Supplementary Information

State-space models reveal a continuing elephant poaching problem in most of Africa

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This supplement includes:

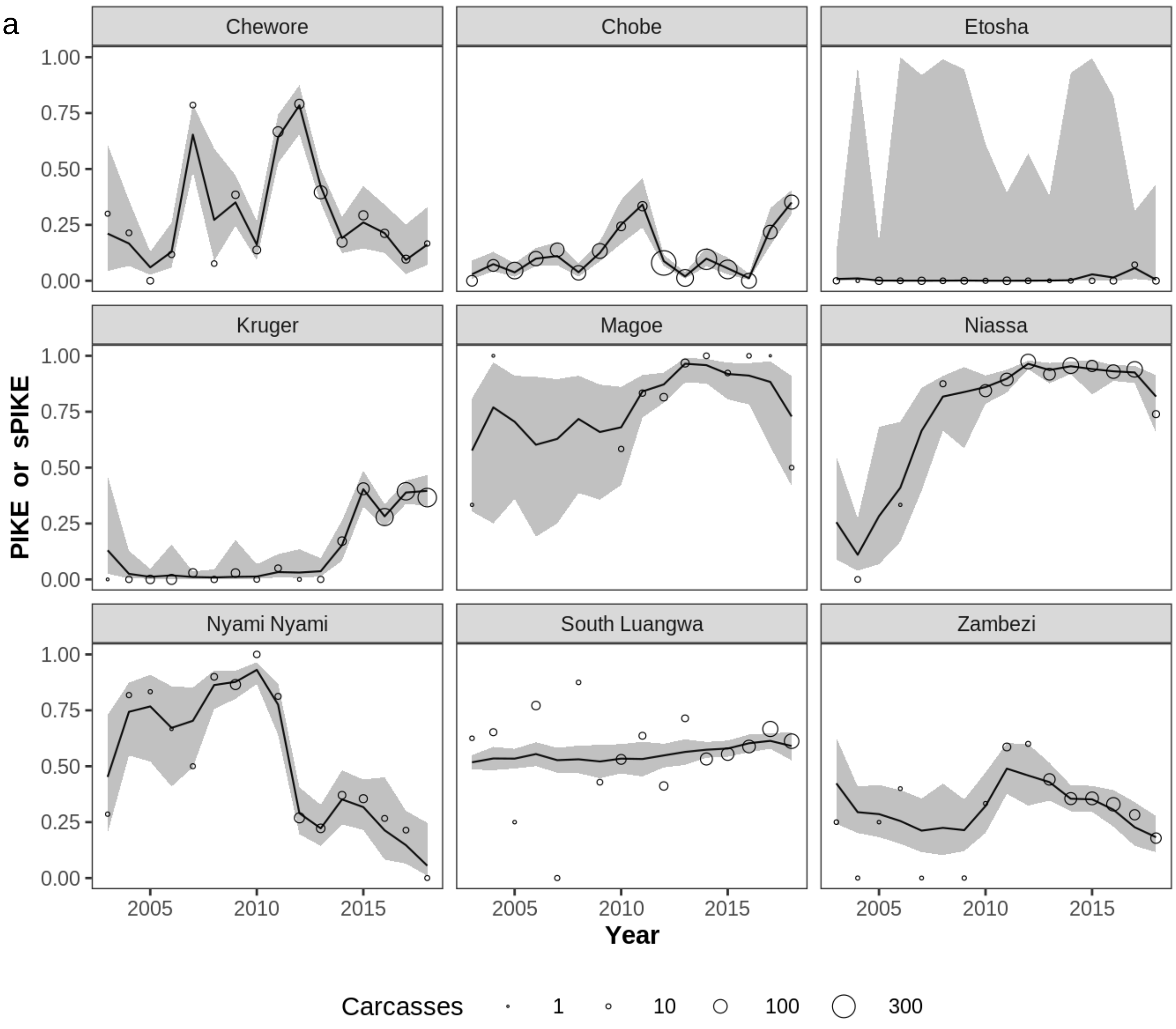
Supplemental Figures S1-S4

Supplemental Table S1

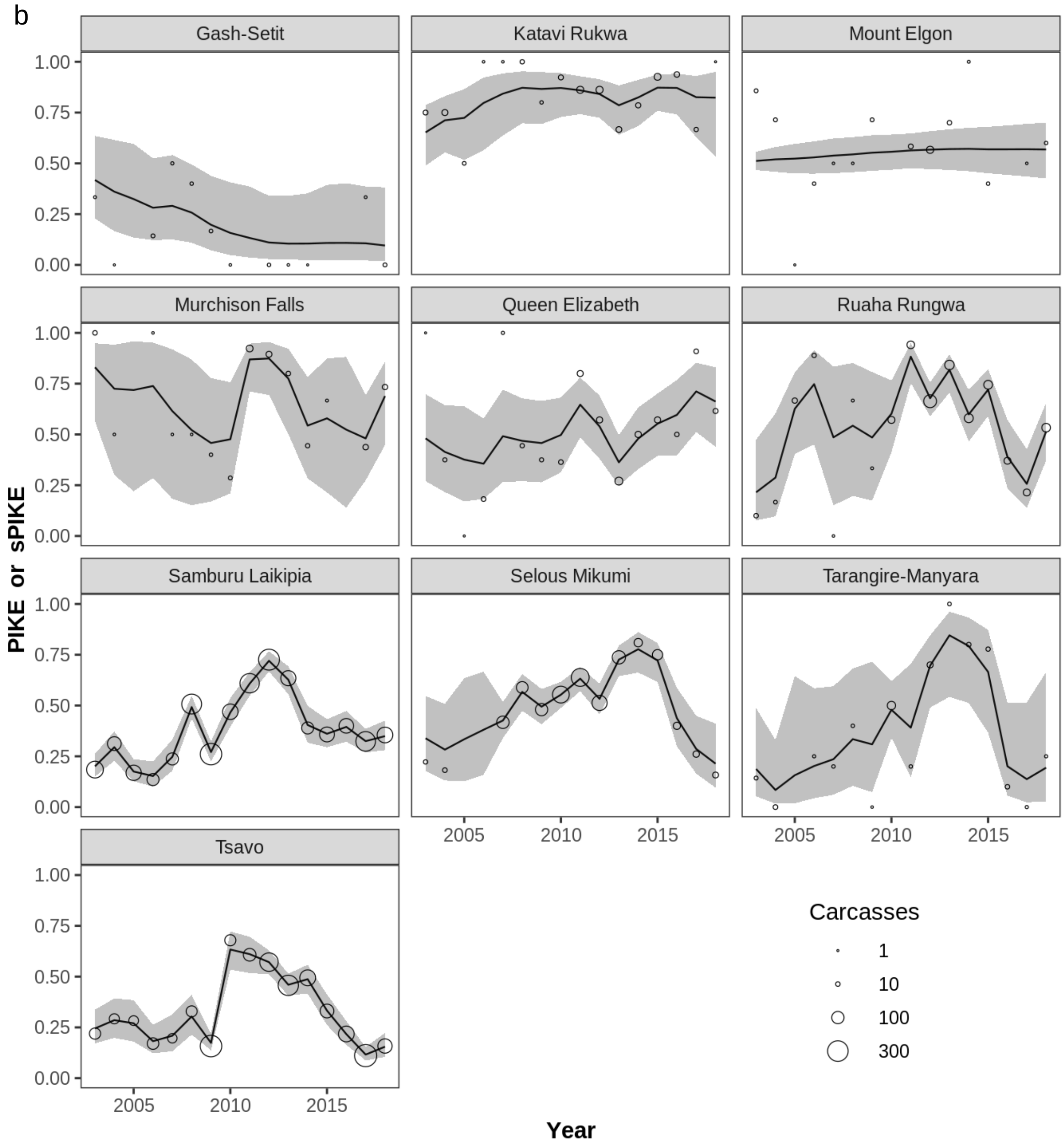
R code to run the state-space models

Supplementary Figure S1. sPIKE estimates for (a) Southern Africa, (b) Eastern Africa, (c) Central Africa, and (d) West Africa. Lines are mean sPIKE estimates. Shading indicates 95% confidence intervals on sPIKE. Circles indicate observed PIKE, and circle area is proportional to the observed total number of carcasses.

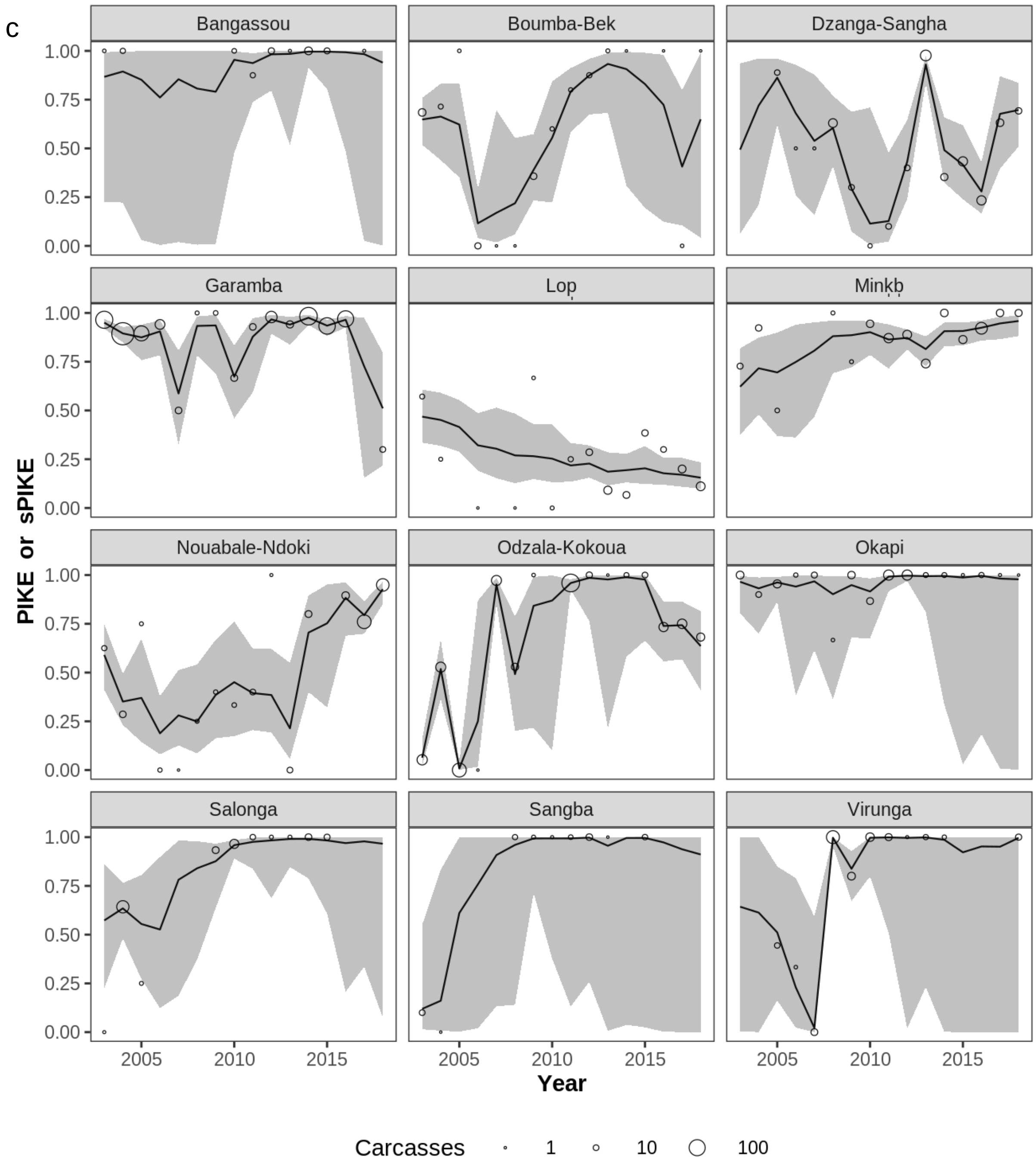
a



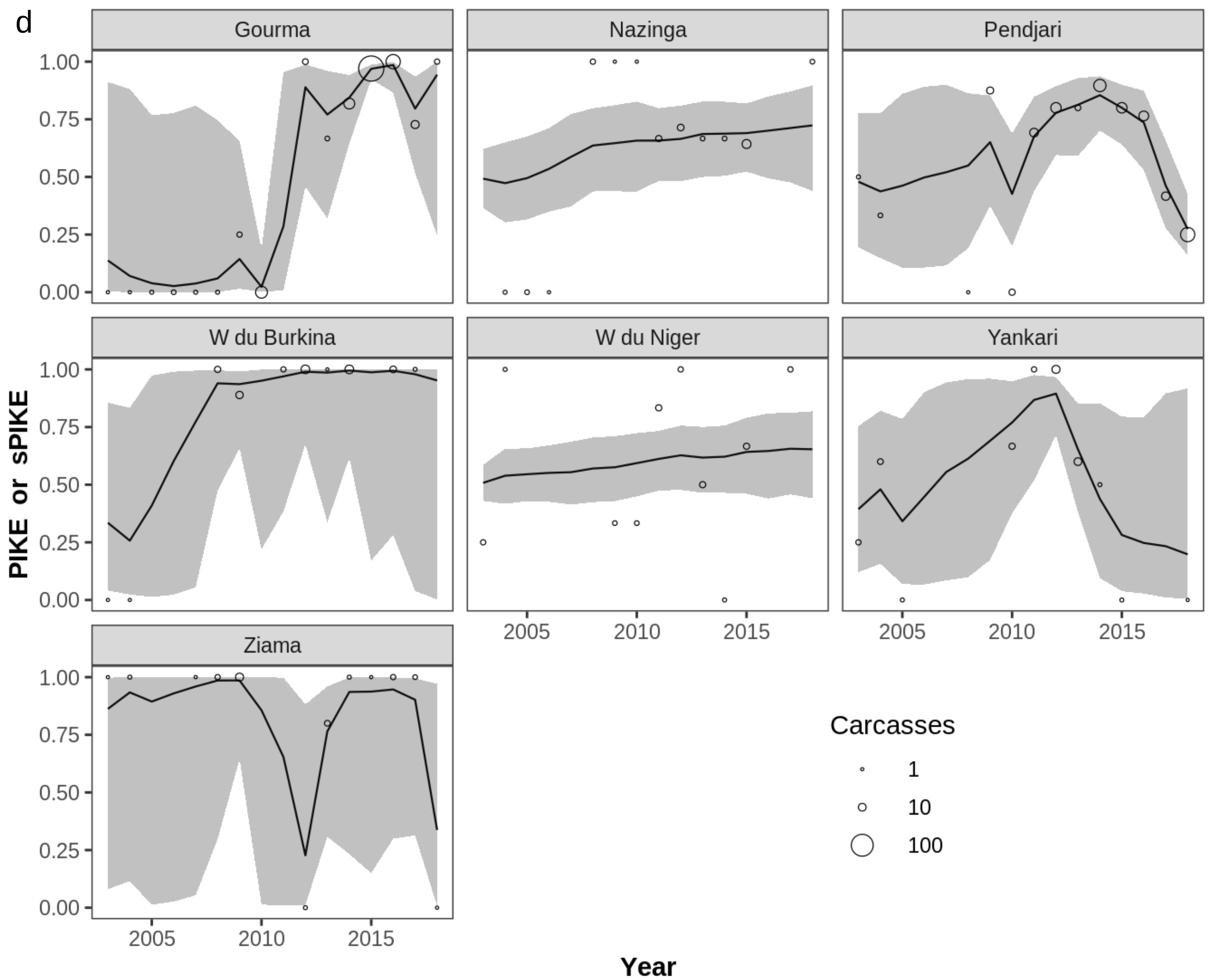
Supplementary Fig. S1 (cont'd)



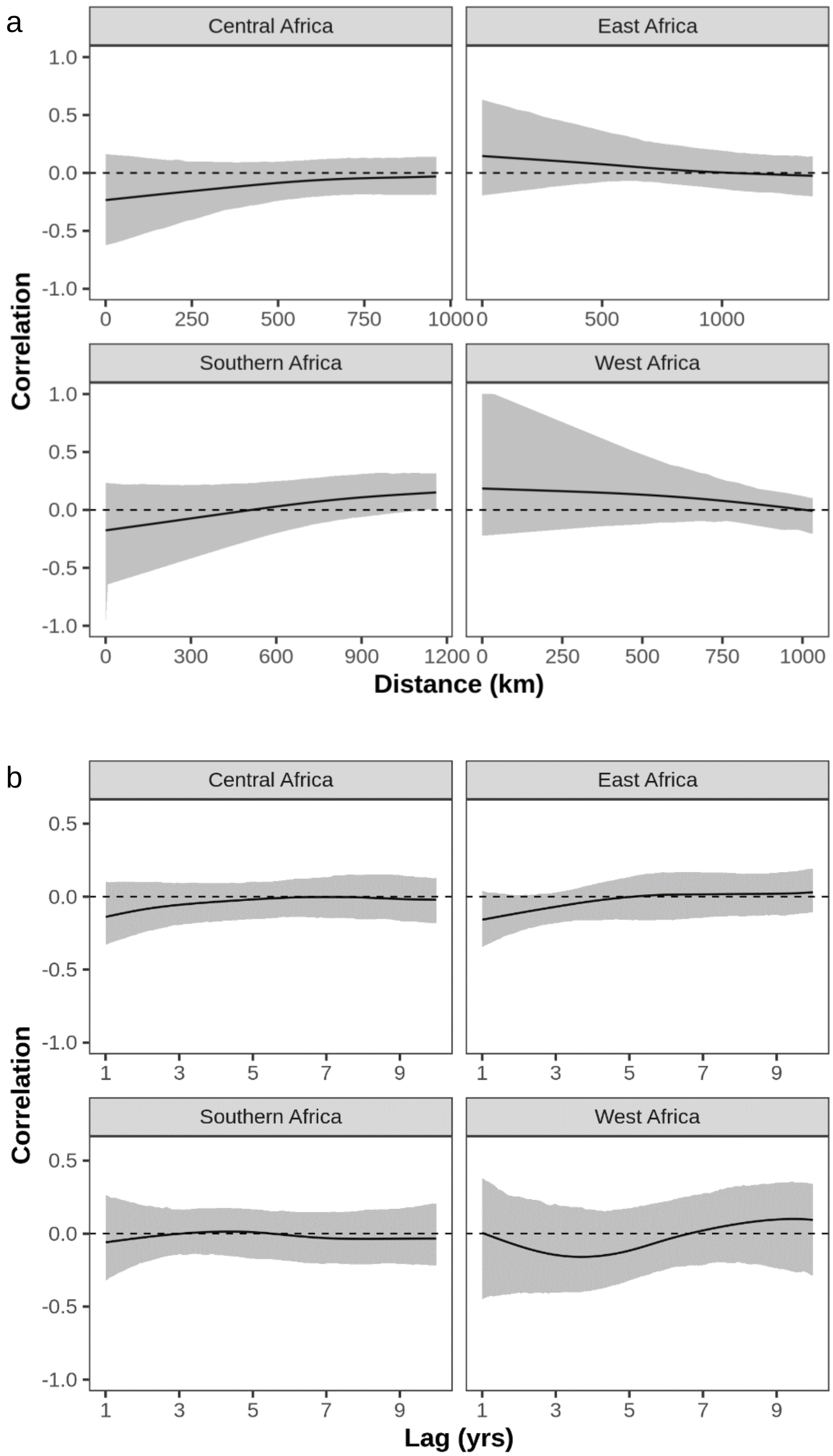
Supplementary Fig. S1 (cont'd)



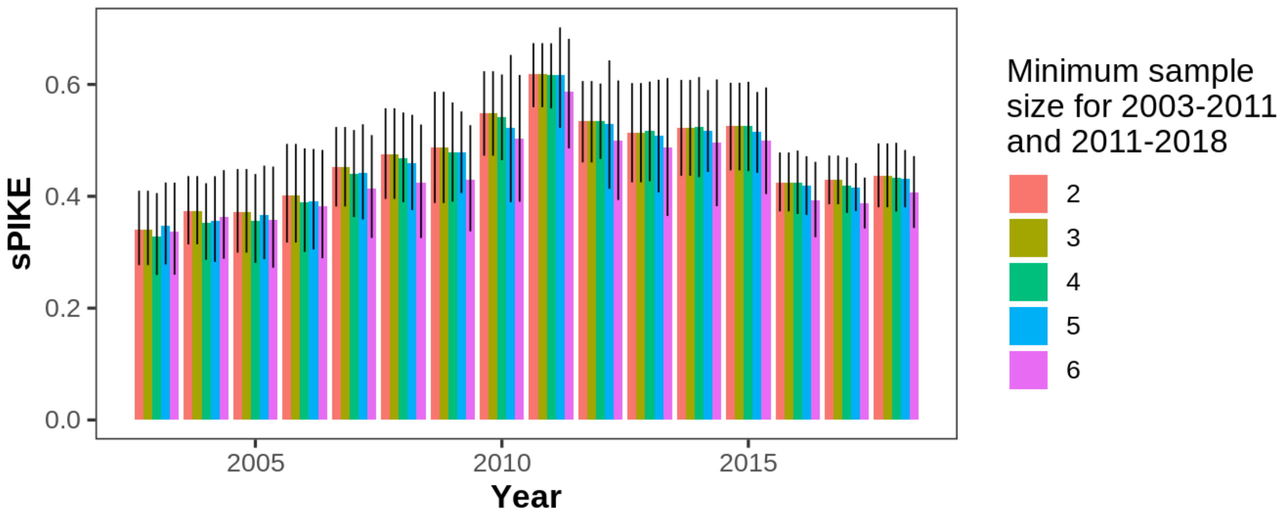
Supplementary Fig. S1 (cont'd)



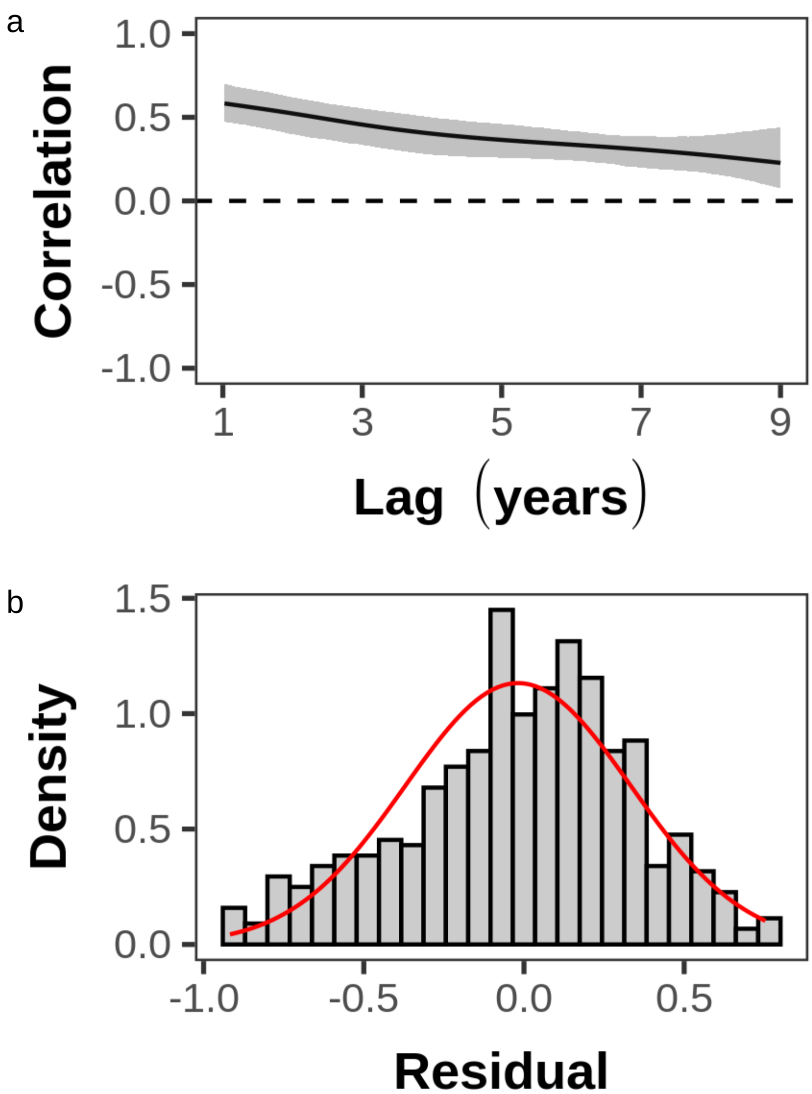
Supplementary Figure S2. (a) Spatial autocorrelation and (b) temporal autocorrelation in residuals of state-space models. Black lines indicate mean autocorrelation, and shading indicates bootstrapped 95% confidence intervals.



Supplementary Figure S3. Effects of alternate minimum sample sizes on continental sPIKE estimates from the state-space model. Bars indicate mean estimates; error bars indicate 95% confidence intervals.



Supplementary Figure S4. (a) Significant temporal autocorrelation and (b) non-normal residuals from the continental least-squares model for PIKE used by CITES. For (b), Shapiro-Wilks test for normality: $W = 0.98$, $P < 0.001$.



Supplementary Table S1. Estimated elephant populations on MIKE sites by year. Sources refer to reference numbers.

Country	Site	MIKE code	Year	Estimate	Source
Benin	Pendjari	PDJ	2003	713	1
Benin	Pendjari	PDJ	2015	1202	2
Benin	W du Burkina	WBF	2003	740	1
Benin	W du Burkina	WBF	2015	1040	2
Benin	W du Bénin	WBJ	2003	54	1
Benin	W du Bénin	WBJ	2015	521	2
Benin	W du Niger	WNE	2003	85	1
Benin	W du Niger	WNE	2015	0	2
Botswana	Chobe	CHO	2002	35317	2
Botswana	Chobe	CHO	2004	35570	2
Botswana	Chobe	CHO	2006	43417	2
Botswana	Chobe	CHO	2010	26609	3
Botswana	Chobe	CHO	2011	21061	2
Botswana	Chobe	CHO	2012	29468	2
Botswana	Chobe	CHO	2013	26598	2
Botswana	Chobe	CHO	2014	17448	4
Botswana	Chobe	CHO	2018	15404	5
Burkina Faso	Nazinga	NAZ	2003	548	1
Burkina Faso	Nazinga	NAZ	2012	893	6
Cameroon	Boumba-Bek	BBK	2004	318	6
Cameroon	Boumba-Bek	BBK	2008	2062	6
Cameroon	Boumba-Bek	BBK	2012	2062	6
Cameroon	Boumba-Bek	BBK	2015	143	6
Cameroon	Waza	WAZ	2002	987.5	7
Cameroon	Waza	WAZ	2007	246	6
Cent. Afr. Republic	Bangassou	BGS	1998	1600	6
Cent. Afr. Republic	Bangassou	BGS	2004	750	6
Cent. Afr. Republic	Dzanga-Sangha	DZA	2005	1035	6
Cent. Afr. Republic	Dzanga-Sangha	DZA	2012	797	6
Cent. Afr. Republic	Sangba	SGB	2005	708	8
Cent. Afr. Republic	Sangba	SGB	2010	68	9
Chad	Zakouma	ZAK	2002	4351	2
Chad	Zakouma	ZAK	2005	3885	2
Chad	Zakouma	ZAK	2006	3020	2
Chad	Zakouma	ZAK	2008	937	2
Chad	Zakouma	ZAK	2009	617	2
Chad	Zakouma	ZAK	2010	542	2
Chad	Zakouma	ZAK	2011	454	2
Chad	Zakouma	ZAK	2012	444	2

Country	Site	MIKE code	Year	Estimate	Source
Chad	Zakouma	ZAK	2014	443	[2]
Congo	Nouabale-Ndoki	NDK	2003	2652	[8]
Congo	Nouabale-Ndoki	NDK	2011	2324	[6]
Congo	Odzala-Kokoua	ODZ	2005	7460	[7]
Congo	Odzala-Kokoua	ODZ	2012	9292	[6]
Cote d'Ivoire	Marahoué	MAR	2002	159	[6]
Cote d'Ivoire	Marahoué	MAR	2010	0	[6]
Cote d'Ivoire	Taï	TAI	2002	53	[7]
Cote d'Ivoire	Taï	TAI	2010	189	[7]
DR Congo	Garamba	GAR	2007	3636	[2]
DR Congo	Garamba	GAR	2012	1717	[2]
DR Congo	Garamba	GAR	2014	1156	[2]
DR Congo	Okapi	OKP	2006	2698	[7]
DR Congo	Okapi	OKP	2011	1701	[6]
DR Congo	Salonga	SAL	2004	1186	[7]
DR Congo	Virunga	VIR	2003	286	[2]
DR Congo	Virunga	VIR	2006	348	[2]
DR Congo	Virunga	VIR	2010	347	[2]
DR Congo	Virunga	VIR	2014	35	[2]
Eritrea	Gash-Setit	GSH	2002	83	[6]
Eritrea	Gash-Setit	GSH	2006	104	[6]
Eritrea	Gash-Setit	GSH	2012	120	[6]
Eritrea	Gash-Setit	GSH	2014	100	[6]
Ethiopia	Babille	BBL	1998	65	[10]
Ethiopia	Babille	BBL	2005	264	[6]
Ethiopia	Babille	BBL	2009	324	[6]
Ethiopia	Babille	BBL	2014	250	[6]
Gabon	Lopé	LOP	2005	2350	[6]
Gabon	Lopé	LOP	2009	4142	[6]
Gabon	Minkébé	MKB	2004	34128	[11]
Gabon	Minkébé	MKB	2015	6956	[11]
Ghana	Kakum	KAK	2000	294	[7]
Ghana	Kakum	KAK	2004	164	[6]
Ghana	Mole	MOL	2004	259	[12]
Ghana	Mole	MOL	2006	401	[6]
Guinea	Ziama	ZIA	2004	214	[7]
Guinea	Ziama	ZIA	2011	101	[7]
Kenya	Mount Elgon	EGK	2002	139	[6]
Kenya	Mount Elgon	EGK	2015	200	[6]
Kenya	Samburu Laikipia	SBR	2002	5458	[13]
Kenya	Samburu Laikipia	SBR	2012	6365	[14]
Kenya	Samburu Laikipia	SBR	2014	7134	[2]
Kenya	Tsavo	TSV	2005	10356	[15]

Country	Site	MIKE code	Year	Estimate	Source
Kenya	Tsavo	TSV	2008	11592	[16]
Kenya	Tsavo	TSV	2011	12000	[17]
Kenya	Tsavo	TSV	2014	11144	[7]
Kenya	Tsavo	TSV	2014	13794	[2]
Liberia	Sapo	SAP	2009	124	[7]
Malawi	Kasungu	KSG	2005	58	[6]
Malawi	Kasungu	KSG	2014	40	[2]
Mali	Gourma	GOU	2002	322	[18]
Mali	Gourma	GOU	2007	344	[19]
Mali	Gourma	GOU	2015	253	[2]
Mozambique	Limpopo	LPP	2010	1425	[20]
Mozambique	Limpopo	LPP	2014	1081	[2]
Mozambique	Magoe	MAG	2003	1628	[21]
Mozambique	Magoe	MAG	2010	1465	[22]
Mozambique	Magoe	MAG	2014	1051	[2]
Mozambique	Niassa	NIA	2002	13061	[2]
Mozambique	Niassa	NIA	2004	12477	[2]
Mozambique	Niassa	NIA	2006	11833	[2]
Mozambique	Niassa	NIA	2009	20364	[2]
Mozambique	Niassa	NIA	2011	12029	[2]
Mozambique	Niassa	NIA	2014	4441	[2]
Namibia	Etosha	ETO	2002	2417	[6]
Namibia	Etosha	ETO	2004	2057	[6]
Namibia	Etosha	ETO	2011	3378	[6]
Namibia	Etosha	ETO	2012	2810	[7]
Namibia	Etosha	ETO	2015	2911	[6]
Namibia	Zambezi	ZBZ	2013	4435	[23]
Namibia	Zambezi	ZBZ	2015	8057	[6]
Nigeria	Yankari	YKR	1999	328	[12]
Nigeria	Yankari	YKR	2006	348	[7]
Nigeria	Yankari	YKR	2011	221.5	[7]
Rwanda	Akagera	AKG	2002	34	[6]
Rwanda	Akagera	AKG	2013	88	[6]
Senegal	Niokolo-Koba	NKK	2002	26	[12]
Senegal	Niokolo-Koba	NKK	2006	6	[12]
South Africa	Kruger	KRU	2003	11672	[2]
South Africa	Kruger	KRU	2004	11483	[2]
South Africa	Kruger	KRU	2005	12467	[2]
South Africa	Kruger	KRU	2006	12427	[2]
South Africa	Kruger	KRU	2007	13050	[2]
South Africa	Kruger	KRU	2008	12930	[2]
South Africa	Kruger	KRU	2009	13573	[2]
South Africa	Kruger	KRU	2010	13750	[2]

Country	Site	MIKE code	Year	Estimate	Source
South Africa	Kruger	KRU	2011	14454	[2]
South Africa	Kruger	KRU	2012	16571	[2]
South Africa	Kruger	KRU	2015	17086	[2]
Tanzania	Katavi Rukwa	KTV	2002	5160	[6]
Tanzania	Katavi Rukwa	KTV	2007	5302	[6]
Tanzania	Katavi Rukwa	KTV	2009	5359	[6]
Tanzania	Katavi Rukwa	KTV	2014	3250	[2]
Tanzania	Mkomazi	MKZ	2002	63	[17]
Tanzania	Mkomazi	MKZ	2005	41	[17]
Tanzania	Mkomazi	MKZ	2008	8	[17]
Tanzania	Mkomazi	MKZ	2011	256	[7]
Tanzania	Mkomazi	MKZ	2014	59	[6]
Tanzania	Ruaha Rungwa	RHR	2013	18562	[24]
Tanzania	Ruaha Rungwa	RHR	2014	7769	[2]
Tanzania	Selous Mikumi	SEL	2002	41021	[6]
Tanzania	Selous Mikumi	SEL	2013	10546	[25]
Tanzania	Selous Mikumi	SEL	2014	12304	[2]
Tanzania	Tarangire-Manyara	TGR	2000	2370	[2]
Tanzania	Tarangire-Manyara	TGR	2004	1886	[2]
Tanzania	Tarangire-Manyara	TGR	2006	1755	[2]
Tanzania	Tarangire-Manyara	TGR	2009	2245	[2]
Tanzania	Tarangire-Manyara	TGR	2014	4095	[2]
Togo	Fazao Mafakassa	FAZ	2002	61	[6]
Togo	Fazao Mafakassa	FAZ	2016	80	[6]
Uganda	Murchison Falls	MCH	2005	516	[2]
Uganda	Murchison Falls	MCH	2010	904	[2]
Uganda	Murchison Falls	MCH	2012	1617	[2]
Uganda	Murchison Falls	MCH	2014	1330	[2]
Uganda	Queen Elizabeth	QEZ	2000	1086	[2]
Uganda	Queen Elizabeth	QEZ	2002	998	[2]
Uganda	Queen Elizabeth	QEZ	2004	2497	[2]
Uganda	Queen Elizabeth	QEZ	2006	2959	[2]
Uganda	Queen Elizabeth	QEZ	2010	2502	[2]
Uganda	Queen Elizabeth	QEZ	2012	3018	[2]
Uganda	Queen Elizabeth	QEZ	2014	2913	[2]
Zambia	South Luangwa	SLW	2002	4459	[6]
Zambia	South Luangwa	SLW	2009	4419	[26]
Zambia	South Luangwa	SLW	2011	3855	[6]
Zambia	South Luangwa	SLW	2012	2813	[6]
Zambia	South Luangwa	SLW	2015	3302	[2]
Zimbabwe	Chewore	CHE	2001	5741	[27]
Zimbabwe	Chewore	CHE	2010	5048	[28]
Zimbabwe	Chewore	CHE	2014	3303	[2]

Country	Site	MIKE code	Year	Estimate	Source
Zimbabwe	Nyami Nyami	NYA	2001	2372	6
Zimbabwe	Nyami Nyami	NYA	2006	3715	6
Zimbabwe	Nyami Nyami	NYA	2014	411	2

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R Code to Conduct Analyses in the Paper

```
# Following is code to run the analyses in "State-space models reveal a continuing elephant poaching
# problem in most of Africa" by Schlossberg et al.

require(MASS)     # needed to use ginv(), the generalized inverse of a matrix
require(KFAS)     # package for running Kalman filter/smoother
require(car)      # needed to access a fast wcrossprod function
require(dplyr)
require(tidyr)
require(tibble)
require(psych)
require(ggplot2)
require(purrr)
require(furrr)
require(zoo)
options(stringsAsFactors = F)

###############################################################################################
#                                     Import and format data                                  #
###############################################################################################

#load MIKE data, available from https://www.cites.org/eng/prog/mike/index.php#Access%20to%20MIKE%20Data
# column names: "continent","region","regionID","country","ccode","site","site.name","year","tot","ill"
# tot = total number of carcasses reported; ill = number of illegally killed carcasses
mike=read.csv("mike_data.csv")

#load elephant population estimates (available in Supplementary Table S1) and join with MIKE data
ests=read.csv("population_estimates.csv") %>% as_tibble
mike.ests=full_join(mike, ests %>% select(-country,-site.name),by=c("site","year"))

#remove 2 sites with no elephant population size estimates
mike.ests= mike.ests %>% group_by(site) %>% filter(!all(is.na(estimate))) %>% ungroup
```

```
#linear interpolation of elephant population estimates for missing years

mike.ests=mike.ests %>% arrange(country,site,year) %>% group_by(site) %>% nest()
interpolate=function(df) {
   df.loc=df
   #add any missing years for 2003-2018
   df.loc=complete(df.loc,year=2003:2018,fill=
      list(region=df.loc$region[1],regionID=df.loc$regionID[1],site.name=df.loc$site.name[1],
      country=df.loc$country[1])) %>% arrange(desc(year))
   #if only one esetimate is available, use it for all years
   if(sum(!is.na(df.loc$estimate))==1) {
      df.loc$estimate.interp=df.loc$estimate[!is.na(df.loc$estimate)]
      return(df.loc)
   }
   nas=which(is.na(df.loc$estimate))
   ests.loc=df.loc$estimate
   interp=na.approx(zoo(x=df.loc$estimate),xout=nas) #Linear interpolation
   ests.loc[index(interp)]=interp
   #assign values prior to the earliest survey or after the latest survey
   ests.loc[(1:length(ests.loc)) > max(which(!is.na(df.loc$estimate)))]=
      ests.loc[max(which(!is.na(df.loc$estimate)))]
   ests.loc[(1:length(ests.loc)) < min(which(!is.na(df.loc$estimate)))]=
      ests.loc[min(which(!is.na(df.loc$estimate)))]
   df.loc$estimate.interp=ests.loc
   df.loc=filter(df.loc,year>2002) #2003 is the earliest year for analysis
   return(df.loc)
}
#run the interpolation and clean up
mike.ests=mike.ests %>% mutate(data=map(data, interpolate)) %>% unnest(data)
rm(ests,mike,interpolate)

#replace missing value for total carcasses with 10 (this is a placeholder and does not affect results;
# model cannot accept missing values for denominator)
mike.ests=mike.ests %>% mutate(tot=replace(tot,tot==0,NA))
```

```
##########################################################################################################
#                                         Run the Kalman smoother                                        #
##########################################################################################################

#function to run Kalman smoother for one region

runmods=function(rgn, min.pre=4, min.post=4) {
   #rgn = one regionID from "mike.ests" as a string
   #min.pre = minimum number of years with data for 2003-2011 to include a site in the analysis
   #min.post = minimum number of years with data for 2011-2018 to include a site in the analysis

   #select data from "mike.ests"
   mike=mike.ests %>%   filter(regionID==rgn) %>%
      group_by(site) %>%
      filter(sum(!is.na(tot[year<=2011]))>=min.pre & sum(!is.na(tot[year>=2011]))>=min.post) %>%
      ungroup() %>%
      mutate(tot=replace_na(tot,10))

   #create matrices with numbers of illegally killed and all carcasses; rows = years, columns = sites
   df.mv=mike %>% pivot_wider(values_from=c(ill,tot),names_from=site,id_cols=year)
   ill=df.mv %>% select_at(vars(matches("ill"))) %>% as.matrix #illegally killed carcasses
   tot=df.mv %>% select_at(vars(matches("tot"))) %>% as.matrix #all carcasses
   n_sites=length(unique(mike$site))

   #set up model
   model = SSModel(ill ~ -1+
      SSMcustom(Z = diag(1, n_sites), T = diag(1, n_sites),
            Q = diag(NA,n_sites),
            P1 = matrix(NA, n_sites,n_sites)),distribution = "binomial",u = tot)
   updatefn <- function(pars, model, ...) {
      Q <- diag(pars[1:n_sites])
      model["Q", etas = "custom"] <- model["P1", states = "custom"] <-crossprod(Q)
      model
   }

   #create initial estimates for sPIKE using actual PIKE values
   pike.init=ill/tot
   #because estimation is on the logit scale, 1's and 0's are not allowed in initial values
   pike.init[pike.init==1]=.9
   pike.init[is.na(pike.init)|pike.init==0]=.1
   init <- chol(cov(logit(pike.init)))
```

```
   #calculate initial values for process error variance
   fitinit <- fitSSM(model, updatefn = updatefn,
      inits = rep(c(log(diag(init)), init[upper.tri(init)]), 2),
      method = "BFGS")

   #calculate final values for covariance
   fit <- fitSSM(model, updatefn = updatefn, inits = fitinit$optim.out$par,
      method = "BFGS", nsim=250)

   #run filtering and smoothing algorithm (by default, KFS function filters and smooths)
   out=KFS(fit$model, nsim=1000)

   return(list(model=out, data=mike))
}

#run models for each region using parallel processing to reduce time required
plan(multisession,workers=4) #set up cluster
models=future_map(c("FS","FE","FW","FC"),runmods,.progress=T)
names(models)=c("FS","FE","FW","FC")


###############################################################################################
#                                   Summarize model results                                   #
###############################################################################################

#get predicted sPIKE values by site and year
   #fit = estimate on logit scale
   #lwr/upr = lower and upper 95% confidence limits
   #se.fit = standard error of estimate on logit scale

sPIKE_by_site = map_dfr(models,~{
   pred=fitted(.x$model) %>% as.matrix %>% logit
   n=dim(.x$model$V)[1]
   ses=map(1:n, function(site) sqrt(.x$model$V[site,site,])) %>% do.call(cbind,.)
   tibble(fit=gdata::unmatrix(pred),se.fit=gdata::unmatrix(ses)) %>% cbind(.x$data,.) %>%
      mutate(lwr=fit-1.96*se.fit,upr=fit+1.96*se.fit)
})
```

```
#plot predicted and actual values for individual sites by region on probability (not logit) scale

plot.region=function(reg) { #reg = 2-letter regionID value
   df=sPIKE_by_site %>% mutate_at(vars(matches("^fit$|lwr|upr")),psych::logistic) %>%
      filter(regionID==reg)
   ggplot(df,aes(year,fit))+
      geom_line(size=.25)+geom_ribbon(aes(ymin=lwr,ymax=upr),alpha=.3)+
      geom_point(aes(y=ill/tot,size=tot),fill=NA,shape=1,stroke=.2)+
            scale_size_area("Carcasses",max_size=3,breaks=c(1,10,100,300))+
      facet_wrap(~site.name,ncol=3)+theme_bw(7)+
      theme(aspect.ratio=0.7,panel.grid=element_blank(),legend.key.height=unit(0.7,"lines"))+
      xlab(expression(bold(Year)))+ylab(expression(bold(PIKE)))
}

plot.region("FS")+theme(legend.position="bottom")
plot.region("FE")+theme(legend.position=c(.8,.1))
plot.region("FC")+theme(legend.position=c(.83,.12))
plot.region("FW")+theme(legend.position=c(.72,.15))


##############################################################################################
#                                   Calculate regional sPIKE                                 #
##############################################################################################

#regional predicted values from KFAS model
sPIKE_by_region=

   #duplicate site data.frame to create a new region for entire continent with regionID = "AFR"
   bind_rows(sPIKE_by_site, sPIKE_by_site %>% mutate(region="All Africa",regionID="AFR")) %>%
   group_by(region, regionID, year) %>%

   #calculate weight for combining sites = (est. # of live elepants)/(sum of est. # of live elephants)
   mutate(weight=estimate.interp/sum(estimate.interp)) %>%
   summarize(n=sum(tot,na.rm=T),sPIKE=sum(logistic(fit)*weight),
      se_logit=sqrt(sum(se.fit^2*weight^2)), #logit scale std. error of sPIKE
      se_p=sPIKE*(1-sPIKE)*se_logit, #probability scale std. error of sPIKE via delta method
      #calculate sPIKE +/- 1 SE on probability scale
      sPIKE_se_upper=logistic(logit(sPIKE)+se_logit),sPIKE_se_lower=logistic(logit(sPIKE)-se_logit),
      #calculate sPIKE 95% confidence limits on probability scale
      lcl_p=logistic(logit(sPIKE)-se_logit*1.96),ucl_p=logistic(logit(sPIKE)+se_logit*1.96)) %>%
   ungroup()
```

```
#plot regional results including confidence regions for +/- 1 SE and +/- 95% CI

gplot(sPIKE_by_region, aes(year, sPIKE)) + geom_line()+
   geom_ribbon(aes(ymin=lcl_p,ymax=ucl_p),alpha=.3)+
   geom_ribbon(aes(ymin=sPIKE_se_lower,ymax=sPIKE_se_upper),alpha=.5)+
   facet_wrap(~region)+theme_bw(13)+theme(aspect.ratio=.7,panel.grid=element_blank())+
   xlab(expression(bold(Year)))+ylab(expression(bold(sPIKE)))


###############################################################################################
#                              Calculate trends in sPIKE by region                            #
###############################################################################################

#Feasible generalized least squares method from Lewis and Linzer (2005)
tr=function(x) { sum(diag(x)) } #trace of a square matrix

#function to run FGLS model

edvreg <- function(mod,omegasq,proportional=FALSE) {
   #  edvreg
   #     mod: Regression formula
   #
   #     omegasq: Nx1 vector of estimated sampling/error variances of the dependent variable
   #
   #     proportional: "True" if omegasq is only proportional to the sampling/error variances of
   #                   of the dependent variables
   #
   # Example call: res <- edvreg( y ~ x, omegasq = est.var.y )
   #
   # Some housekeeping stolen from John Fox's corchrane-orcutt implementation
   X <- model.matrix(mod)
   xnames <- colnames(X)
   y <- model.response(model.frame(mod))

   # When omegasq is known up to a proportion (for example 1/N_i) ...
   if (proportional) {
        residsq <- (resid(lm(y~X-1)))^2
      steptwo <- lm(residsq~omegasq)
        zeroeps <- FALSE
      if (coef(steptwo)[1] < 0) {
            warning("Variance of epsilon estimated to be negative! Setting to 0...")
```

```
            steptwo <- lm(residsq~0+omegasq)
            zeroeps <- TRUE
      }
      predval <- fitted.values(steptwo)
      if (sum(predval<0) < 0) {
         warning("Negative omegaSq estimates encountered, setting to 0.0001")
               predval[predval<0] <- 0.0001 # error check against very rare possibility of negative weight
      }
      model.FGLS <- lm(y~X-1,weights=(1/predval))
       model.FGLS$vareps <- ifelse(zeroeps,0,steptwo$coefficients[1])
       model.FGLS$omegasqFactor <- ifelse(zeroeps,steptwo$coefficients[1],steptwo$coefficients[2])
      model.FGLS$predval <- predval
   }
    # When omegasq is known exactly...
    else {
        N <- nrow(X)
        sigmahatsq <- (sum((residuals(lm(y~X-1)))^2) - sum(omegasq) +
                  tr(ginv(crossprod(X)) %*% wcrossprod(X,X,w=omegasq)))/(N-ncol(X)-1)
        if (sigmahatsq < 0) {
           warning(sprintf("SigmaHatSq estimated to be %7.4f, setting to 0...",sigmahatsq))
               sigmahatsq <- 0.0
        }
        w <- 1/(omegasq+sigmahatsq)
        model.FGLS <- lm(y~X-1, weights=w)
        model.FGLS$sigmahatsq <- sigmahatsq
    }
    names(model.FGLS$coefficients) <- xnames
    model.FGLS
}

#run models and summarize results for state-space models

trends_region=sPIKE_by_region %>% mutate(time=ifelse(year<=2010,"2003-2010","2011-2018")) %>%
   group_by(region,time) %>% nest %>%
   mutate(reg=map(data,~broom::tidy(edvreg((.x$sPIKE)~.x$year,.x$se_p^2)) %>% slice(2))) %>%
   unnest(cols=reg) %>% ungroup() %>% select(-data,-term) %>% mutate(type="State-space")
```