

# Determining the effectiveness and usefulness of three community-led carnivore survey types to wildlife management in the Nyae Nyae Conservancy, Namibia

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Community Based Natural Resource Management in Namibia is known as an exemplary conservation programme giving local communities rights over the use of wildlife resources. Monitoring of wildlife population numbers and trends is essential in conservancies to manage wildlife for sustainable benefits and reduced human–wildlife conflict. Nyae Nyae Conservancy conducts systematic wildlife monitoring, inclusive of carnivores. Monitoring carnivore presence and distribution is important because they are often the leading cause of livestock depredation in the area. Incidences of livestock depredation by carnivores are recorded in the conservancy, helping inform decision-making regarding the need to reduce or relocate problem-causing carnivores. To complement these incidence records, annual foot transect counts and spoor surveys of carnivores were introduced in 2017. This study compared the relative species richness, number of observations and their distribution detected by regular counts, spoor surveys, and human–wildlife conflict incidence reports for ten carnivore species in Nyae Nyae Conservancy. Between 2017 and 2022, there were an average of 17 physical sightings, 25 human–wildlife conflict incidents, and 208 spoor recordings of the ten target carnivore species per year. The highest annual species richness for physical surveys was five, while spoor of all ten species were only identified in 2019. In 2021 and 2022, a total of five carnivore species were involved in human–wildlife conflict incidents, the highest recorded during the study period. Over the six-year period, the relative abundance of species to each other correlated significantly between spoor surveys and human–wildlife conflict incidence frequency, while there was no relationship between spoor surveys and transect visual sightings, or between sightings and human–wildlife conflict incidence. The study indicates that spoor counts are effective in detecting the presence of carnivore species, but do not necessarily provide an accurate indication of the overall abundance and proportional abundance of carnivores.

**Keywords:** carnivores, community conservation, human-wildlife conflict, spoor surveys, walking transects.

## INTRODUCTION

Namibia has practiced sustainable management under the Community Based Natural Resource Management (CBNRM) model since 1998 when the first four communal conservancies were gazetted (Denker, 2021; MEFT/NACSO, 2023).

Under this model, community members are given the rights to manage their natural resources sustainably, and, in return, the members of a declared conservancy are allowed to benefit from their natural resources (Child, 2013). These benefits are commonly manifested in the forms of employment and income from joint-venture tourism and trophy hunting concessions within gazetted communal conservancies. To obtain

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permission from the Ministry of Environment, Forestry and Tourism (MEFT) to consumptively utilize wildlife, communal conservancies need to conduct regular wildlife monitoring to provide evidence of stable or growing populations (Government of the Republic of Namibia, 1996).

Nyae Nyae Conservancy (NNC) is one of Namibia's oldest conservancies, having been registered in 1998. Conservancy income is mostly from trophy hunting, supplemented with joint-venture tourism. Approximately 3000 to 4000 people of the Ju/'hoansi San ethnic group reside in the area (Denker, 2021; Lendelvo, Kazembe & Mfuné, 2019), pursuing a mixed livelihood of activities which combines foraging and subsistence hunting with craft sales and some limited agriculture (Hitchcock, 2023). As more San people resort to livestock farming and the influxes of pastoralists from other areas, the livestock number has increased substantially in NNC (Hays & Hitchcock, 2020). The increased presence of livestock has brought communities into conflict with predators (Pallet & Potgieter, 2022).

Monitoring of wildlife is therefore crucial to ensure that trophy and own-use hunting does not deplete populations, and, additionally, predator monitoring and depredation incidence monitoring can inform conflict mitigation strategies. A simple road strip count (Bothma, 2016) has been used consistently in Namibia's communal conservancies over the past 20 years to monitor trends in wildlife population numbers (MEFT/NACSO, 2023). These surveys do not provide an absolute count of total wildlife populations due to insufficient road infrastructure, the often rugged terrain, and generally clumped distribution of animals. The easily repeatable method and ability for non-specialist observers to consistently participate have been the reasons for its consistent annual application for the past 20 years in Namibian communal conservancies.

Since 2017, the NNC has included spoor observations as part of their annual wildlife survey (NACSO, 2022). The Ju/'hoansi San of the NNC are well known for their exceptional ability to identify and interpret wildlife spoor (Barnard, 2019; Silvester & Gewald, 2003) and have, as such, been used as participants in spoor count surveys in similar studies in Namibia (Stander, 1998). In comparison with most other conservancies, NNC conducts more frequent and diverse wildlife monitoring, making it an ideal site for this study where our focus was on predator spoor and sightings.

Surveying carnivores is often described as challenging due to their low densities and elusive behaviours, necessitating specialized and resource-intensive methods. Accurately surveying carnivores by conventional methods such as aerial census or road strip counts is virtually impossible (Balme, Hunter & Slotow, 2009; Boitani, Ciucci & Mortelliti, 2012). Their relatively low densities compared to common wildlife combined with often cryptic and nocturnal behaviour make sightings rare and sporadic. Spotlighting and call-up surveys for large carnivores are cost- and time-consuming and require specialized skills and equipment (Gese, 2001; Thorn, Scott, Green, Bateman & Cameron., 2009). A systematic, comprehensive, and integrated approach is recommended by Thorn *et al.* (2009), which includes initial habitat mapping, and combining sign surveys, track plates, scent stations, scat detection transects, den counts, call-ups and spotlight surveys. These require the luxury of dedicated field staff and statistically astute scientists to analyse and interpret the results.

The aim of this study was to compare the results of three conservancy wildlife monitoring methods over a six-year period. These were (i) human–wildlife conflict (HWC) incidence reporting, (ii) foot transect surveys and (iii) spoor counts to identify the presence, distribution and relative abundance for carnivore monitoring, and their usefulness to wildlife management in the NNC.

## METHODOLOGY

### *Study area*

The NNC is situated in the Otjozondupa Region, in the northeastern part of Namibia (20°S, 20°E) and has a surface area of 9003 km<sup>2</sup> (MEFT/NACSO, 2023). The NNC falls within the semi-arid ecological zone, receiving between 300 mm and 500 mm of rainfall per year (Atlas of Namibia Team, 2022). There are three main seasons: cold-dry from June to August (average temperature of 24.7°C), hot-dry from September to November (average temperature of 33°C), and wet from December to May (average temperature of 28.3°C) (Weather Atlas, n.d.).

The conservancy is bordered by two boundary fences: in the east along the border with Botswana and in the south by the veterinary fence along the 20th latitude (bordering Ondjoi Conservancy) (Atlas of Namibia Team, 2022). The western portion of NNC is bordered by the N=Ja Jaqna

Conservancy and to the north lies the Khaudum National Park and communal farmland.

The NNC is home to several animal species that are rare or endangered in Namibia or across the African continent (Atlas of Namibia Team, 2022; Pallet & Potgieter, 2022; Skinner & Chimimba, 2005). Elephant (*Loxodonta africana*), wild dog (*Lycaon pictus*), leopard (*Panthera pardus*), and roan (*Hippotragus equinus*) are among the key species that are present in the NNC. There are also lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), giraffe (*Giraffa angolensis*), blue wildebeest (*Connochaetes taurinus*), red hartebeest (*Alcelaphus buselaphus*), eland (*Tragelaphus oryx*), gemsbok (*Oryx gazella*), kudu (*Tragelaphus strepsiceros*), and Ostrich (*Struthio camelus*) present. There is also a population of disease-free buffalo (*Syncerus caffer*) that are enclosed in a quarantine camp (Weaver & Skyer, 2003) as per the required veterinary regulation (Barnes, 2013). This study focuses on carnivores; Table 1 provides an inventory of carnivores that occur in NNC.

#### Game count methodology

Annually, the Natural Resource Working Group of NACSO (Namibian Association of CBNRM Support Organizations) assists the NNC in conducting systematic foot transects across the conservancy (NACSO, 2022). These counts, replicating similar counts in the Zambezi and Kavango Regions, make use of foot transects conducted in the dry season when access to all areas, including the ephemeral Nyae Nyae Pan, is possible. During the

count, approximately 42 volunteers and community game guards from the Ju//Hoansi community traverse a total of 153 line transects that amounts to an average total of 2066 kilometres (representative of an approximate surface area of 4200 km<sup>2</sup>) (NACSO, 2022). Ordinarily, 3–4 people walk in single file to reduce disturbance and detection from the game species that they are counting – game species in NNC, in the context of the annual game counts, refers to the range of medium-sized (e.g. jackal) to large-sized mammals (e.g. elephant) (Erena, 2022). In each group there at least two observers are responsible for spotting wildlife and identifying animal tracks. The leading observer has the dual responsibility of guiding the group on the correct line of latitude or longitude as well as alerting the data recorders to the presence of fresh spoor on the line transect.

For each live sighting, the observers note the species, the number seen, the perpendicular distance from the animal to the transect line (determined as an estimate and is part of a training session before the start of the counts), and the coordinates at which the animals were seen. Similar to live sightings, the spoor of herbivores and carnivores are also noted on each transect line, with special care being taken not to record the spoor of the same animals that have been observed as a live sighting. The spoor data are entered on the same form as live sightings but in a separate, clearly marked column. Spoor estimated to be not older than 24 hours is recorded; fresh spoor can usually be detected as these spoors usually have sharper contours, are less affected

**Table 1.** Carnivore species known to occur in Nyae Nyae Conservancy, their red-list conservation status, and estimated trends (Pallet & Potgieter, 2022).

| Species                   | Scientific name                        | Namibian status       | Namibian population estimate | Trend in Namibia  |
|---------------------------|----------------------------------------|-----------------------|------------------------------|-------------------|
| African wild dog          | <i>Lycaon pictus</i>                   | Critically Endangered | 137–359                      | Stable            |
| Cheetah                   | <i>Acinonyx jubatus</i>                | Endangered            | 1500                         | Decreasing        |
| Leopard                   | <i>Panthera pardus</i>                 | Vulnerable            | <12 000                      | Increasing        |
| Lion                      | <i>Panthera leo</i>                    | Vulnerable            | 800                          | Stable            |
| Spotted hyaena            | <i>Crocota crocuta</i>                 | Vulnerable            | 615–715                      | Stable            |
| Brown hyaena              | <i>Parahyaena brunnea</i>              | Near Threatened       | <3000                        | Stable            |
| Serval                    | <i>Leptailurus serval</i>              | Near Threatened       | 1500–4000                    | Stable            |
| Aardwolf                  | <i>Proteles cristata</i>               | Least Concern         | Unknown                      | Stable            |
| Southern African wild cat | <i>Felis lybica</i> sbsp. <i>cafra</i> | Least Concern         | Unknown                      | Unknown           |
| Honey badger              | <i>Mellivora capensis</i>              | Least Concern         | 15 900–31 800                | Stable            |
| Caracal                   | <i>Caracal caracal</i>                 | Least Concern         | Unknown                      | Stable–Increasing |
| Bat-eared fox             | <i>Otocyon megalotis</i>               | Least Concern         | Unknown                      | Stable            |
| Cape fox                  | <i>Vulpes chama</i>                    | Least Concern         | Unknown                      | Stable            |
| Black-backed jackal       | <i>Lupulella mesomelis</i>             | Least Concern         | Unknown                      | Stable–Increasing |

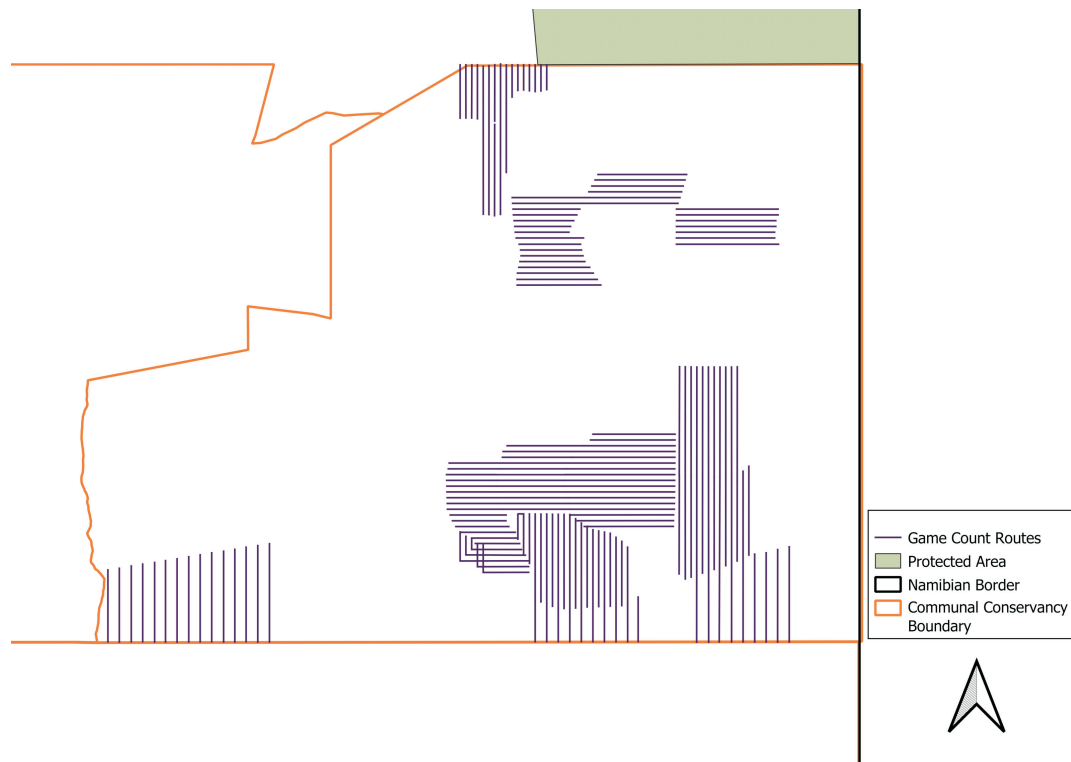
by erosion, and are less covered by organic materials, making them more visible on the transect compared to older tracks (Gielen *et al.*, 2024). Since the Ju//Hoansi game guards are renowned trackers (as are most San groups) (Stander, 1998; Logie, 2010), spoor counts are considered a reliable addition to the traditional live sightings of animals. The opportunity to do spoor counts in NNC was facilitated by the remarkable skill and experience of the San trackers (Stander, 1998) and the low frequency of spoor 'sets' for the carnivores, reducing the probability of double counting. It should be noted that attempts were made each year to ensure that game guards and some volunteers from previous years were present on each line transect. This was done to ensure a certain level of repeatability in the data collection process. While the San people are indeed renowned for their tracking abilities, the emphasis should also be placed on the consistent presence of trained observers, which contributes significantly to the reliability of the data collected over the years.

The transect lines were designed and mapped using ArcGIS, and a total of 153 line transects

(Fig. 1) was defined to traverse different habitat types. Observers walked along a transect using a GPS to navigate the longitude or latitude transect line allocated to the team. The length of each transect, in each year, was measured using a GPS as the observers noted the start and end coordinates for each line transect.

Prior to the count, training is conducted to firstly explain the count objectives and the theory of sample counts. The training then moves into a discussion of how the count would be conducted, which is then followed by a practical training session in GPS usage, distance estimation, and map reading. The training is concluded with a practical session on how to fill in the data sheets using various observation scenarios.

HWC events are recorded by the conservancy game guards and consolidated by the conservancy committee on a monthly basis. The system has been used in the conservancy since 2001 and regular training for new game guards is provided by supporting organizations (MEFT/NACSO, 2023). Reporting bias is possible, which is considered in the discussion section. Though some of the HWC incidents included crop and infrastructure



**Fig. 1.** Line transects used in the annual NNC game counts.

damage (typically caused by elephants in the conservancy), only incidents that were caused by carnivores were included for the purposes of this study. An HWC event is formally recognized when a conservancy resident reports livestock depredation to a game guard (this does not include the mere sighting of a predator). The game guard then visits the site of the reported incident to verify its authenticity. Verification involves examining the scene for evidence, such as identifying predator spoor and assessing the condition in which the livestock was consumed. If the evidence confirms an HWC event, the game guard records the details in their Event Book.

Statistical analyses

Relative abundance (MacArthur, 1960) was used to determine the ratio of sightings per species to overall number of sightings per year per observation type. Kruskal Wallis analysis of variance (ANOVA) with 95% confidence (Ostertagova, Ostertag & Kováč, 2014) threshold was used to compare sightings overall, between observation type, between years and between species. Pearson's correlation coefficient (Schober, Boer & Schwarte, 2018) was used to compare trends over time between observation types (overall and per species).

RESULTS

There were 151 HWC incidents, 99 live sightings and 1,250 spoor observations of the ten carnivore species over the six years (Table 2). The most HWC incidents and live sightings were in 2022, while the most spoor observations were in 2019. Black-backed jackal had the highest sighting frequency (1:1.88), whereas hyaena\* spoor records were far greater than live sightings at a ratio of one live sighting for 198.33 spoor. Noticeably, leopard had no live sighting data within the study period associated with the annual game counts, while spoor was the second most recorded of all carnivore species after hyaena; only 11 leopard depredation incidents were recorded.

The measures of relative abundance for the surveyed carnivore species are described in Table 3. During the study period, hyaena had the highest relative abundance for both HWC incidents and spoor survey records with a mean of 36.44 (S.D. 4.24) and 51.34 (S.D. 4.41), respec-

\*Though both spotted and brown hyaena occur in the NNC (Skinner & Chimimba, 2005), it is often difficult to tell the spoor of both species apart. Therefore, this article will refer to both species simply as 'hyaena'.

Table 2. Summary of the total human-wildlife conflict incidents and game count observations for spoor and live sightings (rows are organized in decreasing order of total spoor data).

| Species               | Human-wildlife conflict |      |      |      |      |      | Spoor data (game counts) |      |      |      |      |      | Live sightings (game counts) |      |      |      |      |      |
|-----------------------|-------------------------|------|------|------|------|------|--------------------------|------|------|------|------|------|------------------------------|------|------|------|------|------|
|                       | 2017                    | 2018 | 2019 | 2020 | 2021 | 2022 | 2017                     | 2018 | 2019 | 2020 | 2021 | 2022 | 2017                         | 2018 | 2019 | 2020 | 2021 | 2022 |
| Hyaena (both species) | 2                       | 2    | 3    | 7    | 14   | 21   | 44                       | 184  | 245  | 81   | 40   | 69   | -                            | -    | -    | 3    | -    | -    |
| Leopard               | 3                       | 3    | 1    | -    | 4    | -    | 10                       | 58   | 74   | 20   | 13   | 28   | -                            | -    | -    | -    | -    | -    |
| Wild dog              | -                       | 2    | 3    | 6    | 16   | 34   | 20                       | 45   | 35   | 9    | 5    | 30   | 1                            | 14   | -    | 1    | 2    | 3    |
| Jackal (black-backed) | -                       | -    | -    | -    | -    | 2    | 10                       | 18   | 22   | 21   | 8    | 8    | 5                            | 5    | 10   | 14   | 8    | 20   |
| Lion                  | -                       | -    | -    | 5    | 8    | 9    | 6                        | 17   | 36   | 9    | -    | 15   | -                            | -    | 1    | -    | -    | -    |
| Cheetah               | -                       | -    | 1    | -    | -    | -    | 1                        | 8    | 9    | 7    | 1    | 2    | -                            | -    | -    | -    | -    | -    |
| Honey badger          | -                       | -    | -    | -    | -    | -    | -                        | 1    | 13   | 1    | 8    | 3    | -                            | -    | 1    | 1    | 1    | 2    |
| Caracal               | -                       | -    | -    | -    | 2    | 3    | -                        | 4    | 2    | 3    | 3    | -    | -                            | -    | -    | -    | -    | -    |
| Wild cat              | -                       | -    | -    | -    | -    | -    | -                        | -    | 1    | 1    | -    | 1    | -                            | -    | 1    | -    | 2    | -    |
| Bat-eared fox         | -                       | -    | -    | -    | -    | -    | -                        | -    | 1    | -    | -    | -    | -                            | 1    | -    | 2    | 1    | -    |
| Total                 | 5                       | 7    | 8    | 18   | 44   | 69   | 91                       | 335  | 438  | 152  | 78   | 156  | 6                            | 20   | 13   | 21   | 14   | 25   |
| Species richness      | 2                       | 3    | 4    | 3    | 5    | 5    | 6                        | 8    | 10   | 9    | 7    | 8    | 2                            | 3    | 4    | 5    | 5    | 3    |

**Table 3.** Relative abundance index for HWC, spoor, and sightings data (data are organized in decreasing order of the spoor data mean).

| Species                  | Human–wildlife conflict |      |      |       |       |       |              | Spoor data (game counts) |       |       |       |       |       |       | Live sightings data (game counts) |             |       |      |       |       |       |      |              |              |
|--------------------------|-------------------------|------|------|-------|-------|-------|--------------|--------------------------|-------|-------|-------|-------|-------|-------|-----------------------------------|-------------|-------|------|-------|-------|-------|------|--------------|--------------|
|                          | 2017                    | 2018 | 2019 | 2020  | 2021  | 2022  | Mean         | S.D.                     | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | Mean                              | S.D.        | 2017  | 2018 | 2019  | 2020  | 2021  | 2022 | Mean         | S.D.         |
|                          |                         |      |      |       |       |       |              |                          |       |       |       |       |       |       |                                   |             |       |      |       |       |       |      |              |              |
| Hyaena<br>(both species) | 40                      | 40   | 37.5 | 38.89 | 31.82 | 30.43 | <b>36.44</b> | <b>4.24</b>              | 48.35 | 54.92 | 55.94 | 53.29 | 51.28 | 44.23 | <b>51.34</b>                      | <b>4.41</b> | 0     | 0    | 0     | 14.29 | 0     | 0    | <b>2.38</b>  | <b>5.83</b>  |
|                          | 60                      | 60   | 12.5 | 0     | 9.09  | 0     | <b>23.59</b> | <b>28.63</b>             | 10.99 | 17.31 | 16.89 | 13.16 | 16.67 | 17.95 | <b>15.49</b>                      | <b>2.77</b> | 0     | 0    | 0     | 0     | 0     | 0    | <b>0</b>     | <b>0.00</b>  |
| Leopard                  | 0                       | 0    | 37.5 | 33.33 | 36.36 | 49.28 | <b>26.07</b> | <b>20.92</b>             | 21.98 | 13.43 | 7.99  | 5.92  | 6.41  | 19.23 | <b>12.49</b>                      | <b>6.88</b> | 16.67 | 70   | 0     | 4.76  | 14.29 | 12   | <b>19.62</b> | <b>25.45</b> |
| Wild dog                 | 0                       | 0    | 0    | 0     | 0     | 0     | <b>2.89</b>  | <b>0.48</b>              | 10.99 | 5.37  | 5.02  | 13.82 | 10.26 | 5.13  | <b>8.43</b>                       | <b>3.76</b> | 83.33 | 25   | 76.92 | 66.67 | 57.14 | 80   | <b>64.84</b> | <b>21.76</b> |
| Jackal<br>(black-backed) | 0                       | 0    | 0    | 0     | 0     | 0     | <b>2.89</b>  | <b>0.48</b>              | 10.99 | 5.37  | 5.02  | 13.82 | 10.26 | 5.13  | <b>8.43</b>                       | <b>3.76</b> | 83.33 | 25   | 76.92 | 66.67 | 57.14 | 80   | <b>64.84</b> | <b>21.76</b> |
| Lion                     | 0                       | 0    | 0    | 27.78 | 18.18 | 13.04 | <b>9.83</b>  | <b>11.77</b>             | 6.59  | 5.075 | 8.22  | 5.92  | 0     | 9.61  | <b>5.9</b>                        | <b>3.32</b> | 0     | 0    | 7.69  | 0     | 0     | 0    | <b>1.28</b>  | <b>3.14</b>  |
| Honey badger             | 0                       | 0    | 0    | 0     | 0     | 0     | <b>0.00</b>  | <b>0.00</b>              | 0     | 0.29  | 2.97  | 0.66  | 10.26 | 1.92  | <b>2.68</b>                       | <b>3.88</b> | 0     | 0    | 7.69  | 4.76  | 7.14  | 8    | <b>4.59</b>  | <b>3.74</b>  |
| Cheetah                  | 0                       | 0    | 12.5 | 0     | 0     | 0     | <b>2.08</b>  | <b>5.10</b>              | 1.09  | 2.39  | 2.05  | 4.61  | 1.28  | 1.28  | <b>2.12</b>                       | <b>1.32</b> | 0     | 0    | 0     | 0     | 0     | 0    | <b>0</b>     | <b>0.00</b>  |
| Caracal                  | 0                       | 0    | 0    | 0     | 4.55  | 4.35  | <b>1.48</b>  | <b>2.30</b>              | 0     | 1.19  | 0.46  | 1.97  | 3.85  | 0     | <b>1.25</b>                       | <b>1.49</b> | 0     | 0    | 0     | 0     | 0     | 0    | <b>0</b>     | <b>0.00</b>  |
| Wild cat                 | 0                       | 0    | 0    | 0     | 0     | 0     | <b>0.00</b>  | <b>0.00</b>              | 0     | 0     | 0.23  | 0.66  | 0     | 0.64  | <b>0.25</b>                       | <b>0.32</b> | 0     | 0    | 7.69  | 0     | 14.29 | 0    | <b>3.66</b>  | <b>6.05</b>  |
| Bat-eared fox            | 0                       | 0    | 0    | 0     | 0     | 0     | <b>0.00</b>  | <b>0.00</b>              | 0     | 0     | 0.23  | 0     | 0     | 0     | <b>0.04</b>                       | <b>0.09</b> | 0     | 5    | 0     | 9.52  | 7.14  | 0    | <b>3.61</b>  | <b>4.21</b>  |

tively. Comparatively, jackal had the highest relative abundance for live sightings with a mean of 64.84 (S.D. 21.76). Leopard and wild dogs had relatively high levels of conflict, and their spoor was sighted at moderate relative abundance. Lions, although not as prevalent in spoor surveys, have a high relative abundance in HWC incidents (Mean 9.83, S.D. 11.77), indicating they are responsible for a high proportion of depredation events. Other species, such as cheetah, honey badger, bat-eared fox, caracal, and wild cat had lower relative abundances within all methods. Three species (leopard, cheetah, and caracal) had no live sightings while honey badger, bat-eared fox, and wild cat were not reported in HWC incidents.

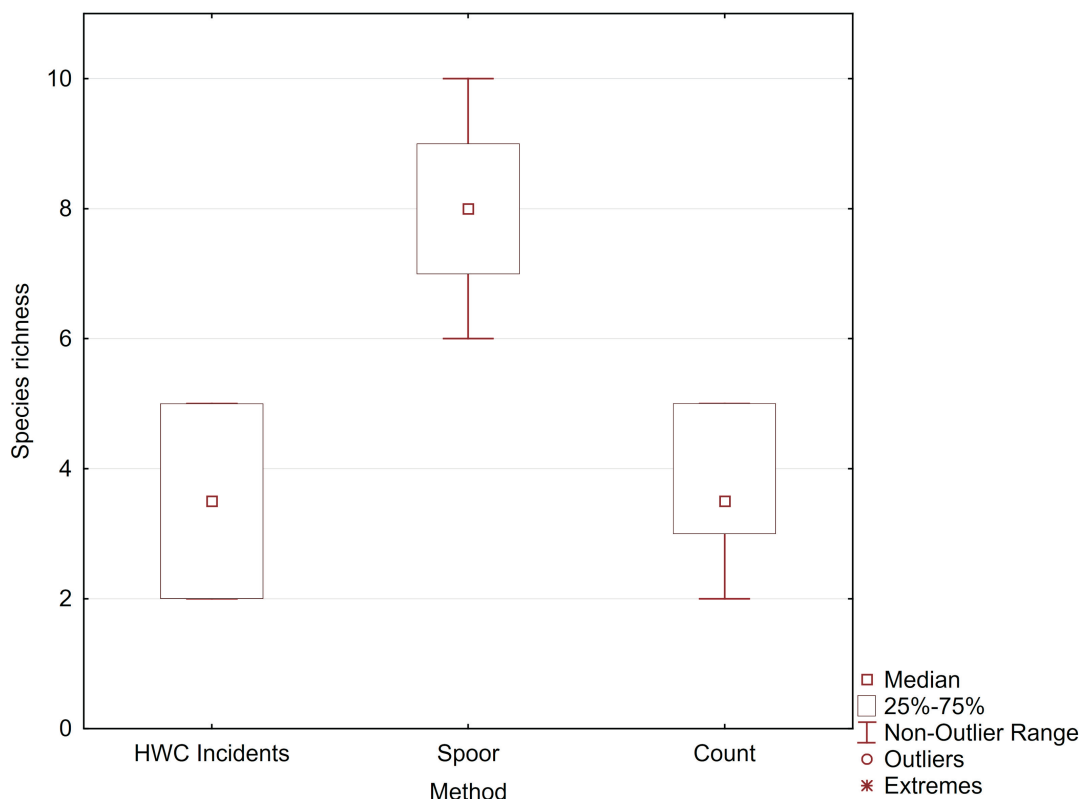
All ten species were identified from spoor, while the maximum species richness (per year) for physical observations was five (Median 3, S.D. 1.05). HWC was reported for a maximum of five species in total (per year median 3, S.D. 1.64). There was a significantly higher species richness ( $H = 11.64$ ,  $P < 0.01$ ) in the spoor data than in the other two modes of observation (Fig. 2).

The distribution of sightings for hyaena (Fig. 3) and leopard (Fig. 4) fell completely within the spatial distribution of spoor counts for these species. HWC incidents were not recorded spatially. There were more spoor observations of wild dog (Fig. 5) and jackal (Fig. 6) in locations than in areas where there were physical sightings of the species. Only in the case of jackal were live sightings significantly more frequent than HWC incidents and spoor counts ( $H = 15.48$ ,  $P < 0.01$ ) (Fig. 6). For hyaena, spoor were most frequently seen, significantly more than HWC incidents reported ( $H = 15.49$ ,  $P < 0.01$ ).

There was a strong positive correlation in the relative abundance of species over time between spoor counts and HWC incidents ( $r = 0.86$ ,  $P < 0.01$ ) (Fig. 7a), while there was a slight but non-significant inverse relationship between HWC incidents and live sightings ( $r = -0.15$ ) (Fig. 7b), and no relationship between spoor counts and live sightings ( $r = -0.02$ ) (Fig. 7c).

## DISCUSSION

This study evaluated three wildlife monitoring methods to assess their effectiveness in determining the presence, distribution, and relative abundance of carnivores, with a focus on their practical applications for wildlife management in the NNC. Of the 14 species of carnivore reportedly occurring



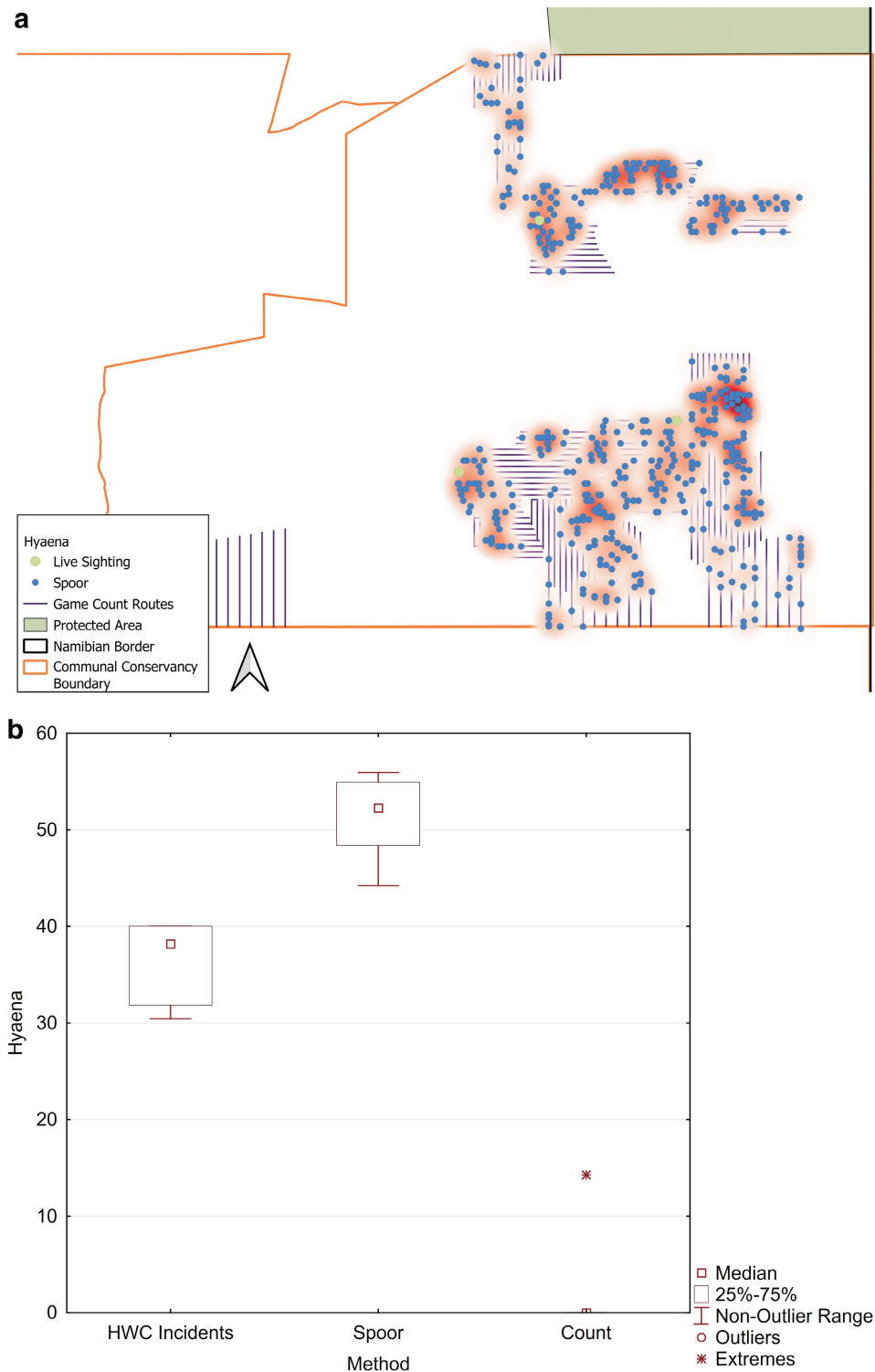
**Fig. 2.** Box plot of species richness per observation method.

in the study area (Pallett & Potgieter, 2022), 10 were identified through the three methods during this study. By far the most species and number of sightings observed were of spoor, with only 74 live sightings over six years. Since most large carnivores are nocturnal, the chances of physically seeing them during a regular daytime survey are scant (Duckworth, 1998). Daytime surveys are therefore a poor method to use for estimating presence and abundance of carnivores. A compounding influence is that since the area is a multiple land-use landscape, carnivores are wary of human presence (Balme *et al.*, 2009). Species known to be shy, such as leopard, were not recorded live once, while their spoor were regularly reported and 11 HWC incidents occurred over the six years.

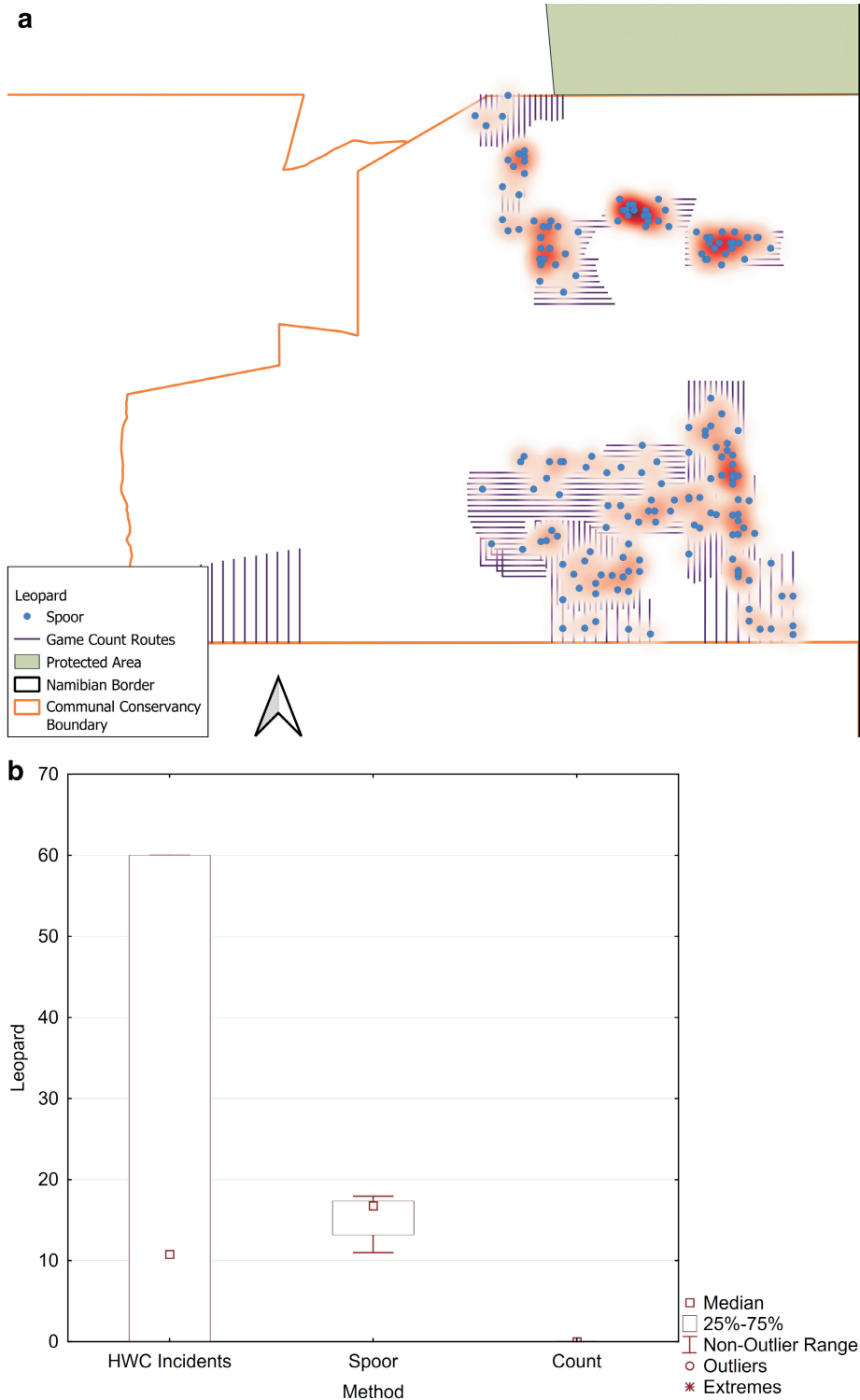
This study considered spoor counts since this is a method that is not used commonly in wildlife monitoring in Namibia. The study found a strong positive correlation between spoor counts and HWC observations, indicating that the relative abundance of species detected by spoor surveys was closely aligned with the frequency of reported

HWC incidents. Although spoor counts provided a good indication of what carnivores occur in the landscape, it is very difficult to estimate the abundance or density of these species from the current methods. Spoor surveys have been assessed by other studies (Funston *et al.*, 2010; Keeping & Pelletier, 2014; Melville & Bothma, 2006; Stander, 1998; Swanepoel, Somers & Dalerum, 2015) and their effectiveness is found to be varied. Factors affecting spoor surveys would include (i) the ability of the animal to imprint on substrate at a constant rate, and (ii) the ability of observers to detect and correctly identify species:

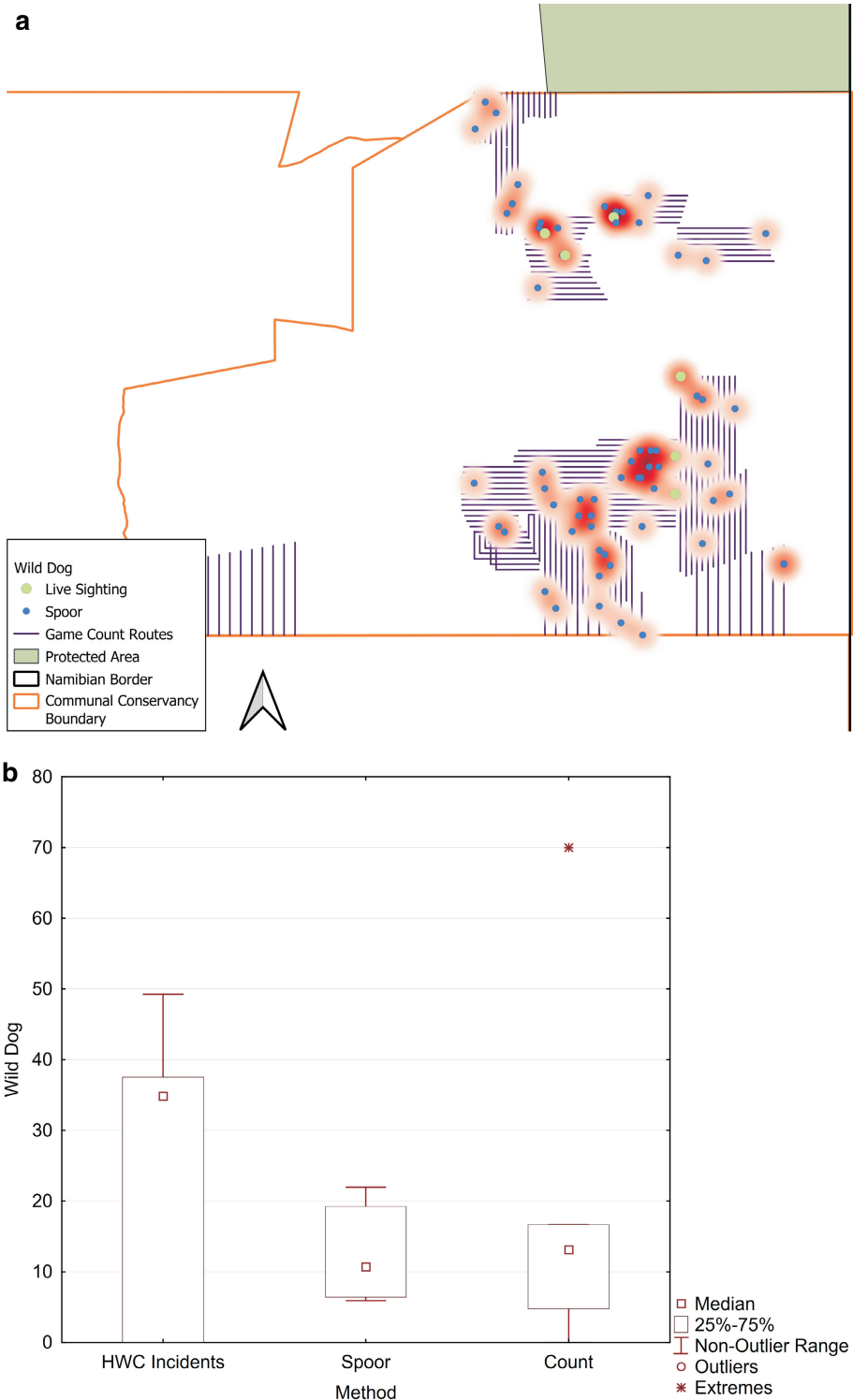
1. Imprinting of footprints is vastly inconsistent generally, and it is often dependent on the suitability of the soil substrate (Jewell, Alibhai & Law, 2001; Lewison, Fitzhugh & Galentine, 2001; Sharma, Jhala & Sawarkar, 2005). Nyae Nyae soils, for the most part, are deep (greater than 180 cm) and are described as calcisols (Atlas of Namibia Team, 2022). This makes the area more suitable than areas with rocky or gravel soils, or areas where basal cover is higher. Rainfall/soil moisture is another



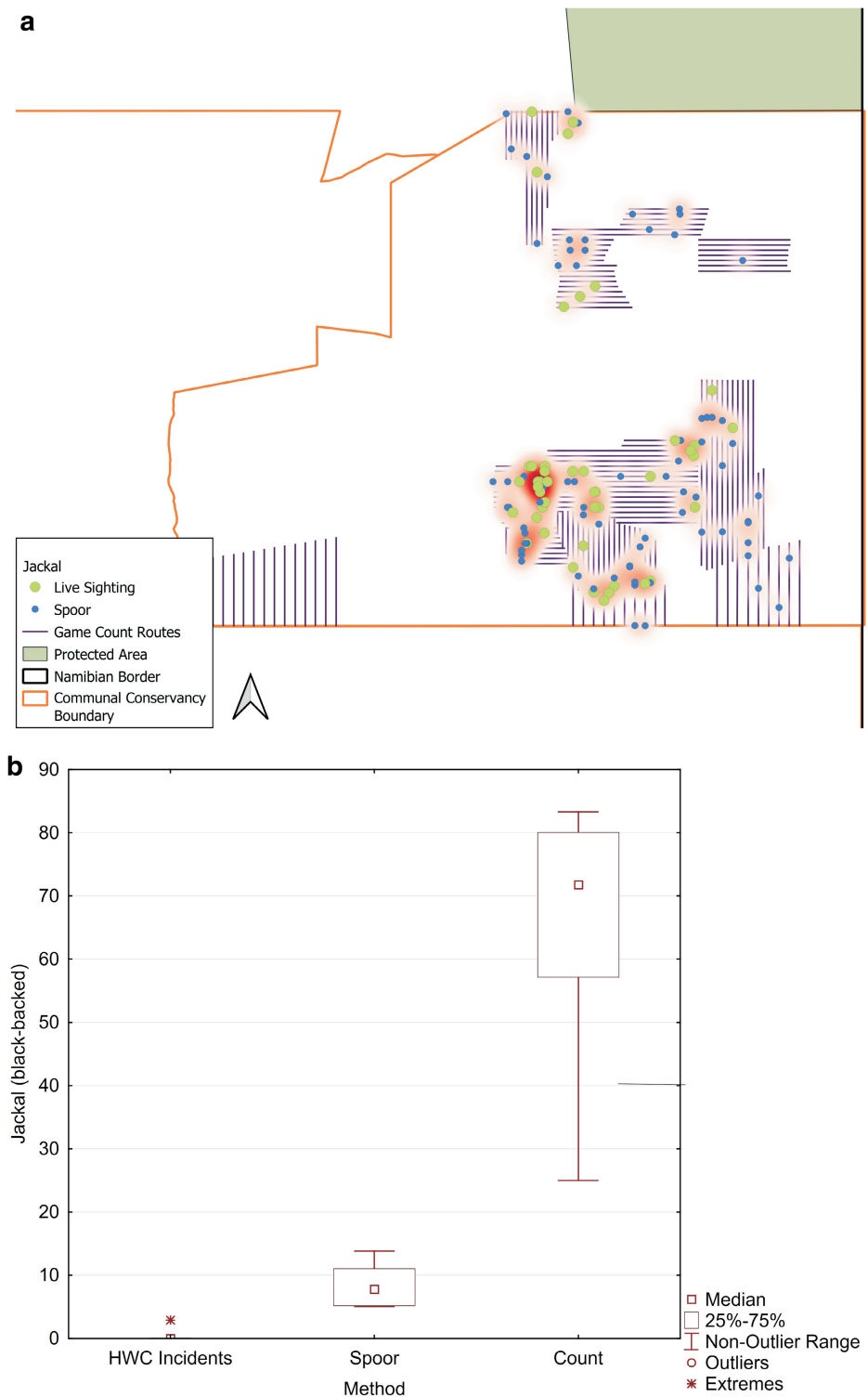
**Fig. 3. a,** Hyaena observations (2017–2022). **b,** Box plot of relative abundance of hyaena per observation method (2017–2022).



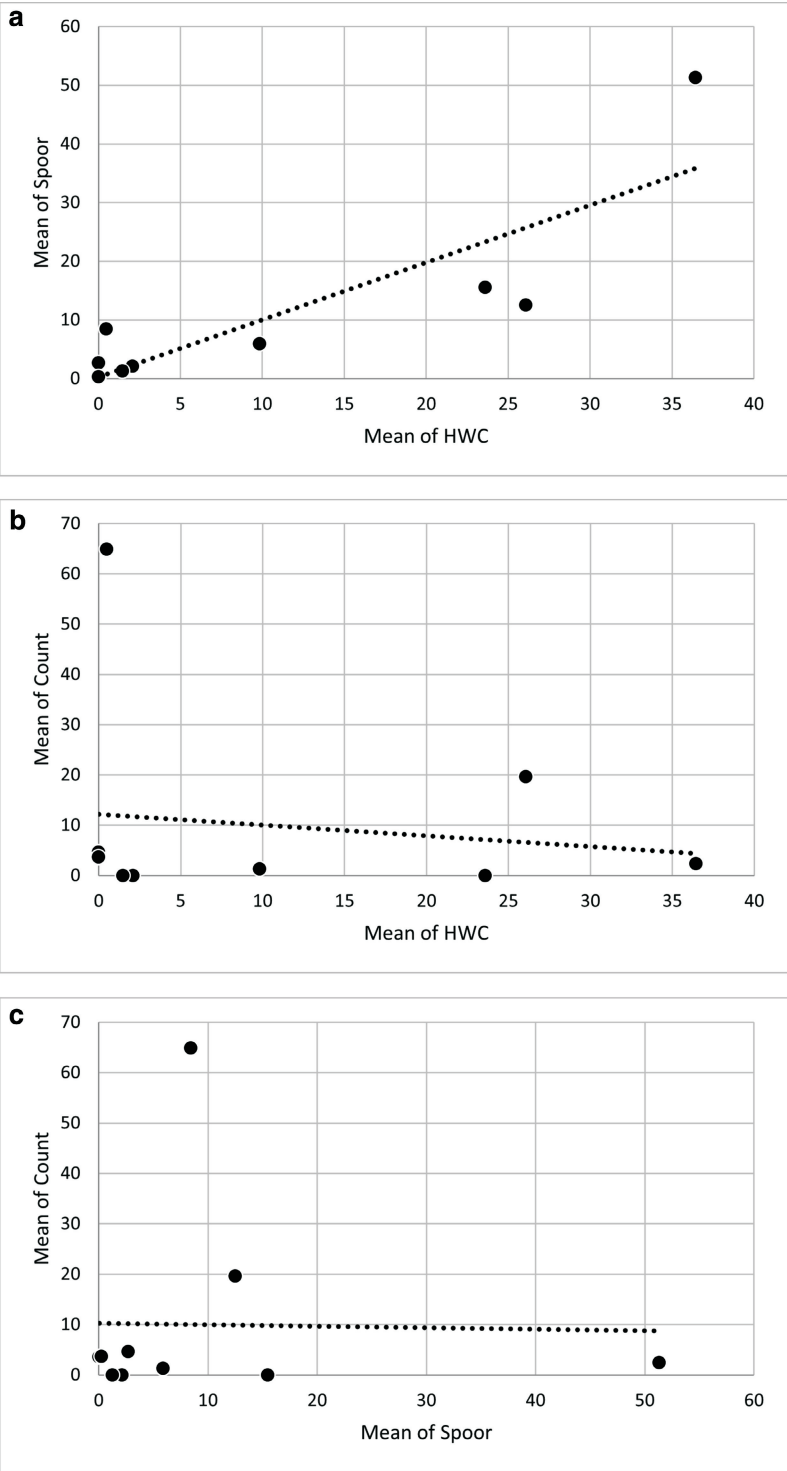
**Fig. 4. a,** Leopard observations (2017–2022). **b,** Box plot of relative abundance of leopard per observation method (2017–2022).



**Fig. 5. a**, Wild dog observations (2017–2022). **b**, Box plot of relative abundance of wild dog per observation method (2017–2022).



**Fig. 6. a,** Jackal observations (2017–2022). **b,** Box plot of relative abundance of jackal per observation method (2017–2022).



**Fig. 7. a,** Correlation of relative abundance of HWC incidences against spoor observations. **b,** Correlation of relative abundance of HWC incidences against live sightings. **c,** Correlation of relative abundance of spoor observations against live sightings.

significant influence. Years with the least spoor recordings (2017 and 2021) were both exceptionally wet (NACSO, 2022), and in contrast, very dry soils often reduce spoor impression frequency due to soil structural variation.

- ii. The ability to accurately identify spoor is a major weakness (Pirie, Thomas & Fellowes, 2016). This particular area is inhabited by San who are particularly competent and experienced at spoor identification (Barnard, 2019; Hitchcock, 2023; Silvester & Gewald, 2003)
- iii. As a factor of both points above, observer bias has an important influence. This is a factor common to all wildlife survey techniques (Mahakata, 2021). As these particular surveys mostly used the same observers (both conservancy game guards and volunteers), the effect is reduced but still present.

This study provided an opportunity to test whether the relative abundance of species reported in HWC incidents related to other survey methods. Using HWC incidents to estimate carnivore occurrence has been used previously (Tavolaro, Woodgate, Brown, Redpath & O'Riain, 2022). While this survey methodology can provide some insights into the distribution and presence of a carnivore species (in areas where other means of direct observations are difficult to obtain) it does have several drawbacks. One of these drawbacks would be the reliance on the presence of affected people to trigger conflict, where the lack of conflict would mean that certain species go unreported. This would be particularly pertinent to communities living in NNC that have not yet invested in livestock as most can typically be found within the town of Tsumkwe (Hays & Hitchcock, 2020). Incorrectly identifying the species responsible for the conflict incident could potentially be a drawback for assessing the distribution and relative abundance of carnivore species. It does also result in a bias of perception towards species (such as wild dogs or lions) less tolerated by humans as opposed to the species that are more accepted or elusive (e.g. brown hyaena, honey badger, or wild cat) (Lindsey *et al.*, 2013).

The most consistent result between all three methods was the spatial overlap of recordings of the most commonly sighted species. Combining the three methods is therefore useful to estimate the distribution of carnivores across a landscape. There were similar studies that mapped species distribution as a result of spoor counts (Bauer,

Schiess-Meier, Mills & Gusset, 2014; Verlinden, Perkins, Murray & Masunga, 1998).

An important factor to consider is that the data from the three methods assessed were local community driven and collected. None of the methods require costly equipment to complete, and results do not require sophisticated analyses. Since the physical observations and spoor surveys are a form of citizen science, the value of this type of data collection is highlighted. Citizen science is seen as a powerful and frequently used method in general science (Bonney, Phillips, Ballard & Enck, 2016) and also in conservation management (McKinley *et al.*, 2017). Citizen or community science enhances stakeholder relationships with wildlife by actively involving local communities in data collection and monitoring. This helps foster a sense of ownership and stewardship over their natural resources, which not only empowers participants but also builds trust and cooperation between stakeholders and conservation efforts.

There was no strong correlation between the trends over time when comparing the three methods. The exception was the strong correlation between sighting and HWC incidents for wild dog and jackal, probably because they are diurnal and therefore more likely to be seen during the daytime surveys. This means neither method could be used as a proxy for the other when looking at long-term trends in population numbers or HWC incidents. This does not preclude the combination of being effective as a trend measure elsewhere, because this particular study area has unique characteristics such as a few HWC incidences compared to other conservancies and areas of ephemeral pans, which are occasionally flooded and not accessible for surveys.

## CONCLUSION AND RECOMMENDATIONS

Ten out of the 14 carnivore species expected to occur in NNC were detected using spoor surveys, live sightings, and HWC incident reports over the six-year period. Spoor surveys provided the most records (with a significantly higher species richness when compared to the other two observation types), while live sightings were limited due to the nocturnal nature of many large carnivores and their wariness of human presence. Despite the challenges in estimating abundance or density from spoor counts, the consistency of spatial overlap across methods suggests a combined approach is useful for estimating carnivore distribution.

HWC incidence reports were also useful, since trends in carnivores over time correlated with the number of spoor detected. A shortcoming is that HWC incidents were not georeferenced and hence the spatial overlap between spoor and HWC incidence could not be analysed. Although camera-trap surveys would be far more effective in determining carnivore density and abundance, the purpose of this study was to evaluate the community-driven monitoring methods that would be repeatable and at a fraction of the cost of other survey methods.

The following recommendations should be considered to strengthen the current carnivore monitoring system within NNC:

1. Future studies should account for the impact of additional environmental variables, such as soil type and moisture, on spoor deposition to improve accuracy in estimating carnivore presence.
2. Determining known population numbers for more common carnivore species and relating these to spoor surveys can help assess the effectiveness of spoor as an indicator. This, however, is challenging due to the transience and large home ranges of many species (e.g. hyaena and wild dog) in the study area and beyond (Pallet & Potgieter, 2022).
3. Including prey species data in future survey analysis may provide more reliable monitoring of carnivore presence, distribution, and abundance by relating predator trends to prey availability.
4. Consider strengthening a monthly data collection methodology and execution based on the fixed-route patrols. Monthly fixed route patrols that are widely spread out across the NNC could potentially add a valuable layer of sampling that could effectively measure relative abundance and density within the NNC.
5. Continuing local community involvement in data collection is a key consideration, as it is cost-effective in comparison to specialist and technologically dependent methods, and does not require sophisticated analyses, enhancing the sustainability and accuracy of long-term wildlife monitoring efforts. It also makes data understandable for local decision-makers.

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