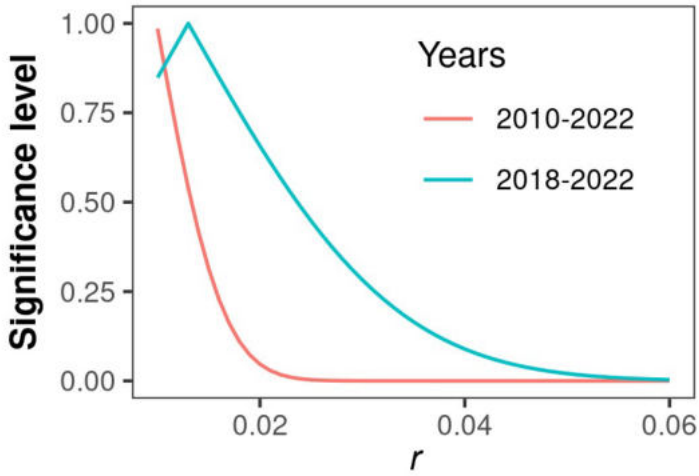

Figure 12. Results of simulations for given exponential population growth rates (*r*) in northern Botswana. The significance level is the probability level of a Z test comparing the actual 2022 estimate against the level projected under exponential growth from the beginning year at the given *r*.

Angola

The 2022 KAZA survey was the first survey of southeast Angola's elephants since 2015 and only the third systematic survey since the end of the civil war in 2002[14,23]. Overall, the elephant

population estimate for 2022 was 80% larger than the 2015 estimate (Table 7). The change, however, was not significant due to wide confidence intervals on the 2022 survey estimate.

Table 4. Population change for elephants between 2022 and 2015, southeastern Angola.

	2022 survey		2015 survey		2015 to 2022 change			
Herd type	**Population estimate**	**SE**	**Population estimate**	**SE**	**Change in estimate**	**SE of change**	**Z**	**P**
All elephants	5,982	3,063	3,316	793	2,666	3,164	0.84	0.40
Breeding herd	5,679	3,060	2,562	713	3,117	3,142	0.99	0.32
Bull	303	165	754	320	-451	360	-1.25	0.21

On the 2022 survey, the Kwando stratum, in the southeast corner of the study area, had a population estimate of 4,267 ± SE of 2,298 elephants. This stratum made up 71% of the entire Angola elephant population in 2022. We identified two other strata on the KAZA survey outside Angola that had numbers of elephants (4,315 and 4,318) similar to Kwando, and both of these strata had SEs <1,300. Thus, the SE for the Kwando stratum in Angola was anomalously large. The resulting wide confidence interval for Angola's population estimate in 2022 make it difficult to draw any general conclusions about changes in Angola's elephant population.

Regardless of uncertainty over the Kwando estimate, the dry-season range of elephants has shifted substantially in Angola since 2015 (Fig. 13). As of 2022, elephant populations had largely disappeared from western portions of the study area, notably in the western Likuwa area (northwestern portion of the study area) and along the Cuito and Kavango Rivers, labeled in Fig. 13. Just to the south of the Angola study area, elephants remain abundant in Namibia and Botswana along the Kavango (or Okavango) River.

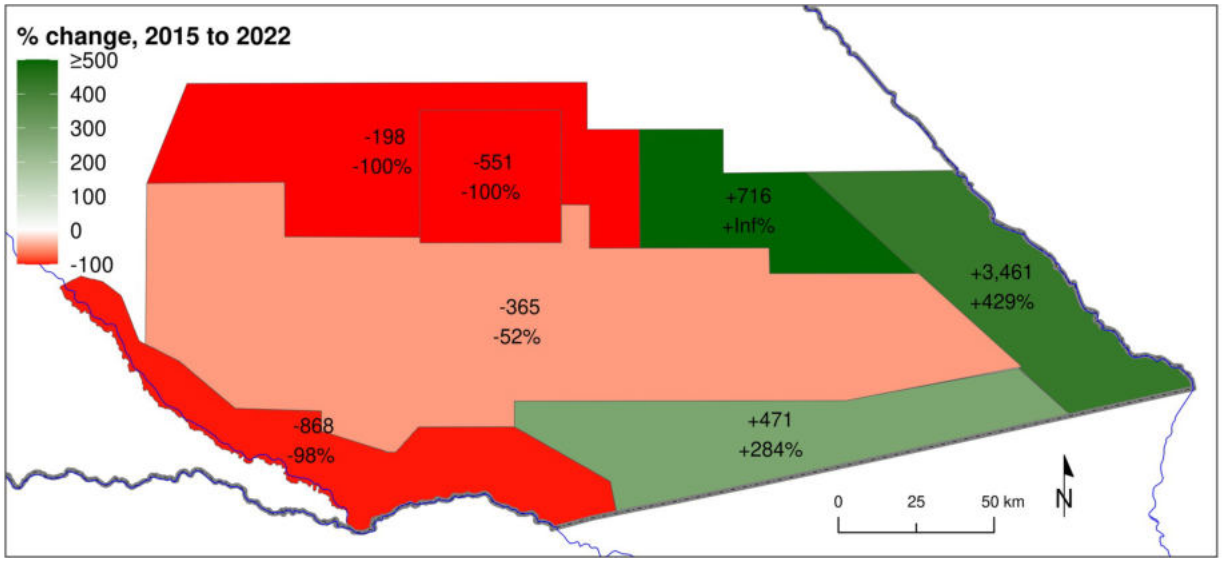

Figure 13. Change in elephant population estimates, 2015 to 2022, southeastern Angola.

Fresh and recent carcass ratios decreased significantly in Angola between 2015 and 2022 (Table 5). This is a potentially a positive development, as the fresh/recent carcass ratio observed in 2015 was extremely high at 10%. For all carcasses, the change in carcass ratios was not significant between years. Also, even with a potentially inflated elephant estimate in the Kwando stratum, as described above, the 16% carcass ratio observed in 2022 is still well above the 8% level considered safe. By stratum, changes in carcass ratios between 2015 and 2022 mirrored changes in elephant populations (Fig. 14).

Table 5. Change in carcass ratios, 2015 to 2022, southeastern Angola.

	2022 ratios		2015 ratios		2015 to 2022 change			
Ratio type	**Ratio (%)**	**SE (%)**	**Ratio (%)**	**SE (%)**	**Diff. (%)**	**SE (%)**	**Z**	**P**
Fresh/recent	0.6	0.6	10.3	3.0	-9.7	3.1	-3.15	0.01
All carcasses	16.3	7.3	29.9	5.5	-13.6	9.1	-1.50	0.13

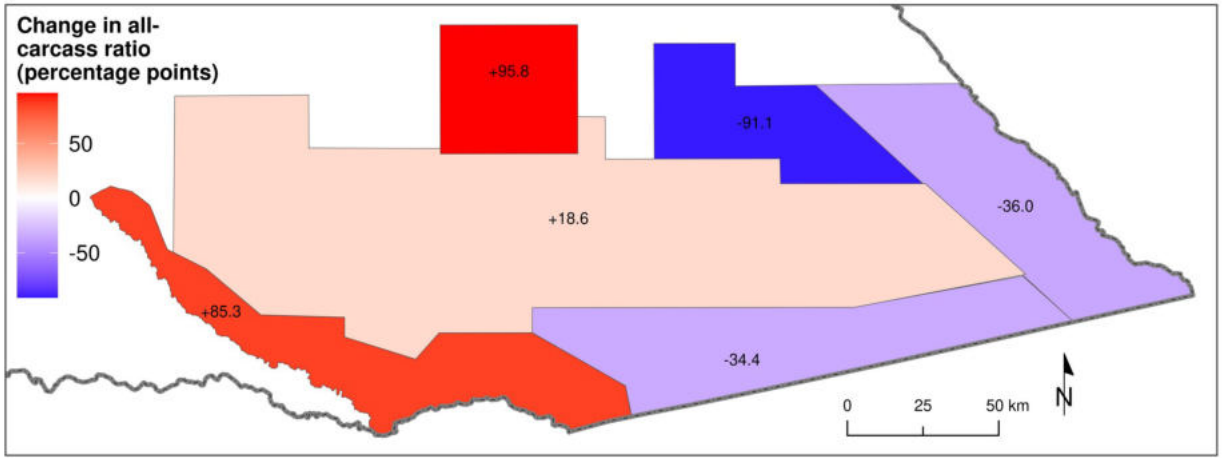

Figure 14. Change in all-carcass ratios, 2015 to 2022, southeast Angola.

Zimbabwe

The most recent elephant surveys before 2022 in Zimbabwe's portion of KAZA took place in 2014 as part of the Great Elephant Census. Between 2014 and 2022, overall elephant numbers increased non-significantly in both Zimbabwe regions, as did breeding herds in both regions and bulls in Matabeleland (Table 6). Bull numbers decreased non-significantly in Sebungwe.

One potential problem with the 2022 survey results is that over half of the increase in estimates for Matabeleland came from a single stratum, Kazungula (see Fig. 15, below). There, the estimated numbers increased from 151 in 2014 to 4,696 in 2022. The estimated density of elephants in 2022 was 10.8 elephants km^{-2}, which was the highest density observed for any stratum in KAZA in 2022 and nearly twice the second largest estimate. This estimate could be an overcount. At the same time, estimated populations also increased by over 3,000 in Botswana's adjacent Chobe River stratum between 2018 and 2022 (Fig. 4). Thus, there may have been an influx of elephants to the Chobe/Zambezi River area.

Table 6. Change in elephant populations by region in Zimbabwe, 2014-2022.

		2022 survey		2014 survey		2014 to 2022 change			
Region	**Herd type**	**Population estimate**	**SE**	**Population estimate**	**SE**	**Change in estimate**	**SE of change**	**Z**	**P**
North-west	All elephants	61,531	4,632	53,991	3,891	7,540	6,050	1.25	0.21
Matabeleland	Breeding herd	54,378	4,511	47,761	3,843	6,617	5,926	1.12	0.26
	Bull	7,154	603	6,230	609	924	856	1.08	0.28
Sebungwe	All elephants	3,499	513	3,407	610	92	797	0.12	0.91
	Breeding herd	3,045	495	2,632	584	413	766	0.54	0.59
	Bull	451	117	775	175	-324	211	-1.54	0.12

Spatial patterns of change in Zimbabwe's elephant numbers are shown in Fig. 15. Change was generally heterogeneous. In Hwange NP, numbers were roughly similar between 2014 and 2022 (exact comparison for the park was not possible because stratum boundaries were not coterminous with park boundaries, and we did not have raw data). The southernmost stratum in Hwange, directly adjacent to Botswana, had a 123% increase while numbers elsewhere in the park decreased. Some of the decreases in eastern Hwange may have been offset by an increase in the strata immediately east and north of the park.

In Sebungwe, both types of carcass ratios decreased significantly between 2014 and 2022 (Table 7). For Matabeleland, only the decrease in fresh/recent carcasses was significant.

Table 7. Change in carcass ratios, 2014-2022, Zimbabwe.

		2022 ratios		2014 ratios		2014 to 2022 change			
Region	**Ratio type**	**Ratio (%)**	**SE (%)**	**Ratio (%)**	**SE (%)**	**Diff. (%)**	**SE (%)**	**Z**	**P**
North-West	Fresh/recent	0.10	0.04	0.35	0.12	-0.25	0.13	-1.96	0.05
Matabeleland	All carcasses	6.7	0.6	7.0	0.6	-0.3	0.9	-0.37	0.71
Sebungwe	Fresh/recent	0.00	0.00	2.15	0.75	-2.15	0.75	-2.88	0.004
	All carcasses	17.5	2.6	30.2	4.2	-12.8	4.9	-2.59	0.01

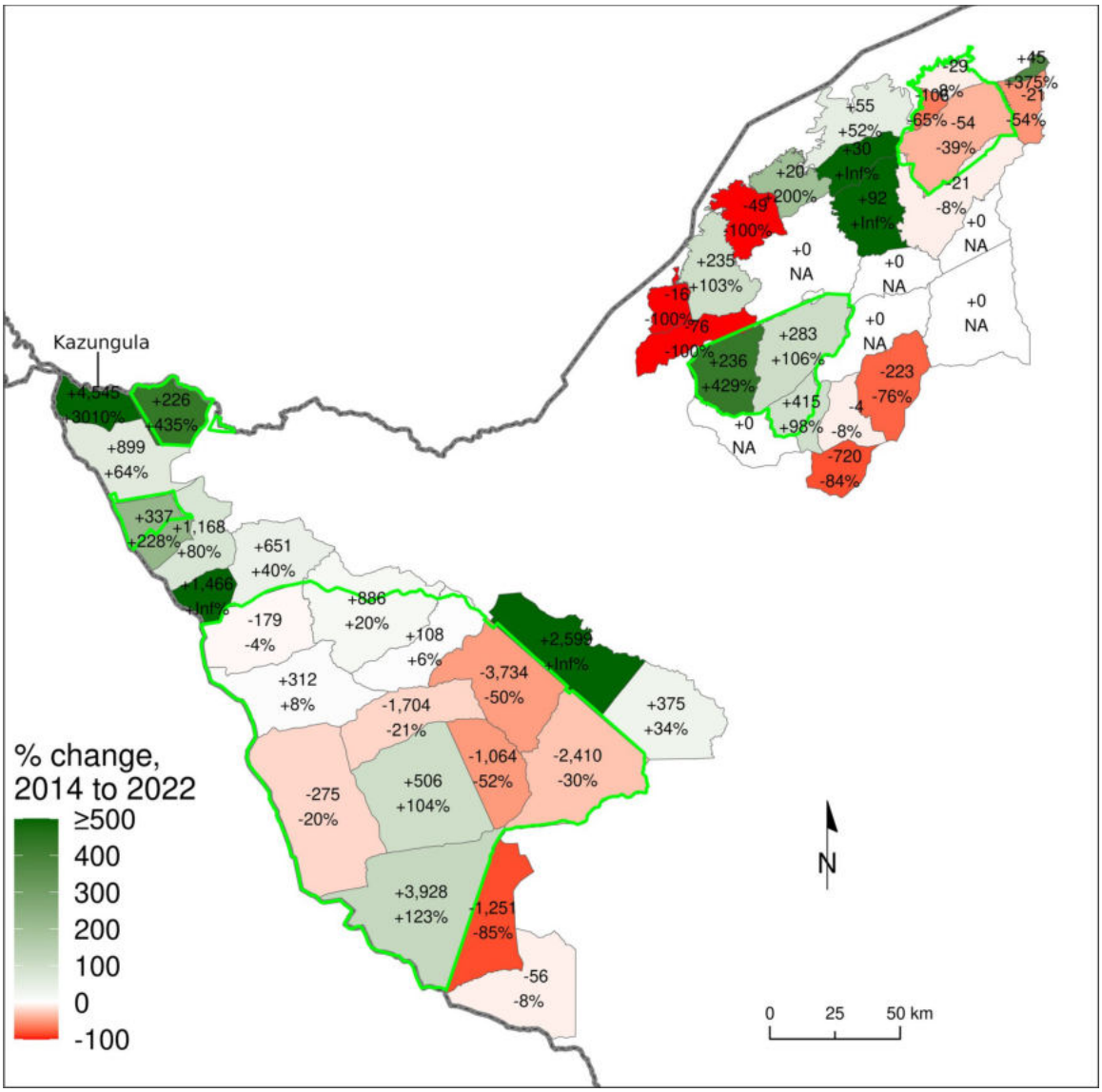

Figure 15. Change in elephant populations, 2014 to 2022, Zimbabwe.

Namibia

For Namibia, data were available only for all elephants combined. In the Kavango-Zambezi region, populations decreased non-significantly by 6% for 2015-2022 (Table 8). In Khaudum Nyae-Nyae, the population increased by 33%, but the difference was not significant.

In the Kavango-Zambezi region, elephant numbers generally declined along the Angola and Zambia borders, with numbers reduced to 0 in two strata (Fig. 16). Modest increases were observed near the Chobe River and in the westernmost stratum, Buffalo, in Bwabwata NP. In Khaudum Nyae-Nyae, numbers increased overall in Khaudum NP.

Table 8. Estimated numbers of elephants (all herd types combined) for two Namibia regions, 2015-2022.

	2022 survey		2015 survey		2015 to 2022 change			
Ecosytem	Population estimate	SE	Population estimate	SE	Change in estimate	SE of change	Z	P
Kavango Zambezi	12,345	1,269	13,116	1,741	-771	2,155	-0.36	0.72
Khaudum Nyae-Nyae	8,519	1,488	6,413	1,297	2,106	1,974	1.07	0.29

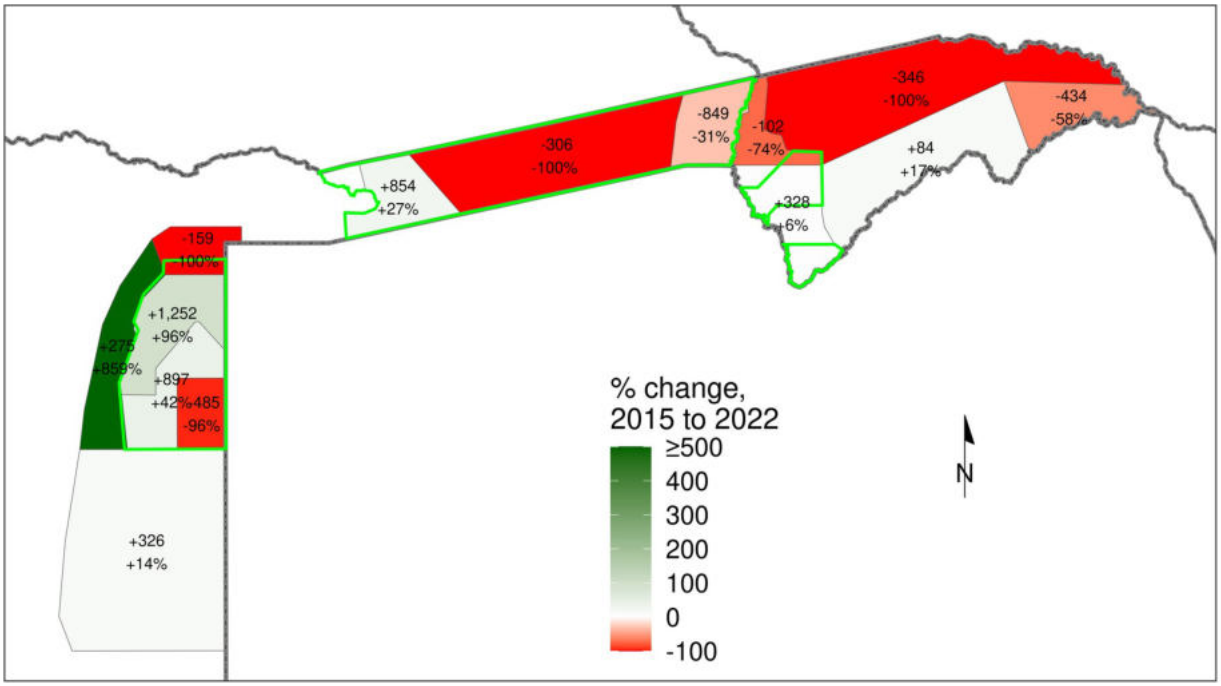

Figure 16. Change in estimated elephant populations by stratum in Namibia, 2015-2022.

Regional change in elephant populations

As a final way to assess elephant population change in KAZA, we compared overall populations between the 2014-2015 survey period and the 2022 survey. Though fences and human-occupied areas block movements of elephants in some parts of KAZA, elephants frequently move between KAZA countries and between regions within countries. Thus, treating the entire conservation area as a single population is worthwhile for assessing KAZA-wide changes. We combined the regions discussed above (again excluding Zambia because of changes in survey area and uncertainty in the Sioma Ngwezi population) and analyzed the area as a single population. One advantage of combining these regions is that results should smooth over any potential effects of seasonal movements that could influence results from a single region.

When we combined the six regions and compared the 2022 survey against the 2014-2015 surveys, elephant populations had not changed significantly for any herd type (Table 9). Overall elephant populations and breeding herds increased non-significantly. Bull numbers decreased non-significantly. Expressed as population growth rates, the elephant population grew at a rate

of 0.012 ± 0.07 or 1.2% per year. For breeding herds, *r* was 0.015 ± 0.08, and for bulls *r* was -0.003 ± 0.008.

Table 9. Combined elephant population change in N. Botswana, Angola, Namibia, and Zimbabwe, 2014-2015 to 2022.

	2022 survey		2014-2015 surveys		2014-2015 to 2022 change			
Herd type	**Population estimate**	**SE**	**Population estimate**	**SE**	**Change in estimate**	**SE of change**	**Z**	**P**
All elephants	214,661	8,232	195,979	6,680	18,682	10,601	1.76	0.08
Breeding herd	166,594	7,741	148,630	6,007	17,964	9,798	1.83	0.07
Bull	27,202	1,282	27,820	1,180	-618	1,743	-0.35	0.72

For the combined Angola, Botswana, and Zimbabwe regions, overall carcass ratios increased significantly between 2014-2015 and 2022 (Table 10). Fresh/recent carcass ratios increased non-significantly over this time. Notably, the all-carcass ratio now exceeds 8%, which is considered the highest carcass ratio compatible with a non-decreasing population.

Table 10. Change in carcass ratios, 2014-2015 to 2022, Angola, Botswana, and Zimbabwe.

	2022 ratios		2014-2015 ratios		2014-2015 to 2022 change			
Ratio type	**Ratio (%)**	**SE (%)**	**Ratio (%)**	**SE (%)**	**Diff. (%)**	**SE (%)**	**Z**	**P**
Fresh/recent	0.51	0.1	0.42	0.06	0.08	0.09	0.93	0.35
All carcasses	11.0	0.5	8.0	0.3	3.1	0.6	4.95	< 0.001

To better understand KAZA-wide change in elephant populations, we mapped stratum-level changes for the contiguous study areas in Namibia, Botswana, Angola, and Zimbabwe between the 2014-2015 and 2022 surveys (Fig. 17). Because the earlier surveys in KAZA took place over two years, Fig. 17 shows change per year rather than gross numbers.

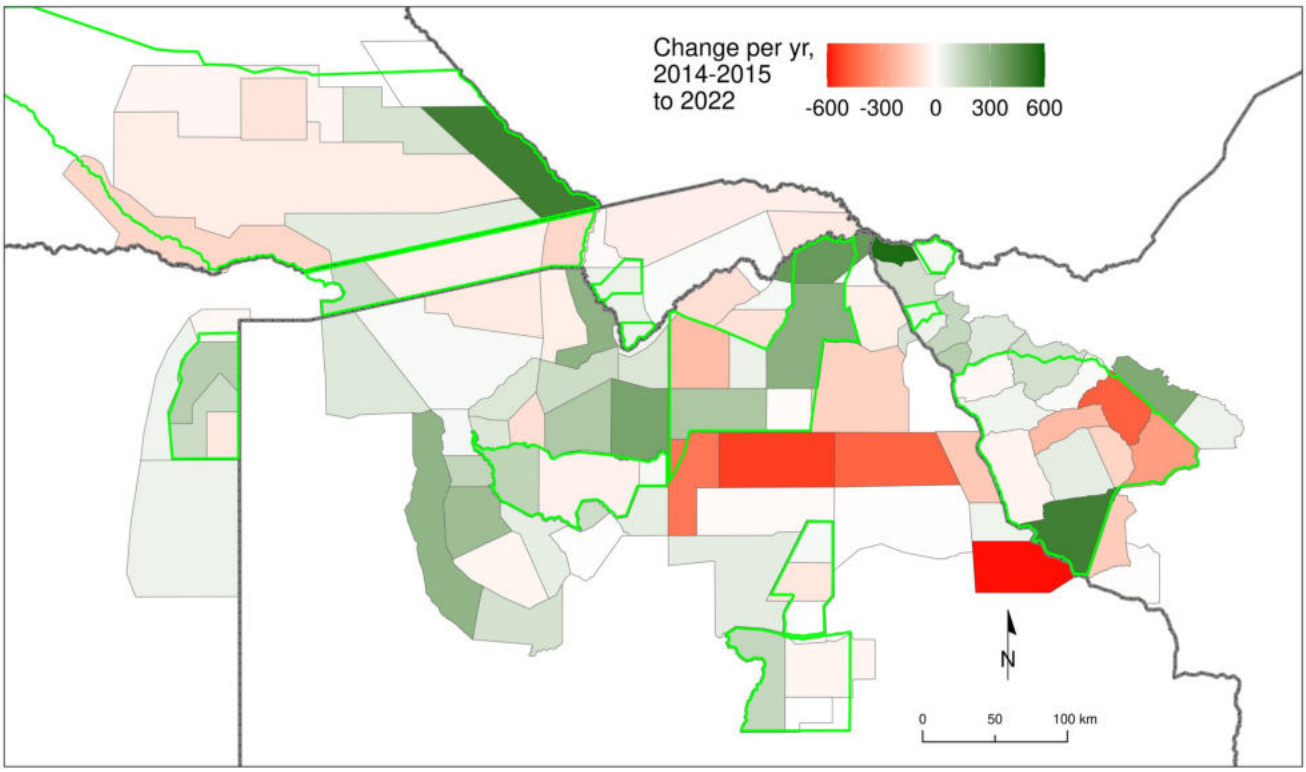

Figure 17. Change per year in estimated elephant populations between 2014-2015 surveys and the 2022 KAZA survey by stratum.

The question of perceived overpopulation frequently arises in the management of KAZA's elephants. To determine how density affects elephant population dynamics, we looked at the relationship between elephant density in 2014-2015 and change in density through 2022 by stratum. Plotting these two variables revealed that higher densities in 2014-2015 were associated with more negative change in density (Fig. 18). In fact, this relationship was statistically significant via linear regression for all three herd types (all $P \leq 0.003$). Thus, high population density may be naturally self-correcting, as elephants move from more crowded areas to less crowded ones.

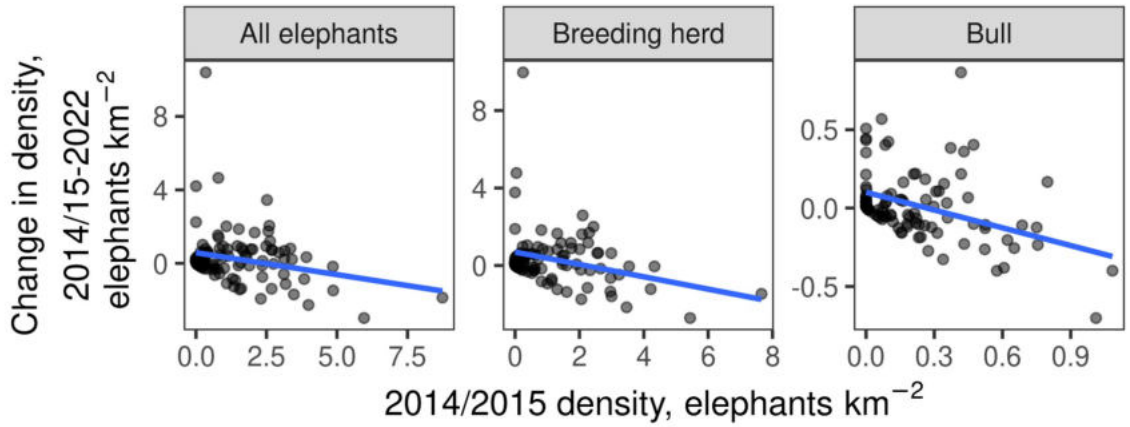

Figure 18. Effects of elephant density in 2014-2015 on change in elephant populations through the 2022 KAZA survey. Each point represents one stratum. Blue lines are least-squares fits from linear regression.

Discussion

Overall, elephant populations in KAZA grew at 1.2% per year between 2014-2015 and 2022. This rate is not significantly different from 0 after accounting for uncertainty in population estimates. Under theoretically ideal conditions, elephant populations can grow through reproduction alone at a maximum rate of ~7% per year[24]. In the mid- to late-20th century, some KAZA elephant sub-populations were likely growing at near those rates[25]. So, the 1.2% population growth rate observed between 2014-2015 and 2022 suggests a population where growth has slowed down greatly in recent years.

Aerial surveys cannot directly tell us why elephant population growth has abated. The data shown here, however, suggest a few potential causes. One possibility is that KAZA's elephant population is growing more slowly, or not at all, as the population approaches carrying capacity or due to density dependence. To date, however, evidence for density-dependent effects on survival and reproduction in elephants is limited[26,27], and some well-studied populations have shown little or no density dependence[28,29]. Fig. 18, above, shows that elephants may be moving to avoid areas of high density, but this does not show that demographic parameters vary with density. Detailed demographic studies would be necessary to evaluate the hypothesis that density dependence is slowing population growth rates in KAZA.

Another possible cause of reduced elephant population growth is increasing mortality rates. The carcass ratio on the 2022 survey was 11% for KAZA as a whole excluding Namibia and Zambia. In general, carcass ratios ≥8% indicate a declining population where mortality exceeds birth rates[20]. Carcass ratios also appear to be increasing in KAZA. Ratios for the same area in 2014-2015 were 8%, and that was at a time when much of Africa was experiencing very high poaching rates[30]. So, the high and increasing carcass ratios suggest increasing elephant mortality rates in KAZA. Because the 2022 survey used a narrower strip width than some previous surveys, we cannot completely rule out the possibility that carcasses were simply more detectable in 2022. However, as shown in Fig. 5, geographic patterns of change in carcass ratios suggest that the differences between previous surveys and 2022 are real.

Data collected in recent years suggests two potential contributors to mortality rate growth in KAZA. First, in 2020, mass elephant mortality events were reported in Zimbabwe and Botswana, affecting 350 and 200 elephants, respectively. In 2023, Foggin et al.[9] showed that some of the deaths in Zimbabwe were caused by bacterial poisoning. The pathogen was a new species, a relative of the *Pasteurella* bacteria that killed 200,000 Saiga antelope (*Saiga tatarica*) in Asia in 2015[31]. The deaths in Botswana were not definitively linked to the bacteria, nor were they ruled out, so more research on this subject is needed.

Second, data from Botswana showed that significant amounts of poaching continue in at least one of the poaching hotspots where we found dozens of carcasses in 2018-2019[11]. Between October 2023 and February 2024, we located 56 poached elephant carcasses, mostly north of the Okavango Delta. Most of these carcasses were in an area of ~2,000 km^2 in NG15 and NG18. Because our flights have been very limited in scope, the 56 carcasses surely underestimates the true number in the ~115,000-km^2 elephant range in northern Botswana. Outside of Botswana, little data on poaching is available. KAZA contains only seven sites for the Monitoring the Illegal Killing of Elephants (MIKE) program, which collects data on poaching from ranger patrols. Of the seven sites, four began operation in 2018 or later. This small sample is not sufficient for estimating poaching rates in an area of over 500,000 km^2. More monitoring of poaching is badly needed in KAZA.

The 2020 bacterial poisoning event in Zimbabwe has tentatively been linked to drought that was occurring in the area at that time[9]. Whether or not this event was caused by drought, drought can negatively impact elephant populations by reducing availability of food and water[32,33]. As of February 2024, much of northern Botswana, the Zambezi region of Namibia, and southern Zambia is in serious drought[34]. Models suggest that climate change will increase the frequency and severity of drought in the Okavango and Zambezi River basins in the future[35]. As a result, the potential for worsening drought should be incorporated into management plans for elephants in KAZA.

Of course, a variety of other factors can affect elephant mortality rates. Human-elephant conflict, diseases, and food depletion caused by high population density can cause elephant deaths[36]. More research would be needed to learn the importance of these factors in KAZA.

Though the elephant populations of the five KAZA nations are closely linked, our results show that the status of elephants varies by country. Below we discuss some of the country-specific results from our analysis.

Botswana

For northern Botswana, elephant populations have changed little since 2010 (Fig. 2). In fact, for the core areas surveyed since 2010, the population fell slightly though non-significantly through 2022. The 2018-2022 survey area showed a non-significant increase.

Despite the evidence of a stable elephant population since 2010, the government of Botswana has claimed that the population is growing at 6% per year[7]. Our simulations, however, showed clearly that we can reject population growth rates ≥2% per year since 2010 (Fig. 12). For 2018-2022, population growth rates cannot have been ≥4.6% per year. The wider range of possible values for *r* in 2018 reflects the shorter time span of the analysis. Change in population over 4

years is relatively small, even at high *r* values. Regardless, elephant numbers are no longer growing rapidly in Botswana.

At the same time, carcass ratios have been increasing in Botswana since our first survey there in 2010. The combination of flat population growth and rising carcass ratios, now exceeding 8% on both the 2018 and 2022 surveys, may be a sign that elephant mortality is on the rise in Botswana. The fresh carcass ratio was essentially unchanged between 2018 and 2022, but 2018 was near the peak of a poaching outbreak that we documented in Botswana[11]. If population health was improving, we would have expected lower fresh carcass ratios. In 2022, Botswana's fresh carcass ratio was the highest of any of the 10 regions on the KAZA survey[1].

Within Botswana, 2018-2022 changes in elephant numbers varied by geographic location and protected status. Within core areas, including Moremi GR, Chobe NP, the Okavango Delta, and the wildlife management areas designated for non-consumptive tourism, elephant numbers have been relatively stable or increasing, with carcass ratios generally below 8%. Outside of these core areas, in the forest reserves, ranching and farming areas, and areas along the Namibia border, elephants are not faring as well (Fig. 2). Compared to the core areas, these non-core areas have higher carcass ratios, and more negative trends in population size. Managers should be especially attentive to these areas, as these are warning signs of vulnerable populations.

As we documented, poaching continues in northern Botswana. On the 2022 KAZA survey, an area with high numbers of fresh carcasses was found in CH1 and the Savuti section of Chobe NP as well as NG15, west of the park. Botswana's government claimed that these carcasses were not poached. Nonetheless, many of these fresh carcasses were in the same areas where we documented poached elephants in 2023 and 2024 (Fig. 10).

One worrying sign with respect to poaching is that the price of ivory on the black market may be increasing again. Black market ivory prices increased from 2000 through approximately 2015[37]. Limited evidence suggested that ivory prices began to decrease thereafter[37,38]. Decreasing ivory prices should be positive for elephants as research has shown that higher ivory prices are associated with higher poaching rates[39]. Recent intelligence gathered in Botswana, however, revealed the ivory prices have increased again to $135 USD kg^{-1}, which is higher than most values reported prior to 2018 (M. Chase, personal communication with confidential source). Rising ivory prices could be a warning sign for more poaching to come in KAZA.

We continue to monitor the elephant range in northern Botswana, and we recommend the Botswana government expand surveillance for poaching as well as anti-poaching patrols so that the problem can be mitigated before it gets worse, as happened in 2018-2019. Chobe NP is the only MIKE site in Botswana, but our monitoring has shown that much of the current poaching is happening outside of the park. Expanding the MIKE site to extend outside the park or adding new MIKE sites in Botswana would be beneficial and would give more realistic estimates of poaching rates.

The return of elephant trophy hunting to Botswana has been controversial. We found that in areas where hunting is occurring, numbers of elephants are decreasing while areas protected from hunting have shown increases since 2018. The causes of these changes are not known, but one possibility is that elephants are moving away from areas disturbed by hunting[40].

Regardless, the sustainability of hunting elephants in areas where numbers are decreasing is questionable. The government of Botswana claimed that elephant hunting was sustainable, in part, because of the purported 6% growth rate of elephant populations in the country[7]. Not only are populations not increasing at 6%, as discussed above, but numbers appear to be decreasing in hunted areas. Maintaining a population of large bulls preferred by hunters requires regular production of adult bulls, either by immigration from non-hunting areas or by maturation of younger bulls. Declining elephant numbers in areas with hunting could result in a lack of large bulls. If hunting is not sustainable, its justification as a source of revenue for communities is weakened, as the trophy quality bulls that command premium prices will be in ever shorter supply. To better assess the effects of hunting in Botswana, we requested elephant hunting records from DWNP, but our request was not answered. If hunting is sustainable, then data on trophy sizes should be made available to the public to back up those claims. Regular monitoring of elephant populations in areas with hunting should be conducted to ensure that hunting has no adverse effects on bull numbers.

Finally, the Botswana government's finding of non-detriment for elephant hunting did not make use of the 2010, 2014, and 2018 EWB surveys of Botswana[7]. This was despite the fact that the EWB surveys produced relatively consistent and stable results (Fig. 2). The DWNP surveys, on the other hand, showed huge fluctuations across years, with country-wide elephant population estimates of 155,000 in 2006[42] and an amazing 208,000 in 2012[,41]. These numbers far exceed the estimates from EWB or the KAZA survey. The Botswana government claimed that EWB surveys were not comparable to earlier surveys[7]. The results of the KAZA survey and this report, however, clearly show that the population estimates on the EWB surveys were credible with respect to those from the KAZA survey. The recent 2006 and 2012 DWNP survey estimates are outliers, and they should not be used to estimate population growth rates for Botswana's elephants, nor should they be used to justify elephant hunting.

Angola

Our 2015 survey of Angola revealed that numbers of elephants had increased since 2004-2005, reflecting some recovery since the end of the civil war[14]. However, carcass ratios in 2015 were very high at 29%, and fresh/recent carcass ratios were extraordinarily high at 10%. That is one of the highest regional fresh/recent carcass ratios ever recorded in savanna elephants. Based on those carcass ratios, we concluded that elephant numbers had increased after 2005 but were likely decreasing by the time of the 2015 survey. No increasing population could sustain such high carcass numbers.

The 2022 KAZA survey found that the population had grown by 80% since 2015. This result, however, comes with a major caveat: the total estimated increase between 2015 and 2022 was 2,666 elephants, but one stratum near the Kwando River had an increase of over 3,000 elephants. The standard error of the 2022 estimate in this stratum was extremely high at 2,298 elephants. The cause of this high variance was a few anomalously large herds observed during the survey[10]. The Kwando stratum was surveyed at an intensity of 6% which is too low for such a large and dense population. During a survey, when a stratum estimate is anomalous and/or has a very large standard error, the results should be excluded, and the stratum should immediately be resurveyed at a higher intensity. If a higher-intensity survey is not possible, a second survey at the same intensity can be conducted, with the two estimates averaged. Even if the two surveys give similar population estimates, the resulting standard error on the average estimate will be much smaller.

We find it implausible that the population of elephants in Angola increased by 80% between 2015 and 2022. A more likely explanation is that a few large herds observed in the Kwando stratum led to a biased population estimate. Regardless of the accuracy of the count, other data from Angola suggest that their elephant population is not healthy. Between 2015 and 2022, nearly all elephants disappeared from the western part of the Angola study area (Fig. 13). Along the Cuito and Kavango Rivers, we found a 98% reduction in elephant numbers, a decrease of 868 elephants. The overall carcass ratio in Angola was 16% in 2022. Though this ratio is lower than the 29% from 2015, it is still very high and could be higher still if the Kwando stratum's elephant estimate were adjusted downward. Also, the large breeding herd sizes observed in Angola (mean = 21.1 elephants vs. 9.8 elephants or the rest of KAZA) are an indicator of a population being persecuted. Elephants under duress often gather together in large herds for protection[43]. All of these signs point to an elephant population in trouble.

We believe that Angola is an attractive population sink for elephants. Elephants in Angola face a number of threats. Poaching is definitely occurring. Luengue-Luiana NP has been a MIKE site since 2019. Over 4 years of data collection, a mean of 71% of elephant carcasses observed at the site were killed illegally. Values over 50% generally indicate an unsustainable poaching rate. Additionally, on both the 2015 and 2022 surveys, high levels of human activity were observed near the Kwando River, which is critical for elephants in Angola. Mines from Angola's 1975-2002 civil war still cover large areas of the elephant range in southeast Angola and have been reported to kill and wound elephants[44]. Though fewer fresh carcasses were seen in 2022 than in 2015, the fresh carcass ratio for 2022 was the second highest of the 10 regions studied in 2022, trailing only northern Botswana. This evidence supports the idea that Angola is a population sink. Still, elephants may be moving into Angola from denser populations in Namibia and Botswana, seeking areas of lower competition for food or mates. Taken together, these factors make Angola an "attractive sink," an area that is appealing to elephants who are looking to emigrate from more crowded areas but where elephants cannot successfully maintain their populations due to extrinsic factors like poaching. Attractive sinks can be very damaging to animal populations in the long run because they continue to "lure" animals to dangerous areas where mortality exceeds natality, contributing to wider population losses[45].

Botswana's government has recently proposed sending 8,000 elephants to Angola, purportedly to reduce crowding[46]. Given the strong evidence that Angola is not safe for elephants right now, sending these elephants to Angola would be a mistake and could result in many elephant deaths. Though the partial recovery of Angola's wildlife populations since the civil war is laudable, the country remains perilous for elephants.

Zimbabwe

In both north-west Matabeleland and Sebungwe, elephant populations were stable to moderately (though non-significantly) increasing from 2014 to 2022. Within those regions, changes have been heterogeneous. In Hwange NP, numbers of elephants were roughly stable overall, but populations have shifted somewhat within the park. Also, the easternmost section of the park has seen decreases while unprotected areas just east of the park have seen a large increase in elephant numbers since 2014. Some of these shifts may be related to the provision of new artificial waterholes in the park since 2014.

Fresh and recent carcass ratios decreased significantly in both regions of Zimbabwe since 2014. All-carcass ratios decreased significantly in Sebungwe and non-significantly in Matabeleland. This could indicate a decrease in poaching pressure in Zimbabwe, though little data is available on poaching rates.

Other threats remain, however. In 2019, drought killed at least 200 elephants in Hwange NP[8]. In 2020, 35 elephants were found dead in a mass mortality event near Victoria Falls. Subsequent analysis revealed that a novel pathogen, an unnamed bacterium related to *Pasteurella multocida*, was likely responsible[9]. Almost nothing is known about this bacteria, so continued monitoring of elephant mortality is important.

Namibia

In Namibia, overall elephant populations did not change significantly since 2015. Khaudum Nyae-Nyae experienced a non-significant increase while the Kavango-Zambezi region experienced a non-significant decrease. Within strata, in Kavango-Zambezi, elephant numbers generally decreased along the Angola border and were more stable along the Botswana border. Whether or not the declines along the Angola border are related to the poaching and other problems being experienced by elephants in Angola is not known.

Zambia

Though we were not able to include Zambia in our analyses, estimated elephant populations for the Kafue region decreased from 6,688 in 2015 to 3,840 in 2022[1]. Both of these estimates have large SEs, and the area surveyed differed somewhat between years. Though the large change in numbers is definitely concerning, the alterations to the study areas and wide confidence intervals mean that no strong conclusions can be made about what is happening in Zambia. The 43% drop in estimates in 8 years, however, is worrying, and more surveys in Kafue are warranted.

Statistical power and methodology

For a Z-test comparing two estimates, as in Table 9, statistical significance depends on the difference in estimates and the variance of that difference, which is the sum of the two variances. The overall estimate from the 2022 survey in Table 9 had a CV of 3.8% versus a CV of 3.4% for 2014-2015. The increase in CV on the 2022 survey may be because the sampling was generally conducted at a slightly lower intensity than in 2014-2015. We understand the practical difficulties involved in conducting a very large-scale survey like the KAZA survey. But sampling intensity should be at least equivalent to previous surveys to maximize the power of statistical comparisons with past studies. If another survey of KAZA is done in the future, we would recommend modestly increasing sampling intensity, especially in strata with relatively large numbers of elephants.

On the need for trend analyses

One motivation for our writing this report is that the report from the 2022 KAZA survey did not include any formal trend analysis[1]. For many surveys of savanna elephants as well as compilations of elephant counts, the count itself seems to be the primary goal, with much less attention paid to trends over time. This is counterproductive to the conservation of elephants. Accurate counts that are not put in the context of previous surveys are not as helpful as they could be in assessing population status. The 228,000 elephants estimated to occur in KAZA seems like a large number. Determining the health of KAZA's elephant population, however, requires interpreting that number in light of how it has changed from earlier estimates.

Some surveys of savanna elephants, including those from Zimbabwe in the past, have done a good job of presenting trends for overall study areas and areas of interest like national parks. Doing trend analysis need not be burdensome. All of the analyses presented in this report took approximately three weeks to conduct. And that time would have been even shorter if strata on the KAZA survey had been identical to those from previous surveys in Botswana. In the future, surveyors in KAZA should consult with those who have experience conducting surveys in each country to ensure the best possible survey design.

Even if surveyors are not interested in conducting a formal trend analysis, they should still design surveys to facilitate trend analyses. One of the best things surveyors can do to this end is to keep stratum boundaries from past surveys unchanged. Trend analyses require that the areas surveyed be identical or nearly so across surveys. If the overall survey area must be enlarged, adding new strata is better than expanding the borders of existing strata on the periphery. We understand that sometimes changes in stratum boundaries are necessary. But any changes should be made with a nod towards facilitating comparison between the new survey and previous surveys.

For the Botswana survey in 2022, we found that many stratum boundaries had small changes compared to 2010-2018 strata that could not possibly have been meaningful in terms of expected elephant densities. Nonetheless, these changes created a significant amount of extra work for us in comparing the KAZA survey with our 2010, 2014, and 2018 surveys. When data from a past survey must be "re-stratified" to compare it a subsequent survey that changed stratum boundaries, this adds error to the sampling process. The estimates from the smaller "strata" resulting from the re-stratification process will have lower precision than the original estimates. Lower precision reduces the power of the surveys to detect a trend.

Conclusion

The tremendous amount of effort required and invested to conduct a survey as large as the 2022 KAZA survey is laudable. The 2022 survey was the second KAZA-wide set of surveys in eight years. KAZA's elephant population appears to be relatively stable overall. One of the main benefits of regular monitoring is the ability to detect population-level problems while they are still nascent. The results for Zambia, Botswana, and Angola show worrisome indications, including high carcass ratios, large declines, and evidence of recent poaching. These areas should have high priority for future monitoring.

Based on our findings here, we make the following recommendations for the future monitoring and management of KAZA's elephants.

For all of KAZA:

1. Aerial surveys should use stratum boundaries from previous surveys wherever possible.
2. Surveyors should increase their consultation with stakeholders and local experts when aerial surveys are designed and flown to ensure comparability with past surveys while maintaining set standards.
3. Localized dry-season aerial surveys should be flown regularly over strata that have high elephant carcass ratios, large recent declines, or any other signs of an unhealthy population. In Botswana, these strata include areas along the Kwando, Kavango, Linyanti, and Chobe rivers, the Khwai-Mababe system and the Ngwasha seeps. Such relatively small surveys can be flown within two to three days and provide useful data on population parameters essential for quick and remedial action.
4. When unusually large numbers of natural elephant deaths occur in a localized time and place, samples should be collected from fresh carcasses and sent for laboratory testing to diagnose the cause. Laboratory results should be disseminated to stakeholders.

For Botswana:

5. An updated Rapid Elephant Population Assessment (REPA) study should be conducted to quantify the age structure and other demographic variables for the elephant population. This would aid in understanding mortality and natality rates as well as the impacts of poaching, drought, and trophy hunting on population structure.
6. Surveillance and anti-poaching patrols are needed along the Linyanti River (Batubaja), around the Katambora-Kazuma border area, and in NG13 (Omega III / Xhoromo). These are notorious crossing points for cross-border poaching syndicates, which require constant policing and interception before poachers kill elephants in Botswana.
7. Effects of elephant trophy hunting in key wildlife dispersal corridors such as the Kwando River should be evaluated. These corridors are critical to the KAZA vision of a connected landscape
8. Detailed records of reports of illegal activity, retaliatory killings, legal off-take, and mass mortality events should be kept to better assess impacts of humans and natural processes on elephant mortality. These records should be shared with stakeholders.
9. Increase the number of MIKE sites in Botswana, and follow procedures for monitoring according to MIKE protocols. Establish or maintain good intelligence networks.
10. Prior to the hunting moratorium in 2014, the Botswana Hunters Association shared reports on annual hunting statistics including trophy sizes, which can be used to estimate elephant ages. Since the resumption of hunting these data have not been shared with the public. A study using these records together with reliable estimates of elephant numbers in hunting concessions is encouraged. These data are necessary to allow adjustments of quotas to keep trophy size within acceptable limits.
11. Improve the opportunities for benign tourism in areas managed by community trusts. Provide support for and facilitate non-consumptive tourism zones within hunting

concessions to provide additional sources of revenue to communities living with elephants.

12. Maintain transparency of any operations that might affect shared elephant populations.
13. Bring information about management activities to the knowledge of communities and other Batswana.
14. Manage hunting activities such that this practice does not impinge on existing photographic tourism operations. Areas must be zoned to ensure that there is no overlap in conflicting activities.

For Angola:

15. The reasons for low numbers of elephants seen along the riparian habitats and floodplains of the Cuito and Kavango Rivers in Angola should be determined.

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Appendix 1. Study area boundaries as used in this report

Botswana

For the 2010-2022 analysis Botswana, study areas are show in Fig. A1. Where 2010 study areas went beyond the 2022 stratum boundaries, we trimmed observations and transects to the 2022 stratum boundaries. The larger 2014 and 2018 surveys (not shown) were also trimmed to the magenta-shaded area in Fig. A1.

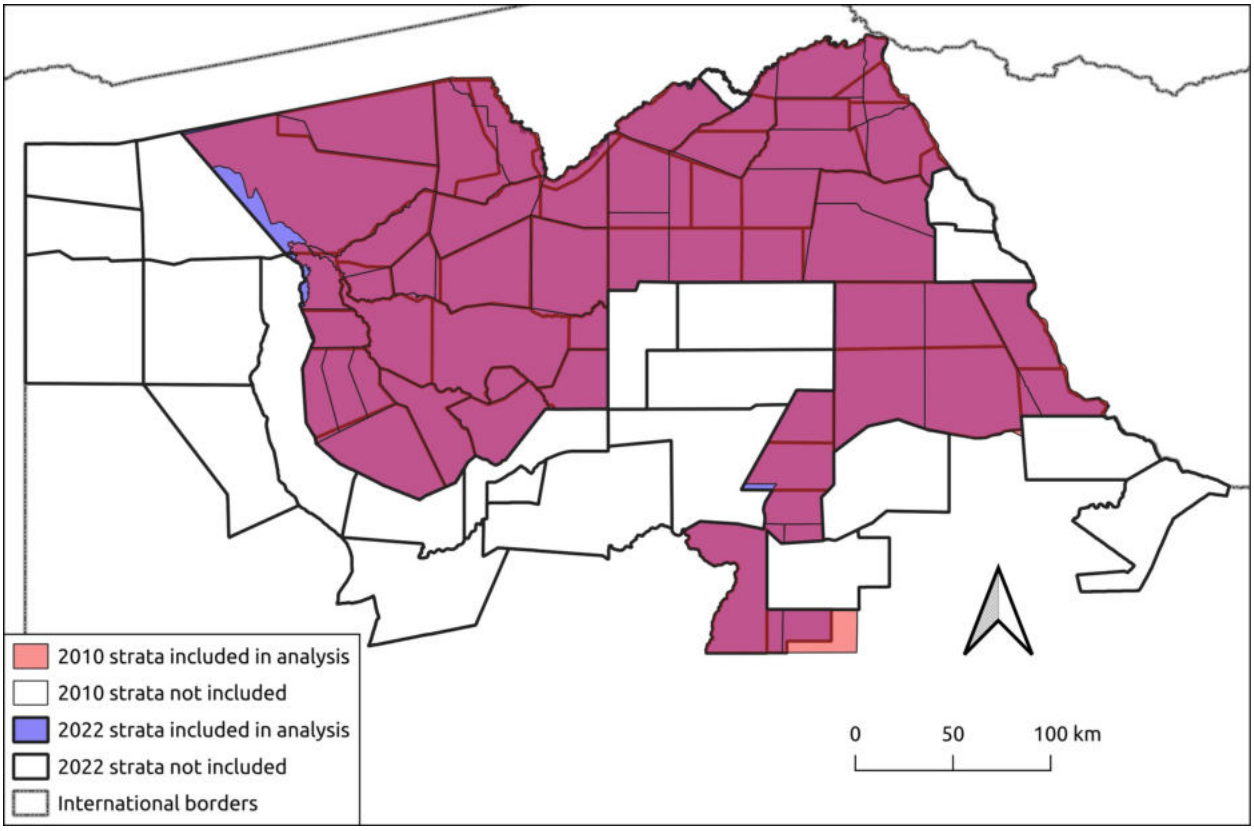

Figure A1. Study area boundaries for the 2010-2022 analysis in Botswana.

The study area for the 2018-2022 analysis was larger (Fig. A2). A few 2022 strata had areas that extended beyond the 2018 study boundaries. These areas had no elephants and, therefore, did not affect the population estimates for the 2022 survey. Including these areas does increase the variance of the 2022 estimate slightly versus what one would expect without those areas. But the total population of the affected strata is small and, therefore, has little effect on comparisons between years.

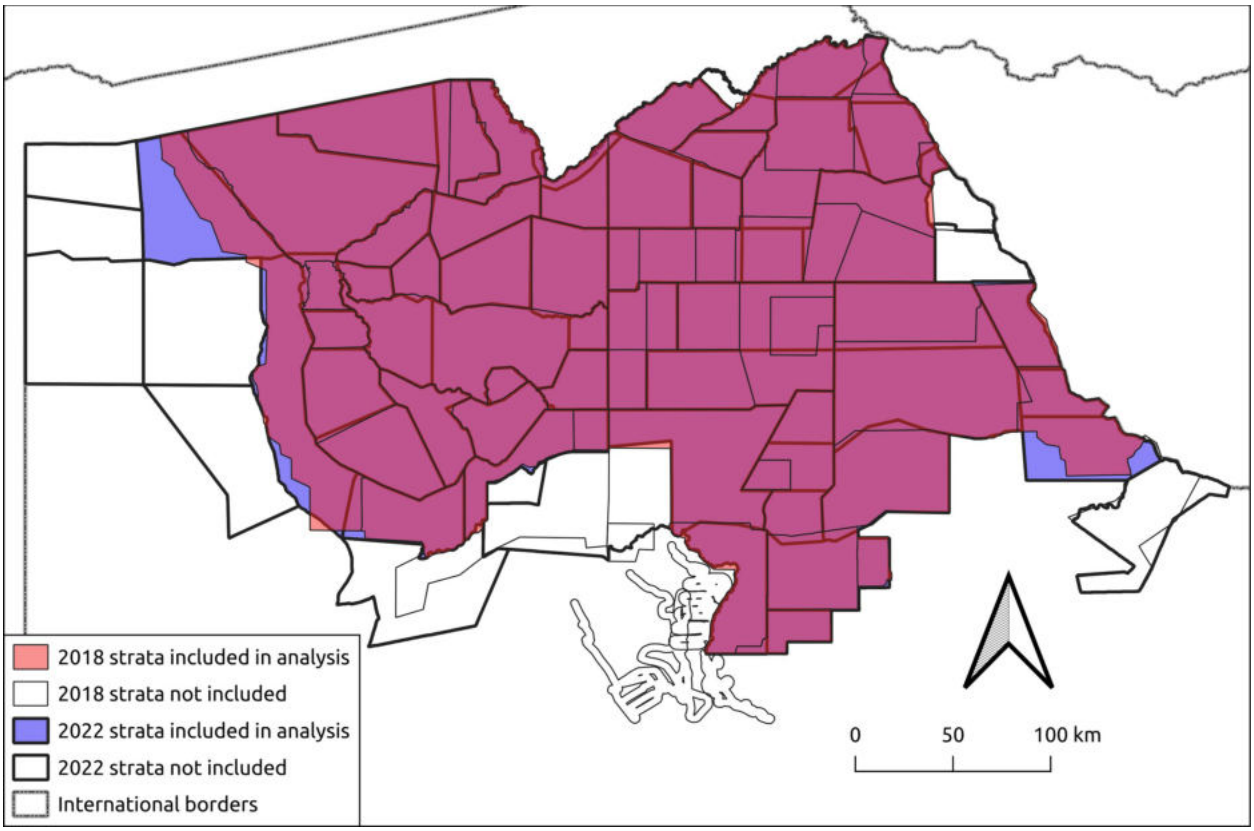

Figure A2. Study area boundaries for the 2018-2022 analysis in Botswana.