

Section A: Research Articles

Scott-Hayward LAS, Mackenzie ML, Walker CG, Shatumb G, Kilian JW, du Preez P, Hauptfleisch M, Cloete C (2025) Assessing the distribution pattern of elephant (*Loxodonta africana*) carcasses in Etosha National Park and its implications for management. *Namibian Journal of Environment* 10 A: 1–12. <https://doi.org/10.64640/d3hf8170>

Thomas B (2025) Understanding market, state and community institutions in the development of smallholder vegetable enterprises in north-west Namibia. *Namibian Journal of Environment* 10 A: 13–29. <https://doi.org/10.64640/yna6vq08>

Shiimi T (2025) Comparing conventional and conservation agriculture for multi-seasonal maize production in the Zambezi Region, Namibia. *Namibian Journal of Environment* 10 A: 30–39. <https://doi.org/10.64640/2b7j9a6d>

Section B: Short Communications

Theart F, Müller M, Klopfenstein M, De Villiers M, De Villiers L, Henn J, de Plessis C, Hauptfleisch M (2025) Movement ecology and post-release success of translocated Western Barred Spitting Cobras in the Khomas Region, Namibia. *Namibian Journal of Environment* 10 B: 1–5. <https://doi.org/10.64640/nz58sc84>

Gerstmeier G, Adlbauer K (2025) Re-encountering *Chemsakiellus taurus* (Coleoptera, Cerambycidae, Lamiinae), a little-known longhorn beetle, in Namibia. *Namibian Journal of Environment* 9 B: 6–8. <https://doi.org/10.64640/56a9xd62>

Roux J-P, Boorman M, Braby J, Braby RJ, Fijn RC (2025) A new longevity record for the Damara Tern *Sternula balaenarum*. *Namibian Journal of Environment* 9 B: 9–12. <https://doi.org/10.64640/d7a2m9b3>

Theart F, Engelking K, Klopfenstein M, Müller M, Berg P (2025) First record of African wildcat (*Felis lybica cafra*) preying on a small antelope, the Damara dik-dik (*Madoqua damarensis*). *Namibian Journal of Environment* 10 B: 13–16. <https://doi.org/10.64640/c7ma82b5>

Assessing the distribution pattern of African elephant (*Loxodonta africana*) carcasses in Etosha National Park and its implications for management

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ABSTRACT Mortality is an important component of understanding elephant population dynamics and disease ecology. We use carcass location data from Etosha National Park, Namibia, collected under the CITES Monitoring the Illegal Killing of Elephants programme, to assess the spatial distribution of elephant deaths, as identified through automated surface feature selection, and explore implications for park management. We modelled carcass location data using a regression spline framework, with targeted flexibility, a spatial term and additional environmental covariates (annual rainfall, distance to water and roads). The novel modelling approach chosen acknowledges the localised and patchy distribution of carcasses and recognises physical barriers (Etosha pan) to substantially reduce the risk of false conclusions about the location of elephant deaths in the park. Our results showed high carcass intensity close to waterholes (<2.5 km) and roads (<5 km) and in areas of the park with average rainfall (~450 mm annually). Some high-risk areas were identified, particularly in the north-east of the park, and the mortality risk did not always coincide with elephant distribution. These findings are useful for understanding population dynamics and drivers for the park's elephant population and park management, particularly for disease surveillance.

KEYWORDS African elephant; CITES MIKE program; disease; mortality distribution; Namibia; presence-only data; spatially adaptive

INTRODUCTION

The African elephant (*Loxodonta africana*) occurs across 37 African countries. Southern Africa holds the largest number of elephants on the continent (Thouless et al. 2016). It is the largest living

terrestrial mammal species and is of great conservation concern (Guldmond et al. 2017, Skinner & Chimimba 2005). On a continental scale, elephant populations are declining rapidly. As a result, the International Union for the Conservation of Nature (IUCN) recently reclassified the species'

conservation status as Endangered (Gobush et al. 2022). Reasons for this decline include habitat fragmentation and loss, unsustainable hunting, conflict with humans, and increasingly scarce resources due to a changing climate (Ripple et al. 2015, Chase et al. 2016).

Mortality is a key factor in understanding elephant population dynamics and monitoring disease. The recent Kavango-Zambezi (KAZA) elephant survey noted a large proportion of elephant carcasses compared to previous surveys (Bussière & Potgieter 2023). Poaching has often been the major focus of elephant mortality studies (Douglas-Hamilton 1987, Wittemyer et al. 2014, Beale et al. 2018, Kuiper et al. 2020), with other causes such as human-elephant conflicts, accidents and natural processes (e.g. disease) less studied. With few non-human predators, natural elephant mortality is often a consequence of food scarcity and water stress during droughts (Mukeka et al. 2022) or of diseases such as anthrax (Huang et al. 2023). However, accurately determining the true distribution of natural mortality may be challenging due to varying patrol effort and distribution of elephants being driven by resource availability and preferences (Kuiper et al. 2020).

In contrast to the rest of Africa, there has been little to no poaching of elephants reported in Etosha National Park (ENP), and the population in the country is apparently increasing (Craig et al. 2021). Elephant mortalities are mostly attributed to resource deficiencies, drought, and disease (Huang et al. 2023). Anthrax (*Bacillus anthracis*) is endemic to the park and a major cause of herbivore mortality, in particular elephant mortality (Lindeque & Turnbull 1994; Turner et al. 2013). The Convention on International Trade in Endangered Species (CITES) Monitoring of Illegal Killing of Elephants (MIKE) programme has been active in ENP for over a decade, and substantial resources are used to collect relevant abundance and mortality data through dedicated aerial surveys under strict survey protocols. Additionally, as part of routine park activities, opportunistic data and carcass detections from biennial helicopter block count surveys are also recorded. Together these form the elephant mortality database for ENP. To date, these data have only been reported to the MIKE project and not analysed on a spatial scale. Analysis of carcass distribution and density could

be advantageous for management of elephants, their resources and disease in ENP.

Statistical modelling of these data is useful since the park is very large (~23 000 km²) and regardless of the survey regime, the observed counts will undoubtedly comprise a subset of total mortalities. Reliable modelling results which accurately estimate the magnitude and location of elephant mortality in ENP are also not guaranteed and require careful consideration of two important factors, namely the largely unused salt pan and the heterogeneous distribution of elephants due to habitat selection and the presence of surface water. Failing to account for the possibly unusual spatial patterns in these data and/or assuming points across the pan are as closely linked as equidistant points without a physical barrier, can unwittingly lead to false conclusions about the magnitude and location of elephant deaths in the park.

This study uses the Complex Region Spatial Smoother (CReSS) to analyse elephant mortality patterns in ENP while considering linear and non-linear covariates. CReSS is a regression spline based statistical modelling method equipped to address both aspects of these data (Scott-Hayward et al. 2014). Spline based regression is a well-established method for estimating relationships when the relationship between the response (mortality) and a set of covariates is unknown and likely non-linear. Splines can return reasonable results with few parameters but can also approximate a wide range of smooth functions. In a regression spline approach the curve flexibility is determined by judicious placement and number of 'knots'. In the CReSS method, straight-line (Euclidean) or 'around the salt pan' (Geodesic) distances can be used to underpin the fitted surface and the method is 'spatially adaptive', which means the flexibility can be targeted to accommodate any particularly patchy trends and/or local surface features (Scott-Hayward et al. 2014, 2015).

While useful, the CReSS method undertakes the crucially important model selection process using a model-averaging approach which can be computationally intensive. Use cases have also shown that this can mask unusual spatial patterns. Walker et al. (2010) presented an algorithm for adaptively placing knots called SALSA (Spatially

Adaptive Local Smoothing Algorithm). This ‘adaptive knot selection’ approach, results in a number and location of the knots which combines a local-search strategy with a restricted forward/backward regression approach for efficient selection. In this paper, we propose using CReSS with a novel automated model selection approach, SALSA2D, (based on Walker et al. (2010)), to identify atypical spatial distributions and reveal patterns, which have implications for park management in this case.

The aim of this study is to investigate the spatial distribution of carcass locations in ENP and whether the distribution and density of elephant carcasses is related to annual rainfall, their distance from waterpoints and distance from roads. We use the CReSS radial basis function (Scott-Hayward et al. 2015), introduce the novel SALSA2D algorithm, for model selection, and apply these methods to presence-only data – the spatial locations of carcasses (presences) – to develop a spatial model to predict the risk of elephant mortality across the park. In a large national park, early detection of carcasses allows for enhanced monitoring and management interventions. We hypothesise that elephant deaths are influenced by environmental factors and not merely by the distribution and density of live elephants in ENP.

METHODS

Study Area

ENP covers over 22 000 km² of Namibia’s northern arid savanna. Rainfall varies from approximately 500 mm per annum in the east, decreasing westwards to about 250 mm. The Etosha Salt Pan covers 4 812 km² and is largely void of vegetation and mostly dry, except for small periods of the rainy season from January to April. The park sustains important populations of most of Africa’s large mammals, including a high density of southern black rhino (*Diceros bicornis bicornis*) and an elephant population of approximately 2 900 (Craig et al. 2021). The population is growing slowly at approximately 1.75% per year, compared to 4.75% in the Zambezi region and 4.85% in the Khaudum-Nyae-Nyae complex (Craig et al. 2021). Most surface water is pumped from underground into artificial waterholes where large herds of wildlife congregate to drink. A small number of natural springs occur mostly in the east. An

extensive road network covers the central and east of the park with limited management roads and firebreaks across the remaining area.

Data Description

The MIKE data (MIKE 2018) consists of 320 carcass locations observed between February 2000 and March 2017 in ENP. The survey protocol for MIKE was published by Craig (2012) and these dedicated aerial surveys are supplemented by approximately biennial helicopter block count surveys, during which carcasses may be recorded. As most of the carcass data are from dedicated surveys, this minimises the possibility of patrol bias driving the distribution of carcasses. The observed fatalities were recorded as being due to anthrax, natural (age-related) causes, poaching and unknown. While a substantial proportion of the carcasses were recorded as being for ‘unknown’ reasons (54%) the largest known cause of death is from anthrax (27.8%; 12.5% confirmed cases and 15% suspected). Less than 1% of the carcasses were confirmed as poached. All reported carcasses were used in the analysis regardless of type. Disregarding 2017 as it was only a partial year, 2006 and 2014 had the fewest recorded carcasses (7–8), whilst 2002, 2003, 2005 and 2011 had the highest recorded (27–28) (Figure 1). As there were a relatively small number of observations per year, no guarantee the deaths occurred in the year of detection and no obvious changes in the spatial pattern of observations, the data were pooled across all years. There was also no evidence that

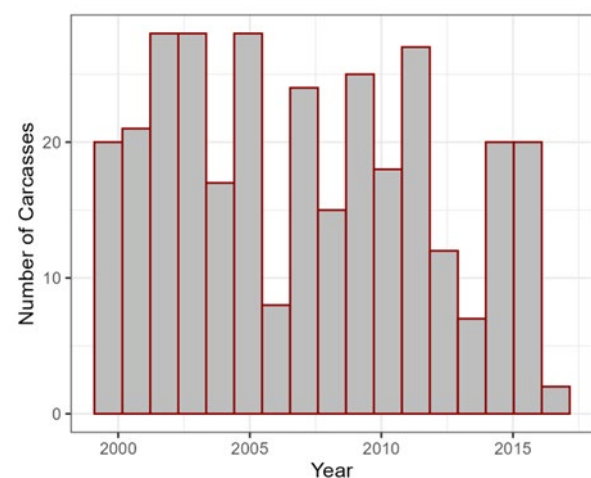


Figure 1 Number of elephant carcasses detected in Etosha National Park, by approximate year of death. The years are estimated based on the condition of the carcasses when found.

there were any differences in spatial patterns when dividing the time series into three equal time periods (2000–2005, 2006–2011, 2012–2017) (space-time Monte Carlo test; $p > 0.95$; Diggle et al. 1995).

Coordinates were converted from WGS84 (World Geodetic System) to Universal Transverse Mercator (UTM) zone 33S and the study region was extended beyond the ENP boundary by 20 km to include carcasses just outside the park. Additionally, the large salt pan was reduced in size by 2 km to include carcasses found near the edge of the pan. The data show that carcasses seem to occur near roads (or, at least, are more commonly observed there) and waterholes (Figure 2). While it is possible that these patterns are due to opportunistic reporting of carcasses as a result of park vehicles moving along the roads, the data were from both opportunistic and dedicated surveys, which are carried out without reference to roads. Furthermore, the movement patterns of collared elephant in ENP do utilise roads/tracks and fire breaks extensively and are known to frequent waterholes (Chamaillé-Jammes et al. 2007, Tsalyuk et al. 2019). Anthrax-related deaths appear to be particularly well correlated with waterholes (Figure 2).

Data Analysis

Density of elephant carcasses, based on the presence and (pseudo-) absence of carcass locations, was modelled using four candidate covariate terms: distance from the nearest road, distance from the nearest water point, mean annual

rainfall and a spatial term based on spatial coordinates. Distance from nearest road and nearest waterhole metrics were considered as candidates in the model to reflect differential mortality rates near roads and waterholes, where that exists. Mean annual rainfall was based on rainfall data collected from 168 rain gauges distributed across ENP which are visited annually, when possible. When annual data were unavailable, this metric was averaged across years for each gauge before detailed interpolation ($df = 150$) to indicate areas with persistently high or low rainfall. Details on the rainfall interpolation can be found in Section 1 of [Appendix 1](#).

Proximity to waterholes was included since elephants frequent waterholes, particularly in the dry season (Tsalyuk et al. 2019) and inhabit areas close to water (Harris et al. 2008). In addition to distribution-based mortality it is thought that anthrax-related deaths may be related to the presence of waterholes (Zidon et al. 2017). The reasons for trialing proximity to roads in the model were due to elephant use of roads for travel (Tsalyuk et al. 2019), and therefore possible increased detection near roads (e.g. easier to observe).

The spatial term was considered to represent spatial patterns in mortality which are not adequately explained by proximity to the other covariates. This term is crucial here - correctly identifying systematic spatial patterns in mortality might provide insights about park features not

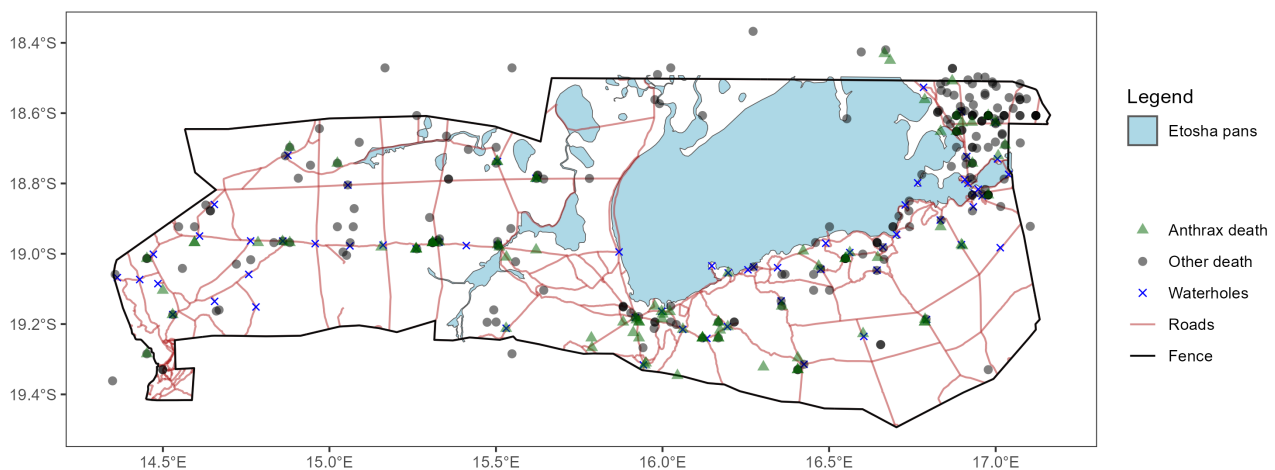


Figure 2 The study area with carcass locations. Green triangles show confirmed or suspected anthrax cases and grey circles all other types of death (natural causes, poaching and unknown). To visualise overlapping points, the colours are semi-transparent, therefore a darker shape indicates overlapping carcass locations.

currently thought related to mortality and overlooking these prevents the mitigation of future elephant mortalities, particularly those related to poaching.

In this dataset, while the carcass locations were available, the survey tracks were not, and so carcass-free locations were estimated for subsequent modelling. The number of carcass locations per unit area ('intensity') was modelled against selected covariates in the study region. 'Intensity' is a relative measure and gives the expected abundance of carcass sightings for a given area. Here, we also use the link between logistic regression and an inhomogeneous Poisson point process model (PPM; Warton & Shepherd (2010)) and the downweighted Poisson regression method (Renner & Warton 2013) to fit a Poisson PPM using a pure regression generalised additive model (GAM) framework. This results in a basic PPM with flexible smooth terms (sometimes referred to as resource selection functions). Pseudo-absences play the role of quadrature points in point process modelling and were selected as a regular grid and the number was based on convergence of the likelihood (Renner & Warton 2013).

Method description

The CReSS approach fits pure spatial regression models to a set of coordinates \mathbf{z}_i of the form:

$$g(\mathbf{y}_i) = \eta_i = \beta_0 + s(\mathbf{z}_i) = \mathbf{X}_i \boldsymbol{\beta} \quad (1)$$

where g is the link function and η the linear predictor. \mathbf{s} is a two-dimensional surface approximated by a linear combination of K exponential basis functions, $bE(h, r)_k$. Each of the k basis functions can be considered as a covariate in the linear predictor and so in matrix form, \mathbf{X} is the design matrix with $K + 1$ columns (K bases and the intercept) and $\boldsymbol{\beta}$ the vector of coefficients.

In each basis function, the range parameter, r , dictates the extent of the decay of the exponential function with distance between points, and thus the extent of its local nature. h indicates a geodesic or Euclidean distance (for some observation i and the k -th knot location). Optional distance metrics are a very useful feature of the CReSS approach as the large salt pan effectively acts as a hole in the domain. This means that distances between points

must be incorporated as the elephant travels (geodesic), not as the crow flies.

Parameter r takes values such that if r is small the model will have a set of relatively local basis functions and if r is large the model will have a set of relatively global basis functions. The exact values of r are dependent upon the range and units of the spatial covariates.

Every data point can be chosen as a knot location, so deciding which basis functions to include in the surface is a standard covariate selection problem. The CReSS with model averaging procedure (Scott-Hayward et al. 2015) fits multiple models with each model evaluated at one of a variety of parameter values for the number of space-filled knots, K , and the effective range parameter r_k . This paper presents CReSS with SALSA2D, which uses the same model framework as for model averaging (Equation 1) but where the best knot locations are chosen using automatically using an iterative procedure. The SALSA algorithm is not a complex modelling algorithm, rather it is a covariate selection method with three intuitive steps and is presented here as it provides an effective tool for non-technical modellers to automatically select which knots to include in the spatial surface.

The algorithm works in (at least) two dimensions and begins with space-filled knots to facilitate spatial coverage and then adaptively moves, adds and drops knots into, or from, locations in line with poor model fit (evidenced by large residuals) and an objective fit criterion. At each stage, the global/local extent of each basis function, via the r value employed, can also be revised as part of the search for a more appropriate surface. So, unlike the model averaging approach, SALSA2D returns one model with specifically selected K and r_k enabling standard regression methods for assessment of fit and uncertainty estimation. Further details on the algorithm and a full comparison of the model averaging vs SALSA2D approach can be found in Section 3 of the supplementary material, [Appendix 1](#).

The SALSA2D algorithm is implemented inside the MRSea R package (Scott-Hayward et al. 2024, R Core Team 2024) for easy use by practitioners (<http://lindesaysh.github.io/MRSea/>).

Model specification

We modelled the intensity of elephant carcass locations as a function of distance to water, roads, mean annual rainfall and as a spatially adaptive smooth function of spatial coordinates. The locations of the carcasses were modelled jointly with the pseudo-absences by maximising the following weighted Poisson log-pseudolikelihood (Berman & Turner 1992):

$$l(\boldsymbol{\beta}; \mathbf{X}) = \sum_{i=1}^N w_i \left(y_i \log(\lambda(\mathbf{X}_i)) - \lambda(\mathbf{X}_i) \right) \quad (2)$$

where $\lambda(\mathbf{X}_i)$ is the intensity at location i , \mathbf{X}_i represents the design matrix at location i , N is the total number of points (presence and pseudo-absence), $\mathbf{w} = \{w_1, \dots, w_N\}$ are quadrature weights. $y_i = \frac{1}{w_i}$ if i is a presence location and $y_i = 0$ for a pseudo-absence.

The log-pseudolikelihood in Equation 2 is a re-expression of the Poisson PPM log-likelihood (Cressie 1993), which means that models can be fitted using standard software. Here we model the expected number of carcasses per km² and so the weights for the pseudo-absence points are specified as the area of the study region, 37 872 km² (ENP plus the 20 km buffer) divided by the number of pseudo-absences. The weights for presence points are set to some small value (10^{-6}).

Likelihood convergence was used to determine the number of pseudo-absences which was estimated to be 9 644 (a grid spacing of 2 km). For more details see Section 2 of [Appendix 1](#).

The GAM model specification was:

$$\begin{aligned} \log(\lambda(\mathbf{X}_i)) &= \eta_i \\ &= \beta_0 + s_1(\text{distWater}_i) + s_2(\text{rainfall}_i) + s_3(\text{distRoads}_i) + s_4(\mathbf{z}_i) \\ &= \mathbf{X}_i \boldsymbol{\beta} \end{aligned}$$

In this case, $\lambda(\mathbf{X}_i)$ is the intensity at location i and \mathbf{X}_i represents the coordinates and environmental covariates (design matrix). $s_1 - s_3$ represent one-dimensional basis functions, while $s_4(\mathbf{z})$ represents a two-dimensional exponential basis function for the spatial coordinates. $\boldsymbol{\beta}$ is a vector of model parameters associated with all columns of the design matrix, \mathbf{X} . The columns of \mathbf{X} comprise the

intercept, spline bases for water, rainfall and roads and the exponential radial bases for the spatial term.

Specifically, quadratic B -splines with SALSA based knot selection (Walker et al. 2010) were used to implement the one-dimensional smooth terms for water, rainfall and roads. The two-dimensional smooth was an exponential basis with Euclidean distances. Knot number, their locations and r_k values were chosen using the SALSA2D algorithm. We used the outputs from a small methods comparison exercise to determine the starting parameters for SALSA2D. The details of this study can be found in Section 3 of [Appendix 1](#). The Bayesian Information Criterion (BIC; Schwarz 1978) was used to govern model selection in all cases. BIC is an information criterion approach to model selection that trades off model fit (the loglikelihood of the model; LL) with the number of estimated parameters (k):

$$\text{BIC} = -2\text{LL} + k \log(n)$$

Where n is the number of data points and in this study is equal to the number of carcass locations, 320. Models with a smaller BIC score are selected for.

Lastly, to determine areas of poor fit, the exchange step requires the calculation of residuals. This was achieved by creating a neighbourhood around each knot location, k , and comparing the observed number of points with the sum of the estimated intensities in the same area. For more details, see Section 3.3 of [Appendix 1](#).

RESULTS

Carcass intensity, the expected abundance of carcass sightings for a given area, is clearly highest near waterholes, roads and locations where annual rainfall is approximately 450 mm (Figure 3). Of these three covariates, the distance to waterhole term has the strongest influence on carcass intensity. Specifically, intensity decreases steeply with the distance from water until approximately 5 km when the relationship subsides. Distance to roads has a smaller effect on carcass intensity and with a less steep decline in intensity to that of distance to water. The relationship flattens off toward zero intensity at approximately 10 km.

The addition of distance from waterholes, distance from roads and mean annual rainfall to the spatial term, improved model results when compared with model results based on a SALSA2D-based spatial term alone (Models 2 vs 3 in Table 1; the BIC scores substantially improved from 11 038 to 2 021).

The spatial term also contributed positively to the model, despite the extra parameters required (Table 1); the BIC score decreased from 2 144 for the univariate model (Model 1) to 2 021 when the

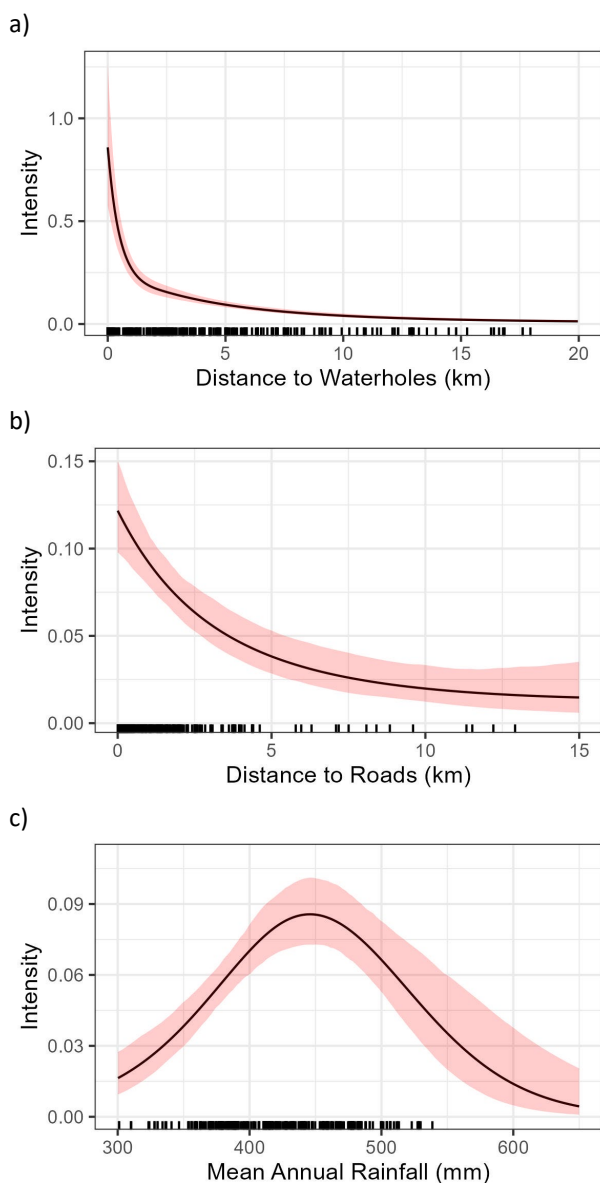


Figure 3 The estimated relationships, from the best model, of each variable to carcass intensity: (a) waterholes, (b) roads and (c) annual rainfall. The red shaded area/line is a 95% confidence interval about the estimated relationship. Tick marks at the bottom of each plot show the distribution of the observed carcass locations across each covariate.

spatial term was included (Model 2). The practical consequences of its inclusion were clearly evidenced by tempering the ‘global’ effect of roads and water which was implicit in the model that included the additional variables (Figure 4a). In some cases, the road and water effects diminished altogether where carcasses were not seen in the data. Crucially, this spatial term also better accommodates carcass locations which are not explained by only their proximity to water, distance to roads or average annual rainfall. Figure 5 shows that in Model 1, the waterhole relationship dominates with a peak of intensity at each one. When the spatial term is added, the waterhole peak is suppressed at a number of waterholes and even increased at others. The peak in intensity is shifted to the north which is in keeping with the high number of carcasses observed there. Overall, our modelling shows that most, but not all, waterholes and some roads have high carcass intensity. Figure 4b shows the top 5% highest carcass intensity areas which form the highest risk areas in the park. These are mainly in the northeast of the park and in the area around Okaukuejo (central south of the pan).

DISCUSSION

We have demonstrated a strong relationship between mortality of elephants and distance to waterholes. Elephants are highly dependent on surface water for drinking, thermoregulation and parasite control (Bothma & du Toit 2010). It is therefore not surprising that carcasses are mostly found near waterholes as a direct factor of distribution density. This relationship extends to

Table 1 Model selection results for the one dimensional smoother-based relationships only (Model 1) and the model with both one and two-dimensional smoothers (Model 2). Model 3 is the model with only a two dimensional smooth. *df* is degrees of freedom of each model term and LL is the Log-Likelihood score. The BIC score in bold is the best selected model.

Model	Term	<i>df</i>	χ^2	<i>p</i> -value	LL	BIC
1	s(rainfall)	3	< 0.0001		-1048.7	2143.5
	s(distRoads)	3	< 0.0001			
	s(distWater)	3	< 0.0001			
2	s(rainfall)	3	< 0.0001		-886.3	2020.6
	s(distRoads)	3	< 0.0001			
	s(distWater)	3	< 0.0001			
	s(xcoord, ycoord)	35	< 0.0001			
3	s(xcoord, ycoord)	52	< 0.0001		-5496.4	11038

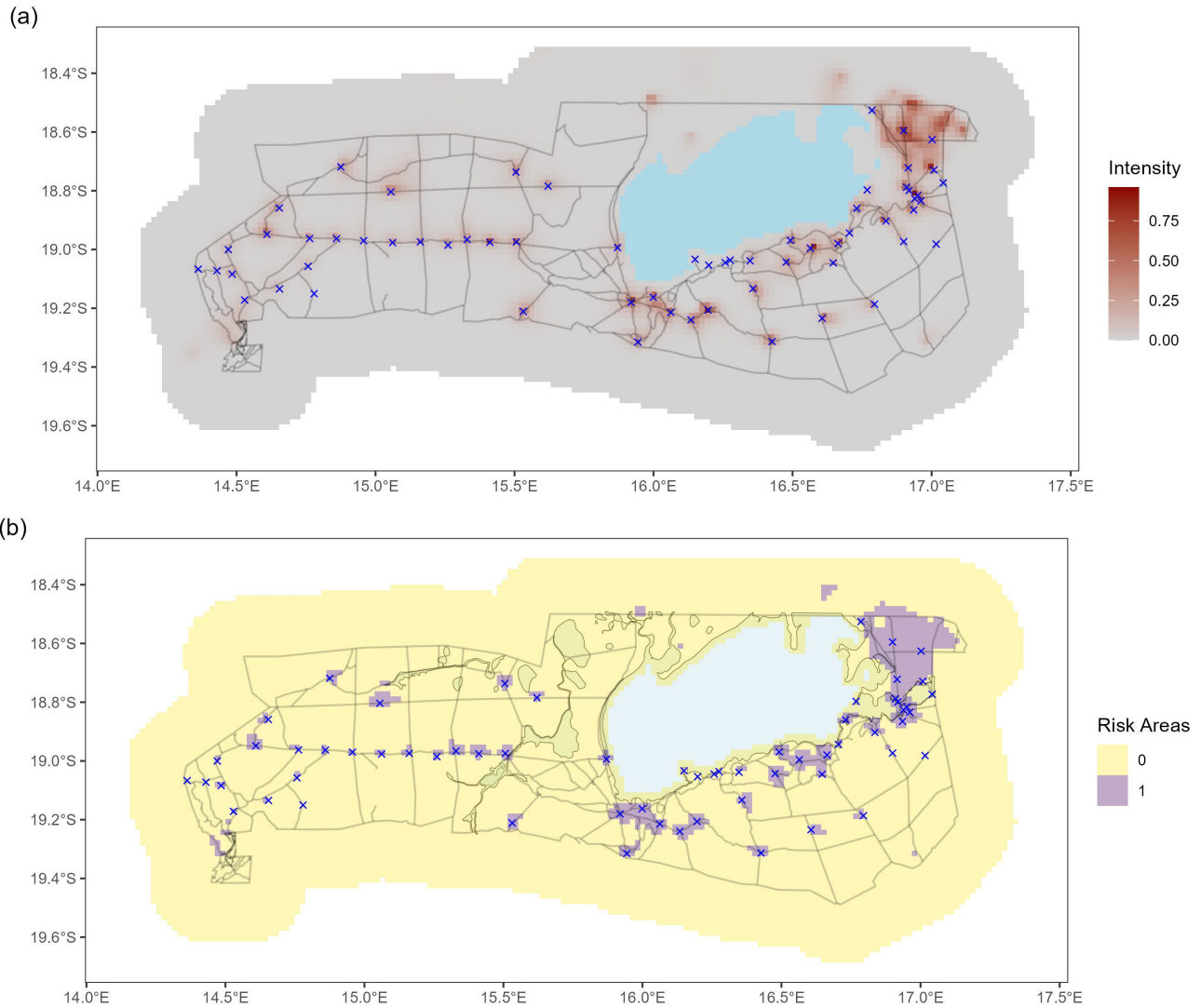


Figure 4 (a) Estimated carcass intensity (the expected number of carcass sightings in a 4 km² area), throughout the study region using the best model, Model 2. (b) The top 5% intensity areas are highlighted to show the areas with the highest risk of mortality in the park. The blue is the Etosha salt pan, the blue crosses are waterholes, and the black lines are roads.

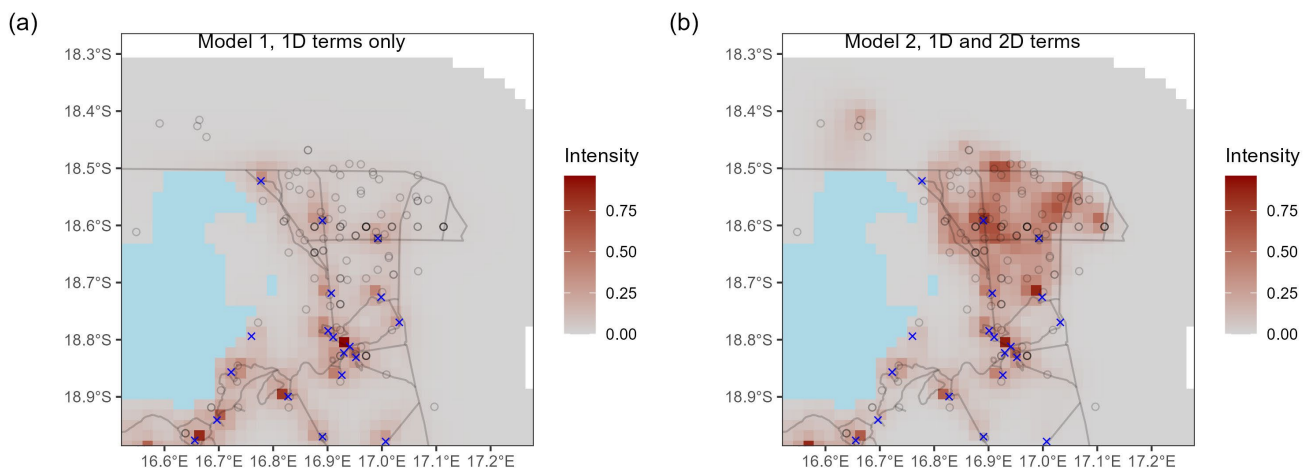


Figure 5 The estimated carcass intensity (the expected number of carcass sightings in a 4 km² area), for the north-east part of the study region for (a) Model 1 (1D variables only) and (b) Model 2 (1D variables and spatial term).

roads, albeit not as strongly as for waterholes. Many waterholes are provided along tourist roads to increase wildlife viewing potential; hence the distribution of waterholes and roads are similar, resulting in a similar probability of carcasses from each variable. Outside of protected areas, elephants often avoid roads to reduce the risk of persecution (Cushman et al. 2010), however, ENP's elephants face few anthropogenic threats and are habituated to tourist vehicles. The elephants likely use the roads to traverse the landscape when the pan and clay areas adjacent are muddy or waterlogged or bush is particularly dense.

Generally, and especially in large parks, wildlife data collection effort is often heavily biased by the spatial extent of roads (Bothma & Du Toit 2010) and can lead to patrol bias, giving a false sense of the true distribution and density of carcasses. The majority of the carcass data analysed here were from dedicated surveys, designed to reduce the potential effects of bias from using roads/tracks. Patrol bias is therefore considered to be minimised in this case.

Simply including proximity to waterholes and roads in the model assumes that any relationships pertain to all waterholes/roads regardless of their location. However, not all roads/waterholes have been associated with carcasses. The addition of the spatial term, with novel spatially adaptive knot selection using SALSA2D was able to suppress/enhance the global relationships with the environmental covariates in particular areas. This resulted in the identification of some critical areas of the park, which is important for effective park management – for example, in terms of disease outbreak, which after 'unknown' was the largest category in the data. It is impossible to patrol the large park area at random and there are areas of the park identified here (particularly those accessed by a subset of roads/waterholes) that are shown to necessitate more monitoring efforts than others.

Elephants are highly mobile and so early detection of carcasses, in particular anthrax-related deaths, is important to identify and monitor disease outbreaks across the park (Lindeque & Turnbull 1994). The area of high intensity of carcasses to the south of the main pan matches well with the area of high anthrax risk identified by Dougherty et al. (2022). This is also the area where the majority of

anthrax or suspected anthrax cases were found in our database. Specifically, we show here that within this anthrax risk area the highest intensity of carcasses is near the waterholes. This is in line with the findings of Ebedes (1976) and Lindeque & Turnbull (1994) where animal activity in the overgrazed bare soil areas around Etosha's artificial waterholes stir up dust-borne anthrax spores which are inhaled by wildlife. In addition, the finding of carcasses closely associated with waterholes is not surprising given several studies report a preference for animals to be close to water (e.g. Harris et al. 2008, Wilson et al. 2021).

In the critical high carcass intensity area identified in the north-east of the park, the cause of death is less clear as the majority of carcasses were of unknown cause. This could be because many of these carcasses were detected during aerial surveys and samples collected were of inadequate quality to establish disease as the cause of death. However, it is interesting to note that the water sources in ENP are a mix of boreholes and springs, with most springs occurring in the north-east. It is possible that in this region, there is higher water stress during drought which may play a role in mortality.

Whilst the density of elephants across the park is shown to be fairly constant (Craig et al. 2021), we have found that the density of carcasses is not. Mortality is one of the key components in population dynamics models and the effects of spatial and temporal heterogeneity must be accounted for to have accurate predictive models for use in conservation and park management (Sibly et al. 2009). This provides valuable input into better understanding dynamics in ENP's elephant population. For example, it is well known that surface water availability drives the distribution and abundance of elephants, and that artificial manipulation of water availability is one of the tools available for the management of elephant populations (Chamaillé-Jammes et al. 2007). ENP, however, has adopted a mostly passive management strategy, which may preclude water source manipulation as a management tool. In light of the probable impacts of climate change on surface water availability, understanding the linkage will be important for park management. It would also be of value to look at the carcass distribution of other large mammals to determine whether population-driven mortalities,

anthropogenic factors, environmental factors, or a combination of these play a role. In this arid savanna system, rainfall is low and erratic, and a key driver of wildlife movements (Hering et al. 2022). The impact of this on anthrax epidemiology is also not well understood and rainfall as a factor could assist predictive elephant population dynamics aiding management of the species in ENP.

If the deaths are natural and, for instance, disease-related (e.g. anthrax) then this provides valuable information about the prevalence and locale of disease in the park. Endemic anthrax occurs in ENP annually (Turner et al. 2013) and plays an important role in elephant population regulation or limitation. The monitoring of the prevalence of anthrax in elephants is important, because it advances our knowledge of a top-down factor limiting a mega-herbivore.

Even though the poaching of elephants in ENP is low (20 deaths reported to MIKE in 2018 and none poached), the general trend of animal poaching in Namibia in more recent years is increasing (GRN 2023). As the number of human-related elephant deaths increases it is very useful knowledge to have a baseline distribution of natural deaths. It is also very important in light of the mass death events seen in Botswana in 2020 and 2021 (Karombo 2021). Understanding the prevalence of natural mortality may provide insights should such events ever occur in ENP.

Critchlow et al. (2017) developed a method for improving the efficiency of ranger patrols using ranger-collected monitoring data. Ranger patrols are not just important for law enforcement but also the conservation of key species as well as ecological monitoring. With limited resources available for patrols, the key is to ensure that the patrol effort is efficient with respect to the activity one wishes to combat. The starting point for the method presented by Critchlow et al. (2017) is a least one geographical map of illegal activity occurrence. However, the activity does not need to be an illegal one and in this case the activity of interest could be risk of disease outbreak. Along with a map of existing ranger effort, the carcass intensity maps presented here could be used to assess and target the existing ranger effort in the park without the need for increased resources. Natural mortalities may be indicative of underlying ecological or

anthropogenic problems, which adaptive park management could address.

In future studies, if a more precise date of death is available, it is possible that the use of more dynamic predictor variables, such as NDVI or fire risk, could improve the model-based outputs. In addition, recording and acknowledging the effort associated with collecting the data (i.e. reporting tracks flown) would enable known zeros (absence of carcass) to be included in the modelling framework and likely further improve estimation. Should poaching increase in ENP, then the novel methods presented here can provide necessary information about the prevalence, locale and patterns of these deaths. Moreover, should poaching occur in areas of low natural mortality risk, then increased or targeted mitigation measures can be efficiently actioned. From a practical perspective, understanding both the magnitude and spatial patterns of elephant deaths in ENP may assist in adapting patrol efforts in and around the park to track the anthrax disease and/or combat any poaching activities.

SUPPLEMENTARY MATERIAL

See [Appendix 1](#) Section 1 for information on the rainfall model, Section 2 for pseudo-absence selection and Section 3 for more detailed SALSA2D information and the model averaging vs SALSA2D comparison.

The code and data for the analyses in this paper can be found at the github site of the corresponding author: https://github.com/lindesaysh/Elephant_carcass_paper.

AUTHOR CONTRIBUTIONS

LSH, MLM and CGW contributed to method development, analysis and manuscript writing. MH contributed to interpretation of results and manuscript writing. CC, GS, JWK and PdP contributed to data collection, local information, reviewed and edited the manuscript.

ACKNOWLEDGEMENTS

We thank the Namibian Ministry of Environment, Forestry and Tourism and the staff at the Etosha Ecological Institute for the recording of carcass locations and maintenance of the mortality database. We also thank Dr. Richard Glennie for his assistance and patience with PPM queries and reading a draft of the paper and one anonymous reviewer who helped improve this paper.

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Assessing the distribution pattern of African elephant (*Loxodonta africana*) carcasses in Etosha National Park and its implications for management

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Appendix 1: Supplementary Material

1. RAINFALL MODEL

Fit a high dimensional smooth term to 156 locations of annual rainfall from 1999 to 2015 (2016/17 unavailable at the time of modelling) to interpolate values for the presence locations and pseudo-absence grid.

```
require(mgcv)
fit<-gam(meanrain ~ s(x.pos, y.pos,fx = TRUE, k=150), data=rainfall2)
analysisdat$meanrain<-predict(object = fit,
                             newdata = data.frame(x.pos = analysisdat$x.pos,
                                                    y.pos = analysisdat$y.pos))
```

The results of the interpolation model are shown in Figure 1.

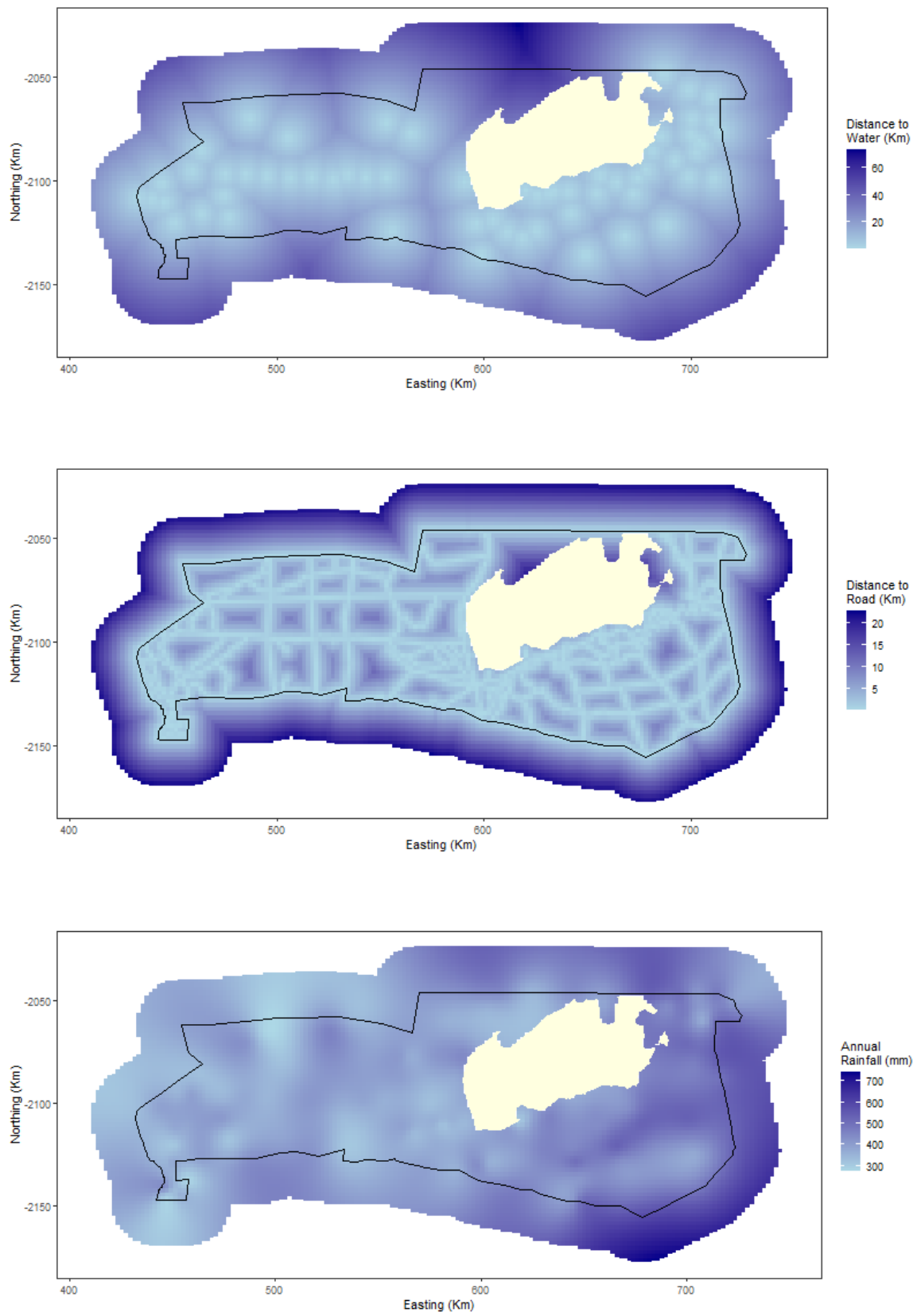


Figure 1 Covariate data in the study region. Distance to water (top), distance to roads (centre) and interpolated annual rainfall (bottom).

2. PSEUDO-ABSENCE SELECTION

- Grid spacings trialled: 5, 4, 3, 2, 1.5, 1.25 and 1 km
- SALSA2D specification
 - knot grid: all non-duplicated presence locations
 - start knot number: 10, 20, 30, 40
 - min knots and max knots equal to start knot number.
 - distance metric: Euclidean
 - basis: Gaussian and exponential
- Fit models for each specification of grid, start knots and basis
- Evaluate the log-likelihood
- Select the coarsest resolution after which, an increase in resolution makes little difference to the likelihood.

Figure 2 shows the log-likelihood scores for the different parameterisations. The vertical dashed line indicates the best grid resolution; 2km².

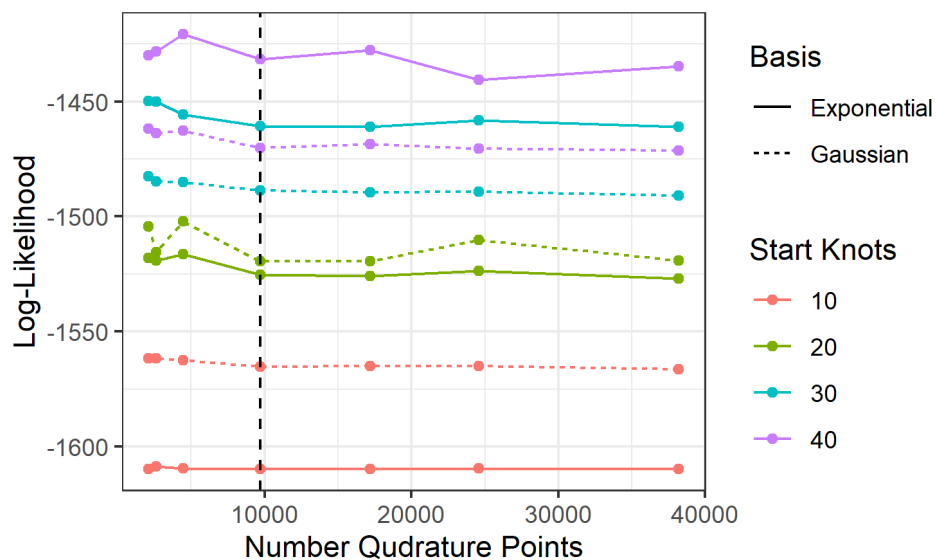


Figure 2 Figure showing the convergence of the log-likelihood for for different spatial resolutions across multiple SALSA2D parameterisations.

3. MODEL AVERAGING VS SALSA2D

3.1 SALSA2D algorithm details

The algorithm that drives SALSA2D has an iterative 3-step structure shown in the pseudo code in Figure 3.

<p>SALSA2D: Given an n-dimensional set K_l of possible knot locations over the region of interest.</p> <p><i>Initialise</i> Initialise knots, K_s within the points of K_l Check for convergence</p> <p><i>Repeat</i> Repeat Simplification step while ($K > K_{\min}$ and fit measure improves) Repeat Exchange step while ($K < K_{\max}$ and fit measure improves) Repeat Improvement step while (fit measure improves) While (an improvement in fit measure is made by one of the above steps)</p>

Figure 3 Pseudo-code outlining the structure of SALSA2D (adapted from Figure 1, Walker et al. (2010)), where K is the number of knots used for fitting.

3.1.1 Initialisation

Each observed location, i , is considered a possible location for a knot position. To avoid estimation issues, only unique knot locations are considered giving K_l legal knot locations. The user specifies a starting number of knots, K_s , where $K_s < K_l$, and these are selected from K_l using a space-filling algorithm (Johnson, Moore, and Ylvisaker 1990). This method provides good coverage across the spatial region as a starting position for SALSA2D. Additionally, the minimum number of knots, K_{\min} ($2 \leq K_{\min} < K_s$) and maximum number (K_{\max} ($K_s < K_{\max} \leq K_l$)) are specified.

To evaluate the basis function, the r_k -value for each basis must also be chosen. The SALSA2D algorithm selects from R possible options for r_k which range from a very local basis to a globally acting basis. The middle option which is neither very local or very global, is chosen to initialize the first model.

To ensure that the initial model fit has converged, there is a drop step component that is activated if the variance of the initialized first model exceeds that of the simpler input model (the variance should not increase with additional parameters/flexibility in the model). If this occurs, knot locations with the largest contributions to the variance are removed one by one until the overall variance of the more complex model is lower than the input model.

3.1.2 The simplify step

Using the fit criteria specified, the simplify step compares the current model with all models obtained by removing an existing knot (as long as this is at least K_{\min}). At each iteration, the model with the best fitness measure is retained and the process repeated until there is no further improvement in the fitness measure. This step can be carried out by fixing r_k or by choosing r_k for each basis as each knot is dropped for comparison.

3.1.3 The exchange step

The exchange step increases the extent of the search of model space by enabling a move away from a local minima (of the fit criterion). It uses the maximum Pearson residual from the current fitted model to identify a possible candidate location for a new knot (although in theory other types of residuals could be chosen and we use an alternative metric for the point process models in the next sections). The algorithm then compares the objective fit criteria for these models that result when each of the existing knots in the current model is moved to this new location, and also the fit criteria from the model that results when an additional knot at this location is added to the current model (if this does

not exceed K_{\max}). The model with the best fitness measure is retained in this step if it has a better fitness measure than the current model. Evaluation of each of these models can be very quick to return but this process is naturally more computationally expensive, if r_k is also chosen for each basis function for each candidate model. In practice, the algorithm uses the knot locations of the five largest residuals as candidates for an exchange or move.

3.1.4 The improve step

The improve steps allows a more nuanced search of the local minima by allowing small adjustments to the location of each knot. Using the fit criteria specified, the improve step compares the current model with all models obtained by moving an existing knot to one of its five nearest neighbours (determined by the distance metric employed: geodesic or Euclidean). At each iteration, the model with the best fitness measure is retained. As with the exchange step, alternative choices for the (r_k) parameter may be considered when fitting each new model and this process is likely to be swift at this stage.

3.1.5 Determining r_k

This routine considers incrementing or decrementing r_k values in the sequence of R possible values, where the sequence is selected using the method from Scott-Hayward et al. (2014). It can be evaluated either once at the end of the exchange, improve and simplify steps or as part of every decision taken during these steps. The process is done by considering each of the radial basis columns in turn, and incrementing or decrementing the r_k values in the index until there is no improvement in the fitness measure. At each step the r_k -values for the other basis columns are maintained at the current solution. The best of these models is selected as the new current model, and the process iterates until no improvement is made. This process can have a large computational overhead and may significantly prolong the procedure but constitutes a broader search of the model space.

3.2 Model specification

To compare the performance of SALSA2D with model averaging as a model selection approach, models with a two dimensional smoother-based term for geographic locations were fitted to the MIKE data. The comparison involved either the published CreSS method which employs model averaging or model selection using SALSA2D to determine knot number and location.

The CreSS approach fits pure spatial regression models to a set of coordinates \mathbf{z}_i of the form:

$$g(\mathbf{y}_i) = \eta = \beta_0 + s(\mathbf{z}_i) \quad (1)$$

where g is the link function and η the linear predictor. s is a two dimensional surface approximated by a linear combination of exponential basis functions bE . The formula for this basis function at observation i and knot location k is:

$$bE_{ki} = \exp(-h_{ki}/r_k^2) \quad (2)$$

where r_k dictates the extent of the decay of this exponential function with distance between points, and thus the extent of its local nature. Notably h_{ki} indicates a geodesic or Euclidean distance (for some observation i and the k -th knot location). Parameter r_k takes values such that if r_k is small the model will have a set of relatively local basis functions and if r_k is large the model will have a set of relatively global basis functions. The exact values of r_k are dependent upon the range and units of the spatial covariates.

As part of recent work, we have expanded the original CreSS approach to include a Gaussian radial basis to the choice of basis functions available for selection (alongside the existing exponential option). The two bases have different shapes, with the exponential being more peaked at the centre.

These choices allow for more nuanced model fitting, akin to link function or distance metric choice. The Gaussian radial basis, bG , is specified as:

$$bG_{ki} = \exp^{-(h_{ki}r_k)^2} \quad (3)$$

where r_k and h_{ki} are as defined for the exponential (Equation 2) except that for the Gaussian basis, a small value for r_k returns a relatively global basis and a large r_k value returns a relatively local basis.

$$Y_i \stackrel{indep}{\sim} Poisson(\lambda(\mathbf{X}_i))$$

For this method comparison section, we model the intensity as a function of coordinates, \mathbf{x} , only.

$$\log(\lambda(\mathbf{X}_i)) = \eta_i = \beta_0 + s(\mathbf{x}) = \mathbf{X}_i^T \boldsymbol{\beta} \quad (4)$$

where η_i is the linear predictor, consisting of the intercept, β_0 , and a smooth function of coordinates, $s(\mathbf{x})$. The smooth function is either the exponential or Gaussian basis function.

For both the model averaging and SALSA2D methods, the following specifications were used to return the columns of the design matrix \mathbf{X} in Equation 4:

- Two basis options: Exponential (bE_{ki} ; Equation 2) or Gaussian (bG_{ki} ; Equation 3)
- Two distance measures (Euclidean or geodesic) to calculate h in the basis equations; the geodesic distances are calculated using Floyd's algorithm (Floyd 1962) and for more details see Scott-Hayward et al. (2014). In this study, geodesic distances are 'around the salt pan' distances.
- 12 choices of fixed knot number (for the model-averaging approach) and 12 choices of starting knot numbers, K_s for the SALSA2D approach. In each case, the fixed/starting knot set was: {5, 10, 15, ..., 55, 60}. A total of 285 legal knot positions (K_l) were considered. These consisted of all non-duplicated carcass locations ($n=245$) and 50 space-filled pseudo-absence locations ($\sim 20\%$ of all K_l).
- 10 choices of r_k (also specified as part of Equations 2 & 3)

Additionally, for SALSA2D, K_{\min} and K_{\max} were set to 2 and 100 respectively, for all model specifications.

In keeping with Scott-Hayward *et al.* (2014), the model-averaging CReSS method was governed by AIC_c weights which were used to choose which models to average ($\Delta AIC_c \leq 10$) and their relative contribution to the overall averaged model. In keeping with Walker et al. (2010), the BIC was used to govern SALSA2D model selection regarding the choice of knot number and their locations across the range of combinations of basis type, distance metric, starting knot number and r_k choices (Schwarz 1978). In all cases, the log-likelihood score was calculated for each model to enable comparison between model selection strategies.

The SALSA2D algorithm is implemented inside the MRSea R package (Scott-Hayward *et al.* 2024, R Core Team, 2024) for easy use by practitioners (<http://lindesaysh.github.io/MRSea/>).

3.3 Finding the largest residual

- Find nearest candidate knot location (of the legal knots remaining and ignoring the already selected knots) to each data point (both presence and pseudo-absence locations). Note that 'nearest' is calculated based on whichever distance metric the model uses. Figure 4 shows the neighbourhood around each knot.
- Sum the observed counts within each knot region

- Make predictions to the pseudo absence grid and sum the estimated intensity within each knot region
- Calculate the absolute residual ($|O - E|$)
- Find the 10 knot regions with the largest score. These become the candidates for the exchange/move step.

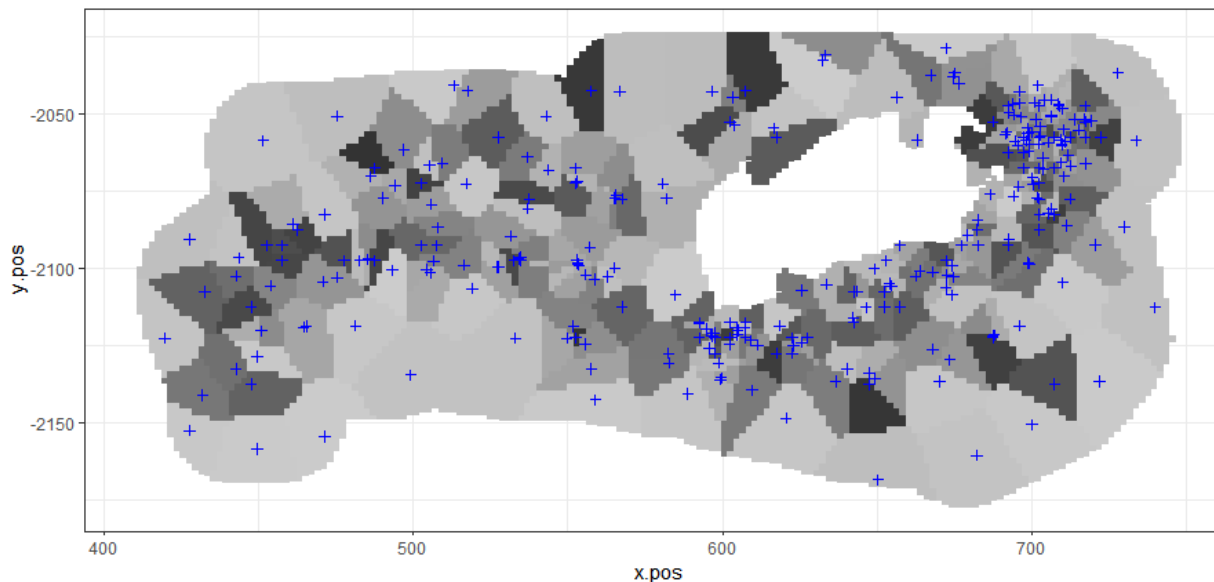


Figure 4 Figure showing the knot locations (blue crosses) and the colour shows the nearest knot on the pseudo absence grid.

3.4 Numerical comparison

The log-likelihood scores returned for the model averaging method were fairly close (maximum difference 14 points) regardless of the basis function and distance metric used in each model (Table 1, Method: 'Model averaging'). The geodesic-exponential combination scored the best (largest log-likelihood) of the 4 combinations trialled. Interestingly, this combination chose 11 models with which to average over to obtain this solution, compared with some options that chose far fewer models to use as part of the average calculation. In general, geodesic distances were preferred to Euclidean regardless of basis.

The log-likelihood scores for the SALSA2D based selection are shown for the model with the highest log-likelihood for each of the basis/distance metric combinations (Table 1, Method: SALSA2D). Across the four combinations, the scores were less homogeneous than for the model averaging results and the exponential-Euclidean SALSA2D model (using 41 knots) was the best of all trialled here. In contrast to the averaging approach, there was a preference for the exponential basis with the distance metric secondary. In reality, the user may prefer to select the best model using BIC (as was used for k/r selection). In this case, the order of the four parameterisations was the same (exponential-Euclidean the best and Gaussian-Euclidean the worst) and the best model using BIC was the same as in Table 1 when log-likelihood was used (see Section 3 of Appendix S1 for an expanded version of Table 1).

Table 1 The results of the model averaging and SALSA2D methods of model selection for a given basis type and distance metric used. The 'No. Models' indicates the number of models chosen to carry out the model averaging in each case, and the 'No. Knots' indicates the number of knots chosen for each model using the SALSA2D selection method. The star indicates the model with the largest log-likelihood (LL) score, and thus the chosen model in each case.

Method	Basis	Distance Measure	No. Models	No. Knots	Log-Likelihood
MA	Exponential*	Geodesic	11	-	-1432.0
	Gaussian	Geodesic	2	-	-1441.5
	Exponential	Euclidean	1	-	-1443.4
	Gaussian	Euclidean	8	-	-1446.3
SALSA2D	Exponential	Geodesic	-	32	-1369.7
	Gaussian	Geodesic	-	32	-1408.3
	Exponential*	Euclidean	-	41	-1301.6
	Gaussian	Euclidean	-	47	-1541.6

Using the 'best' SALSA2D models only, for all but one combination of basis type and distance metric used, all SALSA2D models produced better scores than the model averaging method – sometimes reducing the log-likelihood score by as much as 10%. However, if SALSA2D initialises with too few knots, the algorithm may get stuck in local minima. So long as a large enough number of starting knot locations was selected ($\sim \geq 40$), SALSA2D-based selection resulted in superior scores over the model-averaging alternative (Figure 5). This demonstrates that the SALSA2D model selection method can return improved results and at worst, SALSA2D results were almost indistinguishable from the best model averaging-based result.

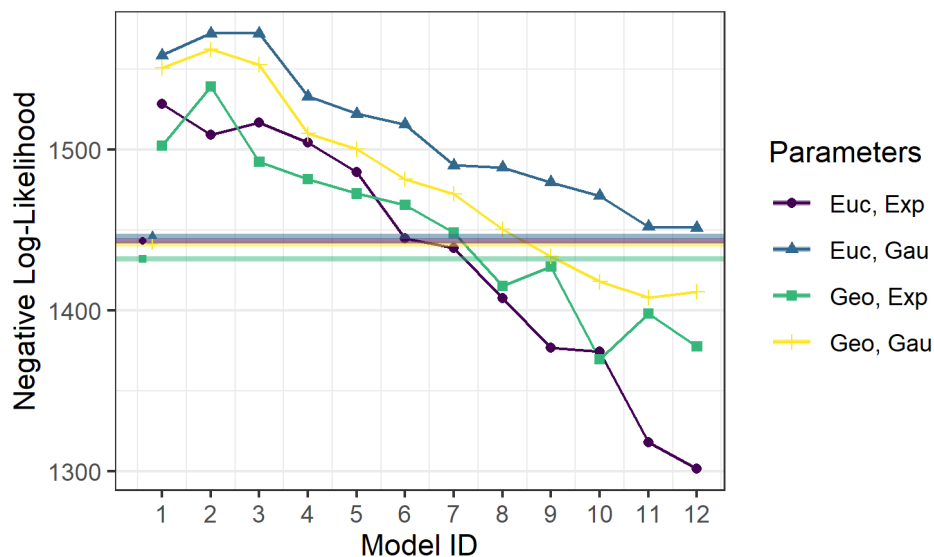


Figure 5 The model identification number (increasing start knots) and the negative log-likelihood score for each of the SALSA2D models resulting from a different start knot number, K_s . The horizontal lines are the scores for the equivalent model averaging result. (Euc - Euclidean, Geo - Geodesic, Exp - Exponential and Gau - Gaussian).

3.5 Visual comparison

Figures 6 & 7 show the best models from the two different methodological frameworks and the four different parameterisations. The best models are selected using BIC for SALSA2D and AIC_c weights for model averaging. Since the two frameworks are compared using the log-likelihood, the figures show the best log-likelihood selected models.

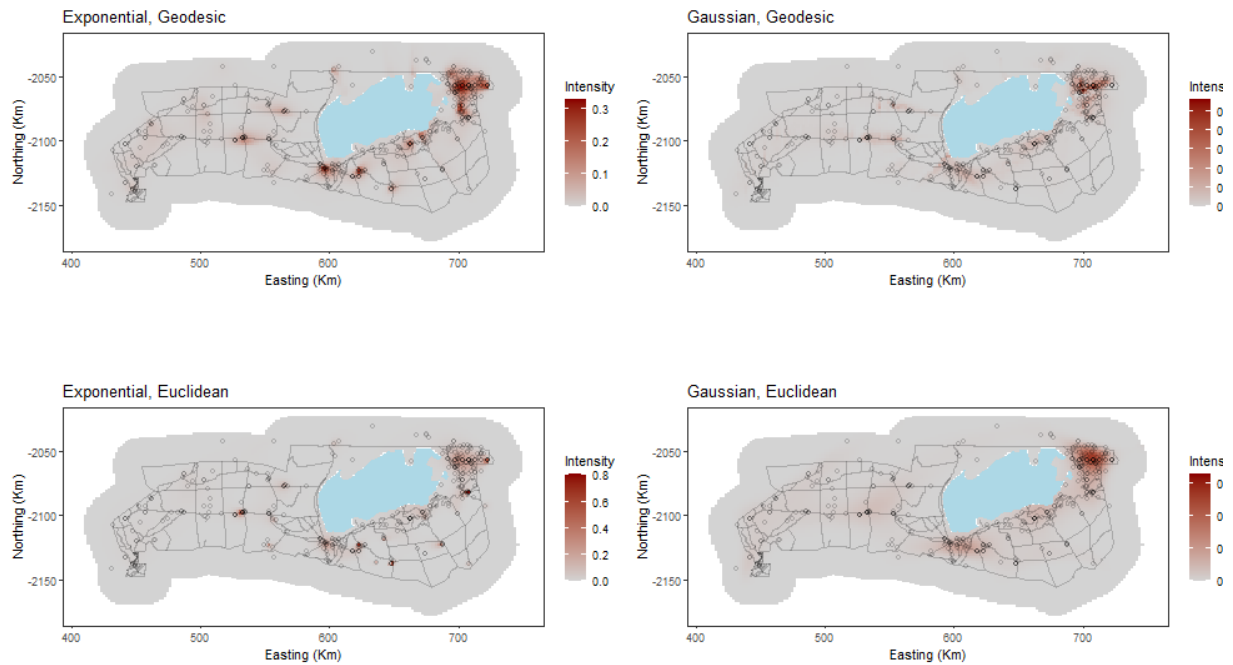


Figure 6 Fitted intensity surfaces for the four SALSA2D models selected using log-likelihood.

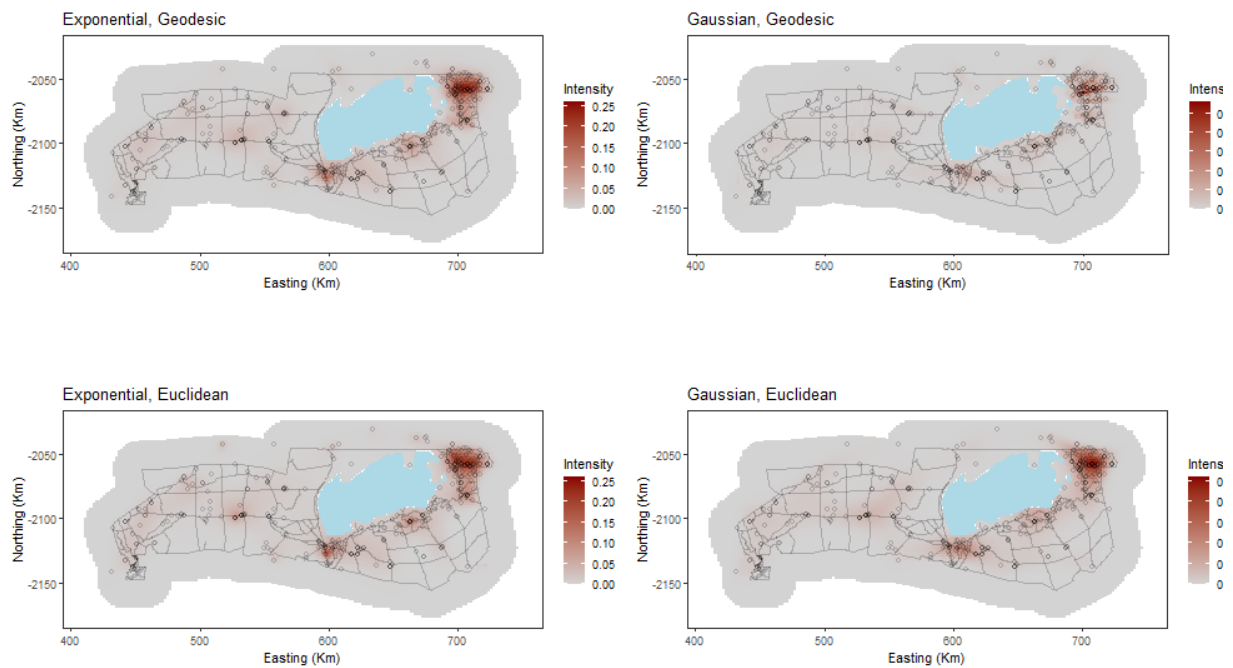


Figure 7 The best model averaged outputs from the four different parameterisations and selected using AIC_c model weights.

Figure 8 shows the selected knot locations and equivalent r parameter from the 11 averaged models (Figure 8 a) and the one best SALSA2D model (Figure 8 b). The averaged knot locations are more difficult to represent but it can be seen that there are multiple r values (ranging from global to very local) across the same locations and occasionally a location where the sign of the coefficient changes between models. The SALSA2D result is more nuanced with very few knot locations selected to the west of the park. For the 41 selected locations, a variety of r 's were chosen. It is interesting that the SALSA2D approach found the Euclidean distance metric to be best and it is possible that the more local knots chosen under this method negate the need for the geodesic distances by limiting the possible leakage across the pan.

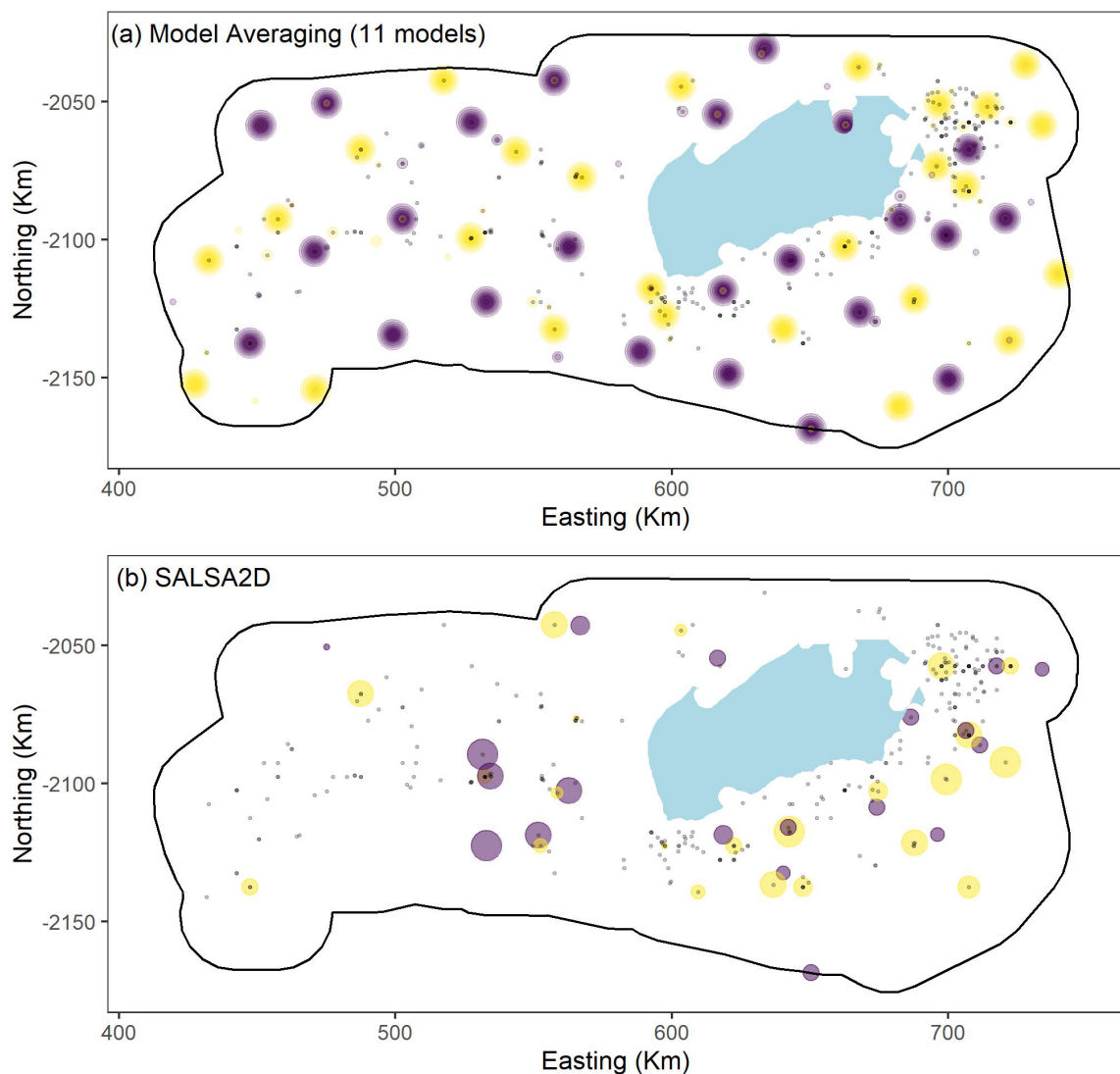


Figure 8 The knot locations and r (effective range of basis function) from the best model averaging (top) and SALSA2D (bottom) models. Yellow is for a positive model coefficient and purple a negative one. The size of the coloured circles is a visual representation of the size of the r parameter. Note that in (a) the concentric rings are from models had the same knot locations with different r . In (b) the colours overlap but each k is in a different location. The carcass locations are shown as grey/black circles. The blue polygon is the Etosha salt pan.

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Understanding market, state and community institutions in the development of smallholder vegetable enterprises in north-west Namibia

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ABSTRACT Agricultural value chains can be affected by the failure of market, state and community institutions either separately or jointly. This failure coincides with the social, economic, political and environmental factors in which farmers operate. The objective of this study is to assess the main challenges based on the interrelationship of the market, community and state institutions in the development of the vegetable industry in north-west Namibia. I used a transaction cost approach to assess vegetable enterprise development in the Smallholder Green Scheme Irrigation Project and among smallholder irrigation farmers in north-western Namibia. The results reveal that one of the challenges in the vegetable value chain is information asymmetry, which is an incentive for administrators (politicians or elites), traditional leaders, farmers and other market actors to behave opportunistically to benefit from government projects. Smallholder vegetable producers in the study area also bring with them their socio-cultural beliefs, values and norms when participating in agricultural projects, which makes it difficult for them to accept certain agricultural practices that would improve their productivity. However, there is a continued problem of access to input and output markets for farmers owing to high transaction costs. Policies to support smallholder farmers should focus on multiple transactions that combine the market, state and community institutions.

KEYWORDS agriculture; incentive compatibility; information asymmetries; Namibia; vegetable enterprises

INTRODUCTION

Agricultural development projects and programmes have relied heavily on public investments across Africa since the 1960s (Mason-D'Croz et al. 2019). In some cases, public investment in agriculture is low and even declining (Resnick 2024, Moguees et al. 2015, Moguees et al. 2012). In other cases, it is sufficient for agricultural development, but as Troskie (2013) argues, the main constraint of such development is a lack of well-defined interventions for the sector. Specifically, the failures most often seen are mainly

due to the unsustainable application of technologies (irrigation, herbicides, pesticides, fertilisers) coinciding with the socioeconomic and agro-ecological context in which the farmers operated (Kumar et al. 2021). Thus, government interventions have failed in most southern African countries, such as Namibia, to uplift farmers because of a lack of markets for both inputs and outputs (Meemken et al. 2021). Other barriers to the success of agricultural development are a lack of appropriate technologies and access to those technologies, should they exist, and to information, inefficient extension services, insufficient physical

and marketing infrastructure, a lack of credit, and insufficient development of processing or manufacturing industries (Touch et al. 2024, Jordaan et al. 2014). One of the major barriers to market entry is imperfect access to market information, which is largely a result of the weak and inefficient public market information systems found in most developing countries (Mwema & Crewett 2019). This can result in high transaction costs in value chains of crops (Mardenli et al. 2024).

Other global studies, especially African, indicate that smallholders cannot meet stringent international quality standards, and, on a consistent basis, the quantity demands set by modern supermarkets and retailers (Touch et al. 2024, Mkansi et al. 2024, Barrett et al. 2022, Thomas & Vink 2020, Meemken & Bellemare 2019, Ochieng et al. 2016, Maertens et al. 2012). As a result, smallholder farmers are excluded from continuous supply to formal markets, such as wholesalers, supermarkets and retailers (Nair 2018). Thus, agricultural cooperatives can help farmers access the market and can be classified into three broad categories based on their main activities (Magakwe & Olorunfemi 2024): (1) marketing cooperatives, which are created to enable their members to bargain for better prices, and handle, process or manufacture, and sell farm products; (2) farm supply cooperatives, which are created to enable their members to purchase in large volumes, and to manufacture, process, or formulate and distribute farm supplies and inputs such as seed, fertiliser, feed, chemicals, petroleum products, farm equipment, hardware, and building supplies; and (3) service cooperatives, which are created to provide their members with services such as transport, storage, drying, irrigation, credit, utilities and insurance. However, several challenges related to agricultural cooperatives have been highlighted in literature (Francesconi et al. 2023, Luo et al. 2020, Marcos-Matás et al. 2013).

Some studies also indicate that smallholders in out-grower schemes (contract farming) can benefit from economies of scale, as they collectively supply to access markets (Barrett et al. 2022, Mwema & Crewett 2019), social capital formation has been pivotal in solving many community development problems because of a high level of trust among members, more altruistic behaviour, and more ties to other organisations within and outside their

community (Mwambi et al. 2020). Challenges related to group management or cohesion have been highlighted in the literature (Mwambi et al. 2016). This implies that community institutions can also contribute to the failure of agricultural projects in developing countries, as these are associated with the long time required for communities to adjust to changing forms of culture, norms, taboos, and traditions regarding the interaction of state and market (Maru et al. 2020). State institutions include landholding, water resources, extension services, and physical and marketing infrastructures, while market institutions are made up of access to credit, access to market information, availability and location of local market and collection centres (Chuma et al. 2024).

According to Hayami (1988), agricultural value chains can be negatively affected by market, state and community institutions, either separately or jointly. For instance, markets fail when they are unable to allocate resources efficiently, which could lead to a common need not being met by the market mechanism, resulting in a missing input and output market (Thomas & Vink 2020). In addition, a government cannot solve market failures arising from asymmetric information, as it does not have access to unobservable information (Qurrata et al. 2020). This implies that community institutions can also fail because people within the community can benefit from free-riding and opportunistic behaviour, due to information asymmetries and incentive compatibility structures as well as imperfect property rights, hence, market failures (Sadeghi et al. 2022).

Some studies have been conducted in developing countries (Maru et al. 2020, Mukherji 2013) which have highlighted the importance of the inter-relationship of community, market and state institutions in economic development. These studies indicate that there is a need for further exploration of information asymmetries and opportunistic behaviours among actors in crop value chains. In Namibia detailed information on smallholder farmers' agricultural development based on linking development programmes to issues concerning the interrelationship of government, market and community institutions is limited. As in other countries, in Namibia failure is attributed to a broad range of environmental, political, economic and social factors. This situation

necessitated an investigation of the inter-relationships between the state, market and community institutions.

The Namibian government invested in physical infrastructure and marketing facilities to address the problem of market access for underprivileged farmers. Owing to information asymmetries and incentive compatibility structures, farmers and other market actors behave opportunistically to benefit from government projects. In this sense, the design of agricultural development initiatives by the government is fraught with a poor understanding of community institutions and is not aligned with market and agro-ecological realities, resulting in the failure of projects and a decline in economic welfare.

The objective of this study is to assess the main challenges based on the reality of the inter-relationship of the market, community and state institutions in the development of the vegetable industry in northwest Namibia. The transaction cost economics (TCE) approach was applied to assess the main transaction costs between market, state and community institutions in light of environmental, political, economic, and social factors. This study adds to the existing literature on transaction costs in smallholder vegetable value chains.

Namibia’s vegetable industry

Namibia’s vegetable production is insufficient to meet the demand. Domestic producers contribute approximately 47% of the total domestic fruit and vegetable demand, while the remaining 53% is supplied by imports, mostly from South Africa (Namibia Agronomic Board [NAB] 2021). The percentage of vegetables produced locally in Namibia is shown in Figure 1. Potatoes, carrots, onions, tomatoes, and cabbages are the main vegetables produced in Namibia.

Vegetable production in Namibia is mainly possible along bordering perennial rivers (Kunene, Orange, Zambezi and Kavango), and where dams feed irrigation schemes or where sub-artesian water can be utilised. The main challenges for irrigated high-value crops in Namibia are the negative effects of climate change, high cost of production, inadequate access to sources of credit and to the market, unavailability of clear product

quality standards, and inadequate infrastructure, such as roads, storage and processing facilities (Neema & Kalitanyi 2023, Thomas & Vink 2020).

Over the years, the country’s ethnic groups have been collecting wild edible plants and cultivating and nurturing a variety of indigenous and, to a limited extent, exotic vegetables in home gardens for household consumption, particularly in rural areas of northern Namibia. The most common indigenous vegetables found in Namibia are *Amaranthus* spp. (mainly *A. thunbergii*), spider plant (*Cleome gynandra*), roselle (*Hibiscus sabdariffa*), and cowpea (*Vigna unguiculata*) (Mushabati et al. 2015). These indigenous species are mostly neglected and underutilised as crops, and there are limited statistics available on their production and consumption, however, the focus of this article is on exotic vegetables, which are also a focal point in the development agenda of the country.

In the early 1990s, the government of Namibia recognised the need to develop strategies for the commercialisation of horticultural industries, especially vegetable enterprises, with the objective of producing exotic vegetables to improve household diets where water is available. The most commonly produced vegetables in Namibia include tomatoes (*Solanum lycopersicum*), cabbage (*Brassica oleracea*), sweet potatoes (*Ipomoea batatas*), watermelons (*Citrullus lanatus*), pumpkins (*Curcubuta maxima*, *Curcubuta pepo*), butternuts (*Cucurbita moschata*) and onions (*Allium cepa*) (NAB 2021). These crops are ready for harvesting three–four months after planting or sowing. Once harvested, vegetables should be processed or sold to the market as fresh produce to prevent postharvest losses owing to their high

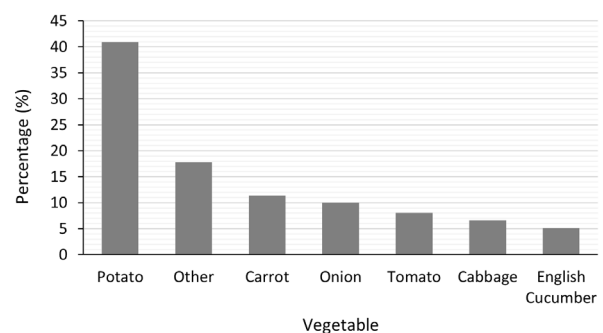


Figure 1 Main vegetables (%) produced in Namibia in 2021. Others include pumpkin, iceberg lettuce, sweet potato, sweet corn, sweet melon, watermelon and gem squash. Source: NAB (2021).

perishability. This timing requirement also has implications for the optimal distance between the market and the vegetable farms.

Fruit and vegetable production and marketing initiatives have been developed and promoted in Namibia under the revised Green Scheme Policy (2008). The Ministry of Agriculture, Water and Land Reform has set a target of putting 27 000 ha of land under irrigation over a 30-year period (Lita 2012). Thus, poor implementation and monitoring of government and uncoordinated farming activities constrain the production and marketing of vegetables in the country. This study highlights important factors (community, state and market institutions) to be considered by participants in the development of vegetable farming in northern Namibia.

Theoretical framework: Institutional arrangements between market, state and community

Hayami's (1988) central tenet is that the inter-relationship of market systems, rural community institutions and government activities is the key level at which decisions are made for economic development in developing countries. The insight obtained from Hayami's framework could lead to an understanding of why market-led and state-led policies have continued to fail in most developing countries in southern Africa since their independence (Oloo & Omondi 2021). Market failures occur because of the presence of externalities, such as the supply of public goods, market power (imperfect competition, monopolistic, monopsonistic, or oligopolistic), and institutional failures (competition distorted due to transaction costs and information asymmetry i.e. when the parties do not have equal access to all relevant information) (Hill & Varone 2021, Mogues et al. 2012). In this situation, transactions in the market result in a divergence between private and social costs and a failure to reach socially optimal levels in either the production or consumption of goods. Thus, market reforms aimed at eradicating barriers to small-holder participation in the market economy have often failed to confront the hidden reasons for the lack of market participation (de Janvry & Sadoulet 2020). These include information asymmetry, unenforceable contracts, lack of skills, and the inability to engage effectively.

As a result, the state has a legitimate reason to intervene through enhanced capacity and new forms of governance, correct market failures, regulate competition, and engage strategically in public-private partnerships to promote competitiveness in the agribusiness sector (Gray 2022). However, in most developing countries, the state has failed to fulfil its role because of inefficiencies and poor implementation of government policies (Oloo & Omondi 2021). One fundamental problem is the weakness or absence of mechanisms through which society can hold the state accountable for its actions on government policies and programmes that do not meet societal needs (Andrews et al. 2017). As a result, the participants (farmers, project administrators and market agents) in the agricultural value chain might be adversely affected by information asymmetry.

Owing to asymmetric information, administrators (politicians) and farmers can behave opportunistically to secure their own benefits from government programmes or projects (Sadeghi et al. 2022). One reason for this is that property rights, for instance, to a particular agricultural project or programme and its benefits, and their costs are not well defined in the marketplace. Therefore, two commitment problems arise (Kroll & Zippere 2020, Ngam 2021). First, politicians (incumbent or rival) cannot make binding commitments regarding their future actions and should be re-elected. Second, voters cannot commit to politicians in the future because the latter no longer possesses the political power to carry out the promises they made when campaigning for re-election. This is mainly because political promises are not formal legal contracts and contractual penalties between politicians and voters are not enforceable by the courts. In addition, it is often assumed that farmers have more information about the effects of agricultural policies on the budgets and interests of different segments of the farming sector. It then follows that farmers can behave opportunistically to benefit themselves because of hidden information that is not known by the administrators or agents involved in agricultural projects (Sadeghi et al. 2022, Mogues et al. 2012).

Community institutions can also fail because of the long time it takes for communities to adjust to changing forms of culture, norms, taboos and

traditions (Maru et al. 2020). Thus, the future of agricultural development in developing countries, especially in Namibia, will depend on a successful model that combines the three pillars of economic organisation of a community, market and state and their complementary role in improving the welfare of society, considering the influence of transaction costs on economic outcomes. This would provide an opportunity to identify key strategies that can guide interventions and policies that link farmers to agricultural markets.

The classical theoretical approach for understanding the interrelationship between market, state and community institutions in agricultural development is the theory of transaction cost economics (TCE) (Williamson 2010). Economic exchange involves transaction costs such as information, negotiations, searching, monitoring and enforcement (Leonardo et al. 2015, Williamson 1985, Coase 1937). According to Williamson (2010), TCE subscribes to the idea that the transaction is the basic unit of analysis and that much of the contractual relationships and dispute settlement actions are dealt with directly by the parties. As a result, trading parties might suffer from information asymmetry, which would inevitably result in opportunism (hidden information known as adverse selection or hidden action known as moral hazard) (Mogues et al. 2012). Technically demanding agricultural projects often have high transaction costs owing to information asymmetries and are more difficult to sustain as a community-driven process (Mukherji 2013). High transaction costs significantly contribute to the failure of agricultural development projects in most developing countries. As shown by several studies in rural areas, farmers are unable to overcome high transaction costs and, as a result, are unable to access the input and output markets (Mmbando et al. 2015). Thus, vertical coordination methods serve to minimise transaction costs (Shahab 2022, Pankowska 2019).

METHODS AND PROCEDURES

Study area

The study was conducted at the Olushandja Dam (with smallholder irrigation farmers) and Etunda Irrigation Project (Smallholder Green Scheme Irrigation Project) in Namibia's Omusati Region. The Etunda Irrigation Project covers an area of

approximately 1 200 ha and is situated on state land that is leased to farmers on a five-year renewable contract basis (Neema & Kalitanyi 2023, Thomas & Vink 2020). Of the 1 200 ha, 900 were cultivated. The Olushandja Dam is an artificial permanent dam with a capacity of 42 331 m³ (millions of cubic metres) and a surface area of 29 km² when filled to capacity (NamWater 2015). The land around the Olushandja Dam, communal land (under the stewardship of the State), is allocated by traditional leaders to farmers to generate income and to support their families. These sites were chosen because farmers specialise in vegetable production and water is available from the Kunene River.

The Omusati Region is sparsely populated, with a population density of 11.9 inhabitants per km² (NSA 2024). Additionally, approximately 70 percent of households in the region depend directly or indirectly on agriculture (MAWLR 2021). The climate in the region is semi-arid, with highly variable rains, ranging from 200 to 600 mm across the region (Mendelsohn & el Obeid 2005). The average temperature varies between 30°C to 35°C, with the hottest months occurring from October to February and the cooler months from May to August when the average temperature drops to around 15°C to 25°C (Wilhelm 2012). The vegetation types in the region range from mopane savanna in the west to forest savanna and woodland in the east. Soils in the Omusati Region are associated with moderate fertility and good drainage and, in some cases, have lower nutrient content but support crop production with proper management (Kangombe 2010).

Research design

This study's primary sources of data were focus group discussions (FGDs) and key informant consultations. Interviews with key informants were necessary to gain additional insight into the study area, review historical data, understand the vegetable industry and assess previous research.

Sampling procedures and data collection

Data were collected in 2018 from the Olushandja Dam (Smallholder Irrigation Farmers) and Etunda Irrigation Project (Smallholder Green Scheme Irrigation Project) in Namibia's Omusati Region. Focus group discussions (FGDs) were held with smallholder irrigation farmers around Olushandja

Dam and beneficiaries of the Etunda Irrigation Project (Smallholder Green Scheme Irrigation Project). Each FGD comprised of eight (n=8) leading smallholder vegetable farmers. The FGD method involves convening a group of respondents (4–8) (Robinson 2020) for an open-ended discussion about a topic. The meetings took place on 8 and 9 May 2018 and lasted for two hours. Participants were carefully selected in consultation with local traditional leaders (headmen), the management of the Etunda Irrigation Project, and government extension officials with selection limited to lead vegetable farmers. Participants agreed to conduct meetings in Oshiwambo and English to facilitate communication between them and the research team. Each meeting commenced with a discussion of the main challenges emanating from the reality of the interrelationship of the market, community and state institutions in the development of the vegetable industry in the study area and suggestions on how the challenges could be solved. The discussion then focused on possible interventions for the success of the vegetable industry in the study area.

Permission to carry out discussions with farmers was granted in meetings held with representatives of local traditional leadership, including the headmen, government extension officials and the management of the Etunda Irrigation Project. The regional office of the Ministry of Agriculture, Water and Land Reform also provided field extension officials who accompanied the research team to the FGDs. These officials were also involved in directly liaising with lead farmers selected for FGDs. The FGDs were conducted by a moderator and an assistant who prepared the list of discussion questions (see Appendix) that guided the discussions, and the notes were summarised by the assistant as per the guiding questions. Questions were based on the institutional arrangements between markets and community and government activities in the development of vegetable enterprises in northwest Namibia. The approach was participatory in nature, in which all farmers were involved in the discussions.

One challenge with FGDs is to create an environment in which participants are willing to freely share their concerns, anxieties and suggestions (Nyumba et al. 2018). Although FGDs have other disadvantages, such as a lack of detail

regarding techniques for data analysis and interpretation (Massey 2011), this method was deemed appropriate given the remoteness of the study area, the lack of a farmer database system for the studied units and the qualitative nature of the information sought.

Moreover, key informants' consultations took place in the form of multiple office visits, in some cases interviews were conducted with different experts via telephone and e-mail. Key informants consisted of experts such as the Ministry of Agriculture, Water and Land Reform extension officials (n=6), agricultural boards or marketing agency officials (n= 5), researchers (n=6), members of producer associations (n=12), local traditional leaders (n =2), and a regional councillor (n =1).

Data analysis

The thematic analysis presented in this paper draws on information gathered from FGDs and key informant interviews. Thematic analysis is a method for identifying, analysing and interpreting patterns of meaning (themes) within qualitative data (Clarke & Braun 2017). Data from FGDs were analysed by first comparing transcribed interviews with field notes and audiotaped recordings to check for the accuracy of information. Each interview transcript was scrutinised through manual open coding, as suggested by Tamubula et al. (2023), to extract evidence related to the theoretical approach components to develop codes. Linkages among the codes were examined to create axial codes, followed by triangulation of codes across data from FGDs and key informants (expert opinions), as suggested by Tamubula et al. (2023). Transcripts from the FGDs were analysed by question using the thematic approach to identify key themes. Qualitative data from the FGDs were analysed using content analysis. Content analysis enables systematic coding of data by organising the information into categories to determine patterns that are undetectable by simply listening to the tapes or reading the transcripts (Nyumba et al. 2018). Qualitative data from key informant interviews (expert opinions) were coded and analysed using Microsoft Excel (COUNT function).

Qualitative data were then grouped according to the themes of the state, market and community based on the model, as presented in Figure 2. All extracted information pertaining to the state,

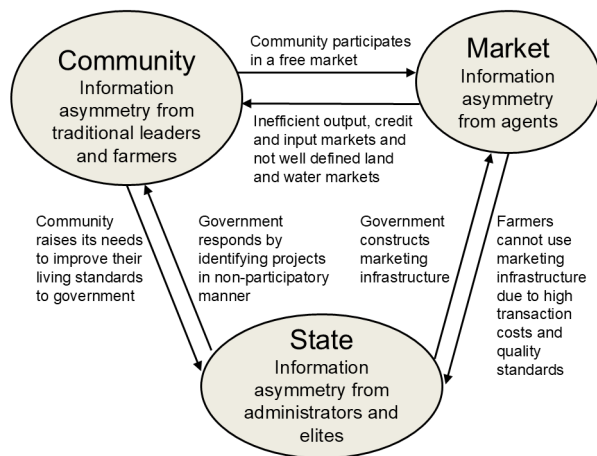


Figure 2 Key relationships between state, market and community institution networks, based on my thematic analysis.

market and community was then grouped together using filtering in Microsoft Excel and presented in the model. Further, the underlying possible solution for each main challenge between the interrelationship of the market, community and state institutions in the development of the vegetable industry was articulated to understand how the vegetable industry can be developed. This analytical emphasis is on the extent to which the empirical interpretations conform to transaction cost economics theory (Williamson 2010).

RESULTS AND DISCUSSION

Main challenges between state and community institutions

Farmers perceived that one of the key challenges in the study area was that agricultural projects were identified by elites (politicians and traditional leaders) and outsiders, without aligning them with the agro-ecological realities of planting specific crops. According to the theoretical framework applied in this study, these challenges are not aligned with indigenous knowledge and community institutions, such as norms, taboos, beliefs, and the organisations that collectively serve the community (Maru et al. 2020). This means little involvement of farmers and the community in identifying the needs concerning their production. Thus, farmers perceived that some of the solutions provided for their needs were not fit for the purpose and often did not consider agro-ecological realities. Specifically, many alleged that the state provides development projects which sometimes bring with them technologies that are not aligned

with the communities’ prevailing practices. This makes them inaccessible and impractical, as communities would have to abandon their current practices for new technologies despite not being trained to do so. Hence, cultural tensions limit economic activities, as community values, norms and beliefs take a long time to adjust to external ideas or technologies because of inadequate information (Maru et al. 2020). As a result, community participation is based on incentives but not necessarily on supporting government interventions.

According to Sadeghi et al. (2022) politicians, traditional leaders, and farmers behave opportunistically to accrue benefits for themselves from government projects, with little or no financial outlay. In some cases, politicians pursue activities that directly benefit them and not necessarily farmers, although they may resonate with community concerns. In this way, politicians promote agricultural initiatives that are not sustainable but may be relevant to food security and employment creation. This means that when the elite and selected few (traditional leaders) in the community identify participants in rural projects, the interventions will not be sustainable, as there will be a lack of ownership of these projects. In addition, the lack of trust in outsiders who are not part of the community is a big constraint on the commercialisation of agriculture, in this case, in the form of vegetables. A strong tie to the local community is an important factor because culture may set limits to an agricultural development activity as community values, norms and beliefs take a long time to adjust to external ideas or technologies due to inadequate information and lack of trust (Maru et al. 2020). Inadequate information on agricultural development initiatives shared among community members (farmers) results in high transaction costs.

Main challenges between the community and market institutions

Smallholder farmers face various kinds of market failure, such as scarcity of production factors (land, labour, capital, and entrepreneurship) and limited access to markets (credit, input, and output) (Langyintuo 2020). Participating farmers revealed that the inputs that are promoted, such as chemical fertilisers and pesticides, do not conform to farmers’ traditional knowledge and farming

methods, which are less costly while acknowledging that they believe that manure and other organic fertilisers are inferior to chemical fertilisers when endeavouring to increase output. Farmers are not supported in the use of their traditional practices, which forces them to adapt to unfamiliar technologies. I learned that farmers also bring with them socio-cultural beliefs, values and norms, which makes it difficult for them to accept other agricultural practices that would improve their productivity. Their socio-cultural background is not linked to the formalised input market, which aims to improve productivity.

With respect to output markets, farmers compete in a free market where market sales are determined by the forces of demand and supply. Global supermarkets require farmers to meet quality standards and consistent supply standards, which they are often unable to do (Jordaan et al. 2014). The problem with market access is that marketing infrastructure is usually established without preparing farmers and the community to meet the required international food safety and quality standards during production. Thus, smallholder farmers are excluded and marginalised, as supermarket chains tend to favour imports from larger South African farmers who are able to comply with their food safety and quality requirements (Thomas & Vink 2020). This means that local supermarkets import their products because they do not see the need to support local vegetable producers such as contract farmers.

Inadequate information shared with farmers prevents them from meeting the stringent requirements for fresh and processed food products as set by supermarkets and wholesalers, who demand consistent quantity (volume), high quality, food safety, timely deliveries, a certain size and type of product, and so on (Thomas & Vink 2020). The result is that farmers limit the usage of marketing hubs such as that of the Agro Marketing and Trade Agency (AMTA), thereby creating the impression that there is no market for farmers despite the availability of market infrastructure. When marketing agents share relevant information with farmers, this information helps farmers farm in accordance with good agricultural practices (GAP) and cropping programmes. Smallholder farmers face numerous challenges when they want to use formal markets, such as the costs associated

with accessing the market, complying with market requirements, and negotiating and managing contractual arrangements (Diao et al. 2023). As a result, it became clear that many vegetable farmers prefer to sell their horticultural produce through informal markets such as the local open markets, roadside stalls and by means of local trade in the community itself. According to Thomas & Vink (2020), in informal markets, the prices obtained are generally lower than those paid by formal markets (supermarkets, shops, and petrol/diesel station outlets).

I observed that the property rights of resources such as land and water for the community (including farmers) residing in communal areas are not well defined, which makes it difficult to obtain credit for investment in production. Land is communally owned, and water is managed by Namibia Water Corporation (NamWater), a parastatal, without any guarantee of continued access to water for the irrigation of crops.

Main challenges between state and the market institutions

One of the key challenges identified by participants in the study area was limited state-sponsored physical marketing infrastructure, such as the cold storage facility at Epapela which only serves farmers who are members of the Olushandja Horticulture Producers' Association. However, this facility does not meet the quality standards demanded by modern markets. This means that the majority of smallholder vegetable farmers in the study area had limited access to delivery load, sorting, washing, and packaging systems required prior to delivery to the markets. Farmers also revealed that the study area lacked processing facilities for high-value crops. In addition, the government has failed to successfully address other supporting activities that take place between the state and market to enable produce to be marketed (Neema & Kalitanyi 2023, Senyolo et al. 2018). These include:

Input market: There is a lack of input (chemical fertilisers, seeds, and pesticides) infrastructure such as manufacturing factories and warehouses in the study area. Farmers revealed that cattle manure is available from cattle posts and commercial farmers but lacks distribution. Consequently, the biggest challenge faced by smallholder vegetable

producers is sourcing inputs, which are mostly imported from South Africa (Thomas & Vink 2020). Farmers perceived the procurement process of these inputs to be associated with transaction costs due to high transport costs. Therefore, farmers' access to inputs and technologies should be improved to potentially increase the production of high-value crops (Ouedraogo 2019). Participants also identified the need to categorise beneficiaries into smaller groups that are easy to manage in the distribution of public goods, such as subsidised tractor services.

Transport of product to market: Farmers indicated a lack of vehicles to transport their vegetables to the markets. It is expensive for farmers to bring their products to the output market when transport is not provided or subsidised because of the significant distances. This affects the availability of products in the market, as some farmers opt for less costly markets, which are usually informal. Thus, lack of transport constrains market access to vegetables (Cooper et al. 2021).

Price setting: Study participants lamented the lack of a state-defined pricing system for vegetable producers making farmers price-takers. When farmers send their produce to the market, they are sometimes not paid well because their produce does not meet the quality standards demanded by the market. It was revealed during our discussions that most domestic consumers do not necessarily demand as high-quality produce as supermarkets, which is yet another reason why farmers sell their produce in informal markets. Additionally, some farmers expressed a desire for heightened product prices and to benefit from government programmes at no cost.

Farmers' organisations or cooperatives: I observed that in the study area, no viable farmers' organisations or cooperatives, based on international principles to address vegetable production and marketing information systems, have been established by the state. Collective action can help smallholder farmers produce large volumes of vegetables that meet the standards set by formal markets (Leonardo et al. 2015).

Interventions for the development of the vegetable production system

I found that it is important to choose the appropriate coordination mechanisms to minimise transaction costs to fully integrate farmers with the market in the commercialisation of agriculture in rural areas such as north-central Namibia. The theoretical framework assessing the transaction costs involved in the interrelationship of the market, state and community institutions in agricultural development shows that there is a need to introduce a vertically integrated (backward and forward) firm (Mindlin & Lebedev 2019) (Figure 3). A vertically integrated firm minimises transaction costs in a crop value chain (Shahab 2022), but I found this type of coordination mechanism to be lacking in Namibia's vegetable value chain. Understanding the constraining factors in the vegetable production system would allow planners and policymakers to review and implement agricultural programmes and projects that would improve people's living standards and contribute to gross domestic product (GDP). The focus is on agricultural projects and their contribution to agricultural commercialisation, the role of public-private partnerships in agricultural commercialisation, and obstacles associated with information asymmetries and principal-agent problems among market, state and community institutions in agricultural development.

Role of private companies

According to Williamson (2010) the introduction of a private company is perceived as bridging the gap between farmers and the market. Hence, the independent vertically integrated (backward and forward) firm is expected to manage the production, marketing and processing of fresh vegetables in northern Namibia. This would enable the company to reduce high input costs, find markets for farmers' outputs and reduce information asymmetry and opportunistic behaviour by both farmers and elites. In addition, smallholder farmers would be coordinated to the input and output markets through contract production, thereby correcting the market failures experienced by high-value crop farmers. This contract would be renewed on a yearly basis in order to review its conditions based on the experience and performance of the farmers. Additionally, the company would divide farmers into farming blocks, which could make it possible

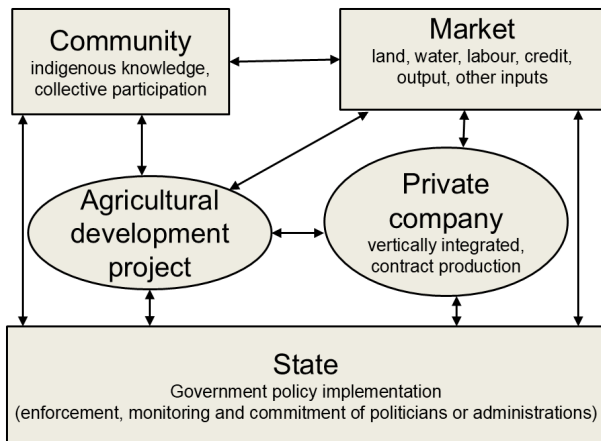


Figure 3 Model of the proposed solutions to relationships in the state, market and community institutions networks. Arrows show produce or contractual information flow or transaction exchange or services provided.

to invest in equipment, undertake joint services (e.g., levelling of land, provision of irrigation canals, bulk supplies of fertilisers and chemicals) and organise labour, harvesting and transport (Matenga 2017).

Moreover, vertically integrated companies are expected to provide expertise in vegetable production and marketing, which would minimise the high transaction costs in the supply chain and reduce the costs associated with research and product development. For this reason, the criteria to select farmers for the commercialisation of agricultural programme should include performance (experience with crop production), availability of productive land, availability of irrigation water, and availability of experienced and skilled labour (growing, grading, and so on). It is expected that vertically integrated firms will also design cropping programmes and train farmers in global good agricultural practices (GAP). Awareness of the importance of global GAP among farmers is a key factor in enhancing competitiveness (Mason-D’Croz 2019).

Proposed solutions between the market and community institutions

My study highlights the need for clearly defined land rights in my study area, which are key to vegetable production. Land belongs to the state (communal land) and is governed by the Communal Land Reform Act No. 5 of 2002 which restricts property rights. Better defined property rights would allow for a land market and the use of

land as collateral to grant farmers access to credit for investment and production. Currently, land in communal areas in northern Namibia is owned by the state and is administered by traditional authorities (De Villiers et al. 2019). Participants revealed that the state and traditional authorities may privatise land at their own discretion and have been accused of allocating large tracks of communal land to themselves, while elites are accused of illegally fencing land at the expense of poor smallholder households. Participants also shared that since land belongs to the state, farmers cannot use it as collateral to obtain credit from financial institutions. The government would need to create institutions that support registration, transfer, and administration of property rights to enable farmers to invest in high-value crop production.

Proposed solutions between the state and the community institutions

My study highlights the role that traditional norms, values, and beliefs play in adaptation and transformation among smallholder vegetable producers. Support services (e.g., education and training) can aid innovation and technology usage among rural farmers, while making sure these align with farmers’ norms and values. Innovations and technologies should incentivise farmers to transform and adapt their practices through employment creation and income generation. The government needs to continue building the capacity of farmers to adjust and adapt to new and changing innovations and technologies. In addition, trust is at the core of new technology transfer, production, and marketing information dissemination in the commercialisation of agriculture (Mwambi et al. 2020).

Moreover, transaction costs associated with monitoring activities in the vegetable supply chain are significant (Senyolo et al. 2018). These include the costs of auditing, inspection, and investment in monitoring devices. This study reveals that the high cost of monitoring government activities and individual farmers is a factor that constrains the production and marketing of vegetables in the studied setting. Consequently, the monitoring processes of the project are compromised, and it is difficult to impose penalties on the non-performance of farmers in the project. Thus, it is anticipated that the selection process of the farmers

to be part of the community project must be transparent, with an independent body to oversee the process. This would force individuals to practice and enhance self-monitoring.

Proposed solutions between the market and the state

During the study, I found that the government has continued to invest in physical and marketing infrastructure. However, smallholder farmers continue to have problems accessing input and output markets. Inputs are mostly imported from South Africa and local smallholder farmers experience high transport costs and other high transaction costs because of incomplete information among agents. The main local output market is Windhoek, the capital city which is located approximately 900 km south of the study area and is supplied with large quantities of high-quality vegetable imports from South Africa (Thomas & Vink 2020). Additionally, information from local smallholder farmers showed that they produce a small quantity of vegetables and experience high transport costs when accessing domestic markets, making them less competitive locally. A perceived solution to this problem is to introduce a vertically integrated company (as discussed earlier), that operates on contract production. The company is expected to source inputs in large quantities and benefit from volume discounts and reduced transportation costs. This will allow local farmers access to the output market through the company which will have the capacity to supply to both domestic and export markets in large quantities and meet the food standards demanded by retailers and supermarkets. However, the government is expected to play a regulatory role in this partnership.

CONCLUSIONS

This study assessed a series of interventions based on the institutional arrangements of market, state and community institutions in agricultural development in northern Namibia. The results revealed that transaction costs have prevented farmers from participating in agricultural projects, mainly because of information asymmetries and the opportunistic behaviour of administrators (politicians or elites), traditional leaders, farmers, and other market actors.

My work adds to the empirical literature by presenting a model that can be used to capture community institutions and organisations that result in high transaction costs in crop value chain analysis. There is a need to introduce a vertically integrated company as an organisational instrument linking smallholder farmers to input and output markets through contract production. Thus, it is suggested that government interventions should be based on market and agro-ecological realities and prioritise community needs. Agricultural development activities should also consider the formation of cooperatives, as organisations of this kind are currently lacking.

ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of farmers, government officials, traditional authorities, and businesses in the Omusati Region, as well as the contributions of the researchers consulted during this study. I would like to thank the University of Namibia (UNAM) for the materials support. I thank and greatly appreciate financial contributions as well as the authorisation (3rd NCRST call/researchers) to carry out the study from the National Commission on Research Science and Technology (NCRST) of Namibia.

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APPENDIX 1**A. Check list of questions for key informants**

1. According to your own opinion what is the contribution of small scale irrigation agriculture for local or national economy?
 2. Do you know how small scale irrigation agriculture started in the North Central of Namibia? If yes how was the project initiated.
 3. What are the bases or criteria of access to land for small scale irrigation farmers?
 4. Do you think the existing land tenure system is fair and helpful for the sustainability of the irrigation agriculture? If yes how?
 5. What are the rules or criteria for water allocation to individual users in North Central (especially small scale irrigation producers)?
 6. What are the supports (services) provided by different stakeholders to small scale irrigation producers in the area?
 7. What are the impacts of small scale irrigation agriculture on natural resources (i.e. water, land, forest etc.,) in North Central regions?
 8. What do you suggest for the improvement of small scale irrigation in North Central regions?
 9. What are the sources of conflict in relation to irrigation agriculture in the area and how are these conflicts managed?
 10. What are the major problems in irrigated crop production and what support do producers need most and from where do they expect it?
-

B. Check list of questions for financial or credit institutions

1. What type of loans, amount borrowed, interest rate and terms of contract are available for small scale irrigation farmers?
 2. Do all the small scale irrigation farmers fulfil their monthly or season instalment payments? If no what happen to the farmers if they default on loan contract agreement?
 3. What do you suggest for the improvement of small scale irrigation in North Central regions?
 4. Could you please give any comment or information that you think is necessary to know about small scale irrigation agriculture financing.
-

C. Check list of questions for farmers' associations or cooperatives

1. What are the socio-economic contributions of small scale irrigation agriculture to the country, especially North Central, for inhabitants?

2. What are the main benefits from joining this organisation?
 3. How many members do you have in your organisation?
 4. Who qualifies to be a member in the organisation?
 5. How much are membership fees?
 6. What is the most important source of funding of this organisation?
 7. Who originally founded the organisation?
 8. How are leaders in this organisation selected?
 9. How is conflict handled in the organisation?
 10. Does this organisation work or interact with other organisations with similar goals in the country or outside the country?
 11. In your opinion what are the problems (challenges) for your organisation?
-

D. Check list of questions for traders

1. Do you source vegetable products from local farmers? If yes where are these local farmers located? If no, why, and go to question 6?
 2. What are the major challenges (problems) from business perspective that characterise the relationship between traders and local small scale irrigation producers?
 3. Do you buy on contractual basis? If yes explain the terms of contract? If no what are your reasons?
 4. How is transport arranged for vegetable products from local producers to your business?
 5. How is price of local vegetables determined?
 6. Could you please give any comment or information that you think is necessary to know about small scale irrigation agriculture in North Central Namibia.
-

E. Check list of questions for Farmers during focus group discussion

1. What is your experience in vegetables production?
2. What types of vegetables have you produced?
3. What are the production challenges experience in vegetables production in your area (inputs, water, irrigation equipment, electricity, fuel etc.)?
4. What are the solutions to vegetable production in your area?
5. Who owns the land you are using for vegetable production?

6. What are the challenges with regards to access to land for crops production?
7. Do you have any form of insurance against theft, loss of income?
8. What are the marketing challenges you experience with your vegetables produce (access to market, transportation, storage, processing, pricing etc.)?
9. What do you do to cope with competition in the market?
10. Do you borrow money for your farming activities (source, security, repayments etc.)?

Comparing conventional and conservation agriculture for multi-seasonal maize production in the Zambezi Region, Namibia

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ABSTRACT Half of Namibia's population resides in rural areas, and many rely on small-scale farming. Crop production declines in the region over recent decades have been associated with the degradation of soils as a result of conventional farming methods. Conservation agriculture has been identified as a smart agricultural technique that can remedy challenges around agricultural land degradation and climatic uncertainty. This study undertook an experimental trial in farmers' crop fields in the Zambezi Region to compare the maize yield performance of conventional and conservation agriculture methods. I collected data from experimental research plots on four participating farming clusters. Data collection commenced during the 2016/2017 cropping season and continued through the 2019/2020 cropping season. I found no statistically significant difference in the average yield of maize biomass across seasons and within the growing season between the two primary tillage systems examined (conventional mould board plough and conservation agriculture using rippers). However, there was a significant difference in the average maize grain yield across treatments (plough, ripper, and ripper intercropped) in the 2018 cropping season. My findings indicate that conservation agriculture can offer a viable alternative to conventional methods, despite implemental inconsistencies. Based on my findings, I also encourage the pursuit of longer-term studies that might better capture soil recovery processes and other long-term effects. This will help compile a more comprehensive evidence base and prepare for a potential transition to conservation agriculture in Namibia.

KEYWORDS conservation agriculture; crop production; maize; Namibia; ripper; rotation

INTRODUCTION

Across Africa, there is a perpetual deficit in staple food, and most African states, including Namibia, are net importers of staple foods (Mushendami et al. 2008, Kiesel et al. 2022, Kristof 2022, NAB 2022a). Approximately half of Namibia's population lives in rural areas (NSA 2024) and a large proportion of this population relies on smallholder, subsistence farming - primarily maize production - for both

food and income generation (Mendelson 2002, Lai et al. 2012, MAWF 2015, Shifiona et al. 2016). Despite efforts toward achieving self-sufficient food production, food security remains unachievable for many rural communities. This situation can be attributed to factors ranging from environmental to structural (Shifiona et al. 2016, Fortunato & Enciso 2023). In Namibia's northern communal areas, the soil is typically nutrient-poor and exhibits inadequate water-holding capacity,

except for the Zambezi Region in the northeast (Krebs 2014). Compounding these issues are the irregular and insufficient rainfall predominantly occurring between October and March, often leading to inadequate crop production. Small-scale farming based on traditional cultivation methods prevails among these rural communities. These cultivation conventions include the use of animal-drawn mouldboards for ploughing, and can lead to poor soil moisture and nutrient retention, and ultimately to reduced long-term agricultural productivity (Grabowski & Kerr 2014, Krebs 2014, Wang et al. 2020).

An alternative to conventional farming methods is conservation agriculture, which represents a shift towards more sustainable agricultural practices and technologies. Defined by its commitment to improving soil sustainability, conservation agriculture encompasses a variety of practices centred around three core principles: (a) minimising soil disturbance through methods like ripping instead of ploughing, (b) maintaining permanent soil cover by adding organic matter, and (c) implementing crop rotation, specifically alternating cereal crops with leguminous ones (Wagstaff & Harty 2010). This agricultural method safeguards soil fertility, bolsters land resilience against drought and other adverse climatic conditions (Akpalu & Ekbohm 2010, Palm et al. 2014), and is applicable across different farming systems (Kassam et al. 2014). Importantly, the shift from traditional to conservation agriculture practices, can also result in enhanced yields (Gebru 2010, Hall et al. 2010). Deep ripping and decompaction are key factors that help restore soil pore space and permeability for water infiltration (Thierfelder & Wall 2009). Krebs (2014) notes that transitioning from conventional to conservation tillage can significantly improve soil carbon levels. Moreover, incorporating organic matter, like manure, into the soil enhances water retention, reduces erosion, and promotes crop growth (He et al. 2009, Krebs 2014). A study in Zambia found that maize yields per hectare were consistently higher on conservation agriculture fields than those using conventional methods, particularly in seasons of low rainfall (Nyanga et al. 2011). Rising environmental concerns have underscored the need for alternative approaches that reconcile development activities, including agriculture, with the imperatives of future investment and

environmental sustainability (Kassam et al. 2016, Xavier et al. 2020). Transitioning to conservation agriculture could help facilitate such a reconciliation (Pittelkow et al. 2014).

This study evaluates the impact of conservation agriculture on maize grain and biomass yields during the first three years of its implementation in Namibia's Zambezi Region – a key maize-producing area where most subsistence farmers rely on rainfed agriculture amid increasingly unpredictable climatic conditions (NAB 2022b; Muradzikwa et al. 2023). With its agricultural potential, subsistence culture and widespread use of conventional agricultural practices (Kiesel et al. 2022), the region presents an ideal experimental setting for a comparative evaluation and builds on other conservation agriculture research in Namibia (Taapopi et al. 2018).

MATERIALS AND METHODS

Study area

The Zambezi Region in Namibia is located in the northeastern part of the country, as shown in Figure 1. It benefits from having Namibia's highest precipitation, with an average annual rainfall of 650 mm, and the lowest water shortage rates (Angombe & Shikangalah 2021, Kiesel 2019). It covers an area of 14 785 km², and has a population of over 142 000 (NSA 2024).

Crops commonly grown are maize, pearl millet and sorghum, and cowpea. Maize is the staple crop in the region, and most farmers who grow maize at a large scale, especially in the floodplain area, are farming for commercial purposes. The soils are heavy with high clay content in areas regularly flooded, such as hydromorphic and organic clay soils (Teweldemedhin et al. 2015).

Research design and layout

A total of 24 farmers volunteered to participate in this study. These farmers were divided into four clusters, with each cluster consisting of farmers from the same village. Each cluster consisted of six farmers. A 0.3-ha experimental research plot was established in the fields of each participating farmer. The study employed a Randomised Complete Block Design (or RCBD), which relies on different treatments being applied to one contiguous block (Figure 2). Participating farmers

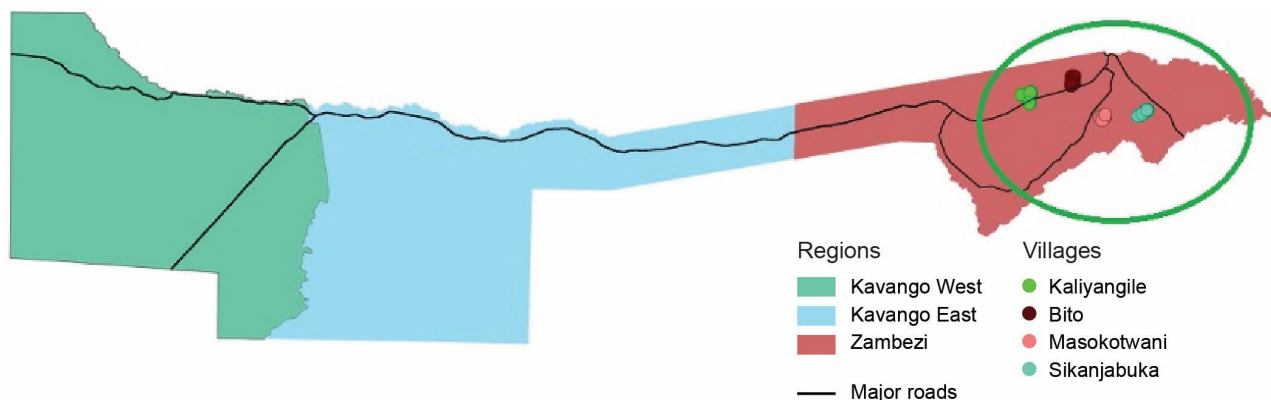


Figure 1: Location of the experimental plots in the study area. Plots are grouped according to farmer clusters. Each cluster consists of farmers residing in the same village.

underwent a week-long training programme tailored to the research objectives.

All farmers planted Maize Zamseed 606. This variety has semi-flint white grain, with good storability and yield potential of 8–9 Mt/ha, and it takes 125–130 days to maturity. For consistency, participants were provided with inputs sufficient for 0.3 ha only. However, farmers had the freedom to replicate the research protocols anywhere in their crop fields. Experimental plots were divided into six equally sized (10 × 50 m) and adjacent subplots separated by only 60 cm. Two different implements were used to prepare the research plots. In the conventional tillage section, an ox-drawn mouldboard plough was used to prepare the land, whereas in the conservation agriculture tillage section, an ox-drawn ripper was used to make ripper lines. The ploughed and ripped sections were retained over the study period and prepared every crop season with a rotation of the crops. Maize seeding was done in rows and in 35-cm intervals, with rows separated by 90 cm. On the intercropped sub-plot, cowpeas were planted between the rows of maize with 25 cm between

planting point. A marked string was used to establish a straight line, and holes for seeding (planting points) were made along the marked string with a dibble stick at a depth of 4–5 cm.

Research plots were prepared depending on the onset of rainfall. Soil preparation and seeding were completed once we deemed soil moisture to be sufficient, which was usually achieved with a minimum of 20 mm rainfall. As a result, seeding occurred in December/January. Basal fertilisers were applied at seeding at a rate of 150 kg/ha, hence every farmer was given 1 × 50 kg bag of NPK (2:3:2). Top dressing of urea was applied at a rate of 75 kg/ha for four weeks after planting and another 75 kg/ha seven weeks after planting, farmers were expected to apply urea the same day. Urea was only applied to maize, both on the sole cropping sub-plots and on the intercropped sub-plots. Thus, every farmer received one 50 kg bag of urea to apply twice per cropping season. Each farmer managed their research plot individually, and weeding was not expected to be done in one day.

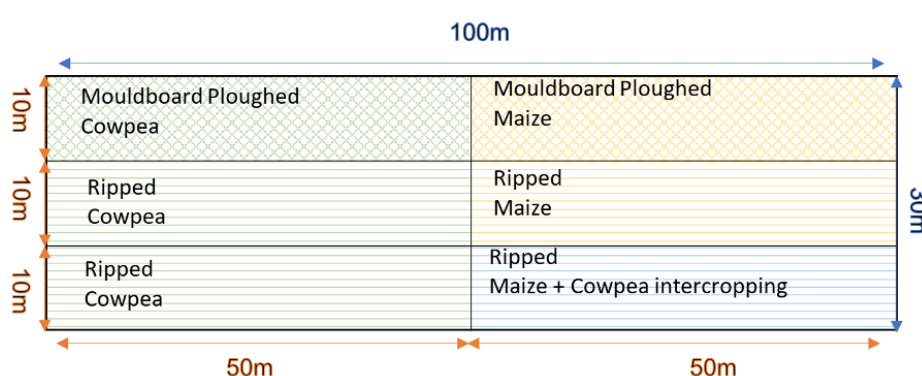


Figure 2 On-farm layout of an experimental plot, with each treatment divided into 10 × 50 m subplots.

Farmers were provided with all inputs and assisted by one research assistant per cluster in managing the research plots in order to ensure that research protocols were properly followed and implemented accordingly. All the crops were grown under rain-fed conditions. This ensured that the experimental variables were treated in a homogeneous way as much as possible, allowing for a clearer comparison between conservation agriculture and conventional tillage systems. Upon completion of the growing season, both grain and biomass yields for the crops were meticulously recorded following established harvesting protocols.

Data collection

To facilitate and ensure a smooth data collection process, I recruited research assistants, with one research assistant being assigned to one cluster. Research assistants were provided with a data collection sheet to record the rainfall figures, dates for each management or measurement activity in the plot, i.e., weeding time and date, or yield taken. All farmers were provided with a rain gauge and trained on how to record the rainfall figures on a data sheet. My research assistants, mobilised with bicycles, ensured that farmers recorded data correctly, which included land preparation, planting, weeding, fertiliser application, pest and disease control. Harvesting protocol training was given to all research assistants, and a harvesting data sheet was designed. Soil samples were taken at 0–20 cm depth before the experiment commenced, with at least ten samples taken at each experimental site. Harvesting was done when the maize plants were dry and the cobs ripe. Five blocks of four rows, each 5 m in length, were demarcated in each treatment, with the following data collected from each block: the distance of the sixth row (one row on each side of the harvesting block), number of planting points within a harvesting block, the number and weight of cobs within each harvesting block, the weight of stalks within the block cut down at the ground level, weighed and recorded as biomass. The maize cob sub-samples and stalk sub-samples were air dried for two weeks before they were re-weighed, the cobs were shelled, and the grain was weighed separately per treatment. An electronic grain moisture tester device was used to determine the grain moisture content after shelling. All the data were entered into a pre-programmed spreadsheet to extrapolate grain and biomass yield per hectare.

Rainfall records

Rainfall patterns showed sporadic variations throughout the experimental period from 2016/2017 to 2019/2020 and between clusters (Figure 3). It is also important to note that rainfall data were collected relatively inconsistently, depending on farmer participation and the occasional theft of rain gauges. In the 2016/2017 season, rainfall was generally fair across all clusters, with a maximum cumulative rainfall exceeding 600 mm. In the 2017/2018 season, the Zambezi Region experienced good rainfall, with the Bitso cluster receiving more than 1 000 mm.

2018/2019 marked the shortest rainy season, with only 169 days. In contrast, the 2019/2020 season was the longest and most favourable, with an average annual rainfall of 800 mm being recorded over 199 days.

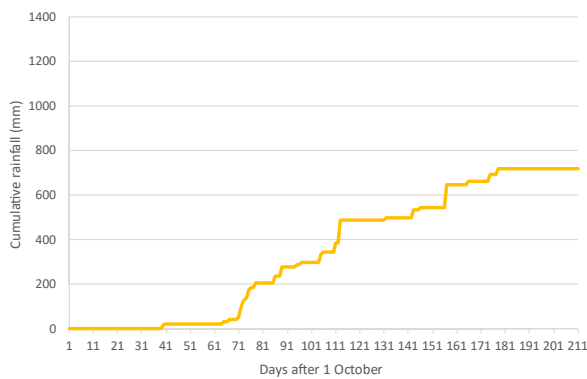
Data analysis

A two-way Analysis of Variance (ANOVA) was used to assess the effect of conservation agriculture on crop yield. This analysis involved comparing the grain and biomass yields of maize. Consequently, conventional (mouldboard plough) sub-plots were compared with conservation agriculture (ripped) sub-plots and conservation agriculture (ripped) sub-plots that were intercropped. To compare the mean yields of biomass and grains of maize, the Welch's t-test was employed. The significance of differences between various treatments across four cropping seasons was determined using the p value from Welch's t-test as the initial analytical step. Subsequently, a second test was conducted to assess whether there were differences in average yields between tillage methods within each cropping season. All analyses were conducted in R version 4.1.3 (R Core Team 2022).

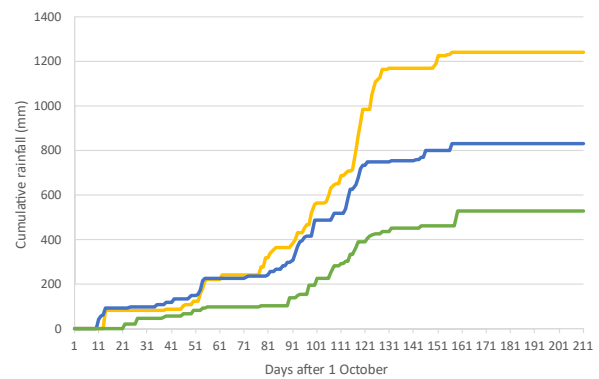
RESULTS AND DISCUSSION

The analysis revealed no statistically significant difference in the maize biomass yield between the conventional and conservation tillage ($p > 0.05$) over four seasons (Figure 4). On average, plough treatment produced 8.07 kg/ha of biomass, followed by ripper intercropped (maize and cowpeas) treatment with 7.64 kg/ha and ripper with an average of 7.63 kg/ha of biomass. Biomass measurements and analyses are critical

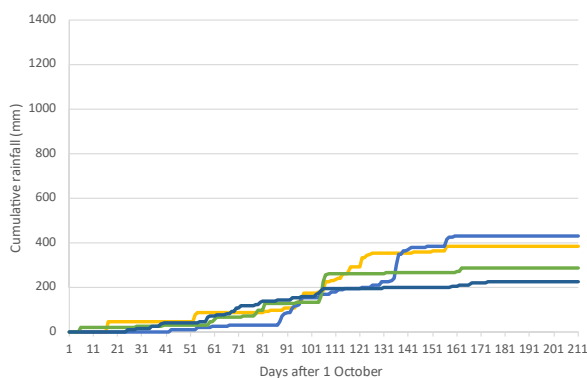
2016/2017



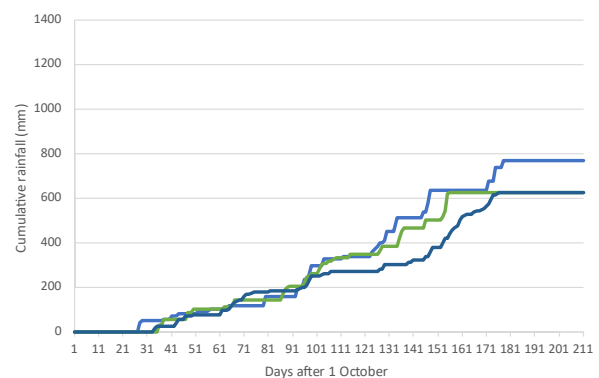
2017/2018



2018/2019



2019/2020



— Bito — Kaliyangle — Sikanjabuka — Masokotwani

Figure 3 Cumulative rainfall at research clusters during the study period, starting on 1 October 2016.

components in quantifying carbon stocks and sequestration rates (Temesgen et al. 2015). The measure of biomass is important to determine the productivity of a given area, as it may be used as a proxy for yield if the crop did not bear a grain yield due to an unexpected cessation of rainfall.

A similar test was done to determine if there was a significant difference in maize grain yields over the study period across the three treatments (Figure 5). There was no significant difference in maize average grain yield between conventional and conservation tillage over the four cropping seasons. In terms of yields, conservation agriculture can only begin to outperform conventional methods after more than a decade, because of the amount of time it takes to restore or improve soil fertility (Giller et al. 2009). This has drawn mixed reactions from farmers and technocrats on whether conservation agriculture is a sustainable intervention in the era of climate change (Eze et al. 2020, Nyirenda & Balaka 2021, Li et al. 2024). However, an investigation into the effects of conservation agriculture on 17 soil properties, revealed soil health improving with

long-term rises in temperatures (Teng et al. 2024). Considering temporal scale as a confounding influence, it is plausible that conservation agriculture's impact was not yet visible in this study and elsewhere (Nyamangara et al. 2013). Additionally, under semi-arid conditions, the performance of conservation agriculture has been found to be enhanced by the addition of small amounts of mineral nitrogen fertiliser and cattle manure, but depressed by surface mulching with high carbon-to-nitrogen crop residues (Nyamangara et al. 2013). When early years of transition might yield discouraging results though, some farmers might opt to abandon conservation agriculture techniques (Hobbs 2007), which presents a substantial challenge for any systemic transitions (Baudron et al. 2015, Ngoma et al. 2024).

There were no statistically significant differences in maize biomass yields across the study's seasons (Figure 5b). In the 2017 cropping season, ploughed plots had on average biomass yield of 10.33 kg/ha, followed by ripper with 8.32 kg/ha, and ripper intercropped with cowpeas with 8.23 kg/ha. In the cropping season of 2018, on average, the plough

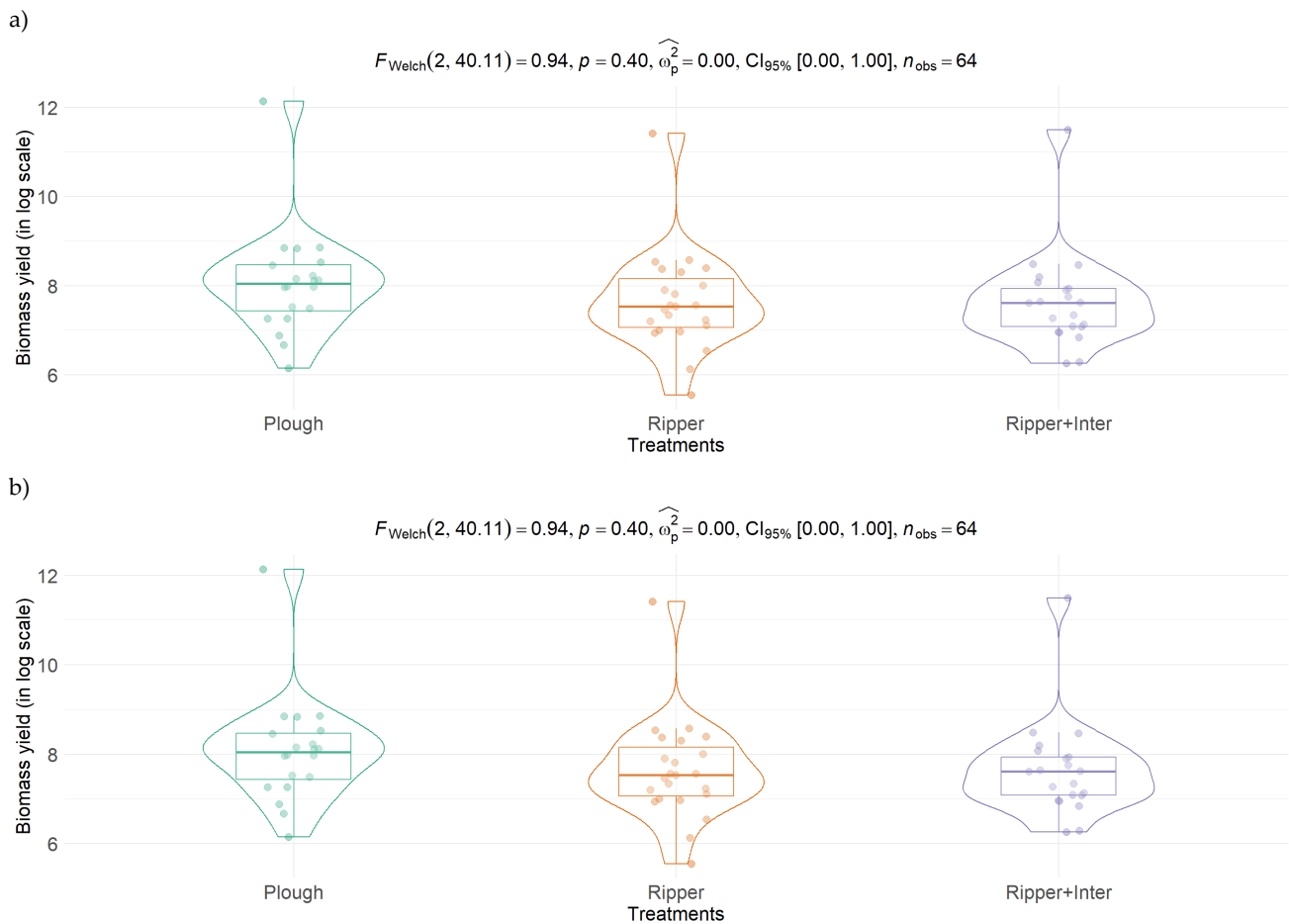


Figure 4 Violin plots illustrating (a) average maize biomass yield and (b) average maize grain yield for different treatments. Mean yield values have been log-transformed to improve visualisation. These plots depict both the central tendency and the distributional shape of the data across treatment groups. Any between-treatment differences are considered significant if the p-value (top) is equal to or below 0.05.

had a biomass yield of 8.09 kg/ha, the ripper yielded 7.54 kg/ha, and the ripper intercropped yielded 7.44 kg/ha. In the 2019 cropping season, on average, ploughed plots yielded 7.48 kg/ha in biomass, followed by ripper intercropping (7.47 kg/ha) and ripper maize (7.31 kg/ha). Notably, data for the 2019/2020 cropping season were not included due to the absence of harvest data - a consequence of movement restrictions imposed nationwide in response to COVID-19.

In the second season, the results demonstrated a statistically significant difference ($p < 0.05$) in the average grain yield of maize between tillage systems, leading to the rejection of the null hypothesis (Figure 5a). Rainfall was comparatively high in the first season. Traditional ploughing yielded more grain than both the ripping and intercropped ripping for that season. This variation in yield could be attributed to the favourable rainfall the Zambezi Region experienced during

the first two seasons, with certain areas in the region receiving more than 1 000 mm. These results are in line with the findings by Donovan and McAndrew (2000) that indicate that zero tillage can be particularly effective in enhancing crop yield during years of relatively low precipitation. Both corn and soybean yields have been found to be greater in mouldboard ploughing than in no tillage because of lower weed density (Mulugeta & Stolenberg 1997). Another study reported that no-tillage treatment yielded less than ploughed treatment (Wilhelm & Wortmann 2004). A study carried out in the northeastern regions of Namibia found a significant difference in maize grain yield in the second year of experimenting, with conventional tillage recording the highest grain yield and minimum tillage being the least productive (Kudumo et al. 2023). However, minimum tillage with selective incorporation of conservation agriculture principles increased maize grain yields in the third year (Kudumo et al.

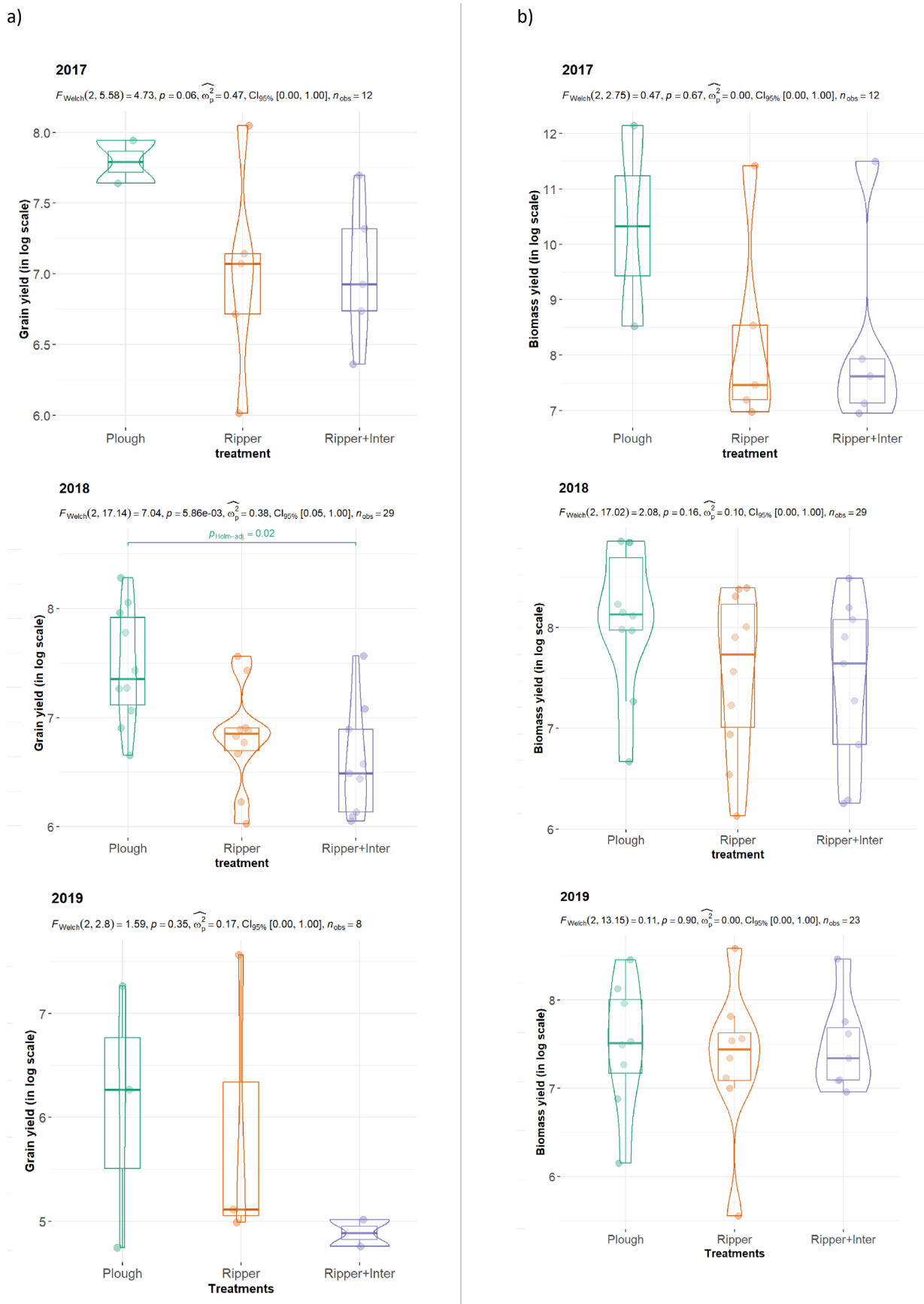


Figure 5 a) Average maize grain yield and b) average maize biomass across treatments within seasons. These plots depict both the central tendency and the distributional shape of the data across treatment groups. Any between-treatment differences are considered significant if the p-value (top) is equal to or below 0.05.

2023). In another study, animal traction conservation agriculture systems had slightly smaller yield benefits on a rip line seeded system compared to a ploughed control treatment (Thierfelder 2015). One of the contributing factors to low yield on the ripper sub-plots in this study is that ripper lines suffered from rat attacks, which were feeding on the germinating seed following ripper lines, necessitating re-seeding on many occasions. This led to delayed establishment and poorer growth of crops in ripper lines compared to those in ploughed sections, where conditions were more conducive to germination and early growth due to a softer, weed-free seedbed. Ripped plots were also disadvantaged because some farmers delayed the weeding process, exposing the crops in the ripper sub-plots to higher weed densities. Additionally, the intercropped areas reported lower average grain yields compared to monocropping with the ripper. This can be attributed to the competition between maize and cowpeas for moisture and nutrients, and aligns with other findings. Huang et al. (2019), for instance, found that maize grain yield from intercropped plots was 34% less than that from double-cropped plots. Intercropping treatments have also been found to produce relatively low number of grains per cob (Suhi et al. 2022). In contrast, other researchers have found that intercropping maize and cowpea enhances maize grain yield (Iderawumi et al. 2017), and has a profound effect on soil organic carbon (Ayele 2020).

CONCLUSION

This study found no observable difference in the average maize biomass yield between two primary tillage systems (conventional and conservation agriculture) and within the growing seasons. These results point towards conservation agriculture as a viable alternative to more conventional methods. During one season, however, a significantly higher average maize grain yield was recorded in conventional plots, which might be attributable to localised and context-specific factors. The research might also not have been conducted long enough for more potential effects to become observable, as other studies have demonstrated. Long-term implementation and monitoring are essential to studying the various principles of conservation agriculture and its influence on biomass and grain yield. Future research should aim to

comprehensively evaluate the impacts of these practices on crop yield, microbial communities, and soil properties. This will not only provide empirical evidence to test the efficacy of conservation agriculture but also guide future policy and practice to enhance sustainable agriculture at large. In Namibia, long-term practical demonstrations could be organised on agricultural demonstration plots in each of the constituencies across the 14 regions, allowing farmers to witness the principles of conservation agriculture in action.

CONFLICT OF INTEREST

The author declares no conflicts of interest.

ACKNOWLEDGEMENTS

The author thanks the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Namibia for their financial support in conducting the experiments; the Ministry of Agriculture, Fisheries, Water, and Land Reform for technical support, and the Namibia University of Science and Technology for relinquishing the author from academic responsibility to collect data in the field. The author acknowledges the contribution of Mr Mwala Lubinda for assisting with data analysis.

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Movement ecology and post-release success of translocated Western Barred Spitting Cobras in the Khomas Region, Namibia

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ABSTRACT Human-snake conflict is increasing globally as human habitation continues to encroach on natural habitats. To mitigate conflict, snakes are often translocated by snake removal services. In Windhoek, the capital of Namibia, the near-endemic Western Barred Spitting Cobra (*Naja nigricincta nigricincta*) is the second most removed snake from houses and gardens. This research aimed to assess the impact of translocation on the survival, body mass, and movement of such snakes. Three translocated Western Barred Spitting Cobras were fitted with transmitters and tracked over a period of six months post-translocation. All three individuals remained alive and showed body mass gain throughout the study period. While additional studies with greater sample size and resident snakes are needed to support the findings of the study, the post-translocation tracking data revealed a larger home range and greater movement in the male compared to the two females. No evidence of homing behaviour was observed in any of the translocated snakes.

KEYWORDS Human-snake conflict; translocation; spatial ecology; home range; zebra snake; *Naja nigricincta nigricincta*; telemetry; Namibia

INTRODUCTION

Snake translocation by dedicated removal services is increasing globally due to growing human-snake conflict (Sullivan et al. 2015, French et al. 2018, Hauptfleisch et al. 2021). However, since post-translocation monitoring is largely lacking in Africa, the effectiveness of this approach as a management practice remains uncertain (Cornelis et al. 2021, Choquette et al. 2023). To address this

gap, our pilot study aimed to expand the knowledge on snake translocation and focused on the Western Barred Spitting Cobra (*Naja nigricincta nigricincta*), a species that frequently comes into conflict with humans in Namibia – especially in urban areas (Hauptfleisch et al. 2021). Following capture in Namibia's capital, Windhoek, we fitted three individuals with trackers, translocated them and monitored their various responses to translocation. This study will form the baseline of a

long-term assessment to help improve the current response to human-snake conflict in Namibia.

METHODS

Study species

The Western Barred Spitting Cobra (*Naja nigricincta nigricincta*) is one of the six true cobras found in Namibia and is one of four species able to spit venom when threatened. It is a medium to large-sized snake, reaching over 1.8 m in length (Marais 2022). The snake is easily recognisable by the black and white stripes on the body. It is primarily nocturnal and typically inhabits dry savannas and semi-arid regions, where it preys on small mammals, amphibians, and other reptiles (Marais 2022).

Snake capture

Snake removal callouts were used to collect the animals in the Windhoek area. In total, three snakes were sampled, including two females and one male. Female 1 was removed approximately 5 km away from Female 2, while Male 1 was removed approximately 10 km away from the two females. These snakes were captured using snake hooks and tongs. They were weighed using a digital scale and restrained using clear acrylic tubes (Antonio 2014). Snout-to-vent length, sex, and scale counts were recorded. The data collected ensured that all snakes were large enough to be fitted with a tracker.

Surgical tracker implantation

A miniaturised VHF model SI-2 transmitter (Holohil Ltd, Ontario, Canada), weighing 9 g and measuring 3 cm x 1 cm, was implanted into each snake by a qualified veterinarian at the Veterinary Academic Hospital, School of Veterinary Medicine, University of Namibia. The trackers weighed less than 5% of the body mass of each snake. The snakes were clinically evaluated preoperatively to ensure health status. Once restrained per tube, the snakes were anaesthetised using isoflurane inhalation. The transmitters were surgically implanted intracoelomically under aseptic conditions, using a technique modified from that initially described by Reinert and Cundall (1982). The snakes were monitored postoperatively for 48 hours to allow full recovery, prior to release.

Snake release

Male 1 was translocated 20 km away from its capture site and the two females 10 km from theirs. The translocation area was a 49.83 km² cattle farm located 15 km east of Windhoek, within the highland shrubland region of Namibia, which is characterised by sweet grassveld (Strohbach 2021).

Data collection

The three tagged snakes were followed on a bi-weekly basis with the use of standard telemetry equipment (AR 8200 wide ranging receiver and standard antenna). The GPS locations of each snake were recorded every second week from April 2021 to October 2021. It is worth noting that not all snakes were located on every occasion when tracked. The three snakes were recaptured after the six-month period to evaluate their physical condition, including their body mass.

Data analysis

Spatial analyses were carried out with the standard geographic information system software package ArcView GIS 3.24.1 (ESRI Software, Redlands, CA). Home ranges were determined utilising the minimum convex polygon method (Gregory 2017). The minimum convex polygon method is a home range estimation method that creates the smallest possible convex polygon based on the GPS locations where the animal was recorded during the time of the study.

Approvals and permissions

An ethical clearance and research permit was provided by the National Commission on Research, Science and Technology (AN 202101050). All research adhered to the guidelines for use of live amphibians and reptiles in the field and laboratory, as per the American Society of Ichthyologists and Herpetologists (Beaupre et al. 2004), ensuring humane treatment and minimal stress to the animals involved.

RESULTS

All three snakes survived the study period.

Male 1 had an initial body mass of 1 098 g which increased to 1 178 g six months after translocation. The snake had the largest home range, covering a total area of 1.45 km² (Figure 1), and utilised the same burrows on more than one occasion. Male 1

was observed foraging near a rock hyrax den and rodent burrows on five occasions in the field.

Female 1 had an initial body mass of 718 g which increased to 839 g six months after translocation. The home range covered an area of 0.26 km² (Figure 1). Female 1 was observed foraging on three occasions, raiding rodent burrows and rock hyrax dens.

Female 2 had an initial body mass of 674 g which increased to 741 g six months after translocation. Female 2 had a home range of 0.17 km² (Figure 1) and was observed on one occasion foraging near a rock hyrax den.

Differences in home range sizes between Male 1 and the two females were noted. The home range of Male 1 was approximately 5.6 times larger than that of Female 1 and approximately 8.4 times larger than that of Female 2. Additionally, the home range

of Female 1 was approximately 1.5 times the size of the range of Female 2.

The home ranges of these snakes overlapped (Figure 1). The home range of Female 2 overlapped almost completely with that of Female 1. Almost half of the home range of Female 1 overlapped with that of Male 1. The home ranges of Female 2 and Male 1 showed little overlap.

DISCUSSION

In the context of the growing human-snake conflict, three Western Barred Spitting Cobras were translocated and tracked for six months. All three individuals remained alive and showed an increase in body mass throughout the study period. Male 1 exhibited a larger home range and greater movement compared to the two females. No homing behaviour was observed during the six-month period.

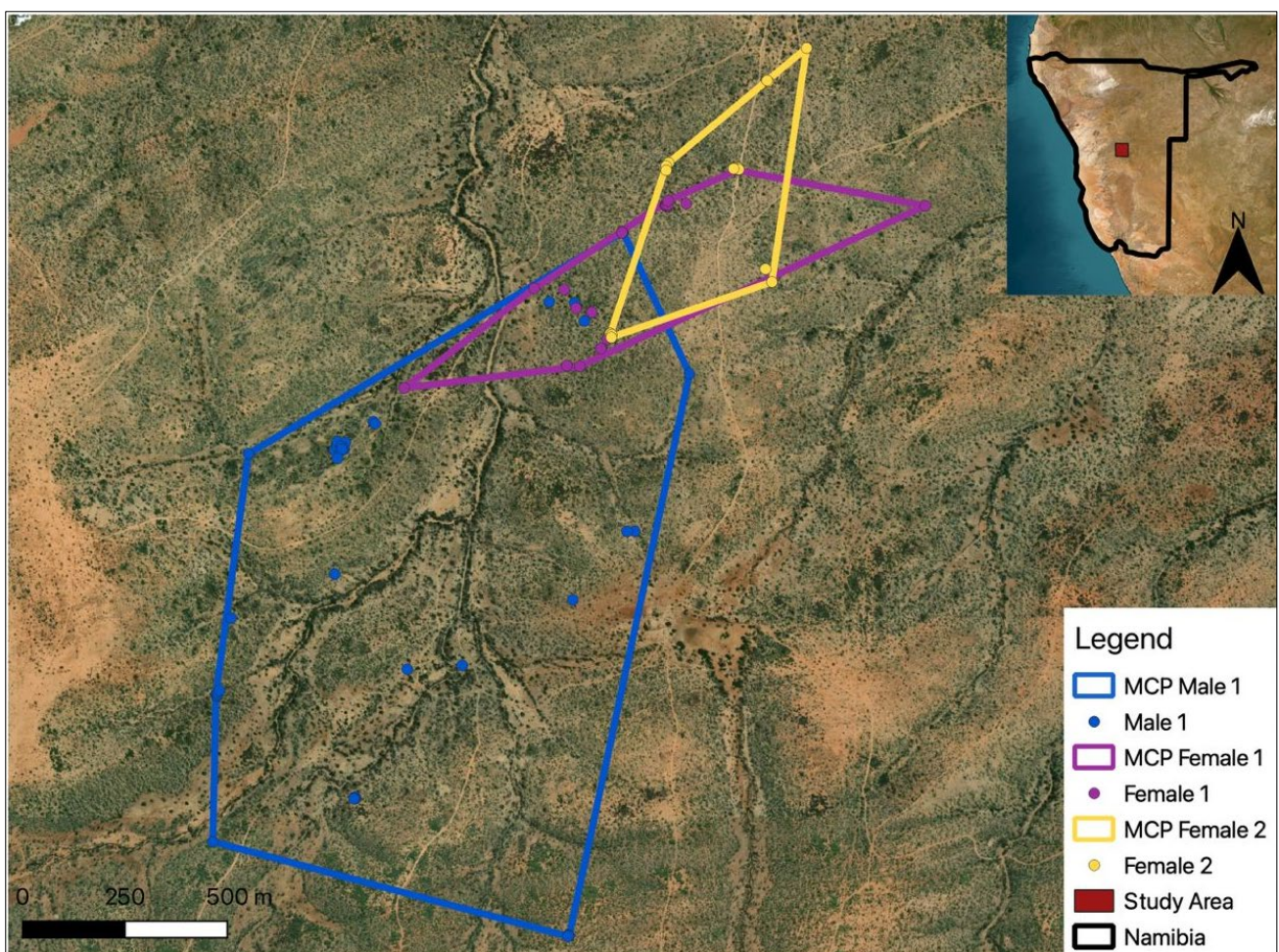


Figure 1 Study location (red square) within Namibia (top right) and minimum convex polygons (MCP) of three Western Barred Spitting Cobras over a six-month period post-translocation. The points represent the bi-weekly GPS locations of the snakes, and the lines connect the outermost points, forming the boundary of their home range.

The survival of all three snakes over the six-month post-translocation period aligned with findings suggesting that translocation does not necessarily lead to immediate mortality (Barve et al. 2013). Considering that the three snakes gained body mass, it is reasonable to assume that all three individuals were feeding during the study period. While the results are promising and could suggest that short distance translocation may be used as an ethical management practice, complementary studies need to be undertaken to confirm the current findings.

Male 1, translocated 20 km away from its initial capture point, established a home range of 1.45 km², while the home ranges of the females, both translocated 10 km away, were considerably smaller (Female 1 with 0.26 km² and Female 2 with 0.17 km²). Two primary hypotheses may explain the differences in movement and home range sizes. First, the distance at which the snake was translocated from the capture site may impact its movement (Cornelis et al. 2021). Secondly, sex could also be a factor in the observed differences (Sperry & Weatherhead 2009, Dubey et al. 2008). The difference between the translocation distances were between 10 km and 20 km and every snake was moved out from their initial home range, suggesting that males may inherently travel more in search of mating opportunities, food, and hibernacula, thereby explaining the longer distances travelled during the night. These findings imply that sex differences may be a key factor in movement patterns.

Translocation aims to mitigate conflict by removing the snake from human proximity. This tool not only ensures the survival of the snake through relocation to a safer environment but also safeguards humans using an approach considered humane and non-lethal (Massei et al. 2010). The absence of homing behaviour observed in this study therefore supports the primary aim of translocation. The potential impact of snake translocation on the trophic interactions at both interspecific and intraspecific levels warrants consideration (Stepkovitch et al. 2022). However, a larger sample size and inclusion of resident snakes are required to confirm the study results.

LIMITATIONS

Several limitations were encountered during this study. The primary limitation was the small sample size of three snakes, with only a single male, due to the lack of available snakes big enough for the transplantation. The minimum body mass required was 500 g and, in most cases, snakes removed during the period of the study had a body mass of approximately 300 g. Consequently, the generalisability of these findings remains restricted until a larger population sample can be investigated. Additionally, the six-month monitoring period may also limit the understanding of long-term behavioural changes post-translocation, particularly in response to seasonal variations and food availability. Finally, typical home range size and movement of this species are unknown. Future studies could improve knowledge by including data from resident, non-translocated snakes, which would provide a baseline comparison and enable differentiation between typical and translocated-induced behaviours.

CONCLUSION

The observed survival and established home ranges of the translocated snakes align with findings from other studies (Cornelis et al. 2021), suggesting that short distance translocation may be a viable tool for mitigating human-snake conflict. The study results show promise, as all individuals survived. Further studies employing identical translocation distances and larger sample sizes would help to validate the results from this study.

ACKNOWLEDGEMENTS

This research was made possible through the generous financial support of the Embassy of the United States of America, Namibia, through their Ambassadors' Self-Help grants program. We are profoundly grateful for their commitment to fostering research in this field. We would also like to acknowledge the School of Veterinary Science, University of Namibia, for its instrumental contribution, offering both expert knowledge and the necessary clinical facilities. Our appreciation also goes to the Namibia University of Science and Technology for guidance and support. For her significant contributions, we thank Kerstin Engelking for assistance with tracking and snake removals.

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Re-encountering *Chemsakiellus taurus* (Coleoptera, Cerambycidae, Lamiinae), a little-known longhorn beetle, in Namibia

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ABSTRACT We report two new encounters with *Chemsakiellus taurus* Villiers, 1982, a longhorn beetle, from Namibia. Until the beginning of 2022, this remarkable longhorn beetle was only known from the holotype. A shortened and translated summary of the French publication is given, complemented with a colour photo, a landscape photo of the locality and a map showing the three known localities in Namibia.

KEYWORDS *Chemsakiellus taurus*; faunistic; longhorn beetle; Namibia; rediscovery

BACKGROUND

The longhorn beetle *Chemsakiellus taurus*, Villiers, 1982, has hitherto only been recorded as a holotype deposited in the Muséum National d'Histoire Naturelle in Paris. The genus is similar to the genera *Dinocephalus* Peringuey, *Chariesthes* Chevrolat and *Rhaphidopsis* Gerstaecker, and indeed *Chemsakiellus* is more closely related to *Plagiomus* Quedenfeldt. All these genera are ranked in the tribe Tragocephalini Thomson, which is primarily known from the Ethiopian zoogeographic region, with about 274 species. Most members are known for their colourful and bright appearance, and many genera are characterised by more or less developed horns on the front of the males. One member of that group is *Chemsakiellus taurus* Villiers, 1982 from Namibia. The original description of *C. taurus* was written in French. Here we present a shortened and translated summary:

Head short, with a fine, longitudinal groove in the middle. The tubercles which carry the antennae are of medium height; eyes deeply emarginate, superior lobe strongly reduced; antennae slightly more than twice as long as body, antennomere 3 very long and thin, much longer than antennomere 4; frons with a large, slightly curved horn on each side, forward and upward directed.

Pronotum transverse, disc convex, very slightly dilated in front and sinuate in the middle, apex and base with a very slight transverse impression; prosternum with an evenly curved process. Scutellum semicircular, twice as wide as long. Elytra narrow, slightly converging towards apex. Legs short.

The only specimen was found in: "Sud-Ouest: 40 km à l'Est de Gobabeb, 26-II-1979, R. Wharton coll., holotype mâle au Muséum de Paris."

Length (minus horns): 12.5 mm

OBSERVATION

A colour photo of the holotype was presented by Adlbauer (2001), and a black and white photo (by K.A.) of the head, showing the horns, was published by Svacha and Lawrence (2014).

During a trip to Namibia in 2022, R.G. encountered a specimen of this longhorn beetle (Figure 1). It was beaten from bushes situated near the base of the rock formations of Spitzkoppe (Figure 2).

The collecting data are as follows: Namibia, Erongo Region, Spitzkoppe, S21°49.883' E15°09.826', 1 078 m, 28 March 2022, R. Gerstmeier leg. #11 (National Commission on Research, Science and

Technology, Windhoek, Namibia: Permit Number RPIV00012018). This specimen (length 9.5 mm, minus horns) is deposited at the National Museum of Namibia, Windhoek, Namibia. The collecting locality is presented in Figure 3. Unfortunately, it was not possible to determine the bush species.

Another specimen is known from a post by Riana Bate on the Cerambycoidea Forum (https://www.cerambycoidea.com/forum/topic.asp?TOPIC_ID=29376; 28 February 2022). The specimen, a hornless female, was found in the Namib Naukluft Park (length 14 mm). The collection date and other details are not known to the authors.



Figure 1 *Chemsakiellus taurus*, from Spitzkoppe, Namibia (Photo: R.G.).



Figure 2 Rock formation at Spitzkoppe, where our specimen of *Chemsakiellus taurus* was found (Photo: R.G.).

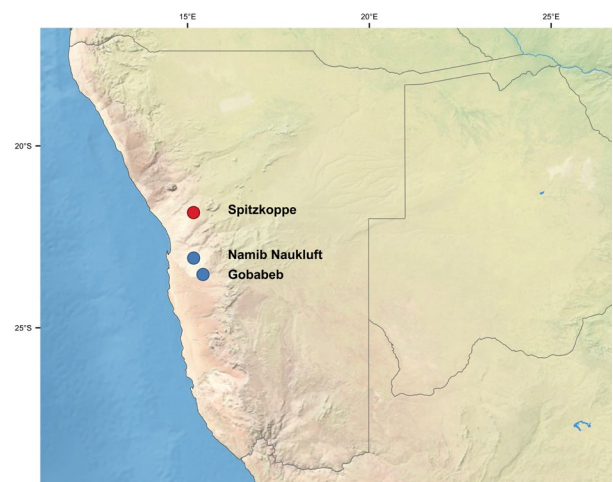


Figure 3 Locations of *Chemsakiellus taurus* in Namibia. The red dot indicates the location from the Namibia trip of R.G. in 2022, while the blue dots represent the Gobabeb and Namib Naukluft type localities, reported by Riana Bate.

ACKNOWLEDGEMENTS

Our sincere thanks go to Justin S. Bartlett (Brisbane) for his critical review of the manuscript.

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A new longevity record for the Damara Tern *Sternula balaenarum*

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ABSTRACT A Damara Tern ringed as an unfledged chick and fitted with a colour ring in March 2008 in southern Namibia has been regularly observed at a roost near Lüderitz in winter and early spring since 2015. The latest confirmed sighting of this bird was on 2 August 2025, i.e. 17 years and four months since ringing. This constitutes the present longevity record for this species. Fifty-seven sightings of this bird since 2015 between mid-May and early October in southern Namibia indicate that it is highly unlikely that it undertook a winter migration to tropical West Africa, at least in most years, during the period 2015–2025.

KEYWORDS Damara Tern; longevity; migration; Namibia; seabird conservation

INTRODUCTION

The Damara Tern is a near endemic species in Namibia where more than 90% of the total population breeds along the Namib desert coastline (Crawford & Simmons 1997, Simmons 2005, Simmons et al. 2015). The biology of this species is relatively poorly understood due to the remoteness of most of its breeding sites, particularly in southern Namibia. Many Damara Terns have been ringed during the last five decades, particularly along the central coast of Namibia (Braby 2011), including c.1250 birds between 1994 and 2010 (Braby 2010). Unfortunately, the small size of the birds (and rings) makes subsequent identification virtually impossible unless the birds were re-captured or found dead. In more recent years, colour rings were additionally fitted to some birds and facilitated individual identification at a distance (e.g., Braby 2010). Here we present a new longevity

record for the Damara Tern based on one of these colour ring deployments.

STUDY SITE AND METHODS

During a previous study (Braby 2011), several Damara Terns were fitted with colour rings in southern Namibia. These included four unfledged chicks that were ringed between 11 and 22 March 2008 with the unique marking combination of a single yellow colour ring on the left tarsus and a metal ring, engraved with a unique number, on the right tarsus at the !Anichab salt pan (26.264 S, 15.000 E), near Hottentot's Bay, about 43 km north of Lüderitz.

Since mid-2013, the presence and numbers of Damara Terns were regularly monitored on the northern part of the Lüderitz Peninsula in the vicinity of Dias Point (e.g. Roux 2022) along the shores of Shearwater Bay (part of the greater

Lüderitz Bay). Observations were mainly made from a vehicle with 10x40 binoculars, and photographs were taken with a DSLR camera fitted with a 300 mm or a 500 mm zoom lens to document plumage phases and behaviour of the birds, including courtship, mating, provisioning of juveniles, as well as the presence of rings and other marks. To date (August 2025), this intensive monitoring consisted of more than 3 700 visits made to the study site in all months since May 2013.

RESULTS

In August and September 2015 two of the four colour-ringed birds that had been ringed at the !Anichab Salt Pan were sighted and photographed at Shearwater Bay (26.644 S, 15.096 E) among flocks of Damara Terns regularly roosting at the site (Figure 1a). One of these two birds had a characteristic profile due to an apparent thickening of the upper mandible forward of the nares, giving the bill - seen in profile - an accentuated decurved shape compared to most other Damara Terns present at the site (Figure 1b).

In the following years, this bird, identified by the combination of its colour ring and unusual profile, was recorded photographically at the Shearwater Bay roost site in all years except 2016 and 2019. In total there were 57 records of this particular individual at the Shearwater Bay roost site between 4 August 2015 and 2 August 2025. This latest sighting indicates that this bird was banded as an unfledged chick at least 6 342 days (208 months, 17.36 years) prior. This constitutes the longevity record for this species to date.

It is noteworthy that all 57 verified sightings of this bird at the Shearwater Bay roost site were in winter or early spring, between mid-May and early October (Figure 2), at a time when the majority of individuals have migrated to equatorial west Africa, between Nigeria and Liberia (Crawford & Simmons 1997, Gochfeld et al. 2020), or just returning to Namibia from there (in September and October). Forty-one of these records (72%) in nine different years were made in June and July (Figure 2). This suggests that this individual most probably did not migrate northward, at least in most years. Moreover, all these sightings at the Shearwater Bay roost site were made on days when the roost was populated by relatively large numbers of Damara



Figure 1 Photographic records of the colour-ringed bird (yellow ring on the left tarsus) a) at the Shearwater Bay roost site in a flock and b) a profile photograph of the same bird showing the characteristic accentuated decurved bill shape. Both photographs were taken on 12 July 2023.

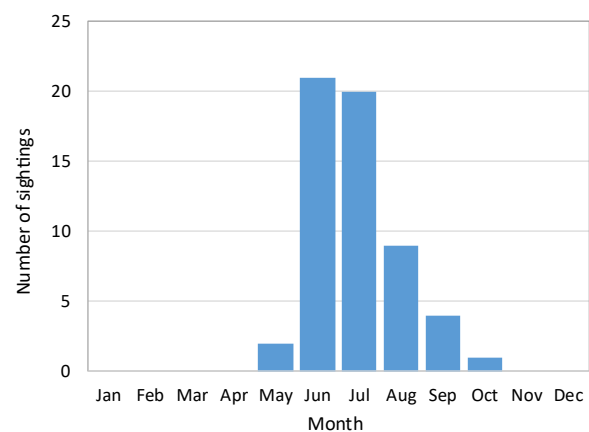


Figure 2 Seasonal distribution (per month) of the 57 sightings of this bird since 2015.

Terns, on average 118 birds ($n = 57$, $SD = 72$, range: 8–314). The average date of these 57 sightings was 13 July ($SD = 31$ days, median: 7 July, range: 15 May–2 October).

DISCUSSION

During previous studies between 2005 and January 2008 colour rings were deployed on Damara Terns of various ages. Among these birds there were 67 individuals fitted with one yellow colour ring or a combination of two colour rings that included a yellow one. These were all marked along the central Namibian coastline (approximately 430 km north of Lüderitz). Furthermore, three breeding adults were ringed with a combination of yellow and green rings at the !Anichab Salt Pan. However improbable, it is not impossible that the bird observed in this study could have been one of these previously marked birds (e.g., having lost one of the colour rings) and relocated to Shearwater Bay in winter, in which case the longevity record described here would be an underestimate, and it could possibly be as old as 20.5 years.

The previous longevity record for this species was 14 years and 11.5 months for a bird ringed as a chick near Swakopmund and re-trapped on the nest as a breeding adult in the same location (Braby 2011). The present result exceeds this by approximately two years and four months. The available longevity records for two other species of the genus *Sternula* exceed our result by slightly less than seven years: *S. albifrons* at 23.9 years (Fransson et al. 2017), and *S. antillarum* at 24.1 years (Klimkiewicz & Fitcher 1989). These differences, compared to our results, may simply reflect the relatively poor research and long-term monitoring efforts in Namibia compared with the more abundant and better studied species in Europe (for *S. albifrons*), or North America (for *S. antillarum*).

Using multi-states capture-mark-recapture models Braby et al. (2011) estimated the annual survival rate of adult Damara Terns in central Namibia as 0.87. Assuming no senescence, that estimate would imply that only 10.8% of adult Damara Terns (aged > 2 years) reach the age of 18 years.

The number of wintering Damara Terns in the Lagos region, Nigeria, was found to be highest between July and September (Wallace 1973).

Repeated sightings of this bird at the Shearwater Bay roost in winter and early spring between mid-May and early October, with an average date in early July, accompanied by up to more than 300 birds, indicate that a fairly large proportion of the southern Namibian Damara Tern population does not migrate northwards in winter and remains in southern Namibia throughout the year. These observations also highlight the Lüderitz Peninsula, and Shearwater Bay in particular, as a very important habitat throughout the year for this near endemic Namibian species.

Seabirds in general are long-lived species (Lack 1968), and a comprehensive understanding of their biology can only be attained through long-term research and monitoring. In addition, our records highlight the value of individual identification marks (such as colour rings) which facilitate identification at a distance without the need to recapture the birds. To that effect a programme was initiated in 2021, aimed at ringing and individually marking Damara Terns with engraved coloured flags to improve our understanding of the biology, movements and migration patterns of this important Namibian species in line with the aims of the Damara Tern Species Action Plan (MEFT 2020).

ACKNOWLEDGEMENTS

Over the years many people and organisations have supported the work on Damara Terns in the region, including the University of Cape Town (Animal Demography Unit), the Ministry of Fisheries and Marine Resources (MFMR), H. Kolberg and K.H. Uiseb from the Ministry of Environment, Forestry and Tourism (MEFT), Namdeb Corporation, Namibia Nature Foundation (NNF), Namibian Chamber of Environment (NCE), Working Group on International Wader and Waterfowl Research, Nijmegen The Netherlands (WIWO), Namibia Bird Club, and Mr. and Mrs. Hwryniak. Dr. J. Kemper (African Penguin Conservation Project) is thanked for constructive comments on earlier versions of this note. This is a contribution to the YourTern Project (yourtern.org), and the SEA-COast-DEsert research group (SEACODE).

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First record of African wildcat (*Felis lybica cafra*) preying on a small antelope, the Damara dik-dik (*Madoqua damarensis*)

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ABSTRACT The diet and foraging behaviour of carnivores are closely linked to their role in ecosystems. The African wildcat (*Felis lybica*) is a highly adaptable small carnivore that is widespread and common but rarely studied. The diet of this solitary felid has been reported to consist mainly of small rodents with the largest recorded prey being the springhare (*Pedetes capensis*). Here, we present the first photographic evidence of African wildcat predation on a small antelope, the Damara dik-dik (*Madoqua damarensis*). This observation expands the known prey spectrum of the species and demonstrates its behavioural flexibility in hunting small ungulate prey.

KEYWORDS African wildcat; diet; feeding habits; Namibia; predation; solitary carnivore; trophic diversity

INTRODUCTION

The African wildcat (*Felis lybica*) is a small, solitary carnivore that is highly adaptable and occurs in a wide ecological range (Skinner & Chimimba 2005). The subspecies *Felis lybica cafra* is widespread in southern Africa (Ghoddousi et al. 2022) and, in most of its range, occurs sympatrically with a whole suite of other carnivores, from small (<2 kg) to very large (>100 kg) species. The foraging behaviour and diet of carnivores, as well as the environmental conditions in which they occur, are important to understand their role in ecosystems (Roemer et al. 2009). Dietary overlap and competition between predatory species may be relevant (Caro & Stoner 2003), but has received attention primarily in the context of large predators

(Hayward & Kerley 2008; West et al. 2024). The African wildcat has a broad prey spectrum and is believed to be the most common carnivore in most of its range (Skinner & Chimimba 2005). However, few studies with limited geographical coverage have been conducted on its feeding ecology and even long-term studies were based on small sample sizes (Herbst 2009; Herbst & Mills 2010). Murid rodents account for a large part of the diet, but depending on availability, a variety of other prey may be taken including reptiles, birds, and insects as well as other invertebrates (Kok & Nel 2004; Skinner & Chimimba 2005; Herbst & Mills 2010; Stadler et al. 2024). Larger mammals appear to be the exception, as only 0.2% of prey items (6 out of 2 553) in the southern Kalahari weigh over 500 g (Herbst & Mills 2010). The largest prey

documented were hare (*Lepus spp.*) and springhare (*Pedetes capensis*) (Kok & Nel 2004; Herbst & Mills 2010), with an average mass of just under 3 kg (Peinke & Brown 2003). A camera trap study reported an African wildcat that had captured a rock hyrax (*Procapra capensis*), and although adult rock hyraxes can weigh around 4 kg, the photographic evidence provided clearly showed a juvenile and hence smaller individual (Greyling et al. 2022). Skinner & Chimimba (2005) mention the identification of remains of a new-born grysbok or steenbok (*Raphicerus sp.*) in a stomach and that young of small antelopes may be taken, but that *F. lybica* was not able to take adults. The presence of sheep (*Ovis aries*) hair in stomach investigations was assumed to be a result of scavenging from sheep carcasses (Stadler et al. 2024). Although the African wildcat is primarily an active hunter and scavenging has not been documented in an extensive study in the Kgalagadi Transfrontier Park (Herbst & Mills 2010), rare cases of carrion consumption have been observed for the European wildcat (*Felis silvestris*) (Ruiz-Villar et al. 2020; Krofel et al. 2021). However, active predation of species larger than springhare and lagomorphs is generally not expected.

Here, we present the first photographic evidence of African wildcat predation on an adult of a small antelope, the Damara dik-dik (*Madoqua damarensis*; previously *M. kirkii*).

METHODS

The observation was made incidentally on 08 June 2024 at Mokuti Etosha (18.823°S, 17.066°E), air temperature was 7 °C. Mokuti Etosha is a 40 km² private reserve in north-central Namibia with typical southern savanna woodland. It borders the eastern edge of Etosha National Park (ENP), a 22 700 km² protected area that hosts a diverse community of predators and ungulates. The eastern part of ENP receives an average annual rainfall of approximately 400 to 450 mm (Turner et al. 2022). The predator–prey interaction was observed from a motor vehicle and was photographically documented by the authors. In the absence of actual measurements, information on average body sizes and mass was retrieved from the literature. No animals were captured, handled or manipulated and the article is based on purely observational data.

RESULTS AND DISCUSSION

At around midnight, an adult Damara dik-dik (*Madoqua damarensis*) emerged from a thicket, pursued by an African wildcat. The dik-dik was chased into the undergrowth beneath a small tree (*Dichrostachys cinerea*) where the wildcat pounced on the dik-dik and killed it by biting its neck (Figure 1). The wildcat subsequently started eating the dik-dik from the rump and dragged it into the bush about 10 minutes after feeding. We observed the wildcat for about 30 minutes in total. The dik-dik was alone and there was no sign of illness or injury. A wildcat had also been observed on 20 May 2024 at about 20h00 at the same location attempting to hunt a dik-dik but had been unsuccessful.

Assuming an average weight of 5 kg and 25 cm shoulder height for an African wildcat and 5 kg and 44 cm shoulder height for a Damara dik-dik (Tinley 1969; Skinner & Chimimba 2005), this represents the largest documented prey actively hunted by an African wildcat (approx. 100% of its own body weight). It is known that other solitary felids such as leopard (*Panthera pardus*) can overpower prey larger than their own body mass, although they preferentially prey upon smaller species (Hayward et al. 2006).

Damara dik-diks are small monogamous antelopes and have been studied in this area (Tinley 1969; Dujardin & Fox 1997) with few documented predation events. Tinley (1969) listed predation by leopard, caracal (*Caracal caracal*), and humans and mentioned African wildcat as a potential dik-dik predator. Dujardin and Fox (1997) reported predation by lion (*Panthera leo*), leopard, and giant eagle owl (*Ketupa lactea*). Because of their small size, dik-diks can retreat into dense undergrowth, but similarly the small African wildcat is able to follow them where larger predators cannot. Antelopes of the genus *Madoqua* do not occur in South Africa, Botswana, and Zimbabwe, where studies on *Felis lybica* diet have previously focused. This observation therefore also shows the importance of prey species presence for studying geographical differences in diet. Although research has been conducted on several carnivores in the Etosha area, the African wildcat has not received much attention (Weise et al. 2021). Herbst (2009) described that the hunting technique for mammals



Figure 1 Successful predation of a Damara dik-dik (*Madoqua damarensis*) by an African wildcat (*Felis lybica cafra*) in Namibia.

larger than 500 g comprised typical feline behaviour similar to the one observed in this case. The success rate was lower for larger prey (6 out of 16, 38%) compared to all hunting attempts (2 553 out of 3 676, 80%) during a 46-month observational study (Herbst 2009).

In 2024, Namibia experienced one of the worst droughts in 100 years (FAO 2024). Whether dik-diks become more susceptible to predation, as reported for some herbivores (Mills et al. 1995; Loveridge et al. 2006), or foraging behaviour of wildcats was altered, is unknown. While the population status of the African wildcat is assumed to be stable, large data gaps exist, and there may be some population declines due to land-use change and the risk of hybridisation with domestic cats (Ghoddousi et al. 2022). In addition, human-wildlife conflict has been reported in connection to predation on poultry (Chisaka et al. 2024) and assumed predation on sheep lambs (Stadler et al. 2024), which often results in culling or poisoning of wildcats. While preying upon poultry is expected, no evidence has been found for active predation on lambs (Stadler et al. 2024). In Namibia, human-

wildlife conflict usually involves larger predators (Walters et al. 2024) but has been reported for the African wildcat in connection with small livestock farming (Küsters 2022). A suspicion of wildcat predation on goats on a Namibian farm has proven to be unfounded (Rust et al. 2016) and although this species is capable of preying on animals up to the size of dik-diks, this appears to be an exception.

CONCLUSIONS

To our knowledge, this represents the first evidence supported by a photograph of African wildcat predation on small ungulate prey. This observation expands the known prey spectrum and maximum prey size of the species. In view of the wide distribution of the African wildcat, further investigation of its diet across previously unstudied areas and the potential influence of environmental factors and seasonal variation appears appropriate.

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