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Editorial

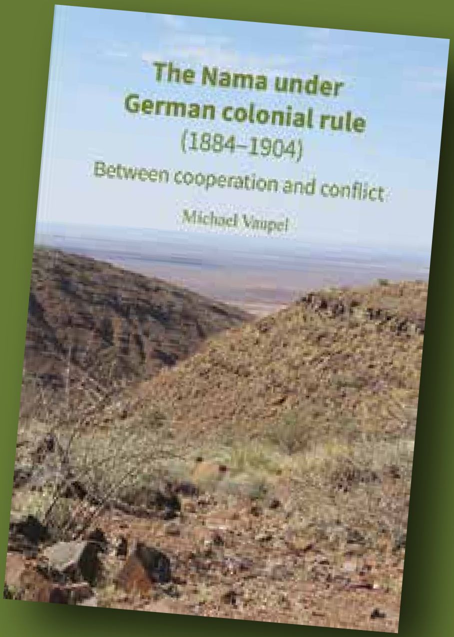
The Namibia Scientific Society will celebrate its 100th anniversary in 2025. During the 99 years of the Society's existence, science has changed in many ways, including the focus of research, the questions being asked, equipment being more sophisticated, analytical techniques having changed, computers allowing for the processing of large datasets, and more. However, some fundamental features of science remain the same, notably that new research work needs to be shared and evaluated by a researcher's peers. This ensures that work is new and of interest to a group of scientists. The internet has revolutionised access to information and research articles and many new journals have appeared. The role of the Journal of the NSS has remained the same through these changes, and that is to provide correct, relevant, and interesting information to its members.

Volume 71 of the Journal starts with two Research Notes: the first one is a cross-disciplinary study on fossil tracks that utilises indigenous knowledge of animal tracking, followed by the first record of a thresher shark in Namibian waters, this providing important information about the distribution and ecology of these sharks with implications for the protection of all shark species.

The third article reviews organisational justice and psychological ownership in the NDF, providing information on how best to reduce turnover, thus saving costs on training. The next article compares walking traverses with dogs to vehicular traverses assisted by dogs to detect cheetah scat. The walking traverses found scat that would have been otherwise unobserved. This may help with estimating population densities of these animals. Older works on biodiversity did not necessarily locate their sampling sites precisely and the fifth article reviews many of these and correctly locates them, providing clarity and useful information for researchers using old data sets. The sixth article covers another non-invasive project, using acoustically detected tags to monitor the movement of sharks, rays, and skates in Namibian waters. This provided new information that can be used in the management and establishment of marine protected areas. The seventh article evaluates lion health using visual assessments of body condition and stomach contents in a private game reserve. The non-invasive study provides information for management in reserves. The eighth and final article looks at the chemistry of a traditional beer and proposes long-term commercialisation of this brew, especially in light of long-term climate challenges.

Thanks must go to all the authors who submitted papers and the reviewers who freely gave of their time to read and comment on the articles.

Michael Backes & Roger Swart
Editors-in-Chief


The Nama under German colonial rule
(1884–1904)
Between cooperation and conflict
Michael Vaupel

Research Note

The contribution of Ju’|hoansi Indigenous Master Trackers to the Cape south coast ichnology project

Charles Helm, Clive Thompson, and Jan De Vynck

Through the Cape south coast ichnology project, based out of the African Centre for Coastal Palaeoscience at Nelson Mandela University, Gqeberha, more than 350 Pleistocene vertebrate tracksites have been identified along a 350-km stretch of coastline (Helm 2023), and 45 peer-reviewed scientific articles have been published, are under review or are in press. One of these was of relevance to a Namibian species, as an extended Pleistocene range was inferred for sand-swimming golden moles like *Eremitalpa granti*, the Namib mole (Lockley et al. 2021a, 2021b). The resulting corpus of knowledge has contributed substantially to the global understanding of Quaternary ichnology (Neto de Carvalho et al., in press a, in press b).

As an ichnological team, we have done our best to do justice to these discoveries, while remaining mindful of the gaps in our communal knowledge base, and consequently of our limitations. In contrast, we recognize that we are at a disadvantage compared with trackers who learned their ichnological skills as part of their earliest life experiences and then never stopped learning, i.e., in whom such an approach was inculcated at a time of brain plasticity. This would seemingly provide a lifelong advantage over relative latecomers such as us. We noted a provocative book title proclaiming that the art of tracking was “the origin of science” (Liebenberg 1990). We concurred with this claim.

We were aware of an increased global interest in indigenous knowledge of palaeontology (e.g., Benoit et al. 2023) and the skill-sets of traditional Indigenous Master Trackers. For example, Ju|’hoansi Indigenous Master Trackers from the Nyae Nyae Conservancy in north-eastern Namibia travelled to caves in Europe in 2014 to collaborate with modern-day scientists in the interpretation of hominin tracksites in the *Tracking in Caves* project (Biesele 2021; Pastoors et al. 2021; Lenssen-Erz & Pastoors 2021). More recently, Ju|’hoansi Indigenous Master Trackers contributed fundamentally to the interpretation of prehistoric tracks in the Namibian rock art record (Lenssen-Erz et al. 2023).

We knew that the Ju|’hoansi are among the last of the San in the greater Kalahari to retain the full suite of ancient hunter-gatherer skills: their lands are still largely wild, with free-roaming game; they still engage in subsistence hunting with bow and poisoned arrow, and a few still hunt by persistence running. They gather food from the veld, they speak their original click language, and they still draw on their healing dances. They are expert in the art of tracking, and their ability to follow and interpret animal tracks is extraordinary. We knew that certification as an Indigenous Master Tracker occurs through the accreditation program developed by CyberTracker, and involves peer recognition within the tracker community. We appreciated that a mere handful of indigenous trackers across the Kalahari are currently recognized as Master Trackers (the highest tracker qualification).

We speculated on how Indigenous Master Trackers/hunter-gatherers might view our work. How would their wisdom and expertise, honed through an unbroken knowledge-train extending over at least tens of millennia, mesh with our modern scientific approach? Might unique insights perhaps materialise? From such questions a 2023 project was initiated, in which two Ju’|hoansi Indigenous Master Trackers from the Nyae Nyae Conservancy, #oma Daqm and |uce N‡amce, spent five days with us on the Cape south coast.

In undertaking such a venture, we understood that examining and interpreting our relatively poorly preserved tracksites in aeolianites (cemented dunes) on the Cape south coast might be more challenging than opining on well-preserved hominin tracks in French caves or on Namibian rock art, and would certainly be different from tracking in the sand and bush of north-eastern Namibia. For example, our best-preserved tracks are often preserved in hyporelief on the undersides of ceilings and overhangs, and a common mode of track preservation occurs in profile in cliff exposures. Moreover, approaches that seem natural to contemporary trackers are not available to us: our track-bearing surfaces on rock are typically small, and there is no opportunity to consider feeding and associated signs or to pick up the spoor some distance away when the tracks are interrupted. We know neither the time of day the tracks were registered, nor the role of dew, and our chances of actually encountering the fossilised trackmaker are close to zero.

On the positive side, the Pleistocene Epoch is not that far removed from the present. Many of the tracks that we encounter in aeolianites on the coastline today were registered by species that are extant, and would therefore be generally familiar to our new research colleagues. The tracks of extinct species which might be encountered (such as the long-horned buffalo and giant Cape zebra) could easily be explained, but nonetheless we knew that a steep learning curve would operate, and that instruction in palaeo-ichnological principles was required.

We then adopted the following method: the first half-day was spent in practical instruction in an area east of Still Bay that contained a concentration of known tracksites with different modes of preservation. We then walked east along the coastline together, pointing out previously-identified tracksites of interest. In such cases we would not provide our own interpretations, thus giving the Indigenous Master Trackers the opportunity to analyse and confer among themselves. This discussion would be followed by a summary of their interpretations, from possible trackmaker identification to evidence of associated behaviour. We would then share our own insights and, where applicable, our photogrammetry data. In general, we would then achieve consensus. Before long, #oma Daqm and ǀuce Nǂamce were providing persuasive interpretations for sites we had considered enigmatic, and had begun identifying freshly exposed fossil tracksites for themselves (Figure 1). A similar approach was adhered to during the days that followed.

A brief summary of breakthroughs resulting from the novel contribution of our San collaborators includes: corroboration of our provisional interpretation of a brown hyena trackway, an evidence-based interpretation that a hitherto confounding trackway had probably been made by a pangolin (the first, as far as we are aware, in the global palaeoichnology record), identifying ostrich tracks which we had previously failed to discern (but were

Figure 1: #oma Daqm and /uce Nǂamce beside a vertebrate tracksite they identified on a loose aeolianite slab (reproduced with permission of Richard Webb)

easy to see under guidance), and detecting the track signature of the scrub hare. We also visited known hominin tracksites together (more than 86,000 years old), and were acutely aware that the trackmakers were in all probability the direct forebears of #oma Daqm and ǀuce Nǂamce. They were visibly moved by the experience, as are we every time we enter the coastal caves that harbour these footprints on their ceilings (Figure 2).

The visit had been intended as a test of concept, and we now had 'proof of concept'. At the end of our time together, we felt a sense of privilege at having been able to enjoy this remarkable ichnological opportunity. From our newly acquired perspective, combining ancient traditional scientific knowledge and modern scientific approaches leads to rich, compelling results and conclusions. As a result, several new scientific papers will be submitted to academic journals. We are agreed that the submitted list of co-authors will include #oma Daqm and ǀuce Nǂamce, with the Juǀ'hoansi Trackers Association as their affiliation. We believe that there are several ways in which scientific qualifications can be measured. Academia typically looks at university degrees and institutional affiliations. However, another way lies in the ability to use the traditional experiential (to wit, scientific) method, taught from childhood, to support and feed one's family and community through tracking, hunting, and gathering.

Figure 2: #oma Daqm and ǀuce Nǂamce after emerging from a cave containing Pleistocene hominin footprints at Brenton-on-Sea

The experience of 2023 is seen as but a starting point for a more comprehensive initiative. Collaborative surveys of the Cape west coast and Cape east coast form a possibility, in which #oma Daqm and |uce N‡amce could be joined by other Indigenous Master Trackers from Nyae Nyae. One hope is that such measures may help promote and preserve the skills and wisdom of traditional ichnological knowledge. We believe that if we succeed in this quest, ichnology the world over will benefit.

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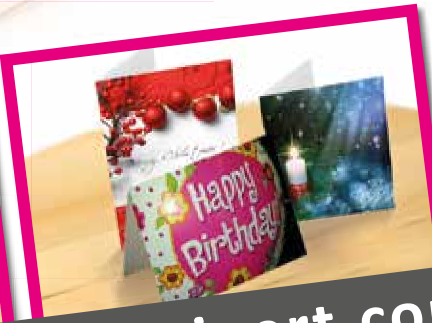

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Research Note

First records of *Alopias superciliosus* (Laminiformes: Alopidae) in Namibian waters

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Key words: Bigeye thresher shark; Atlantic Ocean;
pelagic; bycatch; bottom trawling; fisheries

Abstract

The bigeye thresher shark, *Alopias superciliosus,* is confirmed for the first time in Namibian waters, from four specimens caught as bycatch of bottom trawlers fishing for hake. One specimen was released alive; the other three were dead when brought on board and were utilised by crew members. This species has not previously been documented in Namibia and these records complete the gap in the species' range, between Angola and South Africa.

Introduction

The Benguela Current Large Marine Ecosystem (BCLME) is one of the most productive ocean ecosystems in the world in terms of biomass production and fishery resources (Sakko 1998; Shannon & O'Toole 2003). However, little research has been conducted on the chondrichthyan fauna of Namibia, and current research activities are thus documenting a number of species for the first time in Namibian waters (e.g. Leeney et al. 2023).

There are currently three known species of thresher sharks (order Lamniformes, family Alopiidae) worldwide (Ebert et al. 2021). The pelagic thresher (*Alopias pelagicus*) is found only in the Indo-Pacific Ocean (Ebert et al. 2021). The common thresher shark (*A. vulpinus*) occurs worldwide in tropical to cold-temperate seas (Last & Stevens 2009; Ebert et al. 2021) and has previously been documented in Namibian waters (Bianchi et al. 1999). The bigeye thresher shark, *Alopias superciliosus*, was first described in Lowe (1841) as *Alopecias superciliosus* in a description of fishes from Madeira. It has a circumglobal distribution and is found in both tropical and temperate waters (Rigby et al. 2019; Ebert et al. 2021). *A. superciliosus* is distinguishable from other thresher sharks by its very large eyes, and the lateral deep groove originating behind its eyes and extending along both side of its head, above the gill openings (Ebert et al. 2021). *A. superciliosus* inhabits tropical and temperate seas worldwide, but has never previously been formally recorded in Namibian waters.

Here we report on opportunistic records of *A. superciliosus* which have come to light during research focusing on bycatch of chondrichthyans in industrial fisheries in Namibian waters.

Methods

Specimens of *A. superciliosus* were recorded during ongoing data collection on chondrichthyan bycatch in the Namibian bottom trawl fishery for hakes (shallow water hake *Merluccius capensis* and deepwater hake *M. paradoxus*). For each animal, total length (TL) and sex were recorded, and in the case of the first animal, which was alive when landed, it was then immediately released overboard. Data on the location and depth of each trawl conducted by the fishing vessel were also recorded.

Results

A total of four specimens of *A. superciliosus* were recorded during two fishing trips on which bottom trawling took place between 22nd and 27th November 2023 and between 10th and 17th December 2023. Details of these four animals are provided in Table 1 and the locations of the trawls in which they were bycaught is shown in Figure 1. A female *A. superciliosus* was recorded on 22 Nov 2023, as bycatch of a trawl in 338 m of water (Figure 2). On a subsequent fishing trip in December 2023, three additional specimens (a female and two males) were recorded. They were captured during trawls in water depths of around 403–414 m. These bycaught sharks ranged in size from 186.7 cm TL to 380 cm TL.

Three of the four *A. superciliosus* specimens recorded were dead when brought on board the vessel. The livers of the dead animals were retained and the rest of each carcass was discarded at sea. A crew member also removed the pectoral, dorsal and caudal fins from one shark and stated that he would sell them to a fin trader; no information on where the trader was based or the price such fins would fetch was collected. Crew

Table 1: Records of Alopias superciliosus *caught as bycatch in the bottom trawl fishery for hake in Namibia. Times are in Central Africa Time (GMT + 2).*

Date	**Sex**	**TL (cm)**	**Trawl start/ end time**	**Trawl depth (m)**	**Animal condition**	**Notes**
22 Nov 2023	Female	186.7	09:00-11:20	338	Alive	Released alive
11 Dec 2023	Female	308.0	12:20-14:30	403	Dead	Liver retained, body discarded
11 Dec 2023	Male	380.0	12:20-14:30	403	Dead	Liver retained, body discarded
12 Dec 2023	Male	331.0	07:00-12:00	414	Dead	Liver and fins retained; body discarded

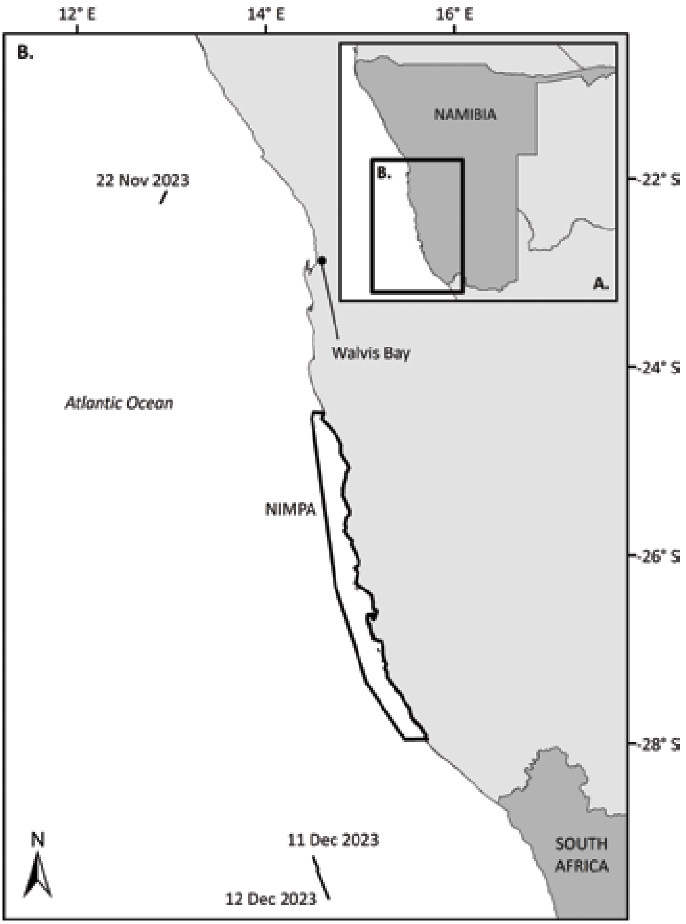

Figure 1: A. Inset: Map of Namibia; black box indicates the coastal area shown in detail in the main map. B. The southern section of the Namibian coastline, showing the location of the bottom trawls on 22 November and 11 and 12 December 2023, during which bigeye thresher sharks were caught incidentally. The location of the Namibian Islands Marine Protected Area (NIMPA) is also indicated.

Figure 2: Alopias superciliosus *caught as bycatch on 22 November 2023, in the hake bottom trawl fishery in southern Namibian waters. Photo ©NaRaS project.*

members processed the livers whilst still at sea by chopping each liver into small pieces and placing them in a bucket, which was left in the drying room (a heated room that the crew use for drying off wet clothing in between periods of work in the on-board factory). Over the course of the trip, liver oil collected in the bucket and was then separated out and poured into plastic soft drink bottles. The crew members take this oil home and either keep it for personal use or sell it in their communities. It was stated to be used as a treatment for coughs and colds (a spoonful taken internally) or for ear infections (a small drop rubbed inside the outer ear canal). Although not observed during the trips where the data presented here were collected, crew members stated that they also retain gulper sharks (*Centrophorus* spp.) for their liver oil.

Discussion

These records are the first for *A. superciliosus* in Namibian waters and for the first time suggest that the species' range is continuous between Angola and the west coast of South

Africa. The lack of records until now may suggest that this species is rarely encountered, or alternatively it may have been misidentified as *A. vulpinus* in the past.

In a study of the reproductive biology of *A. superciliosus* in the Ecuadorian Pacific Ocean, mean size at maturity was documented as 315.7 cm TL for females and 275.2 cm TL for males (Calle-Morán et al. 2023), whilst in the north-eastern Atlantic Ocean and western Mediterranean, length at sexual maturity was estimated as c. 276 cm for males, and the smallest gravid female was 341 cm long (Moreno & Moron 1992). This suggests that at least one of the females documented here was sexually immature whilst both males were sexually mature.

The removal and retention of the livers and caudal fin of *A. superciliosus* (and reportedly, the livers of gulper sharks) by fishers on bottom trawlers in Namibian waters has not been previously reported. Large declines in populations and high vulnerability to overfishing has led the International Commission for the Conservation of Atlantic Tunas (ICCAT) to adopt retention bans and to require live releases of four pelagic shark species, including *A. superciliosus*, in fisheries managed by ICCAT (i.e. in Namibia, the pelagic longline fishery for tuna and swordfish). Retention of any part or whole carcass of *A. superciliosus* is prohibited in those fisheries (ICCAT 2010). Incidental catches of these species, and the corresponding live releases, are also required by ICCAT to be recorded (ICCAT 2012). In Namibia's pelagic longline fishery, fins and trunks of any sharks caught must be offloaded together (M. Block, Fisheries Inspectorate, pers. comm.) and vessels may not have onboard fins that total more than 5% of the total weight of the sharks onboard (ICCAT 2005). However, there is no legislation pertaining to the retention, finning or use of sharks caught as bycatch in any other fishery in Namibia. According to the Namibian Fisheries Inspectorate, the retention of dead sharks for consumption on board fishing vessels is allowed (M. Block, pers. comm.), but neither the extraction of liver oil from bigeye thresher sharks (and reportedly also from gulper sharks) for personal use and sale on land, nor the removal of fins for sale to a fin trader, constitutes consumption at sea. Further investigation is required to assess the scale of the retention and use of these species in Namibian fisheries. However, the gap in Namibian legislation essentially makes these activities permissible and national legislation is urgently needed, particularly for species listed as threatened (Critically Endangered, Endangered or Vulnerable) on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species.

The IUCN Red List lists *A. superciliosus* as Vulnerable globally (Rigby et al. 2019) and Endangered in the Mediterranean and European regions (Walls & Soldo 2015; 2016). Globally, this species is caught as a target and bycatch in commercial and small-scale pelagic longline, purse seine, and gillnet fisheries. Most catch is taken as bycatch of commercial pelagic fleets in offshore and high-seas waters (Camhi et al. 2008) but it is also caught by other gears including coastal longlines, gillnets and by trawl fisheries (Martinez-Ortiz et al. 2015; Temple et al. 2019; Fauconnet et al. 2019). In some areas, the species is retained for its quality meat and its fins (Clarke et al. 2006a; b; Dent & Clarke 2015; Fields et al. 2017), unless there are regulations prohibiting retention. Coelho et al. (2011)

reported that 68% of *A. superciliosus* caught in the Portuguese longline fishery for swordfish in the Indian Ocean were found to be dead on haulback. In recreational fisheries, the post-release mortality for the congeneric common thresher shark (*A. vulpinus*) is also high (78% for tail-hooked animals; 0% for mouth-hooked; Sepulveda et al. 2015) The post-release survival rate of *A. superciliosus* when caught by bottom trawls is unknown. The low fecundity of this species – a maximum litter size of four (two per uterus) but more commonly two (Guitart Manday 1975; Calle-Morán et al. 2023) – and long gestation period (12 months; Calle-Morán et al. 2023) means it has a limited capacity to recover from over-exploitation.

Fisheries-induced mortality of sharks has increased globally over the past ten years (Worm et al. 2024). In Namibia, *A. superciliosus* has thus far only been recorded as a bycatch in bottom trawl fisheries (the records presented here). However, comprehensive data on the bycatch of elasmobranchs is not collected for any other fishery in Namibia at present. The bottom trawl fishery for monk (*Lophius vomerinus*) likely results in bycatch of a wide range of chondrichthyan species and thus may also pose a risk to pelagic thresher sharks. The longline fishery for tuna and swordfish which, according to several individuals employed in the fishery, primarily targets blue and mako sharks (R.H. Leeney unpubl. data), may also pose a threat to *A. superciliosus* and other pelagic shark species. Although a more comprehensive dataset is required to understand the full scale of bycatch mortality of pelagic sharks in Namibian fisheries, south-east Atlantic populations of *A. superciliosus* and other pelagic shark species are likely at serious risk.

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Author contributions

RHL developed the data collection protocol, prepared the map and co-wrote the manuscript. FST collected the data at sea and co-wrote the manuscript.

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Exploring the influence of organizational justice and psychological ownership on turnover intention among the Namibian Defence Force personnel in the Khomas Region

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Abstract

The defence force is important to the well-being, safety, and security of a nation. The availability of competent military personnel maintains national security and enables the country to withstand external threats to safety and security. The purpose of this study was to investigate the influence of organizational justice and psychological ownership on the turnover intention of the Namibian Defence Force (NDF) personnel in Namibia. Understanding turnover intention assists organizations to reduce the influence of turnover, reduce additional expenses related to recruitment, training, and development, and enhance the overall performance of the organization. A quantitative research design (survey) was used to collect data on Namibian Defence Force personnel (n=325). The study found a negative relationship between organizational justice and turnover intention as well as between psychological ownership and turnover intention. A positive correlation was found between organizational justice and psychological ownership (excluding accountability). This study recommends that the organizational culture and working environment be improved to foster inclusivity, collaboration, mutual respect, and improved communication. With enhanced environment and working relationships, employees are likely to experience higher levels of organizational justice, psychological ownership, and reduced levels of turnover intention. This study adds to the limited literature on these variables and on the NDF in Namibia.

Introduction

According to Mitchell (2022) the key role of the military is to maintain peace and to safeguard the well-being of the nation. The Namibian Defence Force (NDF) was established by the Namibian Government on 2 June 1990, as stipulated by the Namibian Constitution under Chapter 15, Article 115. According to this Article, the purpose of the NDF is to defend the territory and national interests of Namibia. Military personnel would not hesitate to sacrifice their lives, if necessary, to maintain security and to enable others to enjoy a state of well-being (Bennet 2020). According to Bennett (2020) it is essential to rely on the military as a factor for stability in a nation. Furthermore, alongside the police, they can help combat drug abuse and crime.

Soldiers also experience social challenges. According to Sasman (2011), Namibian NDF female soldiers were evicted with no prior notice, leaving them homeless and in need of immediate shelter. Prior to their eviction they paid only water and electricity bills (Sasman 2011). They receive low wages that are insufficient to pay for accommodation. Low wages and the inability to satisfy living needs can all lead to turnover intention.

When an individual decides to resign from their place of work, there is potentially a better alternative, implying that their current workplace is not ideal. Turnover intention refers to the likelihood of an employee leaving the current job he/she is doing (Belete 2018). According to Pieters (2018a), while it would be ideal to have no turnover, some turnover is inevitable. Turnover should be minimised and managed effectively. Turnover affects the overall functioning of any organization. According to Pieters (2017), employees who leave an organization will eventually benefit another organization and contribute towards its success. Arif (2018) found a negative relationship between organizational justice and turnover intention.

According to Mengstie (2020) organizational justice entails judgment made by an employee about fairness of decisions at their place of work. These perceptions can in turn influence attitudes and behaviours of the employees. According to Pieters (2018a), when employees are treated fairly, they are more likely to experience satisfaction and engage more actively at work. However, when injustices occur, it may result in turnover intention.

Organizational justice and psychological ownership reported a positive correlation (Ibrahim 2016); however, there is a negative relationship between psychological ownership and turnover intention (Lu et al. 2017). Psychological ownership entails a feeling of possession towards something; it refers to a state in which individuals believe that an object, an organization, or anything that targets ownership, belongs to them (Dawkins et al. 2017). Psychological ownership is an essential tool for organizations to encourage work productivity and certain desirable employee behaviours at the workplace (Pickford et al. 2016). It encourages employees to contribute creatively to their work, as well as increasing motivation.

The primary objective of the study is to assess the influence of organizational justice and psychological ownership on turnover intention of Namibian Defence Force personnel in the Khomas region, Namibia. The secondary objective of the study is to assess whether NDF employees experience turnover intention differently based on sex, age, qualification, tenure, marital status, number of children, and rank.

According to Pieters (2017), when an organization reduces an employee’s feelings of turnover intention, it contributes positively to the effectiveness of the organization. It is equally important for an organization to ensure fairness in the organization to ensure effectiveness and a positive work environment. It is crucial for the Namibian Defence Force to be well acquainted with its members’ perception of fairness within the organization. If the needs of the Namibian Defence Force personnel are well catered for, it will lead to the protection of Namibian lives. This study will also help create awareness among the public by contributing to the availability of data on the turnover intention within the Namibian Defence Force and the factors that influence it.

Literature review and theoretical framework

Literature review

Most challenges that result from employee turnover have a negative influence on the finances and performance of an organization. These include all the costs involved in finding another employee by means of advertising, training, and paying employees who had to step in during the search for a new employee (Pieters 2017). The reputation of an organization is also at stake because turnover intention poses a damaging attitude long after an individual has left (Pieters 2017).

Turnover intention is difficult to measure for employees that have already left the organization (Pieters et al. 2022). There are two types of turnover: voluntary and involuntary. Voluntary turnover refers to an individual leaving an organization of their own accord (with intention) because of factors such as job dissatisfaction (Pieters et al. 2022).

Involuntary turnover refers to the dismissal of an employee, which is often because of poor performance or misconduct at the workplace.

Organizations need to be fair in their distributive, procedural, and interactional justice systems to ensure the job satisfaction, commitment, and loyalty of their employees (Belete 2018). Pieters and Auanga (2018) found that organizational justice showed a positive relationship with organizational commitment and work engagement. Pieters (2018a) found that organizational justice predicted job satisfaction and work engagement. The feelings of injustice increase burnout of employees and their desire to leave the job (Aghaei et al. 2012). Very often, people leave when organizations do not distribute resources equitably or when they pay workers different wages for the same work. Some Namibian Defence Force personnel in low ranks regard their salaries as low. This leads to their withdrawal behaviour and causing them to think about quitting (Namwandi 2015). A study found that there is a negative correlation between organizational justice and turnover intention (Aslan & Uçar 2015).

Impartiality can be defined as the process where decisions are made based on objective criteria rather than the basis of bias and prejudice (Hooley 2023). A term within Industrial Psychology related to impartiality is organizational justice. According to Rusinowitz (2022), organizational justice refers to perceptions of employees about fairness in the workplace regarding processes and decisions, including how equitable they are. Organizational justice is inclusive of distributive and procedural justice. Distributive justice is about how fair the distribution of resources or rewards and outcomes is, whereas procedural justice is about fairness in how decisions are made in the organization whilst following procedures. Equality is the process of decision making based on equal division of resources or opportunities (Belden et al. 2018). Equity on the other hand considers the differences amongst people and their circumstances before making decisions (Belden et al. 2018). Organizational justice applies the principles of equality and equity within the workplace. There are other variables that also influence turnover intention such as psychological ownership.

Recent research suggests that when employees perceive and act as though they own the organization (psychological ownership), they feel they have a greater responsibility for its functioning and success (Lu et al. 2017). Employees eventually experience more commitment to the organization, which reduces their likelihood of quitting their job (Lu et al. 2017).

Psychological ownership is often obtained through gaining knowledge about an organization, as well as investing time and effort in it (Pickford et al. 2016). Psychological ownership developed because of the human desire to achieve ownership over something and to have a sense of belonging. Psychological ownership consists of territoriality, self-efficacy, self-identity, a sense of belonging, and accountability. The more an employee experiences psychological ownership, the more territorial they become and feel the need to defend their territory (Lu et al. 2017). Territoriality is deemed as the mediator between psychological ownership and turnover intention (Lu et al. 2017). An employee's engagement in territorial behaviour enhances their work environment and increases the embeddedness in the organization, which further reduces turnover intention (Lu et al. 2017). Territoriality was regarded as a preventive dimension of psychological ownership because it focused on individualistic behaviour more than on positive organizational behaviour (Olckers & Van Zyl 2020).

Efficacy refers to having a clear sense of self from a psychological attachment to objects (Olckers & Van Zyl 2020). Self-identity has to do with one's own belief in oneself to accomplish something; a sense of belonging refers to feeling at home. Accountability has to do with taking ownership of a task (Olckers & Van Zyl 2020).

There are positive and negative outcomes correlating with psychological ownership, some of which may lead to turnover. Positive outcomes of psychological ownership involve having reciprocity between an organization and an employee, whereas negative outcomes entail becoming overly territorial and reluctant in sharing knowledge (Pickford et al. 2016). According to Pickford et al. (2016), it is significant to understand an employee's perspectives on psychological ownership in an organization so as to know when it is crucial to promote satisfaction, ensure commitment, and encourage collective organizational citizenship.

High levels of organizational justice and psychological ownership may reduce the turnover intention of NDF employees in the Khomas Region. Being able to retain competent military personnel helps in the execution of national and international safety and security duties. Based on the literature discussed, the following hypotheses were developed.

Hypothesis 1: Organizational justice has a positive relationship with psychological ownership.

Hypothesis 2: Organizational justice has a negative relationship with turnover intention.

Hypothesis 3: Psychological ownership has a negative relationship with turnover intention.

Hypothesis 4: Turnover intention is experienced indifferently based on sex, age, qualification, tenure, marital status, number of children, and rank.

Research design

This study made use of a quantitative research design, with the exploratory research method. The purpose of using a quantitative research method is that it works with structured data, which can be presented numerically (Matthews & Ross 2010). Since this study works with a large sample, it is ideal to use the quantitative research method. The study made use of a close-ended questionnaire collecting information on the biographical variables, perceptions of organizational justice and psychological ownership, and turnover intention of NDF employees in the Khomas Region.

This study made use of a short, structured questionnaire (electronic, and pen-and-paper). Questionnaires address the same sets of questions to many people (Matthews & Ross 2010). Section A included a biographical questionnaire which focused on the sex, age, tenure, marital status, number of dependants, highest qualification obtained, and rank of employees.

Section B measured perception of organizational justice with a measure developed by Colquitt (2001) measuring procedural and distributive justice. Sample items include “I am able to express my views and feelings about my organization’s procedures” (procedural justice); “The rewards/punishment issued reflect the effort I put into my work” (distributive justice). Participants were required to respond on a Likert scale ranging from 1 (to a small extent) and 5 (to a large extent). Pieters (2018a) found acceptable reliability of 0.86 for procedural justice. The distributive justice dimension was also found to be a reliable measure in the Namibian context at 0.90 Cronbach’s alpha (Pieters & Auanga 2018).

Section C measured psychological ownership using the *Psychological Ownership Questionnaire* (POQ) developed by Avey and Avolio (2007). Sample items include “I feel that people I work with in my organization should not invade my workspace” (territoriality); “I am confident in my abilities to contribute to my organization’s success” (self-efficacy); “I would challenge anyone in my organization if I thought something was done wrong” (accountability); “I feel I belong in this organization” (sense of belongingness); “I feel this organization’s success is my success” (self-identity). Responses range from 1 (strongly disagree) to 6 (strongly agree). Acceptable reliability was reported by Lee (2017) of 0.83 (Self-efficacy), 0.81 (Sense of belongingness), and 0.84 (Self-identity).

Section D of the questionnaire assessed the employee’s turnover intention. Turnover intention was measured using the *Turnover Intention Scale* (Michaels & Spector 1982). This scale makes use of a 6-point Likert type scale ranging from 1 (strongly disagree) to 6 (strongly agree). Example items include “I intend to quit my current job”. Janik and Rothman (2015) reported acceptable reliability in the Namibian context (0.76).

The population of the study included all members of the Namibian Defence Force in the Khomas Region. There is no known number of NDF personnel as a whole because of confidentiality and security concerns of the Ministry of Defence. A small subset of the Namibian Defence Force personnel was selected. The study made use of availability sampling when selecting the participants (n=325). Availability sampling is non-discriminatory, and everyone had an equal chance of being included in the study. The biographical details are reported in Table 1 below.

Table 1: Biographical Details of Sample

Category	**Item**	**Frequency**	**Percentage**
SEX	Male	230	70.8
	Female	95	29.2
AGE	24-28	30	9.2
	29-31	55	16.9
	32-35	61	18.8
	36-40	61	18.8
	41-45	47	14.5
	46-50	47	14.5
	51 and older	24	7.4

Category	Item	Frequency	Percentage
TENURE	Less than 1 year	1	0.3
	1–2	0	0.0
	3–4	1	0.3
	5–6	18	5.5
	7–8	63	19.4
	9–10	43	13.2
	11–15	102	31.4
	16 and more	97	29.8
QUALIFICATIONS	Grade 12	185	56.9
	Certificate	50	15.4
	Diploma	44	13.5
	Degree	24	7.4
	Honours Degree	8	2.5
	Master's Degree	4	1.2
	PHD	2	0.6
	Missing responses	8	2.5
NUMBER OF DEPENDANTS (children)	None	34	10.5
	1–2	114	35.1
	3–4	93	28.6
	5–6	41	12.6
	7–9	15	4.6
	10 and more	26	8.0
	Missing responses	2	0.6
MARITAL STATUS	Single	213	65.5
	Married	105	32.5
	Divorced	1	0.3
	Widowed	4	1.2
	Missing responses	2	0.6
RANK	Lieutenant/Major General/ Brigadier General	6	1.8
	Colonel/ Lieutenant Colonel/ Major	13	4.0
	Captain/ Lieutenant/ 2nd Lieutenant	20	6.2
	Warrant Officer 1 or 2	25	7.7
	Staff Sergeant/ Sergeant	46	14.2
	Corporal/Lance Corporal	155	47.7
	Private/ Sergeant Major of the Army/ Formation Sergeant Major/ Regimental Sergeant Major	59	18.2
	Missing responses	1	0.3
TOTAL		325	100

Ethics and procedure

The researchers applied for ethical clearance from the University of Namibia's ethical clearance committee. Permission from the Ministry of Safety and Security was obtained, and consultative meetings were held with senior management at the different military bases where the research was conducted. The participants were informed that the questionnaire would be anonymous; they were also instructed not to provide their names, and their responses were treated with confidentiality. The study was voluntary, and participants were allowed to withdraw if, during the study, they felt the need to.

Participants were briefed about the objectives of the study, and informed consent was obtained. The researchers were present during the data collection process to answer any questions from participants. The questionnaires were completed within 5–10 minutes, collected afterwards, and stored in a locked cabinet. The electronic data is stored on a password-protected drive.

Data analysis

The Statistical Package for Social Sciences Version 27 (SPSS, 2020) was used to analyse the data. This study made use of a Pearson correlation to assess the relationship between the three variables. The Mann-Whitney U test was used to assess the relationship between sex and turnover intention. The Kruskal Wallis Test was used to assess the differences between age, tenure, marital status, number of dependants, highest qualification obtained, and rank. The non-parametric statics techniques were used since the sample population is relatively small and groups not equal in size (e.g. size of sample in different age categories, comparative to other age categories). Parametric statistics can be regarded as a more sophisticated technique however require that the sample is normally distributed (e.g. bell-shaped curve) and that the sample is big/sufficient (e.g. 120 per group/category being compared). Non-parametric statistics may not pick up some of the differences that exist like with parametric statistics.

Results

The means (M), standard deviation (SD), Cronbach's alpha and correlations are reported in Table 2 below. Distributive justice (Organizational Justice), Territoriality (Psychological Ownership), and Self-efficacy (Psychological Ownership) did not meet the reliability standards of 0.60 and higher (Resi & Judd 2000); therefore, these dimensions were excluded from further analysis in this study.

Procedural justice and organizational justice (combined) reported positive relationships with psychological ownership (sense of belongingness), sense of identity, and psychological ownership (positive). Procedural justice and organizational justice reported a negative

Table 2: Descriptive statistics and Pearson rank order correlation

Item	Mean	SD	A	1	2	3	4	5	6	7
OJ_PJ	15.09	26.92	0.64	-						
OJ_COM	18.61	31.43	0.66	0.96^{++}	-					
PO_ACC	8.71	3.02	0.76	-0.04	-0.04	-				
PO_SOB	13.95	18.10	0.83	0.00	0.01	0.04	-			
PO_SID	13.65	11.34	0.76	0.01	0.02	0.10*	0.89^{++}	-		
PO_POS	56.54	33.06	0.73	0.03	0.04	0.23*	0.91^{++}	0.86^{++}	-	
TI	8.19	5.52	0.89	-0.03	-0.03	-0.02	-0.06*	-0.06*	-0.09*	-

*Statistically significant: $p \leq 0,05$

$^{+}$ *Practically significant correlation (medium effect):* $0,30 \leq r \leq 0,49$

$^{++}$ *Practically significant correlation (large effect):* $r \geq 0,50$

OJ_PJ: Organizational Justice (Procedural Justice)
OJ_COM: Organizational Justice (Combined)
PO_ACC: Psychological Ownership (Accountability)
PO_SOB: Psychological Ownership (Sense of Belongingness)
PO_SID: Psychological Ownership (Self-identity)
PO_POS: Psychological Ownership (Positive)
TI: Turnover Intention

relationship with turnover intention. Psychological ownership (accountability), sense of belongingness, sense of identity, and psychological ownership (positive) reported negative relations with turnover intention.

Hypothesis 4 of this study investigated the relationship between sex, age, qualification, tenure, marital status, number of children, and rank with turnover intention. Males reported higher levels of turnover intention compared to females. Younger employees reported higher levels of turnover intention when compared to older employees in this sample. Employees with a shorter tenure at the NDF experienced higher levels of turnover intention. Single employees reported higher levels of turnover intention compared to married employees. No significant differences were reported between the number of dependants (children) and turnover intention. Employees with a degree reported the highest significant level of turnover intention. In terms of rank, the senior and junior ranks experience a higher turnover intention than do the middle ranks, both for commissioned and for non-commissioned ranks. In terms of commissioned officers, Lieutenant/ Major/ Brigadier General (high ranked) and Captain/ Lieutenant/ 2nd Lieutenant (lower ranked) reported higher levels of turnover intention compared to Colonel/ Lieutenant Colonel/ Major (middle ranked). The same was observed for con-commissioned officers and enlisted personnel. Warrant officer 1/2 (lower ranked) and Corporal/ Lance Corporal (higher ranked) reported higher levels of turnover intention compared to Staff Sergeant/Sergeant (middle ranked). The high and low ranked personnel also reported the highest level of turnover intention (Private- low ranked; and Sergeant Major of Army/ Formation Sergeant Major/ Regimental Sergeant Major- high ranked). The results related to hypothesis 4 is reported in Table 3 below (interpret with caution considering that some categories have a smaller number of participants).

Table 3: Non-parametric statistics, the relationship between turnover intention and the biographical variables

Biographical variable	**Significance**	**Outcome**	**Category**	**Mean score**
Sex	0.00*	Significant	Males	8.90
			Females	6.46
Age	0.00*	Significant	24–28	218.32
			29–31	183.40
			32–35	172.45
			36–40	159.73
			41–45	151.02
			46–50	136.18
			51 and older	107.38
Tenure	0.00*	Significant	Less than 1 year	265.50
			3–4 years	265.50
			5–6	219.08
			7–8	201.37
			9–10	170.69
			11–15	146.53
			16 and more	139.47
Marital status	0.00*	Significant	Single	176.23
			Married	135.58
			Divorced	62.50
			Widowed	122.88
Number of dependants (children)	0.19	Insignificant	None	188.44
			1–2	167.63
			3–4	143.80
			5–6	164.94
			7–9	173.63
			10 and more	156.48

Biographical variable	Significance	Outcome	Category	Mean score
Qualification	0.01*	Significant	Grade 12	145.83
			Certificate	163.09
			Diploma	177.95
			Degree	206.79
			Honours degree	179.75
			Master's degree	133.38
			PhD degree	252.75
Rank	0.00*	Significant	Lieutenant/ Major/ Brigadier General	158.58
			Colonel/ Lieutenant Colonel/ Major	103.77
			Captain/ Lieutenant/ 2nd Lieutenant	114.08
			Warrant Officer 1/ 2	151.26
			Staff Sergeant/ Sergeant	138.73
			Corporal/ Lance Corporal	157.02
			Private/ Sergeant Major of the Army/ Formation Sergeant Major/ Regimental Sergeant Major	229.96

Discussion and recommendations

The primary objective of this study was to investigate the influence of organizational justice and psychological ownership on turnover intention of NDF employees in the Khomas Region, Namibia. The secondary objective was to assess whether differences exist within the categories of sex, age, qualification, tenure, marital status, number of children, and rank in relation to turnover intention. Except for accountability (psychological ownership), organizational justice and psychological ownership reported a positive relationship, supporting *Hypothesis 1* of this study (weak relationship). Ibrahim (2016) found a positive association between organizational justice and psychological ownership. When the NDF treats employees fairly based on policies and procedures, distributes rewards, benefits and disciplinary procedures fairly, these employees are likely to feel more part of the NDF. Experiencing organizational justice signifies consideration towards employees, thus enhancing their identification with the organization. Pickford et al. (2016) emphasizes the importance and benefits of psychological ownership for the employee and organization. This study sample reported high levels of organizational justice and psychological ownership. Organizational justice and psychological ownership influence job satisfaction (Pieters 2017) and loyalty (Belete 2018), organizational commitment, and work engagement (Pieters & Auanga 2018).

Hypothesis 2 of this study assessed the negative relationship between organizational justice and turnover intention. The findings of this study support *Hypothesis 2* (weak relationship). When employees are not treated fairly, they are likely to leave. The same negative relationship was found between organizational justice and turnover intention (Arif 2018; Aslan & Uçar 2015). Mengstie (2020) noted that the perception of fairness or lack thereof influences the attitudes and behaviours of employees. Pieters (2018a) pointed out that when employees experience organizational justice, they are more likely to experience job satisfaction and work engagement. Apart from increasing feelings of burnout, Aghaei et al. (2012) found that organizational injustice increases the desire to leave (turnover intention). It is thus recommended that the NDF re-evaluates the organizational culture and work environment. The working environment of the NDF is very hierarchical; a more humane and collaborative approach could be considered. Namwandi (2015) reported that many employees were dissatisfied with the conduciveness of the working environment and the poor relationship with supervisors. If employees are considered and involved, their job attitudes could influence the perception of organizational justice and psychological ownership. Pieters and Auanga (2018) found a positive relationship between organizational justice, organizational commitment, psychological meaningfulness, and work engagement. Normative commitment and psychological meaningfulness predicted work engagement of employees. It is also recommended that employees be educated about policies on a regular basis and that superiors explain why certain rewards or penalties are being administered. An understanding of how and why certain decisions are made enhances organizational justice and psychological ownership.

This study explored the negative relationship between psychological ownership and turnover intention. The results of this study confirmed *Hypothesis 3,* a negative relationship between psychological ownership and turnover intention (weak relationship). A negative relationship between psychological ownership and turnover intention was also supported by other studies (Lu et al. 2017). Psychological ownership encourages higher levels of productivity and desirable employee behaviour (Pickford et al. 2016) whilst reducing unwanted behaviour like turnover intention (Lu et al. 2017). Olckers and du Plessis (2015) found that communication needs to be clear, relationships maintained, ethical conduct practised, recognition and acknowledgement awarded, and effective leadership applied to enhance psychological ownership. It is thus recommended that the NDF enhances communication and relationships between subordinates and supervisors. By having improved relationships, employees would become more committed and engaged at work. It is also recommended that the NDF improves or develops recognition and acknowledgement systems for excellence and for diligent employees.

The fourth hypothesis of this study explored the relationship between sex, age, qualification, tenure, marital status, number of children, rank, and turnover intention. *Hypothesis 4* was mostly supported by the results of this study. Apart from the number of dependants (children); sex, age, qualification, tenure, marital status, and rank reported significant differences with turnover intention. It is interesting to note, even in this male-dominated profession of military service, that males reported higher levels of turnover intention. Ammann and Staudacher (2021) noted that the challenges related to being an African male have changed and become more complex with changes related to social, political, and financial changes. Females have equal rights in society and increased access to political and financial resources. Males being predominantly associated with the role of provider may experience significantly more pressure compared to female NDF employees with low salaries and benefits. Sasman (2011) reported that NDF employees were evicted from the military base for not paying their rent. Low wages were cited as the reason for not being able to pay their rent. This study recommends that male employees be educated about gender sensitivity and sensitized to the new world of work. Educating males about equality and equity, dual-career marriages, and how to adopt improved gender roles can help reduce stress related to old-fashioned perceptions and practices.

The significant differences reported for age, tenure, and rank in relation to turnover intention may be related to African practices regarding respect and seniority. Idang (2015) reported that as children, Africans learn about the rituals and practices related to respect for the head of the household, elders, and political leaders. These values and practices are carried over to the workplace and applied. Younger, short-tenured and junior-ranked employees may be regarded as less influential, less insightful, or less resourceful. These younger, short-tenured and junior-ranked employees may experience frustration because they could be ignored, less considered, or less respected, thus increasing their intention to leave. Idang (2015) noted that culture is dynamic. Younger, short-tenured and lower rank employees could foster principles related to equality, democracy, and inclusivity. However, the military is a very authoritarian type of organization where age, seniority, and rank matter, and respect does not necessarily need to be earned. The significant differences between age, tenure, and rank in relation to turnover intention could also be because of fewer opportunities to obtain other employment. When employees become older, settle into the organization, or are progressing within the ranks of the organization, they become more embedded into the workplace, thus experiencing lower levels of turnover intention (Peltokorpi 2013). The lower turnover intention of middle-ranked employees was reported in this study. Higher-ranked employees are usually tasked with more responsibilities and required to respond to queries from top-ranked officials, which could be associated with higher intention to leave. Being responsible for the performance of lower ranked employees may add to the work stress associated with senior work roles. Olckers and du Plessis (2015) noted the importance of ethical conduct. All personnel should be treated with mutual respect and consideration. Mutual respect and consideration can ensure that the relationship between employees is enhanced and that employees become more open to sharing and listening to the ideas and views of others. Feeling respected and engaged in an ethical manner enhances psychological ownership (identifying with the organization) and reduces turnover intention.

Single employees reported higher levels of turnover intention. Karraker and Dorius (2016) noted that married couples reported higher financial net wealth, assets, and income compared to single people. Pieters (2018b) reported no significant difference between marital status and turnover intention. The low wages associated with the NDF could add more financial pressure to single employees than to married employees with dual income. Being married may ensure that the challenges related to the continued rising cost of living are shared and managed collectively. Being married also comes with discussions and insights on financial management. It is thus suggested that all employees, especially single employees, attend financial literacy training and learn how to budget. If single employees do not have the luxury of a second income, perhaps training on how to manage their current income may help. Namwandi (2015) noted that the salary was the biggest motivator to join the NDF.

The number of dependants (children) did not significantly influence the levels of turnover intention for the sample. Employees with no or differing numbers of children experienced similar levels of turnover intention. The same insignificant difference was found by Pieters (2018b) between number of dependents and turnover intention.

Du Plooy and Roodt (2013) found no significant relation between qualification and turnover intention of employees. This study found that level of qualification reported significant differences in relation to turnover intention. Pieters (2018b) noted that when employees gain educational qualifications, they become more hopeful of transitioning into better-paid jobs. Education and experience enhance mobility within (higher ranks) and outside the organization. The Ministry of Defence should review human resource policies by focusing on staff retention and progression. When employees advance themselves in terms of tertiary education, they should be recognized and promoted with better salaries and benefits. Many employees reported that the salary was the motivating factor for them to join the NDF (Namwandi 2015). Promotions should be fair and according to policy guidelines. Advancement policies need to consider working experience, training completed, and educational qualifications. Employee retention is improved by career development and especially when there are somewhat competitive activities in which employees engage and feel that they are learning and improving their skills. Advancement does not always need to be vertical but also through advanced tasks and assignments, deployment, training, and development.

The working environment of NDF personnel should be improved; it is their home away from home. One of the factors that improve job satisfaction is an improved working environment. The working environment also plays a role in terms of organizational justice and psychological ownership, thus reducing turnover intention. A bureaucratic environment may stifle creativity, healthy working relations, inclusivity, and performance.

Some of the limitations experienced when conducting this study include a language barrier as some personnel needed the research content to be explained in languages other than English. There is a lack of previous research studies conducted on the topic, and therefore limited access to literature concerning the Namibian Defence Force and their turnover intention. This study cannot be generalised to the rest of the population, considering that it was done in the Khomas Region. The study was unable to determine cause-effect relationships between the variables considering the nature of survey research. Considering the weak relationships between organizational justice, psychological ownership, and turnover intention; it is recommended that future studies focus on other variables (job satisfaction; job demands and resources; work stress) that may be more significant regarding turnover intention for this population.

Conclusion

The aim of this study was to explore the influence of organizational justice and psychological ownership on turnover intention of NDF personnel in the Khomas Region. The study found a positive relationship between organizational justice and psychological ownership (excluding accountability). A negative relationship was reported between organizational justice and turnover intention. A negative relationship was found between psychological ownership and turnover intention. This study found significant differences between sex, age, tenure, marital status, qualification, and rank in relation to turnover intention. The number of dependants displayed insignificant differences related to turnover intention. Different recommendations are proposed to enhance organizational justice and psychological ownership, whilst reducing turnover intention.

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His research interests include connecting community diets to their underlying scientific and technological principles to improve the quality of life through intelligent consumption of foods. His key focus on food security is directed at understanding the safety of nutritious foods, especially those that are indigenous, in order to develop shelf-stable varieties for consumers from different socio-economic sectors.

Technical and research services rendered to some of the major food industries and laboratories in SADC, Canada, Croatia, and the USA have provided him with experience in dealing with diverse audiences. He has encouraged the development of learners by sponsoring floating trophies in Mathematics, English, and the Sciences in several education circuits and schools in the Oshana and Oshikoto regions of Namibia.

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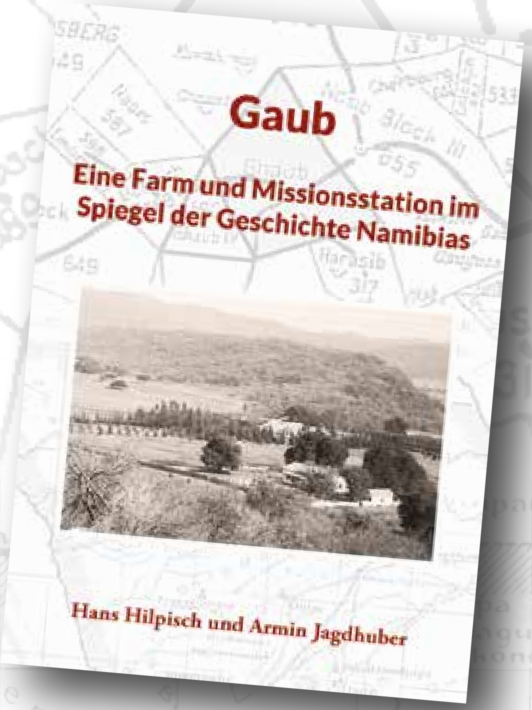
Gaub

Eine Farm und Missionsstation im Spiegel der Geschichte Namibias

von Hans Hilpisch und Armin Jagdhuber



The book met with great interest among German-speaking Namibians. The Gaub portrait is also recommended for travellers interested in historical places in Namibia.

– Sven-Eric Stender

Zusammen mit dem Orts-, Namen- und Quellenregister ist dieses Werk ein wichtiger Beitrag zum Verständnis der Missions- und Landesgeschichte und liegt somit als Nachschlagewerk bereit.

– Eberhard Hofmann

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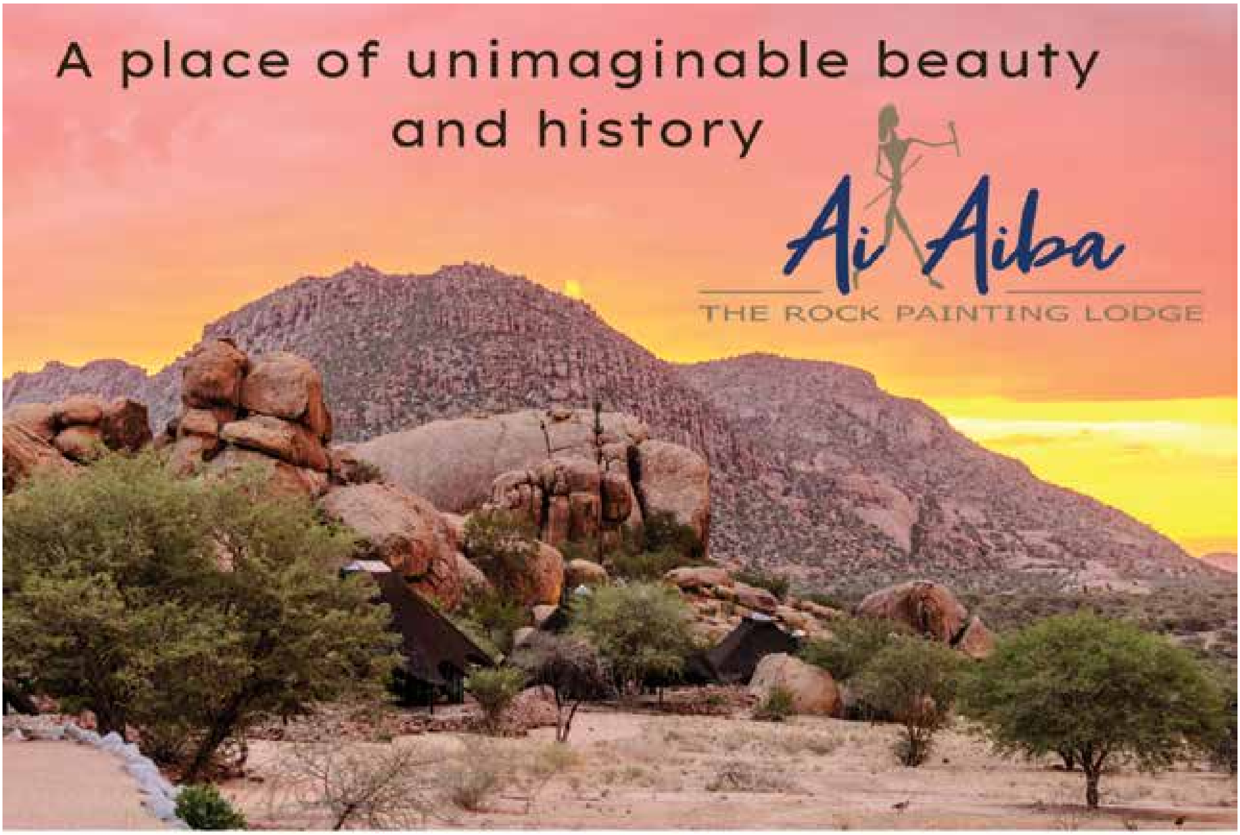
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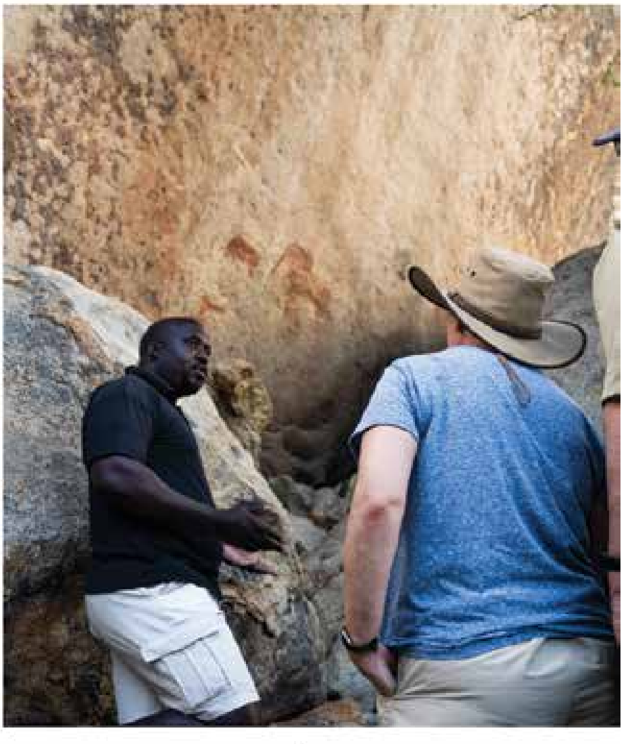

Assessing two detection dog-based sampling strategies targeting cheetah scat in diverse environments of central-east Namibia

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Keywords: cheetah monitoring, detection frequencies, method comparison, Namibia, non-invasive sampling, scat detection dogs, scent marking sites, survey design

Abstract

Cheetah monitoring can be improved with scat detection dogs that efficiently detect marking sites and scats randomly distributed across the landscape. To assess the scalability and adaptability of this method, we applied walking transects and visual searches, both supported by a detection dog, in four areas with varying cheetah densities, land use types, and habitats in central-east Namibia. We successfully detected cheetahs in all four study areas. Walking transects consistently yielded higher detection frequencies and detected cheetah presence in all areas, while vehicular searches were more time-efficient when marking sites were readily available. We recommend using an adaptive strategy to optimize searches depending on environmental characteristics in a given study area.

Introduction

Wildlife detection dogs are increasingly used as minimally-invasive survey tools to enhance the detection of wide-ranging species, such as many large carnivores (Grimm-Seyfarth et al. 2021). Their efficiency, compared to human searchers, is particularly evident in scat sample detection (Hofmann et al. 2021). Scat can provide valuable insights into a species' biology, health, and diet, especially when combined with genetic analysis (Schmidt-Küntzel et al. 2017), thereby holding the potential to inform effective conservation initiatives (Campbell-Palmer & Rosell 2011).

The cheetah (*Acinonyx jubatus*) is experiencing severe population declines, demanding immediate conservation efforts supported by accurate demographic data (Durant et al. 2017). However, monitoring the species poses challenges due to their wide-ranging behaviour and low population densities (Melzheimer et al. 2018; Weise et al. 2017). This can result in insufficient detections, impeding accurate inferences from surveys (Strampelli et al. 2022). Increasing the detection of cheetahs can be achieved by monitoring marking sites (Verschueren et al., accepted). Here, territorial male cheetahs will regularly defecate, whereas non-territorial males and females visit primarily for communication purposes without scent-marking (Cornhill & Kerley 2020).

Marking sites are often located by tracking the movement of radio-collared individuals (Melzheimer et al. 2020; Fabiano et al. 2020). However, this relies on capturing territorial males which may prove expensive, risky, and time intensive, in particular in areas with low cheetah presence (Kelly et al. 2012). Minimally-invasive survey methods, such as visual searches for signs of presence, mitigate those challenges, while holding the potential to increase detections (Kelly et al. 2012; Reed et al. 2011). Visual detection of cheetah marking sites may be possible as these sites are often conspicuous landscape features such as large trees, termite mounds, or rocks (Walker et al. 2016; Caro 1994). However, marking sites are not always conspicuous and may go undetected during visual surveys. This can be remedied through the inclusion of walking transects with a scat detection dog in the survey methodology. Scat detection dogs have been proven effective for the detection of marking sites (Becker et al. 2017), as dogs do not rely primarily on visual cues (MacKay et al. 2008). We presented a combined approach of camera trap and scat detection dog surveys in some of our previous work (Verschueren et al., accepted). There we performed walking transects to detect marking sites as well as scats randomly distributed across the landscape that are not associated with marking sites (hereafter 'random scats'), and conducted visual vehicular surveys to identify additional conspicuous marking sites, which we confirmed with a detection dog to find concealed scats. Understanding how these two scat detection dog-based search strategies perform under varying conditions is crucial to inform their deployment on a larger scale to survey cheetahs and other species with similar monitoring challenges.

Here, we deployed a scat detection dog-team to apply our complementary strategy of walking transects and vehicular searches to four study areas in central-east Namibia. The areas encompass a variety of suspected cheetah densities, land use types, and habitats (Atlas of Namibia Team 2022; Durant et al. 2022; Weise et al. 2017). We assess the results to compare the effectiveness of the different components of our strategy relative to the characteristics of each area.

Materials and Methods

We surveyed four areas in central-east Namibia (Figure 1) characterized by a tree-and-shrub savanna biome and a semi-arid climate with rainfall predominantly occurring in the wet season from October to April (Atlas of Namibia Team 2022). All surveys were conducted during the dry season to maximize the chances of finding scat. Areas 1 and 2 are freehold farmland, where the primary agricultural activity is cattle farming, supplemented by wildlife-based economies (Atlas of Namibia Team 2022). Area 1 is estimated to have the highest cheetah density among our study areas (Weise et al. 2017). Area 2 is a well-researched landscape for cheetahs, likely possessing the second highest cheetah density (Fabiano et al. 2020; Weise et al. 2017). Areas 3 and 4 are communal farmlands designated as communal conservancies (NACSO 2024), with Area 3 situated in the south-western

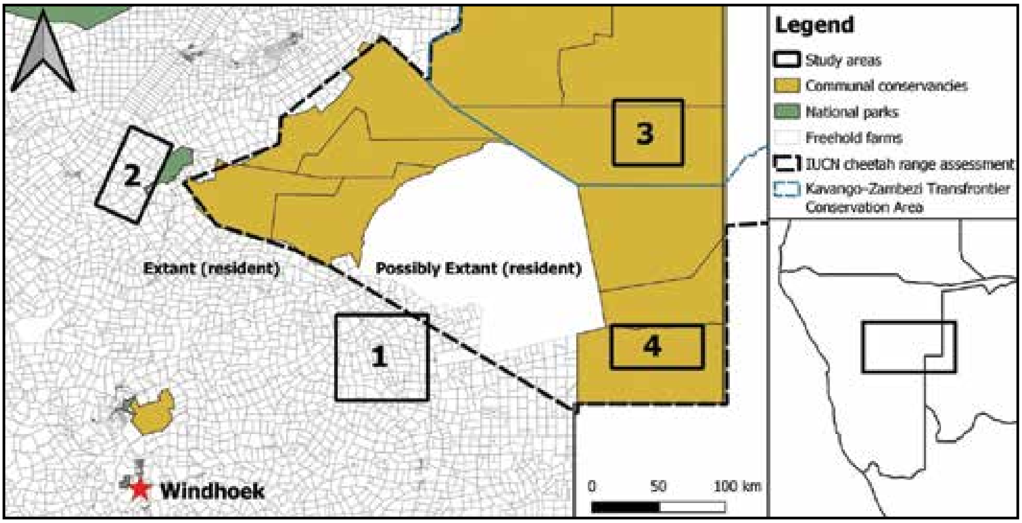

Figure 1: Overview of the study region in central-east Namibia, depicting the four study areas. The dashed black line indicates the confirmed resident cheetah range (Durant et al. 2022).

part of the Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA), and Area 4 bordering Botswana to the east and south. In Areas 3 and 4 cheetahs are possibly resident, albeit with presumably lower density than in Areas 1 and 2 (Durant et al. 2022; Weise et al. 2017). We overlaid each study area with a grid where each cell (sampling unit) measured 16 km x 16 km (256 km^2), approximating the minimal home range of cheetahs in comparable ecosystems (Melzheimer et al. 2018; Marker et al. 2008). The surveyed area varied among the study areas, ranging from 2,048 km² in Areas 2 and 4, to 4,096 km² in Area 1 (Table 1).

The scat detection dog and the handler are hereafter referred to as 'dog-team'. The dog (female spayed Belgian Malinois) was trained to indicate cheetah scat by sitting next to it, following the general methodology established in this field (MacKay et al. 2008). The handler Tim Hofmann was a certified dog trainer with expertise in identifying tracks and signs of African mammals. In each area the dog-team conducted both walking transects along roads and vehicular surveys. For road searches, the dog-team systematically searched approximately 16 km (Area 1–3) or 10 km (Area 4) per cell, subject to road availability. For vehicular searches the dog-team drove an average of 30.2 km (Area 3) to 66.9 km (Area 1) per cell to find conspicuous marking sites, which the dog-team subsequently investigated on foot, to confirm the marking site through the presence of scat. We documented survey effort as kilometres driven for vehicular surveys and kilometres walked for transects.

We confirmed cheetah scats by verifying the species identity of the collected samples at the Namibia-based Cheetah Conservation Fund's conservation genetics laboratory (Details of genetic analysis in Wong et al. 2024). We summarized our detection data descriptively by presenting the count of marking trees and random scats found per survey strategy and

Table 1: Overview of the four study areas within the study region, their environmental characteristics and the sampling design.

Study Area	Biome [a]	Vegetation type [a]	Average annual rainfall [mm] [a]	Land use type [a]	Survey period	Survey area [km^2]	Cells [#]
1	Acacia savanna	Central Kalahari	350–450	Freehold farmland	May – Sep. 21	4,096	15.5 [b]
2	Acacia savanna	Thornbush shrubland	400–500	Freehold farmland	Jul. – Oct. 22	2,048	7.75 [b]
3	Broad-leafed savanna	Northern Kalahari	350–400	Communal farmland	Jul. – Oct. 22	2,304	9
4	Acacia savanna	Central Kalahari	350–400	Communal farmland	Aug. 23	2,048	8

[a] According to the Atlas of Namibia Team (2022).

[b] Due to incomplete accessibility of the sampling unit.

study area. Subsequently, we calculated detection frequencies as the number of marking trees per 100 km covered for each strategy and the number of random scats per 100 km for walking transects.

Results

We found cheetah scat in all four areas through walking transects and in three areas with vehicular searches, both supported by a scat detection dog (Table 2 & Figure 2).

In **Area 1**, we found 9 marking sites and 5 random scats along 248 km of walking transects (16.0 km per cell; detection frequency of 3.6 marking sites and 2.0 random scats per 100 km). During vehicular surveys we discovered 30 marking sites over 1,037 km (66.9 km per cell; 2.9 marking sites/100 km).

In **Area 2**, we identified 2 marking sites along 124 km of walking transects (16.0 km per cell; 1.6 marking sites per 100 km) and found no random scats. During vehicular surveys we discovered 5 marking sites along 423 km (54.6 km per cell; 1.2 marking sites per 100 km).

In **Area 3**, we found 3 random scats along 145 km of walking transects (16.1 km per cell; 2.1 random scats per 100 km), but no marking site. We also found no marking sites along the 272 km vehicular surveys (30.2 km per cell).

In **Area 4**, we covered 80 km of transects (10.0 km per cell) and 320 km of vehicular searches (40.0 km per cell), some of which overlapped for logistical reasons. We detected 1 marking site independently with both methods, resulting in 1.3 marking sites per 100 km for walking transects and 0.3 marking sites per 100 km for vehicular searches. We did not find any random scats while walking transects.

Table 2: Survey effort in each study area for both sampling methods and their respective results.

Study area	Method	Effort [km]	Marking sites [#]	Random scats [#]
1	Walking transects	248	9	5
	Vehicular searches	1037	30	NA [b]
2	Walking transects	124	2	0
	Vehicular searches	423	5	NA [b]
3	Walking transects	145	0	3
	Vehicular searches	272	0	NA [b]
4	Walking transects	80	1 [a]	0
	Vehicular searches	320	1 [a]	NA [b]

[a] The same marking site was identified independently by both methods.

[b] Not applicable, as random scats cannot be detected during vehicular surveys.

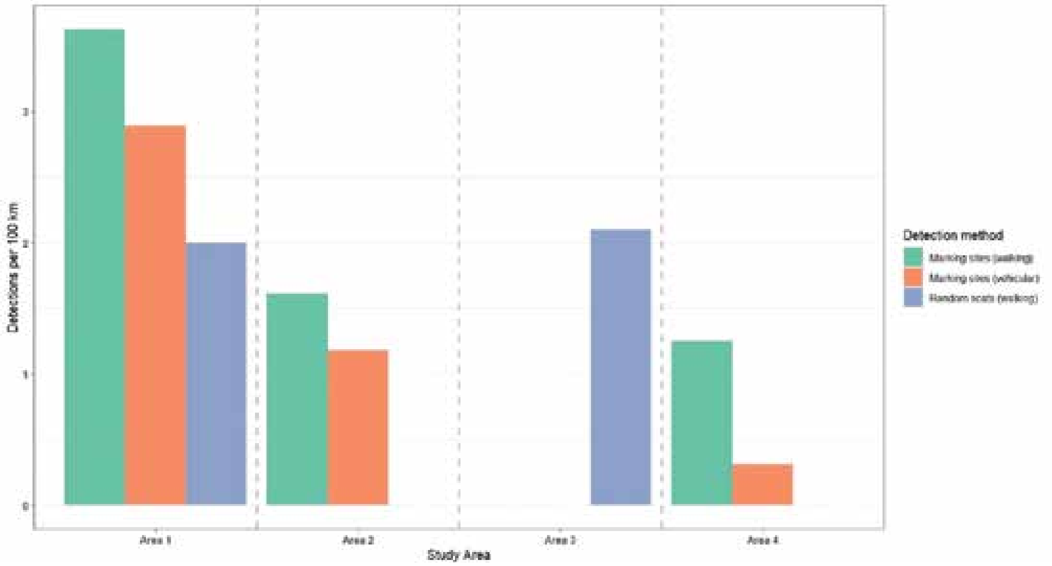

Figure 2: Marking sites and random scats detected per 100 km for each method in each study area (indicated by dashed vertical lines). Note that no marking sites were detected in area 3 and no random scats in areas 2 and 4.

Discussion

We were able to confirm cheetah presence in all four study areas using our complementary strategy of walking transects with a detection dog to find marking sites irrespective of their morphology as well as random scats, and vehicular searches confirmed by a detection dog to find additional conspicuous marking sites. This extends to areas with unknown status of cheetah residence (Durant et al. 2022) and diverse habitat characteristics (Atlas of Namibia Team 2022), highlighting the effectiveness of the scat detection dog as a minimally-invasive survey tool for cheetah monitoring.

As expected, random scats were found only during walking transects, while marking sites were detected with both methods. As such, walking transects alone yielded detections in all study areas, including areas where no marking sites were detected. The detection frequency of marking sites per 100 km was also consistently higher for walking transects than for vehicular searches (Figure 2). We attribute this difference to the capacity of the dog to detect marking sites irrespective of their morphology. However, vehicular searches confirmed with the dog required less effort in terms of time investment, which allowed coverage of larger areas, leading to a higher total number of marking sites detected. As such, in areas where the road network and habitat allow for vehicular searches and the detection of marking sites is the primary study objective, this combination may be considered as the preferred method.

We were not able to confirm marking sites in Area 3, even though we found trees that matched the morphology of marking sites (Walker et al. 2016), albeit in fewer numbers compared to the other areas. Based on our results from these other areas, where we successfully found and confirmed marking sites using the same complementary strategy, we assume that in Area 3 marking sites were rare, rather than not detected. Fewer marking sites could be a reflection of lower cheetah densities reported for this area (Weise et al. 2017). Interestingly, we found an almost identical frequency of random scats in Area 3 compared to Area 1 (2.1 and 2.0, respectively), which had the highest cheetah density of all study areas (Weise et al. 2017). Therefore, another contributing factor may be differences in defecation behaviour associated with an individual's territoriality. Higher proportions of non-territorial males and females may result in an increased detection of random scats on roads relative to the total density of cheetahs (Cornhill & Kerley 2020; Melzheimer et al. 2018; Broomhall et al. 2003). Indeed, cheetahs in Area 3 may be non-resident individuals straying into the study area from the bordering Nyae-Nyae Conservancy, which has stable records of cheetah occurrence (NACSO 2024). In either case, walking transects with a detection dog may be the only way to detect scats under such circumstances.

We found that the variation in detection success for the two methods can be largely attributed to the intrinsic characteristics of each study area. Subsequent analysis of the study areas and the collected scats will help clarify this assumption and assess the extent of the correlation. Furthermore, it is noteworthy that the frequency of detected marking sites in the four study areas corresponded with the density estimates indicated on Figure 3B by Weise et al. (2017) for these areas. Therefore, the frequency of marking sites might serve as a relative abundance index for cheetah population densities, although this warrants further investigation.

We conclude that the combination of walking transects and vehicular searches with a scat detection dog is an effective strategy for detecting cheetah presence through locating marking sites and random scats, irrespective of the characteristics of the study area. Walking transects were consistently more successful, while vehicular searches were more time-efficient when conspicuous marking sites and a sufficient road network were available. The flexibility of this complementary strategy allows for adaptation to the characteristics of each study area and thus promises scalability across a range of target species and their habitats.

Ethical statement

The fieldwork was conducted under the authority of the Namibian National Commission on Research, Science & Technology, in accordance with Section 21 of the Research Science and Technology Act No. 23 of 2004, under the research permit AN2028011402 of the Cheetah Conservation Fund (Namibian-based research institute RCIV00122018). The fieldwork was carried out with the consent of the landowners. The training and handling of the detection dog was endorsed by the animal welfare officer of the University of Goettingen.

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About the Author

Tim Hofmann holds a Master's degree in Nature Conservation Biology and is currently pursuing a PhD in wildlife sciences at the University of Goettingen, Germany. He is a certified dog trainer with several years of experience working with dogs in various conservation settings. Since 2018 Tim has been leading the scat detection dog project for the Cheetah Conservation Fund (CCF) in Namibia. His expertise extends to field projects across Namibia and Angola, where he works with CCF's dogs to detect and conserve rare wildlife species. Passionate about innovative wildlife conservation approaches, Tim's work focuses on the intersection of dog training and conservation biology.

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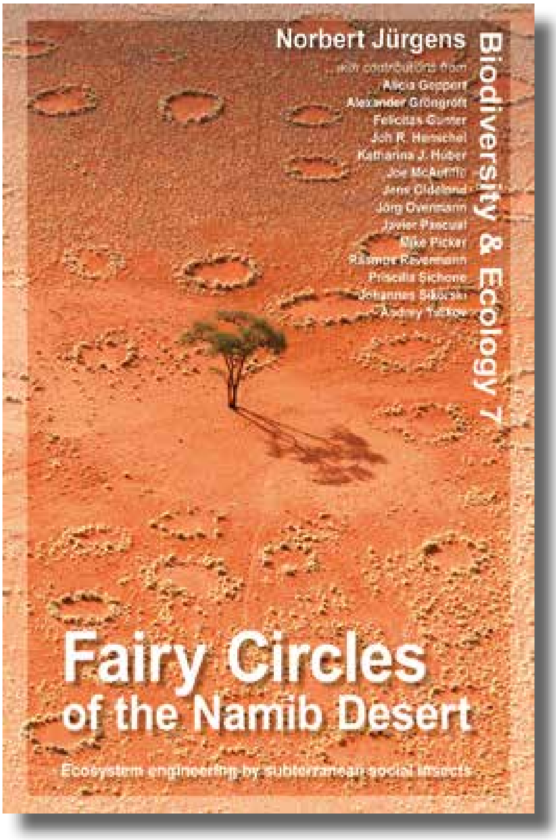

Norbert Jürgens et al.

Fairy Circles
of the Namib Desert

Ecosystem engineering by subterrainean social insects

Co-authors: Alicia Geppert, Alexander Gröngröft, Felicitas Gunter, Joh R. Henschel, Katharina Huber, Joe McAuliffe, Jens Oldeland, Jörg Overmann, Javier Pascual, Mike Picker, Rasmus Revermann, Priscilla Sichone, Johannes Sikorski, Andrey Yurkov.

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On the eastern edge of the Namib Desert—probably the oldest continuous desert in the world—millions of ochre-coloured bare patches in the grass have created landscapes of unique beauty that are often regarded as one of the greatest mysteries in ecology: the fairy circles of the Namib Desert.

Building on more than four decades of ecological research in all parts of the Namib in Angola, Namibia, and South Africa, Norbert Jürgens and fourteen renowned authors present the natural history of the phenomenon, with all the facts understood so far, and also describe the remaining open questions.

In the Namib Desert, sand termites from soil-dwelling termite families have been found to cause the fairy circles. These termites must be understood as ecosystem engineers that—comparable to the beavers in rivers of the northern hemisphere—profoundly alter the landscape and make permanent life in the desert possible.

This book offers a wealth of information based on numerous in-depth studies on the morphology, ecology and biology of fairy circles and the organisms which create, use and maintain them. Other regular vegetation patterns of the Namib Desert and neighbouring biomes are introduced and discussed, as well. Hundreds of stunning photographs invite the reader to enjoy a journey to the diversity of fairy circle landscapes in Namibia, Angola and South Africa.

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Clarifying elusive, obscure, or misleading historical Namibian biodiversity collecting localities

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Keywords: Namibia, biodiversity, historical collecting localities

Abstract

Some previously ungeocoded or poorly geocoded historical biodiversity collecting localities of Namibian relevance are clarified, including those that have usually been treated as Namibian but are actually in neighbouring countries, or vice versa. Collectors treated are: J.F. Drège, J.A. Wahlberg, K.J. Andersson, A.W. Eriksson, H. Schinz, A. Lüderitz, L. Schultze, the South African Museum expeditions, the Swedish South Africa Expedition, G. Hobohm, and F. Gaerdes.

Opsomming

’n Aantal Namibies-relevante geskiedkundige biodiversiteitsversamelingspunte met geen of swak vorige geokodering word opgeklaar, insluitende daardie wat dikwels as Namibies beskou was maar eintlik in buurlande geleë is, of andersom. Versamelaars wat behandel word is: J.F. Drège, J.A. Wahlberg, K.J. Andersson, A.W. Eriksson, H. Schinz, A. Lüderitz, L. Schultze, die Suid-Afrikaanse Museum-ekspedisies, die Sweedse Suid-Afrikaanse ekspedisie, G. Hobohm en F. Gaerdes.

Introduction

Every student of biology is (or should be) taught that killing a living being for scientific purposes can be morally justified only if one utilises the act to extract the maximum possible useful data from it, and also conserves it so that future workers can continue to benefit from it. An essential part of the scientific data legacy of any biological specimen is a collecting label that includes the collecting locality. Unfortunately, the collecting data for historical material is often less satisfactory, with locality names that are no longer in use or were obscure to begin with. A few such historical 'problem' localities of Namibian relevance are treated below.

A parallel source of biogeographical confusion that is seldom mentioned is the apparent historical practice of foreign museums to relabel collectors' material with generalised localities, or of specialists who studied the material to publish over-simplified versions of localities even when the collector's label carried more precise data. When one reads the surviving journals of prolific collectors like J.A. Wahlberg (Hummel 1994) or Gustaf de Vylder (Rudner & Rudner 1998), one is impressed with their geographical awareness. They knew where they were and what the places were called. It is inconceivable that they did not label their material accordingly, and some surviving specimens confirm that they did. Yet all of Wahlberg's South African beetle material (luckily not his Namibian/Botswanan material) was published by Boheman (1848, 1851, 1857) as being merely from 'Caffraria', a name never used by Wahlberg himself. De Vylder's Namibian insects are labelled 'Damara', despite the fact that he traversed the entire country from south to north. One can only wonder how much potentially useful biogeographical data has been lost or rendered practically inaccessible in this way.

It becomes a wider scientific problem when subsequent workers first misinterpret these already deficient locality data and then base taxonomical decisions on, or draw conclusions from, what is essentially a geographical fallacy. In the case of Boheman/Wahlberg's 'Caffraria' above, even today workers will confidently equate it with the Eastern Cape of South Africa on the basis of a former British administrative area with the same name that was located there. In fact, Wahlberg made no significant collections in or near the Eastern Cape; instead, he worked in the present-day Kwazulu-Natal, eastern Free State, North West, Gauteng, Mpumalanga, Limpopo, and far eastern Botswana. It then becomes a Namibian irritation when non-South African Wahlberg localities get relocated in print to 'Caffraria' simply by virtue of being Wahlberg material, e.g. Loew (1862: 14), and are then evermore treated as South African records. Hopefully the following information can help to reduce or rectify similar misrepresentations.

Materials and methods

Historical geocoding is not an exact science. It becomes necessary because of the imperfection of original sources, and consequently is heavily reliant on the availability of accessory sources, the use of inference, and personal experience in the areas concerned. When determining coordinates I have generally attached the greatest significance to information from the own writings and maps of the collector; next, any primary self-surveyed maps or relevant writings by near-contemporaries of the collector; lastly, any later secondary compilation maps. Available information was supplemented by my personal knowledge of the areas, or by topographical assessment from aerial photographs for areas with which I am less familiar. I attached lesser significance to the unsubstantiated coordinate claims of subsequent publications, and did not use on-line gazetteers after finding that their claimed coordinates even for unambiguous localities in the studied areas might be wrong by up to half a degree. Final geocoding was done by visually locating the appropriate place on Google Earth and noting the coordinates. Coordinates were rendered as Cartesian decimal degrees and rounded to four decimals, giving an approximate resolution of 10 m on the ground in Namibia. I have noted my sources throughout. Many of the maps quoted are represented in the library of the Namibia Scientific Society and are accessible through their web site. In the many cases where my determinations differ from previous attempts, users may assess the relative reliability of the respective sources cited and draw their own conclusions.

Results

Collectors are treated chronologically.

1. Drège

Johann Franz Drège (1794–1881) was a German botanical collector who travelled widely in South Africa in the early 19th century. He exhaustively documented his collecting localities and collections in Drège (1843). On one of his expeditions he travelled north from the Cape, reaching the Orange River in September 1830 and travelling downriver to the mouth before returning to Cape Town. The fact that he also collected in what is now Namibia, and that these are some of the earliest surviving biodiversity collections made in the country, seems since to have gone unnoticed and his Namibian material has generally been treated as South African.

Drège reached the Orange River at *Verleptpram,* (also rendered *Verlepttpram*) where he made two collections, one of the vegetation of the riverbank and its fringing bouldery alluvial strip, and a second on the adjacent mountains. He then crossed the river to collect

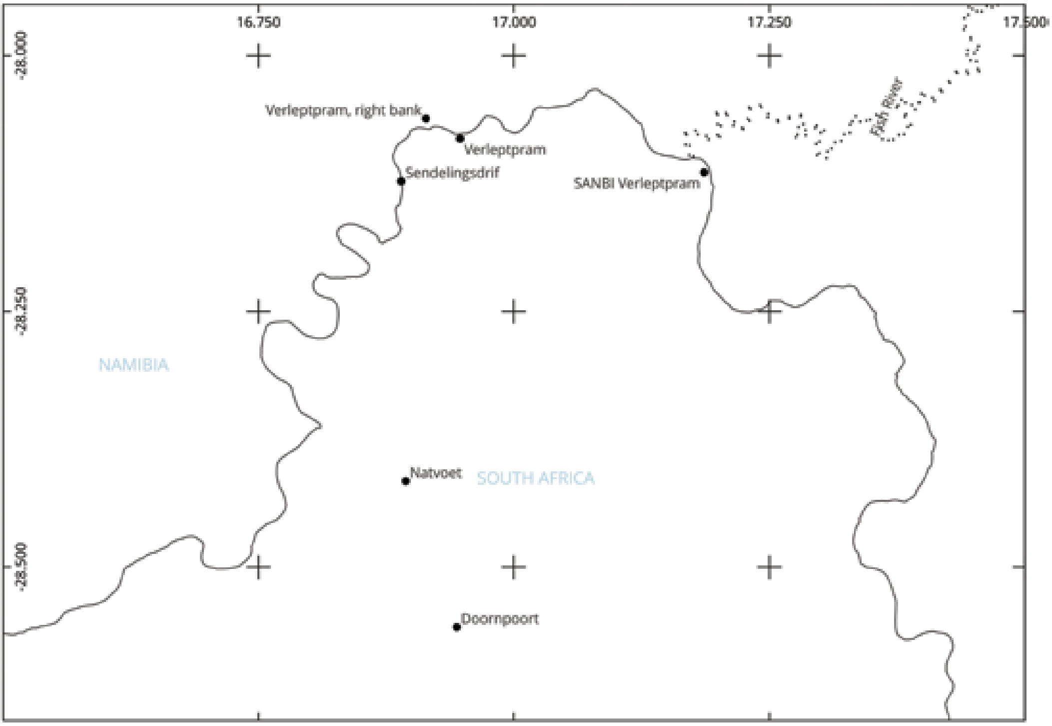

Figure 1: Namibian and near-Namibian Drège localities and relevant other places

on the right hand (northern) bank, before returning to the south bank and proceeding to the river mouth. He documented the relevant collections as:

- *Garip, bei Verleptpram, am Ufer des Flusses und in der steinigen Niederung* (= Orange River at Verleptpram, on riverbank and in the stony flat)
- *Garip, auf steinigen und felsigen Höhen bei Verleptpram* (= Orange River, on stony and rocky heights at Verleptpram)
- *Garip, Sandhügel am rechten Ufer des Flusses bei Verleptpram* (= Orange River, sandy hills on right hand riverbank at Verleptpram)

No place named *Verleptpram* appears on any modern or historical map to which I have had access, except the one in Drège (1843), which is not very useful. It depicts the Lower Orange River as flowing more or less straight east to west to the sea, but it does help to confirm that *Verleptpram* is on the south bank, and that it is downstream of the Fish River confluence, which is also marked. Enquiries to the custodians of Drège's botanical heritage, the South African National Biodiversity Institute (SANBI), indicated that they believe *Verleptpram* to be located opposite the Fish River Mouth with coordinates -28.1141, 17.1861 (pers. comm., Les Powrie and Marinda Koekemoer, 2017), and it is correspondingly referenced with quarter degree square 2817Aa in SANBI works, e.g. Boatwright et al. (2018: 54). The basis for their geocoding is the location near to the Fish River and the finding of some Drège *Verleptpram* species there. This is very oblique evidence indeed. Besides the fact that the coordinates are actually upstream of the Fish River Mouth, not downstream as Drège has it, the location is also off the beaten track. My research on historical travellers in arid southern Africa has shown me that their overall routes tended to go from one available water point to the next, while their specific routes between water points were constrained by topography and generally followed the path of least resistance. They also tended to follow in each other's footsteps. A route that goes where SANBI maps *Verleptpram* does not fit this pattern.

However, about 22 km west of the SANBI coordinates there is a mountain on the south bank of the Orange River called *Pokkiespramberg* (RSA 1:50 000 topographical sheet 2816Bb, Sendelingsdrif, 1979). *Pokkiespram Hill* appears on earlier maps at least as far back as 1942 (South Africa 1:500 000 sheet 2715 Richtersveld, 1942). *Potjiespram,* the current name for the National Park camp site there, is evidently a neologism. Most Afrikaans place names in areas where Khoekhoegowab is spoken are translations, and it is conceivable that different informants could have translated the same unknown original Khoekhoegowab place name as *Verleptpram* (= wilted breast) for Drège and as *Pokkiespram* (= a breast scarred by smallpox) for later cartographers. Both are highly unusual and unique names and finding two similar proximate toponyms is suggestive that they might be the same.

Pokkiespram is near *Sendelingsdrif,* an established river crossing which was first documented by Schmelen (1818), and which was in use with an established route to it during Drège's time (Alexander 1838) and thereafter (Andersson 1855), up to the present day. It is more likely that Drège would have travelled here than at the Fish River Mouth. The case for *Pokkiespram* is further strengthened by considering the two localities that Drège lists immediately before reaching *Verleptpram: Natvoet* and *Doornpoort.* They happen to be the last two water points before reaching Sendelingsdrif from the south along the historic (and current) route.

Natvoet is 32 km due south of *Sendelingsdrif* and is today called *Annisfontein* (RSA 1:50 000 topographical sheet 2816Bd, Khubus, 1973). Natvoet means 'wet foot' in Afrikaans and Alexander (1838: 250) calls the place '*Aneip,* or wet foot'. We know that Aneip is *Annisfontein* because Alexander mentions the nearby (ca. 700 m distant) cave of Heije Eibib, today called Wondergat. The Khoekhoegowab words for 'wet' and 'foot' are respectively ǀ*aa* and ǂ*aib/s* (Haacke & Eiseb 2002) and one can imagine how the conjunction can be rendered by non-speakers as either *Aneip* (masculine) or *Annis* (feminine). *Doornpoort* is also mentioned by Alexander (1838). It is 17 km further south, again along still existing roads, and still carries the name *Doringpoort* on modern maps (RSA 1:50 000 topographical sheet 2816Db, Rooibank, 1973).

The location of *Pokkiespramberg* near an established route, with traceable preceding localities, and conceivable name-correspondence, strongly argue that it is Drège's

Table 1: Cartesian coordinates for relevant Drège localities. Mapped in Figure 1.

Locality	Country	Coordinates
Verleptpram (as Pokkiespramberg, taken at northern foot)	ZA	-28.0811, 16.9473
Verleptpram, right bank (as Lorelei Valley, taken at prominent sandy hills centrally in mouth of valley)	NA	-28.0615, 16.9139
Natvoet (as Annisfontein, today dry, taken at approximate water point location as it was in 1977; personal observation)	ZA	-28.4158, 16.8941
Doornpoort (as Doringpoort, taken at location of water point on topographical map, not visited by me)	ZA	-28.5586, 16.9440

Verleptpram. So does the description of Drège's Namibian locality, across the river from *Verleptpram,* which mentions 'sand hills'. The Lorelei Valley on the north side of the Orange River at this point is very sandy and all hills are sand covered. The prevailing south-westerly winds funnel a sand stream up the Orange River Valley that gets deposited in the Lorelei valley when the river turns abruptly eastwards. The nature of the Orange River bed here, rocky with numerous small islands in one place, would also have facilitated Drège's crossing of the river.

2. Wahlberg

Johan August Wahlberg (1810–1856) was a Swedish naturalist who collected much early material in southern Africa, starting in 1838. What we know of his time in southern Africa is based on his surviving journals and letters, as compiled by Hummel (1994), which is the source of everything below that is not otherwise referenced.

Wahlberg arrived at *Walfish Bay* on 14 April 1854 initially not intending to spend time in Namibia. His main goal was Lake *Ngami* in north-western Botswana and the country beyond, but he was delayed and by late 1854 he was still at *Walfish Bay.* Besides specimen labels, letters dated 22 June and 15 December 1854 contain the sum total of information we have on his movements during the eight or nine months in 1854, during which most of his Namibian collections were presumably made. He eventually started for *Ngami* in January 1855 (judging by a specimen labelled *Onanis* on 11 January: Gyldenstolpe 1926: 99) and by March was already at Lake *Ngami,* where his journal re-commences on 30 May 1855, but we have virtually no information on the journey from *Walfish Bay.* On 6 March 1856, still in Botswana, he was killed by an elephant, so he never wrote the travelogue that might have answered the questions we have today.

During his time at *Walfish Bay* Wahlberg stayed at the mission station *Scheppmansdorf.* On 10 May 1854 he set off towards the Swakop River, which he followed upstream to near *Otjimbingwe,* and then along the established route across the Khomas Hochland to *Windhoek,* down to *Rehoboth,* and then cross-country westwards to reach *Scheppmansdorf* again on 16 June. The purpose of this first trip inland was mainly business; he does mention some collecting, but given the distance traversed in a relatively short time, this is not expected to have been significant. Subsequently he made a longer trip from 19 July to 11

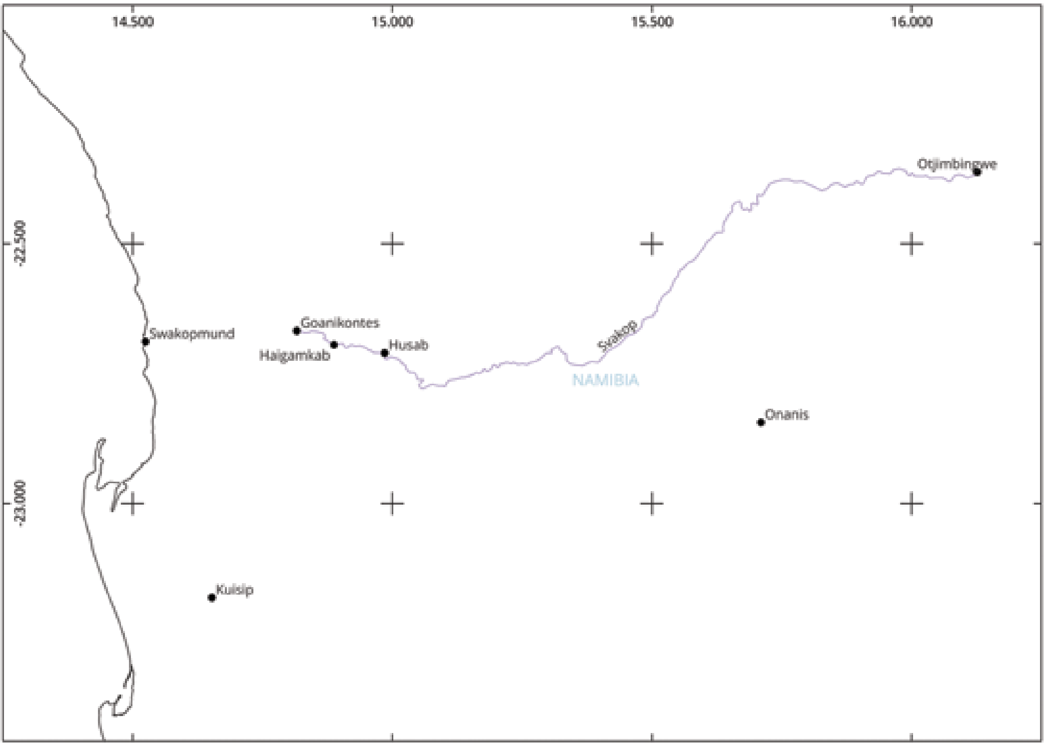

Figure 2: Wahlberg localities and relevant other places in central western Namibia

October, specifically for hunting and collecting along the Swakop River, again returning to *Scheppmansdorf.*

Wahlberg localities relevant to Namibia are the following:

Svakop

Svakop is a rendition of 'Swakop' that is unique to Wahlberg. Because his May/June visit to the Swakop River was short and business-orientated, we can presume that most of Wahlberg's *Svakop* material originate from the longer July to October journey. The route is no more precisely specified than just 'along the course of the Swakop River', and the journey started and ended at *Scheppmansdorf.* Contemporary established routes from *Scheppmansdorf* reached the Swakop River at the water points of *Goanikontes, Haigamkab,* or *Husab,* between 30 and 45 km from the coast. *Svakop* specimens do not include coastal Namib Desert species, so it is unlikely that Wahlberg proceeded downstream from either of these places. In modern studies that treat Wahlberg material, *Svakop* has often been equated to *Swakopmund,* either implicitly without comment, or explicitly as e.g. in Londt

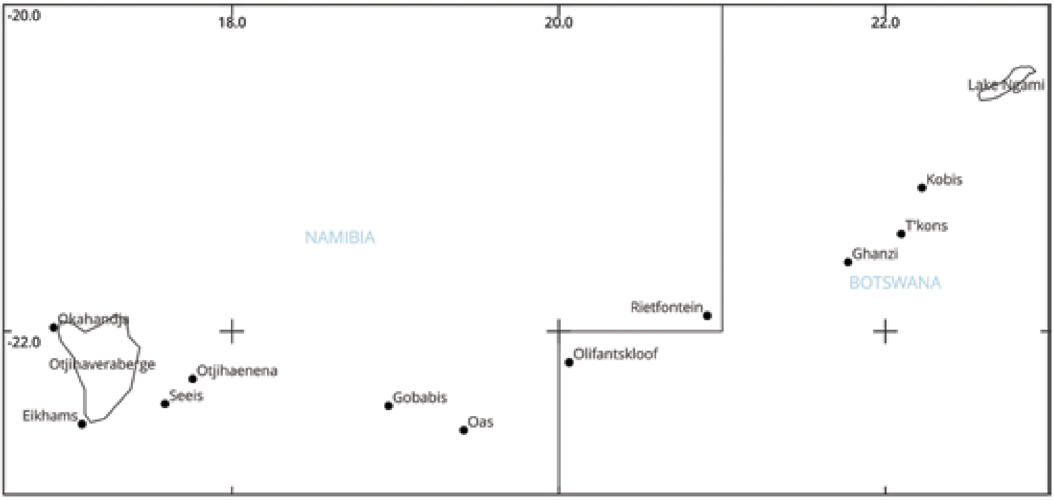

Figure 3: Wahlberg localities and relevant other places in eastern Namibia and western Botswana.

(2010: 456), but this is wrong. Exactly how far upstream he went is unknown. We can assume that he went at least as far as *Otjimbingwe,* for two reasons: a) he had already travelled this route for non-collecting purposes two months previously and was familiar with it, and b) *Otjimbingwe* was the first major settlement inland from the coast and all routes passed through it. It is also clear that by *Svakop* we must understand the Swakop River Valley or the Swakop catchment rather than a route confined to the actual river, as witness specimens from this time originating from e.g. Onanis (Gyldenstolpe 1926: 55), 35 km from the Swakop River. We are left with 'Swakop River catchment between about *Goanikontes* and at least *Otjimbingwe*', which may not be entirely accurate but is the best estimate possible under the circumstances. At least the time spent and the taxa collected are consistent with such a route, albeit admittedly not exclusive to it.

Of his Swakop trip Wahlberg said: 'I scarcely managed to collect anything, and indeed there was not much of any value to collect' (Hummel 1994: 154). Looking at the published results I have to disagree, since it is the most prolific of Wahlberg's Namibian localities. Maybe he was comparing it to the easier collecting in wet green south-eastern Africa that he was more used to. At least some of Wahlberg's Svakop insect species have never since been recorded, e.g. the small moth *Arcyophora ledereri* (Wallengren 1863).

Kuisip

The name refers to the Kuiseb River. All of Wahlberg's *Kuisip* material was probably collected during his stay at *Scheppmansdorf* (today: Rooibank) on the Lower Kuiseb River. He also briefly travelled along part of the Kuiseb River upstream of *Scheppmansdorf* on his way back from *Windhoek* during his May/June trip, but since they nearly died of thirst at the time, conditions were probably not conducive to collecting. The high proportion of Namib- and dune sea-specific taxa that are labelled Kuisip, combined with the absence of any material labelled *'Scheppmansdorf,'* despite the fact that he spent a total of at least four months there (mid-April to early May, mid-June to late July, and again from mid-October to at least mid-December 1854), all argue for Wahlberg's *Kuisip* being *Scheppmansdorf. Kuisip* material includes iconic Namib dune-specific insect taxa such as the jewel beetle *Julodis mitifica* Boheman 1860, the tenebrionid beetles *Pachynotelus albonotatus* Haag-Rutenberg 1872 and *Stips stali* (Haag-Rutenberg 1872), and the narra cricket *Acanthoproctus diadematus* (Stål 1858), all originally described from Wahlberg material and all occurring at Rooibank.

Eikhams

The name *Eikhams* is well known as a historical rendition of *ǀAeǁgams*, one of the original names of *Windhoek.* Wahlberg visited *Windhoek* during his initial May/June trip. Hummel (1994: 161) maps his later route to *Ngami* as bypassing *Windhoek* by proceeding from *Okahandja* directly to *Otjihaenena* on the White Nossob River, north-east of *Seeis.* The inspiration for the latter route is likely Gyldenstolpe (1934: 285), who lists *Okahandja* and *Otjihaenena* as sequential localities where Wahlberg collected bird specimens. However, such a route would have had to cross directly over the *Otjihavera* Mountains, and no such route existed; all documented contemporary eastward travellers proceeded along the established route from *Okahandja* to *Windhoek* and then towards *Gobabis.* I believe it is most likely that Wahlberg, too, did this, and passed through *Windhoek* a second time in early 1855. This fact has some bearing on the next locality. Relatively little Wahlberg *Eikhams* material is known.

T'kons fountain

The location of *T'kons* has not been traced before, but because it is associated with Wahlberg's other Namibian material it has till now usually been treated as Namibian. It is not mentioned in Wahlberg's journals or letters. By analogy with places he does mention, like *t'Kuisji* (for *!Khuiseb*), or *t'Eit'kams* (for *ǀAeǁgams*), we can deduce that the *T'* in the name is Wahlberg's rendering of a click sign, though he did not distinguish between different clicks. Material also exists that is labelled '*inter Eikhams et T'kons fountain*'. Since we saw above that Wahlberg likely travelled through *Windhoek* twice, this places *T'kons* either south or west of *Windhoek* en route to *Scheppmansdorf,* or east of *Windhoek* en route to *Ngami.*

A direct search for the place name yielded no results. Considering the 'south/west of *Windhoek*' option first, I was unable to find *T'kons* or a similar name on any historical map of the relevant parts of Namibia (Irish, unpublished map indices). Presuming it to be a Khoekhoegowab name, and knowing that many places in Namibia have names in multiple languages that often have similar meanings, I explored a range of phonetically similar permutations of *kons* (gom, goms, gon, gons, khom, khoms, khon, khons, each respectively preceded by ǀ, ǁ, ǂ or !) in Khoekhoegowab (Haacke & Eiseb 2002), and then proceeded to look for place names in the target area that represent the same meanings translated into English, Afrikaans, German, or Otjiherero (using Viljoen & Kamupingene 1983), without success. I repeated the process for the 'east of *Windhoek*' option, additionally considering maps of Botswana (Irish 1988) and expanding the languages to include Naro (Visser 2001) and Setswana (Matumo 1993), again without success.

As stated above, it is unlikely that Wahlberg did significant collecting on his May/June 1854 trip that proceeded south from *Windhoek,* but the sequential bird specimens mentioned in Gyldenstolpe (1934) show that he was collecting when he passed through again on the way to *Ngami,* so it then becomes more likely that *T'kons* is east of *Windhoek.* The route to Lake *Ngami* from Namibia was first documented by Andersson (1856) following his journey of 1853. The central part of the route was much constrained by the scarcity of reliable water points and proceeded successively through Gobabis, *Oas/Twass, Elephant's Kloof, Rietfontein/Tunobis, Ghanzi, Thounce,* and *Kobis.* All contemporary documented travellers followed the exact same route, and it was still being used 30 years later (Schinz 1891a). There is no reason to believe that Wahlberg deviated from the established route and the sequential localities from Gyldenstolpe (1934) support this.

Andersson (1856) describes but does not name a water point in Botswana, north-east of *Ghanzi* en route to *Ngami.* Chapman (1868), who travelled the same route in 1855 a few months after Wahlberg but in the opposite direction, calls it *Thounce,* and Baines (1864), who travelled the same route with Chapman in 1861, includes it on his detailed map. *Thounce* is phonetically very similar to *T'kons,* and the differences in spelling may be explained by different speakers attempting to render the same foreign sound using respectively English and Swedish orthography. I believe *Thounce* and *T'kons* to be the same place since it fits best with all available information. The otherwise very broad locality 'between *Eikhams* and *T'kons*' then makes sense as a receptacle for lumped material collected opportunistically en route to the actual intended collecting area. It also means that *T'kons* is not in Namibia. Previously, the insect species collected there were compatible with its being in either Namibia or Botswana.

Thounce does not appear on modern maps of Botswana (consulted: Botswana 1:250 000 series. 1972–1984, Department of Surveys and Lands, Gaborone; and: Bechuanaland Protectorate 1:1 250 000. 1935. Ordnance Survey, Southampton). Baines' map locates it about halfway between *Ghanzi* and *Kobi* Pan (as Kobies), which do appear on modern maps. Chapman's tables of distances agree with Baines' relative location of *Thounce,* and both Chapman and Baines list alternative names for *Thounce.* Skead (1973) lists all their names and adds more, and the following then all refer to the same single place:

- *Thounce, T'kons, Wolf Fountain.* Baines gives the alternative name 'Wolf Fountain' for *Thounce.* The Naro word for spotted hyena, called 'wolf' in much of southern Africa, is *xàu* (Visser 2001). In Naro orthography 'x' represents the ǁ-click, and in spoken Naro *xàu* does sound very similar to Thounce or T'kons (van Rooyen, pers. comm.).

- *Leetsia Piere, Leetjee Pierie, Leetsia Pierie.* Baines gives one version as an alternative name for Thounce, and Skead adds two spelling variants. The proper Setswana place name is probably Metsiphiri, from *metsi,* water, plus *phiri,* hyena (Matumo 1993), i.e. Wolf Fountain.
- *Stink Fountain, Stinkfontein.* Baines gives 'the Stink Fountain of Andersson' as an alternative name for Thounce. The name *per se* was not used by Andersson (1856), but he did mention the disagreeable taste of one water point in this general area.
- *Kameel Pan,* also *Camel Pan* and *Giraffe Pan,* were listed by Skead as synonyms for Thounce, without specifying a source. Schinz (1891a) maps a water point *Aus,* and in his text mentions the alternative name *Kamelpan. Aus* is phonetically close to *xàu.* The first mapped appearances of Kameel Pan under that name that I could find were by Kiepert (1893), Gentz (1903), and Passarge (1904).
- The original owner of farm Kameelpan north-east of *Ghanzi* was J. P. F. du Plessis, and his granddaughter, E. van Rooyen (pers. comm.), still lives in the area. She confirmed with her father, who grew up on Kameelpan farm, that the original Kameelpan water point was not actually on the farm of the same name, but on an adjacent cadastral unit for which they provided me with the coordinates listed in Table 2, below. The coordinates previously published by Skead for Kameelpan are only 2.5 km distant, but those do not correspond to a water point on the ground. Neither *Thounce* nor any of the other 'wolf'-based names remain known in the area today.

On balance of evidence, Wahlberg's *T'kons* is likely the same as *Thounce* or *Kameelpan.*

Nolagi

Nolagi is another Wahlberg locality, associated with his Namibian and Botswanan localities, that has never been traced. It has mostly been treated as Namibian, and Häckel & Farkač (2013: 319) even specified that it is in the Erongo Region, solely on the basis of the same single species that Wahlberg collected at both *Svakop* and *Nolagi,* and because they wrongly equated *Svakop* with *Swakopmund.* At least Holm (1978) stated that *Nolagi,* albeit untraced, could be either in Namibia or Botswana, while Louw (1979, 1982) located *Nolagi* in Botswana, and specifically western Botswana, but did not give his reasons for doing so.

Boheman (1860) in a reversal of his earlier treatment of Wahlberg's South African material, listed fuller label data for Wahlberg's Namibia/Botswana beetles and in the process provided us with useful clues about *Nolagi,* notably that it is a river, and that some specimens were collected in March, although the year was not specified. In the same publication, one *Ngami* record is also marked 'March'. Since Wahlberg was still en route to Namibia in March 1854, and he was killed on 6 March 1856, *Nolagi's* March can only be

Table 2: Cartesian coordinates for relevant Wahlberg localities. Mapped in Figures 2 and 3.

Locality	Country	Coordinates
Svakop (as Swakop River Valley between about Goanikontes and at least Otjimbingwe)	NA	cannot be precisely geocoded, see fig. 2
Kuisip (as Scheppmansdorf / Rooibank, taken at approximate location of historical mission station)	NA	-23.1802, 14.6490
Eikhams (as Windhoek, taken centrally in Tal Valley)	NA	-22.5680, 17.0810
T'kons fountain (as Thounce / Kameelpan, taken centrally on pan)	BW	-21.4046, 22.0967
Nolagi (as Lake Ngami area)	BW	cannot be precisely geocoded, see fig. 3

March 1855. *Ngami* specimens also labelled March suggest that *Nolagi* is close to Lake *Ngami,* and the *Nolagi River* is most likely one of the watercourses feeding into Lake *Ngami.* By 3 April 1855 Wahlberg had already left *Ngami,* travelling northwards along the *Okavango (Doughe)* River (Gyldenstolpe 1926: 7).

I can therefore confirm Louw's location of *Nolagi* in western Botswana, and furthermore that it is proximate to Lake *Ngami,* but have no more specific information. It is tempting to refer *Nolagi* to *Nhabe,* a watercourse feeding into Lake *Ngami,* on grounds of phonetic similarity, but I am not confident that this is necessarily correct. Needless to say, the name *Nolagi* appears on no maps that I have had access to, nor in the writings of Wahlberg or any other visitors to the *Ngami* area that I could trace. Previously, the insect species collected there were compatible with its being in either Namibia or Botswana.

Wahlberg's well

A locality in Botswana, south-west of *Ghanzi.* It is not a Wahlberg collecting locality, nor does it have any bearing on his actual localities. It was named posthumously (Baines 1864: 126).

3. Andersson

The Swedish-English hunter-trader Karl Johan Andersson (1827–1867), better known under his print name of Charles John Andersson, collected mainly birds in Namibia, but also smaller numbers of many other taxa. Much material exists that is well-labelled with detailed locality information, but there is also much that is labelled only *Damaraland,* as central-northern Namibia was known at the time. A subset of this *Damaraland* material does not attribute it to Andersson or any other collector. Material from all three groups is usually cited as being in the British Museum (today, Natural History Museum, London).

Besides Namibia, Andersson's material also includes specimens from *Knysna,* on the south coast of South Africa. They are mentioned in Finsch & Hartlaub (1870), Sharpe (1871), and Layard & Sharpe (1875), to name a few, with dates ranging from December 1865 to March 1866. As Andersson, at the time, was bedridden in Cape Town, he sent his apprentice, Axel Eriksson, to collect at *Knysna* (Rudner & Rudner 2006: 30), but the material has since been universally attributed to Andersson.

There are a number of species recorded or described from unattributed *Damaraland* material that do not occur in Namibia, but that do at *Knysna.* The best-known example of this is the dwarf chameleon, today known as *Bradypodion damaranum* (Chamaeleonidae), described by Boulenger (1887), which is a range-restricted endemic occurring only in wet coastal forest near *Knysna* and adjacent areas. Another example from the same work is the skink *Acontias meleagris* (Scincidae); in Boulenger (1885) there is the gecko *Afrogecko porphyreus* (Gekkonidae); and in Westwood (1876) the wormlion fly *Leptynoma sericea* (Vermileonidae). Another *Knysna* species, the bird *Cossypha dichroa* (Muscicapidae) is recorded by Sharpe (1871) purportedly from *Otjimbingwe* in Namibia, and stated to have been collected by Andersson.

In combination, the evidence suggests that besides the otherwise well-labelled Andersson material, some was labelled, or relabelled, with a generic Namibian locality without specifically attributing it to Andersson, and that the latter material includes a variety of non-Namibian, primarily *Knysna,* Andersson/Eriksson material.

Surviving original Andersson labels generally refer to localities that are relatively easy to locate on maps of the time or through Andersson's own writings, and need not be treated here, with one exception:

Elephant Vlei

Numerous bird specimens, as well as the type specimens of two bat species, carry the label *Elephant Vley, Elephant's Vley* or *Elephants Vley.* The name is also secondarily rendered as *Olifantsvlei,* or even *Elephant Valley* (Tomes 1861, recognisable by collector and date). All recorded dates are between August and November 1859.

At the time Andersson had already started on his way from the *Okavango River* back to *Otjimbingwe,* but was unable to proceed for lack of viable water points along his intended route and therefore remained stationary for almost four months while waiting for rain. He describes this in his travelogue (Andersson 1861) but does not name the place. The last date he mentions before arriving there is 3 August. He specifically mentions spending the time there collecting natural history specimens, and he also describes killing an elephant there, which may have inspired his later choice of a name. On 23 November he proceeded south. Based on the above this unnamed place must be what he called *Elephant Vley* on labels. It was never a real place name in use in the area. On Andersson's own map of his journey, appended to Baines (1866), the place is denoted simply as 'Vley (waggon long stationed)'.

The closest place to his vlei that is unequivocally identifiable and mapped by Andersson is *Ombongo,* today *Mpungu,* which he maps at coordinates only about 8 km north-east of actual *Mpungu.* Applying the same offset to the mapped coordinates of his vlei results in a location, but there are no obvious water points visible on aerial photographs of the area.

Table 3: Cartesian coordinates for relevant Andersson localities. Mapped in Figure 5.

Locality	Country	Coordinates
Mpungu (taken approximately centrally at historical water point)	NA	-17.6677, 18.2311
Mpungu (as Ombongo, coordinates from Andersson's map)	NA	-17.6314, 18.2964
Vley, wagon long stationed (coordinates from Andersson's map)	NA	-17.9048, 17.8240
Elephant Vlei (based on Mpungu/Ombongo offset applied to 'Vley')	NA	-17.9412, 17.7588

Several maps subsequent to Andersson depicted his convoluted once-off route through the area as if it were an actual road. The first subsequent map that appeared to add new first-hand information was Sprigade et al. (1913), where the place corresponding to the vlei on Andersson's map was depicted as a pan and given the name *Kuiseb.* Sprigade's coordinates for *Ombongu* are offset by 30 km and barely inside Namibia, although when applying this offset to *Kuiseb* it ends up only 8 km distant from Andersson's location.

Thomas (1906) cited the coordinates for *Elephant Vley* as 18° S, 17° 30' E, about 28 km west of Anderssons's location, without providing a source for his information. These coordinates are too broad to be taken seriously, but variations on them have since been repeatedly quoted in the literature, including some with the latitude and longitude reversed, or the longitude in the western hemisphere.

I have decided to accept Andersson's offset-corrected coordinates (figure 5). Although not precise or proven, they are probably the closest we are likely ever to get with the information available. They were calculated by the only person who truly knew where his Elephant Vlei was, and his coordinates for *Mpungu show* that he was impressively accurate under the circumstances.

4. Eriksson (as treated by Trimen, Péringuey, and Hesse)

Axel Wilhelm Eriksson (1846–1901) was a Swedish trader based in Omaruru for many years. In later life he continued the bird collecting that he started under C.J. Andersson. Eriksson's bird collections and bird localities have been well documented, e.g. Rudebeck (1955), Lundevall & Ängermark (1989), and Demasius (2022a,b), but his insect localities less so and the following brief treatment attempts to remedy this. His insect collecting may have been a one-off event in 1887 and the material was donated to the then South African Museum in Cape Town. He provided a brief list of localities and dates which Trimen (1891) published as part of his treatment of the butterflies. Péringuey (1892) treated Eriksson's beetles. In the title he said the material was from 'tropical south-western Africa' and in the introduction he calls this *Northern Ovampoland,* but he lists no localities at all for any of the many new species he described. Subsequently in Péringuey (1896, 1898, 1900, 1902, 1904) he described numerous species simply as from *Ovampoland,* again usually without specifying localities, and when he did name places some were mangled beyond recognition. Hesse (1925) treated the bugs and this is the only other large-scale treatment of Eriksson's insects that I am aware of. All Eriksson material had historically been treated as Namibian, although much of it is not. Mendes et al. (2013), in a gazetteer of Angolan beetle and butterfly collecting localities, labelled several Eriksson localities as 'reported to be in Angola, as a matter of fact in northern Namibia (in the former Damaraland)' without providing details.

As an aid to identifying proximate localities and placing them sequentially along a route, I investigated the relevant collecting chronology. I compared Eriksson's itinerary from Trimen (1891) with Eriksson's bird material for the same months as listed by Lundevall & Ängermark (1989) (Table 4). I also considered the bird chronology of an earlier 1880 journey to many of the same places (Table 5). The list shows minor internal chronological discrepancies (specimens with the same date from different localities, or overlap between date sequences for adjacent localities); therefore I have also indicated the number of specimens involved in each case. The reasoning was that any errors, whether on the original labels or in subsequent transcriptions, would likely affect single specimens only. Numbers of specimens with a consistent locality/date combination were likely accurate. The chronology was then used in placing relevant localities below.

Ovaquenyama and Ombuela

Neither of these is a collecting locality, but Eriksson mentioned them in his itinerary to place other localities. Both are tribal names which refer to the areas inhabited by the tribes at the time, not to actual places. Their extent as mapped in fig. 5 are based on a composite average of the sometimes very different areas depicted in the listed contemporary sources. The Ovakwanyama (modern spelling; also as Ovaquenjama, Cuanhama) live on both sides of the Namibia-Angola border (Bernsmann in Brincker 1896, Tönjes 1911, Nitsche 1913, Loeb 1962 in Dobler 2008: 18), while the Ambwela (also as Ombuel(l)a, Ambuel(l)a, Amboellas) live further north in Central Angola (Serpa Pinto 1881: 317, 358; Sprigade *et al.* 1913). Mendes *et al.* (2013) treated Ombuella as a place and located it in Namibia without further information.

Table 4: Eriksson's 1887 insect collecting chronology as provided to Trimen (1891), compared to his bird specimen dates derived from Lundevall & Ängermark (1989). Number refers to number of bird specimens for each place and date. Anomalous place/date combinations (possible errors of labelling or transcription) in italics.

Date (1887)	Locality	No.	Trimen (1891)
Aug 8, 12	Omrora	3	1-25 Aug: Omrora
Aug 19	*Ehanda*	*1*	
Aug 23, 24	Evari	3	
Sep 10, 16, 18, 20, 21, 30	Ehanda	6	26 Aug – 30 Sep: Ehanda
Oct 10	Ehanda River	1	Oct: Humbe
Nov 15	Evari	1	
Nov 15, 21	Omlola	3	Nov: Omrora again
Dec 10, 12, 13, 14	Otjimbora	5	20 Nov – 3 Dec: Otiembora
Dec 15, 20, 17, 25	Okavango River	4	Dec: Okavango River
			Jan 1888: Omuramba Omatako

Table 5: Eriksson's 1880 bird specimen dates for some of the same areas as in Table 4, derived from Lundevall & Ängermark (1989). Number refers to number of specimens for each place and date. Anomalous place/date combinations (possible errors of labelling or transcription) in italics.

Dates (1880)	Locality	No.
Jun 29, 30; Jul 2, 4, 5	Oquambe	9
Jul 5	*Oquambe*	*1*
Jul 5	Ombanja	5
Jul 6, 8, 9, 10, 11, 12, 16, 18, 19, 20, 21, 22	Ombanja	21
Jul 13, 17, 18, 20, 23, 24	Cunene River	8
Jul 22	*Oquambe*	*1*
Jul 24	*Ombanja*	*1*
Jul 25, 26	Cunene River	10
Jul 26	*Ombanja*	*1*
Jul 27, 28, 29, 30; Aug 1, 2, 4, 6, 7, 9, 10, 11	Cunene River	51
Aug 16, 17	Evari	2
Aug 20	Cunene River	1
Sep 1	Omrora	1
Sep 4	Omrora, Evari	1
Sep 5, 6, 7, 8, 9, 10	Omrora	21
Sep 10	Omaramba, Omrora	1
Sep 12, 13	Omrora	2
Sep 16	Evari	1
Sep 19, 20, 21	Omrora	7
Sep 24	Evari	1
Sep 26, 28, 29, 30; Oct 1	Omrora	13
Oct 2, 5, 7	Evari	8
Oct 9	Omrora	1
Oct 10, 11	Ovaquenjama	2
Oct 14, 16	Oquambe	5

Ehanda

The name *Ehanda* appears marginally on the map of Schinz (1891a), outside the top border. Nitsche (1913) maps *Ehanda* as a tribal area on the Cuvelai River in southern Angola. The latter area fits the statements in Trimen & Bowker (1889), presumably provided by Eriksson himself, that *Ehanda* is 'between Northern *Ovampoland* and *Ombuella*', and in Trimen (1891) that it is 'in the Southern *Ombuela* (or Ambuella) country'. In the same area Sprigade et al. (1913) map Handa as both a regional name and a place, located about 5 km south of the present town of *Cuvelai.* Because their mapped course for the Cuvelai River and its sharp change in direction here is offset by only 1.5 km west and 2 km north of its actual location, I have accepted their mapped coordinates for *Handa* in good faith after applying the same offset. Demasius (2022a) also identified *Ehanda* with *Cuvelai,* but provided coordinates that correspond to *Mupa,* some 50 km further south, instead (Demasius 2022b), while Mendes et al. (2013) stated that *Ehanda* is not in Angola, but in northern Namibia. There is indeed a place called *Ehanda* on modern Namibian maps (SWA 1:50 000 1715Ad Okalongo, 1991), about 50 km west of Oshikango, but it does not appear on maps contemporary with Eriksson, nor does it fit the chronology.

Evari/Evare/Evale

Trimen (1891) does not mention the locality but Péringuey (1900 and later) lists unattributed beetle material from *Ovampoland (Evari River).* It is a known Eriksson bird locality (Rudebeck 1955). *Evale* is a well-known place in southern Angola, located on the Cuvelai River. Contemporary maps (Schinz 1891a, Sprigade et al. 1913) show it as a tribal area centred on the modern town.

Oquambe

Not an insect locality, but included in the 1880 chronology (Table 5) in order to link the start and end of the route to a known place. It is the historical name (Ukuambi, Uukuambi) for *Elim* in Namibia.

Ombanja

Ombanja/Ombandja (also Ombandya) is a tribal area in southern Angola, centred on the mission station of *Cuamato.* It appears on contemporary maps by Schinz (1891a) and Sprigade et al. (1913).

Humbe, Cunene River

Eriksson, in Trimen (1891), calls the locality *Humbe, Cunenè River.* Péringuey calls it either *Ovampoland (Humbe)* or *Ovampoland (Cunene River). Humbe* is a well-known town in southern Angola and about 8 km from the Kunene River.

Omrora, Omrramba, Omaramba and variants

Eriksson (in Trimen 1891) stated that Omrora was 'between *Ovaquenyama* and *Ombuela*'. I have been unable to find *Omrora* or any similar place name on any map of southern Angola or northern Namibia to which I have had access. The sequential chronologies suggest that *Omrora* and *Evari* are proximate localities. In 1887 there are bird specimens for the same day from both Evari and Omrora (as Omlola) (Table 4). They are also recorded alternatively throughout September 1880, and there is one label that has both place names on it (Table 5). The Trimen (1891) itinerary does not mention *Evari,* but the route sequence places *Omrora* both south of *Ehanda,* and east of *Humbe,* which is broadly near *Evari.*

Rudebeck (1955) similarly concluded that *Omrora* must be east of the Kunene River and close to *Evari,* although the probable area he delimited is far from *Evari,* centred on *Ombanja* (fig. 5). Plausible coordinates were provided by Chapin (1954); he mentions his sources as 'the best maps available' without specifying any, but Omrora could not be found on any historical Angolan maps available locally or at Chapin's workplace, the American

Museum of Natural History (Mai Reitmeyer, pers. comm.). Chapin's handwritten card catalogue of localities (Paul Sweet, pers. comm.) confirmed the absence of any cartographic basis for his coordinates. In correspondence with Chapin, Dr Wilhelm Meise of Berlin and Prof. Bernhard Struck of Jena had provided him with two overlapping probable areas for *Omrora,* based on bird labels for collections from 1880 and 1887 respectively. When plotted together (fig. 5) it becomes clear that the *Omrora* coordinates of Chapin (1954) are no more than Meise and Struck's combined areas reduced to a single central point, explaining the lack of the name on maps near that location. Overall, Meise and Struck's areas fit well with all available information, and Chapin's derived coordinates are probably the best possible approximation for the location of *Omrora.*

Demasius (2022a) also used sequential bird localities, but from 1880 only, to place *Omrora* between *Evali* and *Otiembora.* The interpretation hinges on Otiembora material dated 1 September 1880, which was not represented in my dataset (Table 5). It requires Eriksson to have travelled from the Kunene River to Otiembora within ten days, and then back to Evali again within the next 16 days, which is improbable. Referring to Tables 4 and 5, a more plausible explanation would be that the September *Otiembora* material may represent yet another instance of subsequent mistranscription of Eriksson labels. Demasius (2022a: 17,18) delimited an approximate area for his interpretation of *Omrora* (fig. 5), but the coordinates he provided (Demasius 2002b) are located outside this area and are identical to the coordinates for *Otiemboro* given in Trimen & Bowker (1889). Mendes et al. (2013) located Omrora in Namibia without further details. There is no doubt that Omrora is in Angola, but it cannot be more accurately geocoded than 'in the vicinity of *Evale*'.

The majority of Péringuey's locality-specified Eriksson material was published with locality *Omrramba* or *Omrromba,* occasionally rendered as *Omramba* or *Omaromba.* There are no such places to be found on any maps, in fact, *rr* is unknown in many of the possible languages in the area. There is reason to believe that they are all Péringuey transcription errors of Eriksson's *Omrora.* At least one specimen label published as *Omrramba* has been checked and found to be labelled *Omrora* instead, albeit handwritten in ways that are difficult to decipher unless one already knows that *Omrora* is a possibility (fig. 4; pers.

Figure 4: Eriksson 'Omrora' specimen label published by Péringuey (1892) as 'Omrramba'. (Photo courtesy of R. Stals.)

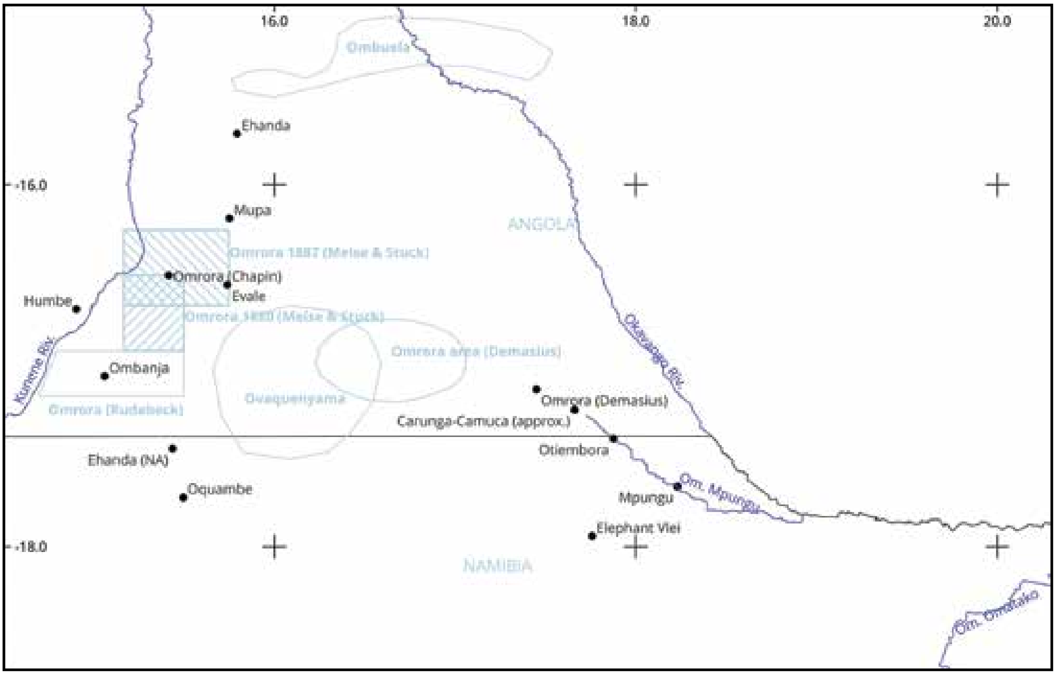

Figure 5: Eriksson and Andersson localities with relevant other places and areas in northern Namibia and southern Angola.

comm., R. Stals, 2023). Trimen (1893) may also have struggled with the handwriting, as witnessed by his *Ourrora.*

Hesse (1925), working on the same collection as Péringuey, lists no *Omrramba* material at all, but many Eriksson specimens with locality *Omaramba.* The word *omuramba* in Namibia denotes a particular type of seasonally dry watercourse; Eriksson would have known that it can make no sense as a label, as he proves when he specifies particular omiramba on other labels. It is highly unlikely that *Omaramba* is an original Eriksson label. It is more likely that Hesse transcribed similar labels to those that Péringuey called *Omrramba,* with the linguistically more plausible Omaramba.

However, *Omaramba* may also have a different explanation, in that there was a river near *Omrora.* Lundevall & Ängermark (1989) document the bird specimen A778, labelled *'Lefver i stora flockar in Omaramba, Omrora',* or, 'lives in large flocks in the Omaramba (note spelling), Omrora'. Trimen & Bowker (1889), who had contact with Eriksson, also stated that *Omrora* was a river. An entry on Chapin's card catalogue indicates that Meise and Struck informed him in 1949 that the meaning of *Omrora, Omlola,* or *Mulola* is what they termed a 'wadi', although the language is not specified. Demasius (2022a) confirms the meaning with additional sources. Against this background, Péringuey and Hesse's *Omrramba/Omaramba* look more like interpretive translations than mistranscriptions. However, I find it difficult to believe that an otherwise conscientious collector like

Eriksson would have used an essentially meaningless geographical description in place of a locality. The collected material is more suggestive of an actual place, and it is significant that he repeatedly spent extended time periods there. Possibly the place had no established name and only Eriksson ever called it *Omrora,* analogous to Andersson's *Elephant Vlei* above.

Whatever the case, it appears that all of these sometimes very different locality names probably refer to the same single place that Eriksson called *Omrora.*

Otiembora

Otiembora is Eriksson's rendering of what contemporary accounts tended to call the Otjimpoloveld, an area located on both sides of the Angola-Namibia border, west of the *Okavango* River, which appears on maps by Schinz (1891), Baum (1903), Tönjes (1911), and Sprigade et al. (1913). It is also spelled Ochimbora, Ochimboro, Ojimbora, Okimboru, Oshimboro, Oshimpolo, Oshimporo, Osthimboro, Otjiborra, Otjimbora, Otjimboro or Otjimpolo.

The Otjimpoloveld was an important elephant hunting ground at the time, and it is usually implied to have been uninhabited and mostly waterless. If Eriksson spent time there (two weeks according to Trimen's 1891 itinerary), and remembering that he travelled by ox wagon, he would have had to be near a dependable water point. The primary, and usually only mapped, water point in the area is the so-called *Otjimpolo* Fountain.

Otjimpolo Fountain has been variously mapped in Namibia, in Angola, or exactly on the border, at locations spanning half a degree of longitude. It is located on the Omuramba *Otjimpolo* which was initially mapped as draining northwards, later draining southwards, and finally as unconnected to anything. The river first appeared on the map by Andersson (in Baines 1866), along a route attributed to Palgrave and Hartley, dated 1864. Langhans (1897) lists Andersson (1866) as the source for Palgrave and Hartley, and I have been unable to locate any independent source for them. There do not appear to have been any repeat surveys and all subsequent maps quoted above were based on this same single source.

Today we know that the only significant watercourses crossing the border anywhere in the relevant area are the upper tributaries of the Omuramba *Mpungu.* They were first correctly mapped in 1954 (Suidwes-Afrika 1:500 000 Blad 3 Okavango 1954) where a water point *Ombongola* is located on a watercourse in a position compatible with Andersson (1866) and successors. I believe this to be the *Otjimpolo* Fountain of mapmakers and the *Otiembora* of Eriksson. It still exists and is visible on recent aerial photographs at the exact location where it was mapped in 1954. It did not appear again on any maps, but the name survived and is still used as a label for the river on current maps (Namibia 1:50 000 1717BD Ombongola, second edition, 2001).

Okavango River

For his 1887 insect specimens, Eriksson specified this locality as the course of the *Okavango* River 'between the tributaries Omaramba-Caronga and Omaramba-Oamatako'. The Omuramba *Omatako* is well-known, but I have not found an Omuramba *Caronga* on any map. Contemporary maps do have a place *Carunga-Camuca* in southern Angola north-west of *Otjimpolo* Fountain and near what we now know are the sources of the Omuramba *Otjimpolo,* while Baum (1903) maps a short tributary of the *Okavango* River, just north of the Namibian border which he calls *Kalonga, od. Maramba von Otjiborra.* Baum's expedition did not visit this place, so we can discount the imaginary location of the Omuramba *Otjimpolo,* but the alternative name for it is of interest. *Kalonga* and *Carunga* are both associated with the Omuramba *Otjimpolo* and both names are virtually the same as *Caronga.* The most straightforward route for Eriksson from *Otiemboro* to the *Okavango* River would have been to follow the Omuramba *Otjimpolo* downstream. It remains an established route to this day, while different stretches of the river still have different names, changing from *Ombongola* to *Mpungu* to *Ekuli.* It seems possible that in Eriksson's time the final stretch of river could have been called *Caronga/Kalonga.* This means that Eriksson's *Okavango* River locality, and what Péringuey calls *Ovampoland (Okovango River)* is that part of the river between the mouths of the Omiramba *Mpungu* and *Omatako,* depicted on fig. 5. Because Eriksson travelled on the south bank, the locality is Namibian.

Rudebeck (1955) mentions an untraced Eriksson locality *Omaramba Carriconna* or *Cerriconna,* which has a vague resemblance to *Caronga.*

Omaramba-Oamatako

Eriksson in Trimen (1891) mentions two localities along the course of the Omuramba *Omatako: between its junction with the Okavango and Otjitoë,* where he collected from 2–14 January 1888, and *between Otjitoë and Omborombongo,* from 15–25 January 1888. The endpoints of the two stretches of river are well-known places, but Trimen does not distinguish them in his text and records both as simply *Omaramba-Oamatako* (January). Neither Péringuey nor Hesse mention the Omuramba *Omatako* nor the places along it at all, which raises suspicion that some of their many *Omaramba* or similar-sounding localities may be misquoted Omuramba *Omatako* material.

Péringuey's *Ovampoland*

Péringuey located all known Eriksson localities in *Ovampoland,* which resulted in their being treated as Namibian ever since, but as noted above most were actually in Angola. He also recorded many specimens from *Ovampoland* without any specific locality and unattributed to any collector. The latter are most likely also Eriksson material, and because it is

Table 6: Cartesian coordinates for relevant Eriksson localities. Mapped in Figure 5.

Locality	Country	Coordinates
Ehanda (taken as Handa on Sprigade et al.'s map, offset relative to course of Cuvelai River)	AO	-15.7175, 15.7943
Evari (as Evale, taken centrally in settlement)	AO	-16.5528, 15.7412
Oquambe, Ukuambi, Uukuambi (as Elim, taken centrally)	NA	-17.7283, 15.4969
Humbe (taken centrally in town)	AO	-16.6866, 14.9052
Omrora (according to Chapin 1954, based on Meise and Struck's combined 1880 / 1887 areas, see fig. 5)	AO	-16.5000, 15.4166
Omrora (according to Rudebeck 1955)	AO	cannot be precisely geocoded, see fig. 5
Omrora (according to Demasius 2002b)	AO	-17.1300, 17.4500
Otiemboro (as Otjimpolo/Ombongola fountain)	NA	-17.4024, 17.8769
Okavango River (between mouths of Mpungu and Omatako omiramba)	NA	cannot be precisely geocoded, see fig. 5
Otjitoë (as Otjituo, taken at historical water point, not at modern town of Otjituuo)	NA	-19.6592, 18.5786
Omborombongo (as Otumborombonga, taken in the course of the Omuramba Omatako at the settlement)	NA	-20.5156, 17.6675

highly unlikely that Eriksson would have used a vague regional name like just *Ovampoland* as a label, the actual labels of the affected specimens may potentially be more informative. The same applies to anything Péringuey or Hesse published from *Omrramba/Omaramba* (e.g. fig. 4). Workers quoting these specimens should be aware that the published localities may not be correct and the only sure way to determine the true locality would be to examine the actual specimen labels.

5. Schinz

Hans Schinz (1858–1941) was a Swiss botanist who collected mainly in Namibia from 1884 to 1886, but also in neighbouring parts of Angola and Botswana, although the latter material has often also been treated as Namibian. Schinz's plant specimens carry detailed locality labels, and since his travelogue (Schinz 1891a) includes a route map that simplifies the geocoding of most of his plants, it is not necessary to treat the majority of his localities here. He also made zoological collections, subsequently published on by at least Boettger (1887) (Reptilia), Mousson (1887) (Mollusca), Simon (1887) (Araneae), Fairmaire (1888) (Coleoptera), Berlese (1889) (Acari), and Noack (1889) (Mammalia). The bulk of Schinz's zoological material, at least in print, was over-simplified to just four uninformative regional names (Gross-Namaland, Hereroland, Amboland, and Kalaχari), while Simon published no localities at all and called the material 'South African' in his title, resulting in later geographical miss-allocation of species. However, the occasional animal specimens that were published with useful locality data on a par with Schinz's plants suggest that at least some of this deficiency may be only in print. As with Eriksson, one hopes that actual labels might carry more information.

Angolan localities

Between 10 and 30 September 1885 Schinz travelled from *Olukonda* in Namibia, where he was based, to *Humbe* in Angola and back. Any Schinz material referring to the *Kunene* River is Angolan; he did not access the river anywhere in Namibia, and the Namibian coordinates that he provides for some *Kunene* material (e.g. Schinz 1891b: 52) are simply wrong. His only Angolan collecting localities are *Ombandja* (rarely as Ombandja onene), *Onkumbi,* and *Kilevi.* Because he specified *Amboland* for all, they have been widely treated as Namibian. All other Schinz *Amboland* localities are indeed Namibian.

Botswanan localities

From April to July 1886 Schinz travelled from *Grootfontein* in northern Namibia east to Lake *Ngami* in Botswana, and then south and west to *Gobabis* in Namibia. Schinz designated most collections along this route as *Kalaχari,* and they have generally since been treated as Namibian. Localities on or relevant to the Botswanan leg of his journey have been geocoded below, regardless of whether or not I have been able to trace references to specimens from those localities. The work of Passarge (1904) was particularly useful in this regard.

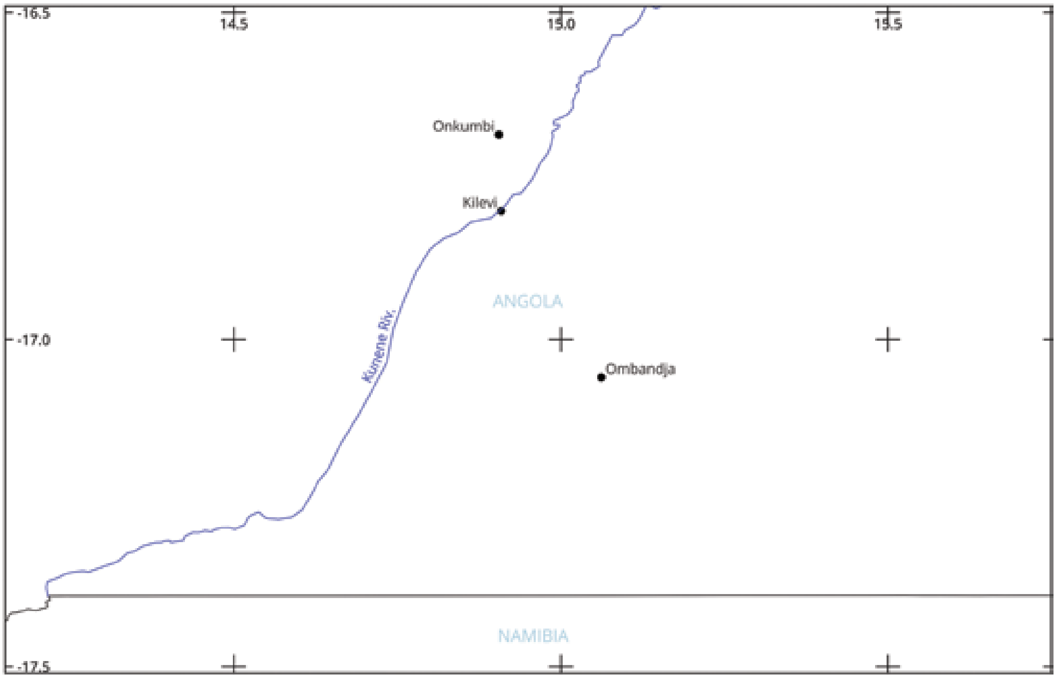

Figure 6: Schinz 'Kunene' and other localities in southern Angola.

I have followed Passarge's location for *Lewisfontein* here because it fits better with Schinz's travelogue and map, and the purpose here is to geocode the places where Schinz collected. Another interpretation of *Lewisfontein* places it much further north and in Botswana (Wilmsen 2003).

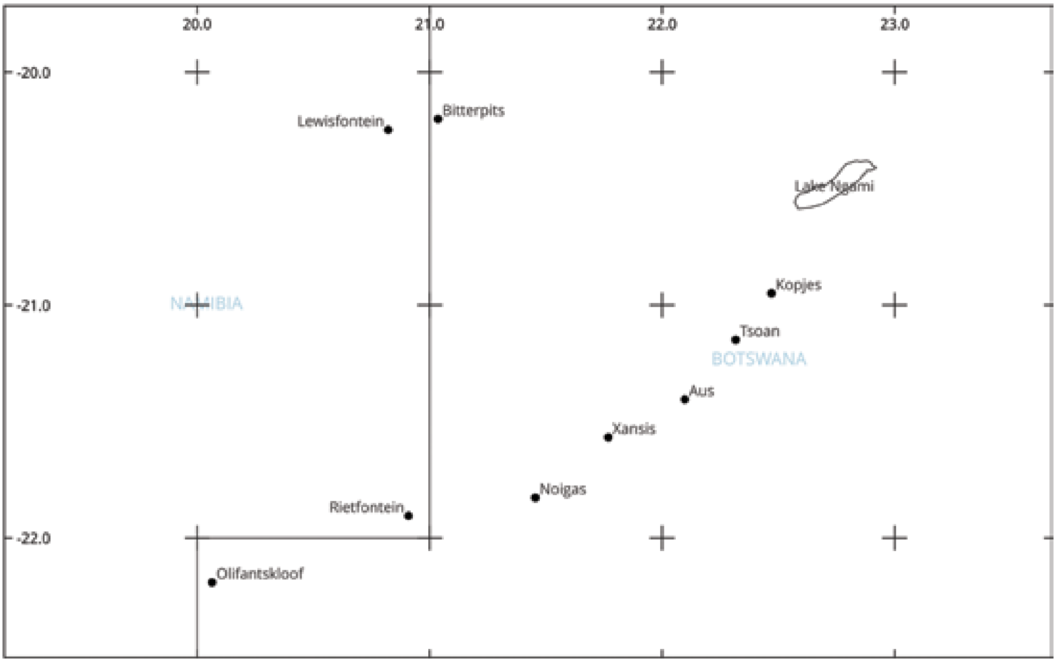

Figure 7: Schinz 'Kalaχari' localities and relevant other places in western Botswana and adjacent Namibia

Table 7: Cartesian coordinates for relevant Schinz localities. Mapped in Figures 6 and 7.

Locality	Country	Coordinates
Ombandja (taken as Cuamato mission station)	AO	-17.0577, 15.0619
Onkumbi (= Humbe, as in Table 6, above)	AO	-16.6866, 14.9052
Kilevi (as Kilavi on Kiepert (1893b : Blatt 3), with map coordinates offset relative to known locations Humbe and Xangongo)	AO	-16.8032, 14.9088
Lewisfontein (as Gam; according to Passarge, 1904)	NA	-20.2472, 20.8211
Bitterpits (as Kumganni, Passarge 1904)	BW	-20.2004, 21.0358
Kopjes (as Mabeleapodi Hills, western end)	BW	-20.9491, 22.4698
Tsoan (as Tscho-in, Passarge 1904)	BW	-21.1488, 22.3160
Aus/Kamelpan	BW	see Wahlberg above
Xansis (as Chanse, Passarge 1904)	BW	-21.5677, 21.7681
Noigas/Noixas/|Noi xas (as Nucha, Passarge 1904)	BW	-21.8269, 21.4543
Rietfontein/Tunobis	NA	-21.9050, 20.9091
Olifantskloof	BW	-22.1910, 20.0640

6. Lüderitz

Franz Adolf Eduard Lüderitz (1834–1886) was a German merchant who collected a modest number of biological specimens in Namibia in the early 1880s. His localities are vague regional designations like *Hereroland* or *Kaoko.* Subsequent workers were prone to misinterpret the collector's surname as being the town of *Lüderitz* in southern Namibia, resulting in some strange distribution records. The confusion may be avoided by considering the context and date of each record. While Adolf Lüderitz was alive, there was no town named *Lüderitz;* it was known as *Angra Pequena.* When it was renamed in his honour after 1886, its name became *Lüderitzbucht.* The name *Lüderitz* (without the *-bucht*) first appears on British maps from 1930 onwards (Irish, unpublished map indices).

7. Schultze

Leonhard Schultze (1872–1955) was a German anthropologist who conducted a study tour to southern Africa between 1903 and 1905 (Schultze 1907). His biological material was published in volumes 13, 14, 16, and 17 (1908–1912) of the *Denkschriften der Medicinisch-Naturwissenschaftlichen Gesellschaft zu Jena.* He collected in Namibia, the northern Cape Province of South Africa and southern Botswana, but subsequent workers have often listed his Namibian material as South African, while they were also prone to

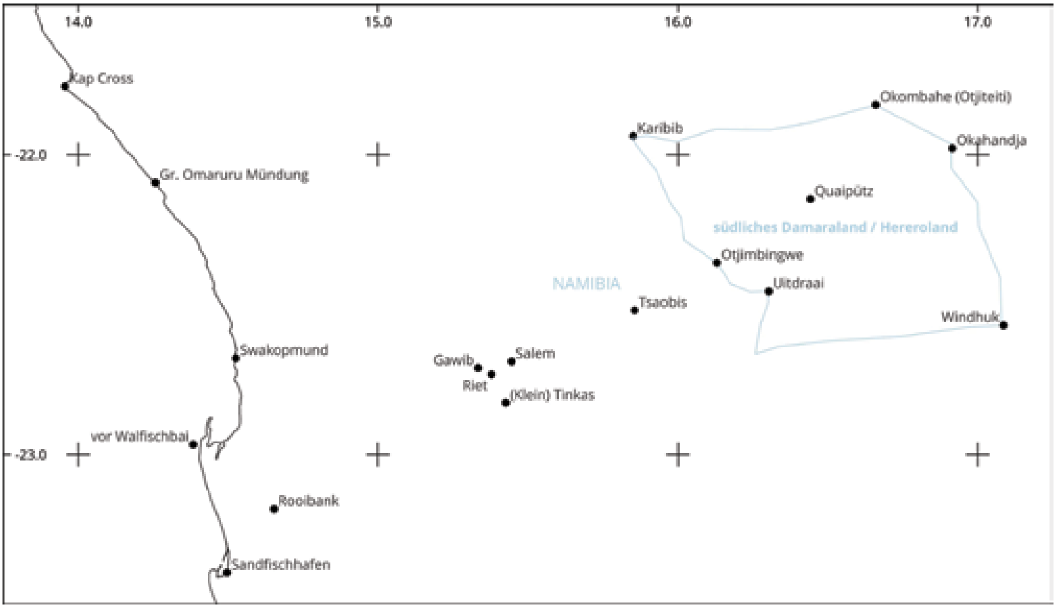

Figure 8: Schultze localities and other relevant places in west-central Namibia; 'südliches Damaraland / Hereroland' depicts the area where Schultze was active during September and October 1903, corresponding to dates on labels with this locality.

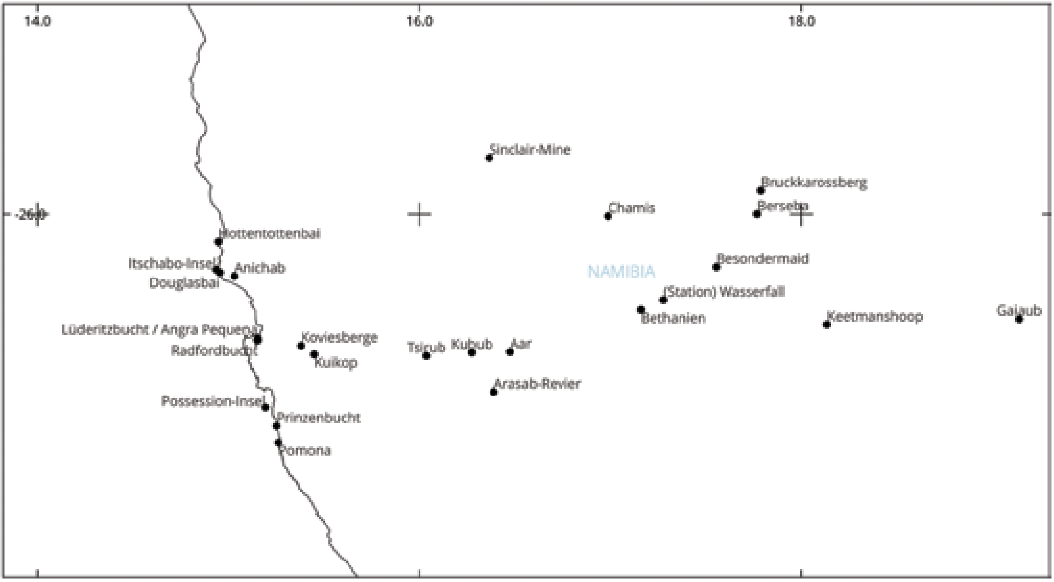

Figure 9: Schultze localities in southern Namibia.

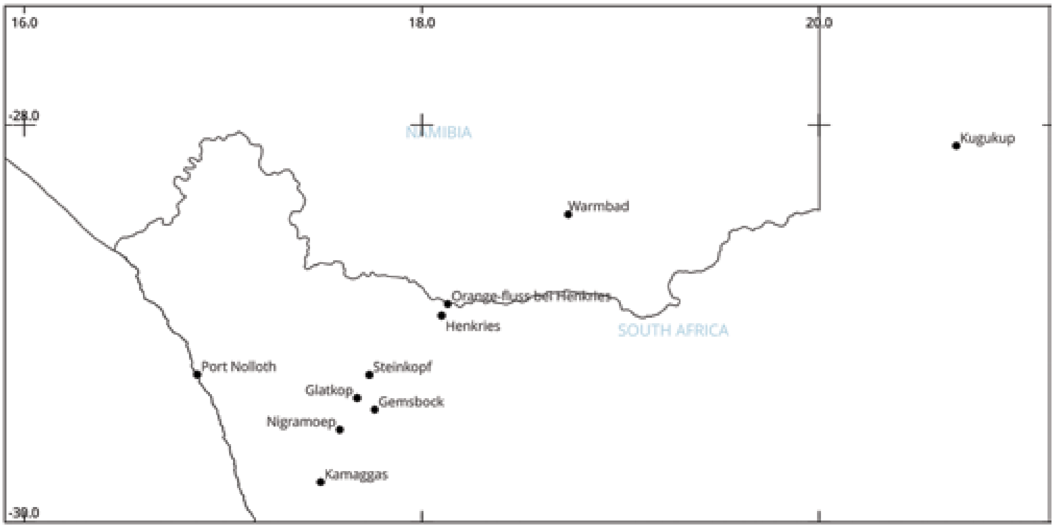

Figure 10: Schultze localities in northwestern South Africa and adjacent Namibia.

listing both his Botswanan material and material from north-western South Africa (under the name of 'British South West Africa'), as Namibian. Haddad & Marusik (2019) previously clarified Schultze locations for two spider papers. Below, the published localities from all papers in all four volumes of Schultze's results have been considered and geocoded at the most likely collecting locations, based on his travelogue and the included map, and cross-referenced with available contemporary and modern maps. For Botswana, the first edition of the 1:250 000 series, as indexed by Irish (1988), proved particularly useful. Schultze did not survey his route and plotted it afterwards on a pre-existing map of southern Africa; he also mapped only his main route and excluded many side excursions, e.g. his visits to Aar, Arasab, or Sinclair Mine from Kubub are not mapped.

Whenever Schultze collected en route between two named places, his labels consist of the two place names separated by a hyphen, e.g. *Severelela-Kooa.* In print, most workers repeated this verbatim, but some interpreted it (to use the same example), as *zwischen Severelela und Kooa,* while others rendered the same as *Severelela and Kooa,* or *Severelela, Kooa* or *Severelela Kooa.* The latter cases can be ambiguous as to whether an 'en route' locality or two separate localities are intended. They may be resolved by considering the number of specimens (a single specimen cannot come from two places), considering the proximity of the locations, and looking at how other, unambiguous 'en route' locations are handled in the same work. 'En route' localities cannot be precisely geocoded and only their endpoints were treated below. Regional appellations (Damaraland, Kalahari, etc.) were stripped from localities, and spelling variants and lapses (by subsequent workers) are noted.

Especially Schultze's Botswanan localities with similar names have been confused in the past: *Kanya* and *Kanyane* are different places, as are *Katsane* and *Kwatsane, Moshaneng* and *Matshaneng.*

Many workers who treated Schultze's material opportunistically included locality records from other collectors as well, recognisable by the collectors' names or their location far from Schultze's routes; these localities have not been considered here, nor have Schultze's collections from Cape Town and vicinity been included. One Schultze locality needs some discussion:

Ku-Gudië

The locality names *Ku-Gudië* and variants appear on specimen labels, some of which state it to be between Kooa and Phitshane; the place is not mentioned in Schultze's travelogue. In the latter (page 571-2), daily weather observations are provided for the *Kooa-Phitshane* route; day one is labelled *between Kooa and Phitshane;* day two: *Kgogoye (Wasserstelle im Rivier)* (= water point in riverbed); day three: *between Kgogoye and Phitshane;* and day four: *before Phitshane.* There are no specimens with label *Kgogoye. Ku-Gudië* and *Kgogoye* are phonetically similar, and their mutual exclusivity, despite both being on the *Kooa-Phitshane* route, suggests that they could be the same. They may respectively represent a field label using German orthography and a later linguistically improved version of the same name for print purposes, using Setswana orthography.

I have been unable to find either *Ku-Gudië* or *Kgogoye* on maps or anywhere other than in Schultze context. Assuming a relatively straight route from *Kooa* to *Phitshane,* as suggested by Schultze's map, and knowing that *Kgogoye* is on a watercourse, there are

Figure 11: Schultze localities in central Botswana. Southeastern corner of map overlaps with Figure 12.

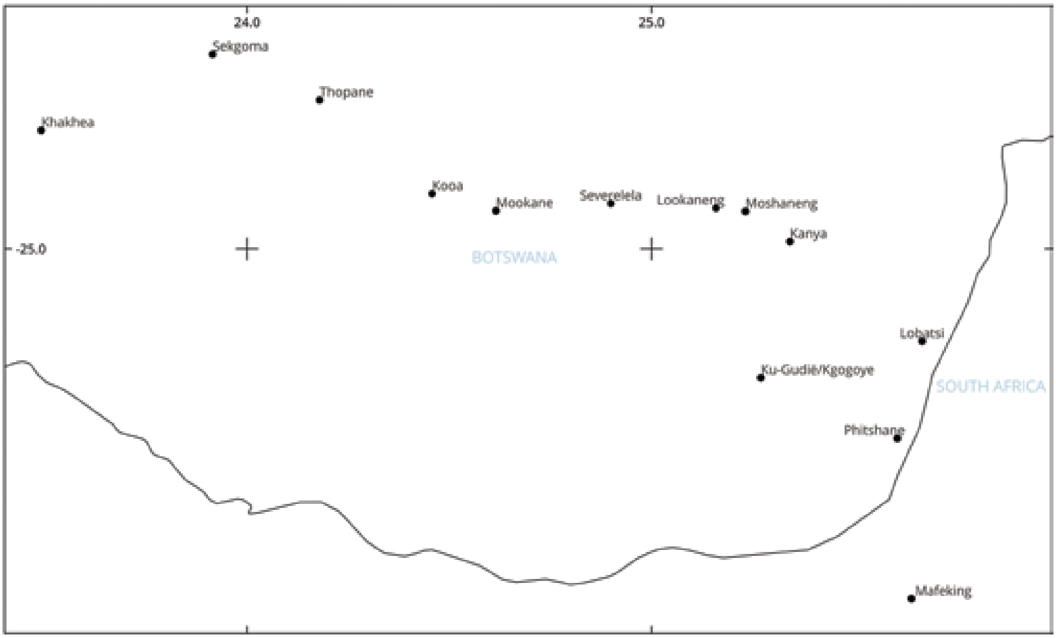

Figure 12: Schultze localities southeastern Botswana and adjacent South Africa. Northwestern corner of map overlaps with Figure 11.

Table 8: Cartesian coordinates for relevant Schultze localities. Mapped in Figures 8–12.

Locality	**Country**	**Coordinates**
Aar, Aar-Revier, Aar bei Kubub, also Aaar in error (taken at historical water point)	NA	-26.7200, 16.4737
Angra Pequena (as Lüderitz, taken at historical town centre)	NA	-26.6474, 15.1536
Anichab (taken at historical water point)	NA	-26.3242, 15.0315
Arasab Revier, bei Kubub, also Arsab Rivier in error (taken at closest point on watercourse to Kubub)	NA	-26.9308, 16.3887
Berseba (taken centrally in town)	NA	-25.9994, 17.7677
Besondermaid (because Schultze calls it a *Wasserstelle*, taken at the historical water point, which lies outside cadastral unit Besondermaid 5)	NA	-26.2762, 17.5544
Bethanien (taken centrally in town)	NA	-26.5003, 17.1602
Chamis (*nördlich von Bethanien am Koankip*, taken at historical water point)	NA	-26.0101, 16.9876
Douglasbai (as Douglas Bay, taken centrally on beach)	NA	-26.3046, 14.9550
Gaiaub (as Gross Aub, taken at historical water point)	NA	-26.5476, 19.1399
Gawib, Gawieb (taken at location of historical water point)	NA	-22.7117, 15.3336
Groß-Bruckkarroßberg, Brukkarossberg (taken at southern entrance to crater, after photo in Schultze 1907: 139)	NA	-25.8762, 17.7870
Gr. Omaruru Mündung (as Omaruru River Mouth, taken centrally in main channel)	NA	-22.0935, 14.2570
Hottentottenbai (as Hottentot Bay, taken on beach centrally in bay)	NA	-26.1445, 14.9486
Itschabo Insel (as Ichaboe Island, taken centrally)	NA	-26.2891, 14.9365
Kap Cross, Cap Kross (as Cape Cross)	NA	-21.7725, 13.9557
Keetmanshoop, also Ketmanshoop in error (taken at historical town centre)	NA	-26.5771, 18.1333
Kovisberge, Koviesberge (as Kowisberge, taken at southern end next to Schultze's route as per his map)	NA	-26.6876, 15.3803
Kuikop (taken at summit)	NA	-26.7334, 15.4494
Kubub, Gubub (taken at historical location)	NA	-26.7230, 16.2755
Lüderitzbucht, Lüderitzbai, also Lüderitzburg in error (= Angra Pequena, both names are used interchangeably by Schultze)		
Okahandja (taken at historical town centre)	NA	-21.9788, 16.9153
Okombahe (Otjiteiti) unweit Okahandja (taken at centre of cadastral unit Okombahe 16)	NA	-21.8336, 16.6600
Otjimbingwe (taken at historical town centre)	NA	-22.3605, 16.1299
Pomona (taken on mainland adjacent to Pomona Island, based on description in Schultze 1907)	NA	-27.1943, 15.2615
Possession-Insel (taken at historical landing point)	NA	-27.0101, 15.1940
Prinzenbucht, Prinzenbai, Prince of Wales Bay (taken on beach centrally in bay as it existed before destructive mining)	NA	-27.1081, 15.2523
Quaipütz (former location, based on Südwestafrika 1:200 000 Blatt 13 Khomas Hochland 1918)	NA	-22.1480, 16.4421
Radfordbucht, Radford Bay, also Redford Bay in error (taken centrally on shore)	NA	-26.6593, 15.1548
Riet (taken at ruins of historical homestead)	NA	-22.7326, 15.3785
Rooibank (taken at approximate location of former water point, which was flowing in Schultze's time)	NA	-23.1814, 14.6527
Salem (taken at ruins of historical homestead)	NA	-22.6897, 15.4446
Sandfischhafen (as Sandwich Harbour, taken at former location of historical settlement)	NA	-23.3935, 14.4956
Sinclair-Mine (taken at historical location)	NA	-25.7055, 16.3661
südliches Damaraland / Hereroland (September and October 1903; mapped route = Otjimbingwe – Windhoek – Okahandja – Karibib - Otjimbingwe)	NA	cannot be accurately geocoded, see fig. 8
Swakopmund (taken in historical town centre)	NA	-22.6790, 14.5251

Locality	Country	Coordinates
Tinkas (taken at Klein Tinkas, as per Schultze’s map)	NA	-22.8273, 15.4254
Tsaobis (taken at historical water point)	NA	-22.5192, 15.8554
Tsirub, also Tsibub in error (approximate location; was a rain-dependent seasonal settlement area rather than a fixed place)	NA	-26.7408, 16.0375
Uitdraai (as per map of Baines (1864), and Schultze’s route)	NA	-22.4557, 16.3028
vor Walfischbai (locality at sea; Schultze’s own coordinates)	NA	-22.9667, 14.3833
Warmbad (as current town, taken at historical water point)	NA	-28.4497, 18.7361
(Station) Wasserfall (as cadastral unit Wasserfall 64, taken where historic route breaches the escarpment, at the approximate location of the photo in Schultze 1907: 149)	NA	-26.4484, 17.2778
Windhuk, Gr. Windhuk (as Windhoek, taken at historical town centre)	NA	-22.5692, 17.0859
Gemsbock bei Steinkopf (as Gemsbok: South Africa 1:250 000 sheet 2916 Springbok 1974)	ZA	-29.4321, 17.7620
Glatkop (as Gladkop, same source as above)	ZA	-29.3735, 17.6733
Henkries (taken centrally in settlement)	ZA	-28.9588, 18.0990
Kamaggas (as Komaggas, taken at historical town centre)	ZA	-29.7968, 17.4899
Kugukup (as Koegoekoep, from Schultze’s map)	ZA	-28.1044, 20.6890
Mafeking, also Mafking in error (as Mahikeng, taken at city centre)	ZA	-25.8642, 25.6426
Nigramoop (as Nigramoep, taken centrally in settlement area)	ZA	-29.5327, 17.5857
Nobob (not traced, near Steinkopf)	ZA	
Orange-Fluß bei Henkries (taken on south bank of Orange River, north of Henkries)	ZA	-28.9006, 18.1294
Port Nolloth (taken in historical town centre)	ZA	-29.2551, 16.8689
Steinkopf, also Steinkopff in error (taken at historical town centre)	ZA	-29.2567, 17.7350
Bonche, also Bonce in error (name not traced; based on its position relative to Mahuratlake and Kang Noa, modern Mahuditlhake and Kangwa Pans, this is the unnamed pan at the given coordinates)	BW	-24.1880, 22.4825
Chakamakuë (name not traced; based on its position relative to Letlake and Diphofu, this is likely the Tshawe Pan of modern maps; taken centrally)	BW	-23.9315, 22.0533
Diphofu (as Dimpho Pan, taken centrally)	BW	-23.9085, 21.9345
Kang, also Kong in error (as Kang Pan, taken centrally)	BW	-23.7023, 22.7973
Kanya, also Konya, Konyo in error (as Kanye, taken at modern town centre)	BW	-24.9821, 25.3420
Kanyane (as Kangnyane Pan, taken centrally)	BW	-23.8699, 22.1427
Katsane, Kotsane, also Kotsare in error (as for Bonche above)	BW	-24.1936, 22.5226
Khakhea, also Kakir in error (as Khakhea Pan, taken centrally)	BW	-24.7072, 23.4908
Kooa, Sekuaa, also Koos in error (as Kue Pan, taken centrally)	BW	-24.8638, 24.4575
Kgokong, Kokong (as Kokong Pan, taken centrally)	BW	-24.3568, 23.1021
Ku-Gudië, Ku Gudie, Ku-Gu-Di, Ku-Gui-Di, Kugudie, Kgogoye (taken at river crossing at Mmathethe, see above)	BW	-25.3185, 25.2700
Kwatsane (not traced, coordinates calculated, based on offset from Kang and Letlake, then centred on nearby large pan)	BW	-23.8105, 22.5819
Letlake, also Leclake in error (as Lotlhake Pan, taken centrally)	BW	-23.7966, 22.3337
Lehututu, also Lekututu in error (as Lehututu Pan, taken centrally)	BW	-23.9370, 21.8407
Lobatsi (as Lobatse, taken at historical town centre)	BW	-25.2284, 25.6692
Lookaneng (not traced; coordinates calculated at 7.5 km west of Moshaneng, based on Schultze’s map)	BW	-24.8994, 25.1595
Mookane, also Moocane (taken at historical water point: spring on Mookane Pan)	BW	-24.9061, 24.6152
Moshaneng, also Mashoning in error (taken at modern town centre)	BW	-24.9074, 25.2322
Matshaneng (as Matshaneng Pan, taken centrally)	BW	-24.0059, 22.2912
Phitshane, Phitsane, Pitsani, Phetsane (as Pitsane Pan, taken centrally)	BW	-25.4682, 25.6078
nördlich von Phitshane (= Ku-Gudië/Kgogoye, see above)		
Sekgoma, Sekuma, also Segkoma in error (as Sekoma Pan, taken at water point)	BW	-24.5195, 23.9145
Severelela (as Seherelela Pan, taken centrally)	BW	-24.8881, 24.8996
Thopane, Tepane, Vleij/Vlej Topani, Topan (as Tobane Pan, taken centrally)	BW	-24.6325, 24.1790

only two possibilities: the Selakolela River, crossed near *Gasita,* and the Moselebe River, crossed near *Mmathethe.* The route stages as suggested by the weather observations are too broad to allow us to choose one or the other river. However, there are also many specimens with the imprecise locality *nördlich von Phitshane* (= north of Phitshane), which in one case (Silvestri 1908) is specified as *circa 20 miglia a nord di Phitshane* (= about 20 miles north of Phitshane). Interpreted literally, twenty miles due north of *Pitsane* is already north of *Lobatsi,* which would make it incompatible with Schultze's route, but if one interprets it as *20 miles away from Phitshane on the route from Kooa, which is north of Phitshane,* the resultant location is virtually at *Mmathethe.* On balance of probabilities, I have considered all these locations to be different versions of the same, and geocoded them at the river crossing at *Mmathethe.*

8. South African Museum expeditions

Between 1916 and 1927 the then South African Museum, now Iziko Museum, of Cape Town, partly in collaboration with the Geological Survey of South Africa, undertook several collecting expeditions to Namibia, as summarised by Connolly (1931: 278).

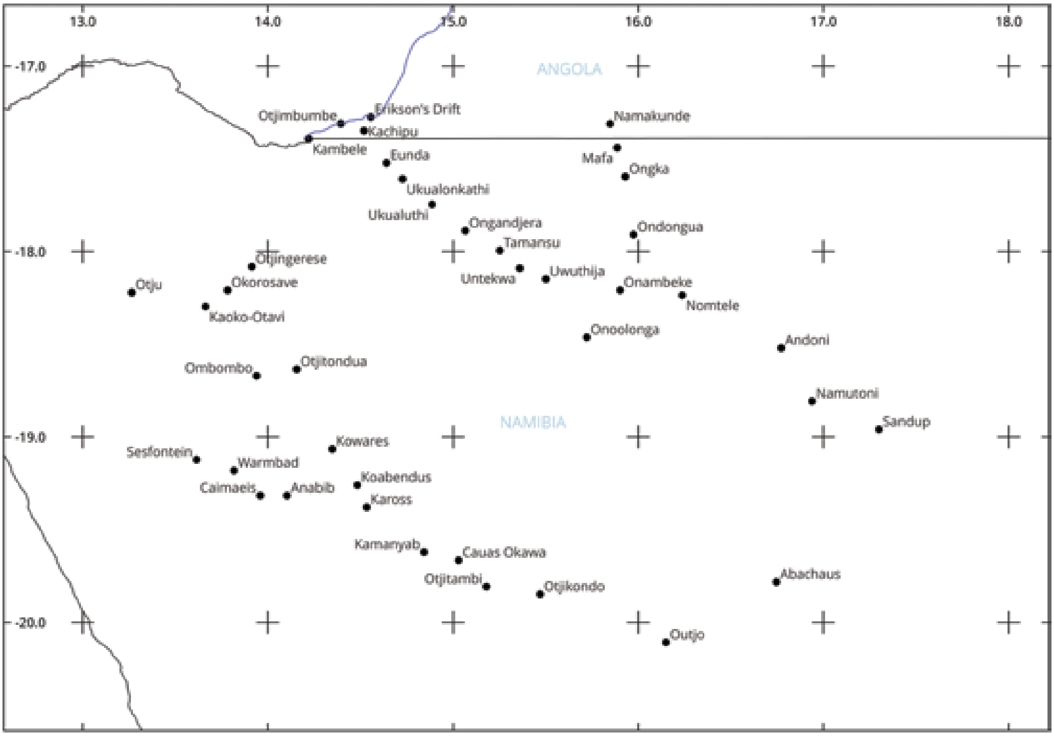

Figure 13: South African Museum expedition localities in northern Namibia and adjacent Angola, plus one Hobohm locality.

Table 9: Cartesian coordinates for selected (see text) South African Museum expedition localities. Mapped in Figure 13.

Locality	Country	Coordinates
Anabib (taken at water point; not the same place as the Swedish Expedition *Anabib*, Table 10, below)	NA	-19.3162, 14.1031
Andoni (taken at water point)	NA	-18.5201, 16.7721
Caimaeis, Camaeis, Gaimaiais (taken at the origin of the easternmost resurgence in Khowarib Schlucht; collecting site may have been anywhere along the ca. 8 km downstream extent)	NA	-19.3160, 13.9585
Cauas Okawa (as cadastral unit Cauas-Okawa 30, taken centrally)	NA	-19.6646, 15.0295
Erikson's Drift (submerged by Calueque Dam; taken at approximate location relative to Etaka confluence)	AO	-17.2745, 14.5559
Eunda (taken centrally in area)	NA	-17.5224, 14.6397
Great Falls (= Kambele Falls, Ruacana Falls; see below)		
Hoarusib River, Hoarusib W of Kaoko Otavi, Hoarusib (Otshu)		see Otju below
Kachipu (Kashipu, Gachibu of maps; taken at average mapped position of 9 km SSW of Erikson's Drift; near but not on Kunene River, despite some labels suggesting latter)	AO	-17.3486, 14.5197
Kalkfontein, or Kalkfontein South (the contemporary name for Karasburg; taken centrally)	NA	-28.0170, 18.7484
Kamanyab (as Kamanjab, taken centrally)	NA	-19.6209, 14.8434
Kambele, Kambele Falls (as Ruacana Falls, taken at modern viewpoint; exact collecting site unknown)	NA	-17.3924, 14.2196
Kaoko Otavi (taken at water point)	NA	-18.2970, 13.6636
Kaross (taken at historical water point)	NA	-19.3785, 14.5338
Koabendus, Choabendus (as Otjovasandu, taken at approximate position of former historical water point)	NA	-19.2594, 14.4830
Kowares (taken at historical water point)	NA	-19.0651, 14.3476
Kunene River, Cunene: see Erikson's Drift, Kambele Falls, Otjimbumbi, Kachipu (localities that state only 'Kunene River' may be any of the former, they are mostly in Angola, up to 40 km upstream from the Namibian border)		
Mafa (as Omafo, taken centrally)	NA	-17.4403, 15.8861
Namakunde (as Namacunde, taken centrally)	AO	-17.3115, 15.8474
Namutoni (taken at water point)	NA	-18.8072, 16.9387
Nomtele (as Omuntele, taken centrally in settlement)	NA	-18.2355, 16.2371
Okorosave, Okorosawe (taken at water point)	NA	-18.2088, 13.7818
Ombombo (taken at historical water point)	NA	-18.6703, 13.9387
Onambeke (based on 1:50 000 sheet 1815Bb Uukwiyu 1975, taken at Ekuma crossing)	NA	-18.2085, 15.9023
Ondongua (as Ondangwa, taken centrally)	NA	-17.9091, 15.9745
Ongandjera (as Okahao, former Ongandjera, former Rehoboth, taken centrally)	NA	-17.8879, 15.0661
Ongka, Oncka, Onka (as Ongha, taken centrally in settlement area)	NA	-17.5962, 15.9303
Onoolonga, Onolongo (unnamed on modern maps, placement based on: Suidwesafrika 1:500 000 Ovamboland 1963)	NA	-18.4629, 15.7222
Otjikondo (taken centrally)	NA	-19.8479, 15.4698
Otjimbumbe, Otjimbombe (Tschombumbi, Otshombumbi of maps; position topographically determined relative to adjacent hills)	AO	-17.3104, 14.3942
Otjingerese, Otjijerese (taken at water point)	NA	-18.0812, 13.9134
Otjitambi (taken at historical water point)	NA	-19.8070, 15.1794
Otjitondua (as Otjitunduwa, taken at historical water point)	NA	-18.6350, 14.1554
Otju, Otshu (as Otjiu, taken at resurgence; collecting site may have been anywhere along the ca. 5 km downstream extent)	NA	-18.2212, 13.2648
Outjo (taken centrally in town)	NA	-20.1076, 16.1502

Locality	Country	Coordinates
Sandup (as Sandhup Pan, taken centrally)	NA	-18.9595, 17.3003
Sesfontein, Zesfontein (taken in historical centre)	NA	-19.1228, 13.6141
Tamansu (as Otamanzi, taken centrally in settlement)	NA	-17.9947, 15.2528
Ukualonkathi, Ukualonkanthi (as Okorongasi, taken centrally in area)	NA	-17.6096, 14.7272
Ukualuthi (as Tsandi, taken centrally)	NA	-17.7468, 14.8865
Untekwa near Tamansu (as Omutekua, taken centrally)	NA	-18.0901, 15.3601
Uwuthija, Uwuthya (as Uuvidhiya, taken centrally)	NA	-18.1486, 15.5008
Warmbad (as Warmquelle, taken at water point; not the same place as the town in southern Namibia)	NA	-19.1813, 13.8166

Zoological, mainly arthropod, results were published in nine parts under a common heading in volumes 20, 23, 25, and 29 of the *Annals of the South African Museum* (1924–1931), with a single botanical contribution in volume 16 (1925). All published collecting localities from all ten contributions have been considered here. The majority are well-known places and are still known by the same names today, and with a few exceptions, have not been included below. All localities from the 1921 and 1923 Ovamboland expeditions, and the 1925 Kaokoveld expedition, have however been treated below. They introduced some sources of confusion, including the similar names *Otju* and *Outjo,* different places with the same names *(Anabib, Warmbad),* and yet more Namibian-Angolan ambiguity. The expedition route map included in Lawrence (1928: 218) provides an overview. Additionally, maps 'Deutsch-Südwestafrika, Vorläufige Ausgabe, Blatt 3 Rehoboth (Amboland) 1912', Sprigade et al. (1913), 'Travellers' Map of Kaokoveld, C.N. Manning 1923' and 'Suidwesafrika 1:500 000 Ovamboland 1963' were especially useful.

9. Swedish South Africa Expedition

The Lund University Museum of Sweden collected much material mainly in South Africa in 1950 and 1951, and also made one short visit to Namibia. Their results were published in 15 volumes between 1955 and 1973 as *South African Animal Life.* The material is well-labelled, and there is a list of localities (Brinck & Rudebeck 1955) with maps, but no coordinates. The latter are provided below for Namibian localities, excepting those that refer to large towns under names still in use. Distances were measured along routes in use at the time.

Along the route between *Orupembe* and *Rocky Point* localities were denoted by distance from *Orupembe.* On the return journey the first locality (number 337) was denoted by distances from both *Orupembe* (35 miles) and *Rocky Point* (26 miles). Measuring from both places resulted in two localities 5.5 miles apart. Site 337 was therefore geocoded halfway between these two endpoints. The next site chronologically (338) was denoted as *30-32 miles S Orupembe.* I decided to geocode this at 31 miles (halfway between 30 and 32); however, since they wrongly believed they were 35 miles south of *Orupembe* at site 337, I geocoded site 338 at 4 miles north of site 337, rather than at actual 31 miles south of Orupembe. This fits best with their map, which places site 337 much closer to 338 than to 332 *(30 miles S Orupembe).*

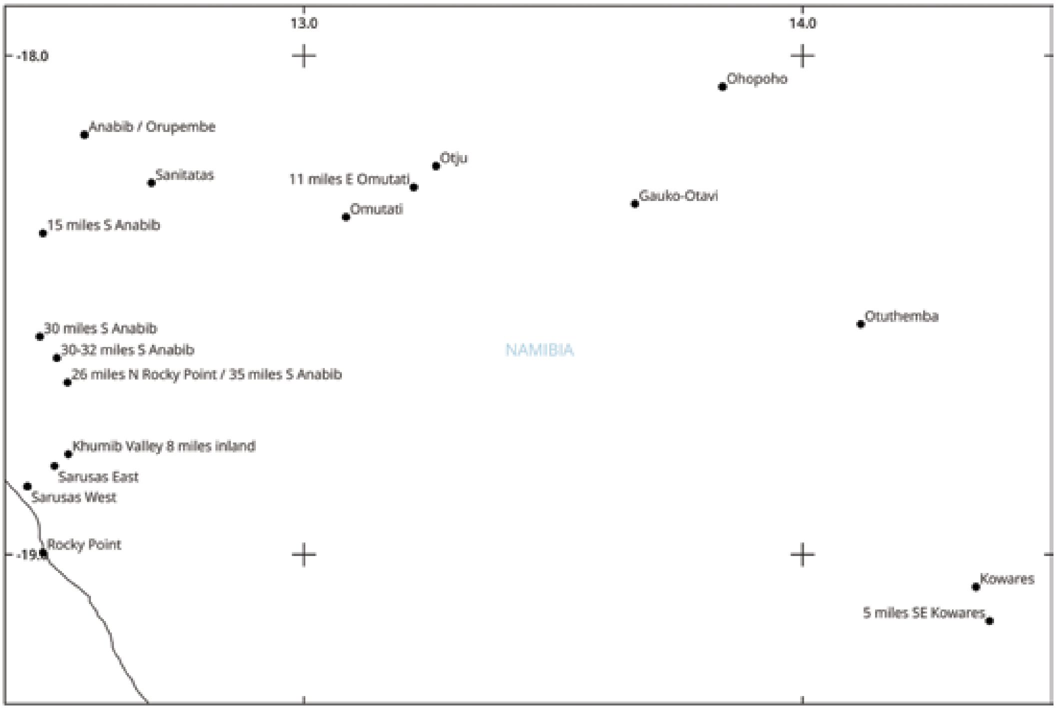

Figure 14: Swedish South Africa Expedition localities in north-western Namibia

Table 10: Cartesian coordinates all Namibian Swedish South Africa Expedition localities. The numbers are the expedition's locality numbers. Mapped in Figure 14 (only northwestern Namibia),

No.	Locality	Country	Coordinates
330, 339	Anabib (Orupembe), about 100 miles W Ohopoho (taken at former site of natural water point)	NA	-18.1585, 12.5597
331	15 miles S Anabib (Orupembe), about 100 miles WSW Ohopoho (measured along route)	NA	-18.3561, 12.4765
332	30 miles S Anabib (Orupembe) about 110 miles WSW Ohopoho (measured along route)	NA	-18.5631, 12.4702
338	30-32 miles S Anabib (Orupembe), about 110 miles SSW Ohopoho (taken at 4 miles north of locality 337)	NA	-18.6061, 12.5042
337	35 miles S Anabib (Orupembe), about 26 miles N Rocky Point (taken halfway between measured distances)	NA	-18.6552, 12.5257
326	Gauko-Otavi (Kaoko-Otavi), 20 miles SSW Ohopoho (taken at water point)	NA	-18.2970, 13.6636
321	Kamanjab, 100 miles NW Outjo (taken centrally)	NA	-19.6209, 14.8434
333	Khumib Valley 8 miles inland, about 110 miles SW Ohopoho (taken in Khumib riverbed, 2.5 miles upstream of locality 336)	NA	-18.7989, 12.5273
323	Kowares, 90 miles SE Ohopoho (taken at historical water point)	NA	-19.0652, 14.3476

No.	Locality	Country	Coordinates
322	5 miles SE Kowares, 90 miles SE Ohopoho (taken along road)	NA	-19.1332, 14.3746
316	30 miles S Marienthal (as Mariental, taken along road, measured from centre)	NA	-25.0519, 17.8851
325	Ohopoho (as Opuwo, taken in historical centre)	NA	-18.0622, 13.8399
324	Otuthemba, 40 miles SE Ohopoho (as Otuzemba, taken at water point)	NA	-18.5383, 14.1164
318	40 miles N Okahandja (taken along road, measured from centre)	NA	-21.4131, 16.8452
329	Omutati, 70 miles WSW Ohopoho (as Okomutati, taken at water point)	NA	-18.3236, 13.0842
328	11 miles E Omutati, 60 miles WSW Ohopoho (taken by road starting from river crossing at Okomutati)	NA	-18.2637, 13.2200
319	20 miles S Otjiwarongo (taken along road, measured from centre)	NA	-20.7127, 16.7920
327	Otju, 45 miles WSW Ohopoho (as Otjiu, taken at water point)	NA	-18.2212, 13.2648
340	Sanitatas, about 85 miles WSW Ohopoho (taken at water point)	NA	-18.2550, 12.6941
335	Rocky Point, 10 miles S Sarusas West (taken at point)	NA	-18.9964, 12.4764
337	26 miles N Rocky Point (= 35 miles S Anabib, see above)		
336	Khumib Valley, Sarusas East, 5.5 miles inland (taken at water point)	NA	-18.8226, 12.4997
334	Khumib Valley, Sarusas West, 1.5 mile inland (taken at water point)	NA	-18.8637, 12.4452

10. Hobohm

Gerd Hobohm (1900–1991) was a Namibian farmer and amateur entomologist. Virtually all his specimens were collected on his farm *Abachaus* and the bulk of his material is in the Ditsong Museum, South Africa. *Abachaus* has proved elusive since no farm by that name appears on any current or former Namibian maps. An *Abachaus* Mountain may be found on maps as far back as 'German S.W. Africa Sheet 11 Otawi 1914', but it is misspelled *Abaehausberg* on all modern official maps (e.g. 'Namibia 1:250 000 sheet 1916 Tsumeb, 3rd edition 2002'). Different text descriptions of the location (e.g. 160 miles N of Windhoek) and purported coordinates for *Abachaus* exist in print, but they are inconsistent and the extremes cover an area of more than 75 km in diameter.

Thanks to farmers' almanacs and other historical resources held in the library of the Namibia Scientific Society, and a competent librarian, Hobohm could be definitely linked to cadastral unit *Valhal 331,* located just south of *Abachausberg* (pers. comm., Armin Jagdhuber, 2023) (fig. 13).

Table 11: Cartesian coordinates for discussed Hobohm locality. Mapped in Figure 13.

Locality	Country	Coordinates
Abachaus (taken as cadastral unit Valhal 331)	NA	-19.7818, 16.7456

11. Gaerdes

Fritz Gaerdes (1892–1975) was a Namibian educator and amateur entomologist who collected widely in Namibia. The bulk of his surviving insect material is kept in the National Museum of Namibia. He created a few 'problem' localities of his own, notably a confusion between *Tinkas* and *Tiras,* and the abbreviation of the name of his farm *Ongombaenavita* on labels to just *Ovita,* a name that cannot be found on any map. Irish (1997) previously clarified Gaerdes' collecting localities at a quarter degree square resolution.

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Results of a pilot study using acoustic telemetry to assess the movements of coastal elasmobranchs in Namibia's only marine protected area

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Abstract

Many elasmobranch (shark, skate and ray) species inhabit the Namibian Islands Marine Protected Area (NIMPA), but little is known about the home ranges and movements of these species. Such information is essential for understanding whether a marine protected area provides effective protection to species of conservation concern. This study describes the first effort to tag and acoustically track three elasmobranch species in Namibian waters. A total of eleven individuals of three species – *Mustelus palumbes, Acroteriobatus blochii* and *Raja straeleni* – were tagged in February 2023. Three acoustic receivers were deployed at sites in the vicinity of Lüderitz Bay and a fourth was deployed further south, in Grosse Bucht. Data collected over 12 months revealed some of the small-scale movements of nine of the eleven tagged animals, but the limited spatial coverage provided by the four

receivers was not enough to fully describe the movement behaviours of these animals. Nonetheless, this research – the first study to internally tag and track chondrichthyans in Namibian waters – has revealed how tracking studies can contribute valuable data that can inform the management and protection of mobile species like sharks, skates and rays, and the design of future marine protected areas.

Introduction

Biotelemetry – the use of electronic tools to track the movements of animals – is now widely used to study the movements and behaviours of aquatic animals (Hussey et al. 2015). Acoustic telemetry is one of the most widely used methods for tracking the movements of marine animals. 'Coded' tags are used in conjunction with an array of acoustic receivers, positioned to give adequate coverage throughout the study area. The tags, each transmitting a unique code, are surgically implanted into animals; when a tagged animal passes within detection range of a moored receiver, the identity code, time and date of the detection are logged. Receivers are downloaded periodically by researchers to obtain data on animal detections. Acoustic telemetry facilitates the monitoring of the long-term movements of multiple individuals in a continuous and largely automated way, and results in large volumes of data that provide invaluable insight into spatial and temporal patterns of habitat use and large-scale movements of aquatic animals. This information can in turn be used to describe species' critical habitats, to inform fisheries management, to evaluate the level of protection provided by existing marine protected areas (MPAs) and to design new MPAs (Alós et al. 2022; McGowan et al. 2017; Abecasis et al. 2014).

MPAs are established for a variety of reasons and with a diverse array of objectives, including the protection or restoration of specific species or habitats and the maintenance of existing ecosystem services. These are often achieved by designating areas of ocean where human activities, such as fishing, are restricted to varying degrees, thereby theoretically safeguarding marine biodiversity from anthropogenic activities (Gaines et al. 2010; Halpern et al. 2010; Duarte et al. 2020). However, whilst MPAs have been documented to contribute to the protection and recovery of teleost populations (e.g. Ojeda-Martinez et al. 2007; Rojo et al. 2019), their contribution to the protection of elasmobranchs is not as well understood. Some evidence of MPAs benefitting elasmobranchs exist, but the outcomes can be variable, and the extent of the protection may not be sufficient, especially when isolated MPAs are implemented (Dwyer et al. 2020).

Effective conservation of marine vertebrates including chondrichthyans relies on a good understanding of their patterns of habitat use, movements and migrations (e.g. Daly et al. 2023; Kraft et al. 2023a; Doherty et al. 2017). Many MPAs are not designed specifically to protect elasmobranchs and thus were likely designed without knowledge of the movements and home ranges of these species, many of which are highly mobile and undertake long migrations (Kraft et al. 2023a; Dwyer et al. 2020; MacKeracher et al. 2019). Movement data can provide insight into the habitats a species uses, as well as the threats it may encounter as it moves from one region to another, both of which have direct implications for conservation (Lennox et al. 2023). Understanding the movement behaviour of elasmobranch species of conservation interest is thus essential to improve the protection offered by established MPAs and to more effectively design new MPAs.

Namibia's only MPA, the Namibian Islands Marine Protected Area (hereafter NIMPA), was designated in 2008. At the time of its declaration, one of its primary objectives was to protect the breeding sites and main foraging areas of the populations of three threatened seabird species – African penguins (*Spheniscus demersus*), Cape gannets (*Morus capensis*) and bank cormorants (*Phalacrocorax neglectus*) – that breed and feed along Namibia's coast and that were, at that time, in rapid decline (Ludynia et al. 2012; Kemper et al. 2007). There has, until recently, been almost no research focusing on elasmobranchs in Namibian waters, including within the NIMPA, and thus the state of knowledge of this group of species is extremely limited (Leeney et al. 2023; Leeney 2024; Leeney and Tshimwandi 2024). As such, there is no understanding of the status of elasmobranch populations within this MPA, or whether its boundaries encompass the home range of any elasmobranch population sufficiently to provide a reasonable level of protection.

This paper describes the first ever acoustic tracking study on chondrichthyans in Namibian waters and the first time that any of the study species have been tracked with acoustic tags. The small receiver array limited the amount of data that was collected, but the results nonetheless demonstrate the contribution this type of research can make to developing appropriate management and conservation plans for elasmobranchs within and outside of MPAs.

Methods

This study was conducted in collaboration with the National Research Foundation - South African Institute for Aquatic Biodiversity (NRF-SAIAB) Acoustic Tracking Array Platform (ATAP). The equipment used for this study was fully compatible with that used by ATAP, allowing for the data collected to be integrated into the ATAP database and ensuring that any large-scale movements into South African waters by animals tagged in Namibia would have the possibility of being detected on the ATAP array.

Study area

This study took place in the NIMPA, which is located in the Benguela Current Large Marine Ecosystem (BCLME), one of the four major upwelling systems on the eastern boundaries of the Atlantic and Pacific Oceans and one of the most productive ocean ecosystems in the world in terms of biomass production and fishery resources (Shannon and O'Toole 2003; Sakko 1998). The NIMPA encompasses 9,500 km^2 of marine environment in southern Namibia and extends from the shoreline to c. 30 km offshore, reaching depths of over 160 m in some places.

Tagging procedure

Elasmobranchs were caught from shore using conventional rod-and-line tackle. Angling took place from land at both Radford Bay and Griffith Bay (Fig. 1). Barbless circle hooks (sizes 4/0 to 6/0) baited with sardine *Sardinops sagax* were used. No specific species were initially targeted during fishing, but once three different species had been caught and tagged, only additional individuals of those three species were tagged, to ensure that data were collected from multiple individuals of each species.

Once an elasmobranch was hooked, it was reeled in to shore as quickly as possible. The overall health of the fish was assessed and tagging only proceeded for healthy animals that were not overly distressed. The size of each fish was also assessed as soon as it was landed, to ensure that the body cavity was of sufficient size to accommodate the transmitter. The fish was then placed on a tarpaulin. Fish were inverted (i.e. with the ventral surface of the body facing upwards) to induce a state of tonic immobility - a reflex that causes a temporary state of inactivity in elasmobranchs. Tonic immobility is widely used and recognised as an acceptable anaesthetic technique for surgical procedures on elasmobranchs (Kessel and Hussey 2015). On the sandy beach at Radford Bay, a hole was dug in the sand (c. 120 x 50 cm and c. 20 cm deep) near the water's edge, before fishing began. The tarpaulin containing the elasmobranch could then be placed into this hole and filled with seawater, acting as a pool. The animal's gill slits were kept submerged throughout the tagging process, and additional seawater was regularly added using a bucket, to maintain oxygen levels in the water. At Griffith Bay, anglers fished from a rocky outcrop and a small channel in the rocks was used to support the tarpaulin during tagging. The transmitters used for this study have an estimated battery life of 3650 days for the V16-4L transmitters (16 mm in diameter and 68 mm in length) and 1091 days for the V13-1L transmitters (13 mm in diameter and 30.5 mm in length). The minimum size of each species tagged, and the tag size used, is shown in Table 1.

The standard operating procedures for tagging developed by the South African Institute for Aquatic Biodiversity were followed for all tagging work for this study, including aseptic surgery techniques. All surgical equipment and transmitters were stored in ethanol prior to initiation of surgery. All sterilised equipment, including transmitters, was not touched until needed. The individual(s) conducting the surgery sterilised their hands before each new tagging event. Surgery was conducted only by a trained and authorised individual (MCP) and, after sufficient experience, RHL under the supervision of MCP.

Intracoelomic implantation (i.e. surgical implantation into the body cavity) was used as it is considered international best practice, despite its relative invasiveness. Transmitter retention using this approach is higher than for other forms of tagging and once the individual recovers from the surgical procedure, the transmitter is thought to have little to no

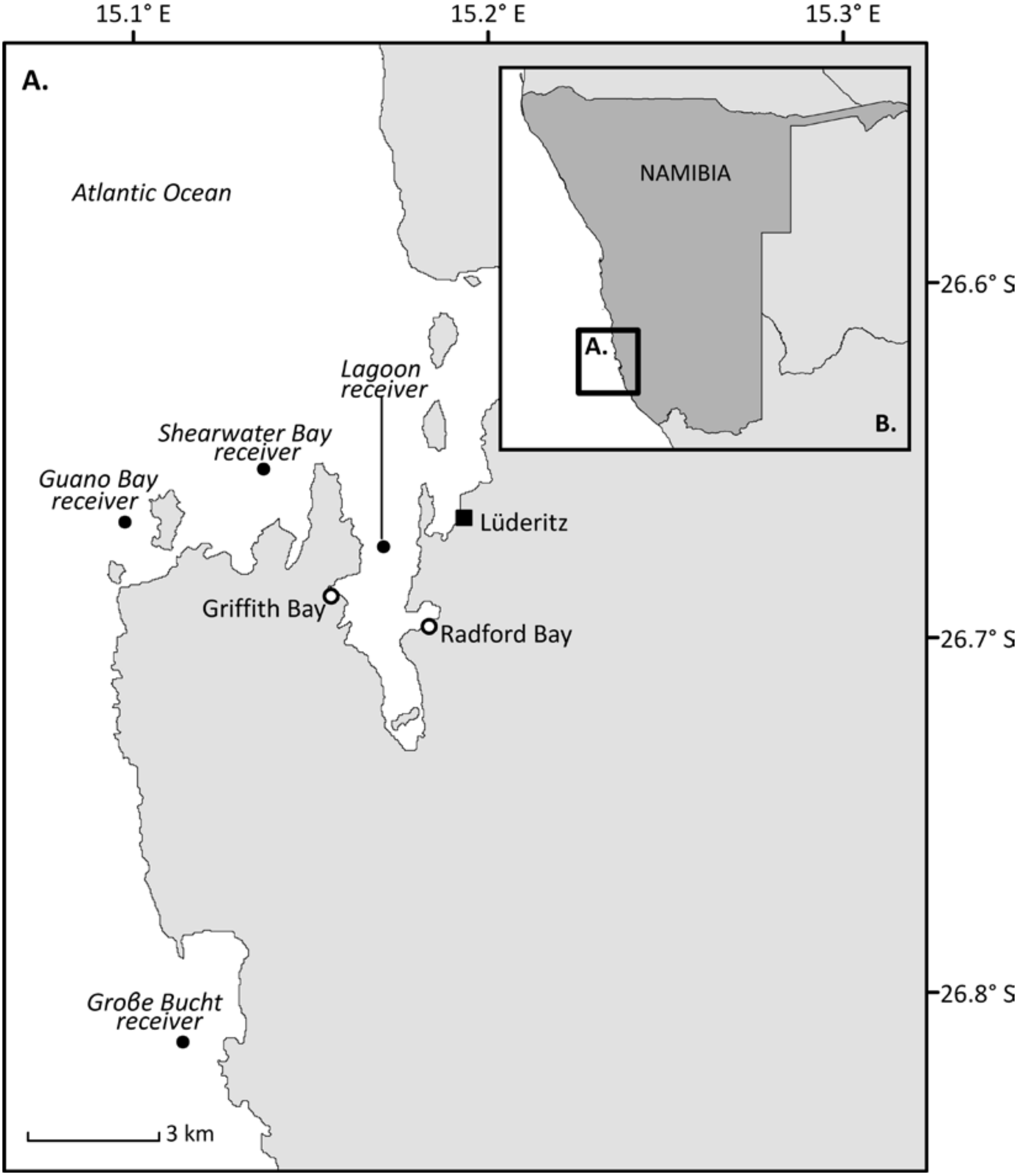

Figure 1: A. Map of the study area showing the sites where shore-based angling took place (white circles) and the receiver stations (black circles). B. Location of the study area relative to Namibia's coastline.

impact on the fish's behaviour, physiology or survival (Brown et al. 2011). A single incision was made in the ventral surface of each fish, into the coelomic cavity, using a sharp, sterile scalpel blade, and care was taken not to injure or inflict damage on internal organs. The size of the incision was kept to the minimum required to accommodate the specific transmitter to be implanted. After air drying following removal from alcohol sterilant, the transmitter was inserted into the intracoelomic cavity. The incision was closed using multiple independent pseudo-monofilament sutures (2/0 thickness) and topical antibiotic powder was applied to prevent secondary infection. The surgery was completed as efficiently as possible to minimise the amount of time that the fish was handled. Once the surgery was complete, the animal's total length or disc width and sex were recorded, and the fish was then carried in the tarpaulin into the shallows, where its body was righted. One or two individuals then walked into deeper water carrying the tarpaulin, allowing the animal to swim away when it had recovered sufficiently to do so.

A registered veterinarian oversaw the tagging training provided to RHL and the tagging process for the first two days, to ensure it was in line with the requirements of the Namibian Veterinary Council.

Monitoring array

An array composed of four acoustic receivers equipped with acoustic releases (Innovasea VR2AR 69kHz) was used to detect the presence of tagged animals (Figure 1). The acoustic release mechanism – whereby the receiver is released from its mooring once a signal from a vessel-based hydrophone has been issued, and floats to the surface for retrieval – allowed receivers to be retrieved using remote interrogation from a vessel. The mooring for each receiver comprised a 50-kg concrete anchor attached to a rope that attached to the release lug of the receiver. The receiver was attached to a separate length of rope with a sub-surface float at one end, which kept the mooring upright underwater.

Receivers were deployed on 12 February 2023 in Lüderitz's second lagoon (in water 6.6 m deep), Shearwater Bay (15 m), Guano Bay (18 m) and Grosse Bucht (26 m) and retrieved on 11 February 2024. The receiver deployment locations are shown in Figure 1.

Data Analysis

The data processing and analysis for this study were conducted using the statistical software R (R Development Core Team, 2011). To evaluate fish residency patterns, two indices were calculated: the residency index (*IR*) following the method proposed by Afonso et al. (2008), and the weighted residence index (*IWR*) based on the approach by Lino (2012). The IR was estimated by dividing the total days a fish was detected (D_d) by the number of monitoring days (D_t) (Equation 1). The IWR accounts for the number of days a fish was detected (D_d) as a proportion of total monitoring days (D_t), weighted by the interval between the first and last detection (D_i) relative to the total monitoring days (D_t)

(Equation 2). Both indices vary from 0 (no residency) to 1 (full residency) (Kraft et al. 2023b).

$$(1)\ IR = \frac{D_d}{D_t}$$

$$(2)\ IWR = \frac{D_d}{D_t} \times \frac{D_i}{D_t}$$

Indices for each individual fish were calculated for the whole array and for each receiver station.

To assess potential differences in diel detection patterns, each detection was classified into day/night using the R package suncalc (Thieurmel & Elmarhraoui 2019). The number of detections during day and night periods was compared using a Mann-Whitney U-test. In situations where two values tied for the same rank, the Monte Carlo approximation method was used to compute *p*-values and the Bonferroni correction was applied to control for multiple testing.

Results

In total, 11 elasmobranchs (ten females and one male) of three species (*Mustelus palumbes*, *Acroteriobatus blochii* and *Raja straeleni*) were tagged between 10 and 12 February 2023 at either Griffith Bay or Radford Bay south (Table 1). The mean surgery time was 9 minutes 34 seconds.

Two of the tagged animals (Mp1 and Rs4) were not detected on any of the receivers. The number of detections of the remaining animals varied considerably (Fig. 2). The only *M. palumbes* individual (Mp2) detected was the most frequently and consistently detected of all the tagged animals, being first detected on 13 February 2023 and last detected on 26 December 2023, and with detections on 90 days. The residency indices for Mp2 were thus the highest of all the tracked animals (*IR*=0.243; IWR=0.243; Table 2), with highest site-specific residency values at the Lagoon (*IR*=0.116) and Grosse Bucht (*IR*=0.073) receiver stations (Appendix 1). In contrast, the remainder of the tagged fishes were detected on between 1 and 25 days over the study period (Table 2; Fig. 2), and these fishes had lower residency indices (Table 2).

All animals presented a higher number of detections at the Lagoon station (Appendix 1) and 56% of the tagged animals for which there were detections (5 out of 9) were exclusively detected at this station. Only Mp2 was detected at all four stations (Appendix 1).

Visual inspection of the number of detections per diel phase suggested that some individuals were more frequently detected at night than during the day (Figure 3), but there were no significant differences in the number of detections between day and night periods for any of the individuals (Mann-Whitney U-test; *p*>0.05).

Table 1: Details of the tagged elasmobranchs, including the code given to each fish in the manuscript and each fish's total length (TL) or disc width (DW).

Species	**Code**	**Sex**	**TL/ DW (cm)**	**Tag type**	**Tagging location**	**Tagging date**	**First detection**	**Last detection**
M. palumbes	Mp1	F	120	V16-4L	Radford Bay	11/02/2023	no detections	n/a
M. palumbes	Mp2	F	95	V16-4L	Radford Bay	12/02/2023	13/02/2023	26/12/2023
A. blochii	Ab2	F	98	V13-1L	Radford Bay	11/02/2023	14/03/2023	24/10/2023
A. blochii	Ab3	F	103.5	V13-1L	Radford Bay	11/02/2023	05/03/2023	19/03/2023
A. blochii	Ab4	F	98	V13-1L	Radford Bay	11/02/2023	24/03/2023	25/03/2023
A. blochii	Ab5	F	102	V13-1L	Radford Bay	11/02/2023	22/02/2023	02/11/2023
A. blochii	Ab5	F	87	V13-1L	Radford Bay	12/02/2023	06/05/2023	07/05/2023
R. straeleni	Rs1	F	53 (DW)	V13-1L	Griffith Bay	10/02/2023	13/02/2023	23/03/2023
R. straeleni	Rs2	F	53.5 (DW)	V13-1L	Griffith Bay	10/02/2023	13/03/2023	13/03/2023
R. straeleni	Rs3	F	57.5 (DW)	V13-1L	Griffith Bay	10/02/2023	28/04/2023	13/01/2024
R. straeleni	Rs4	M	47 (DW)	V13-1L	Radford Bay	12/02/2023	no detections	n/a

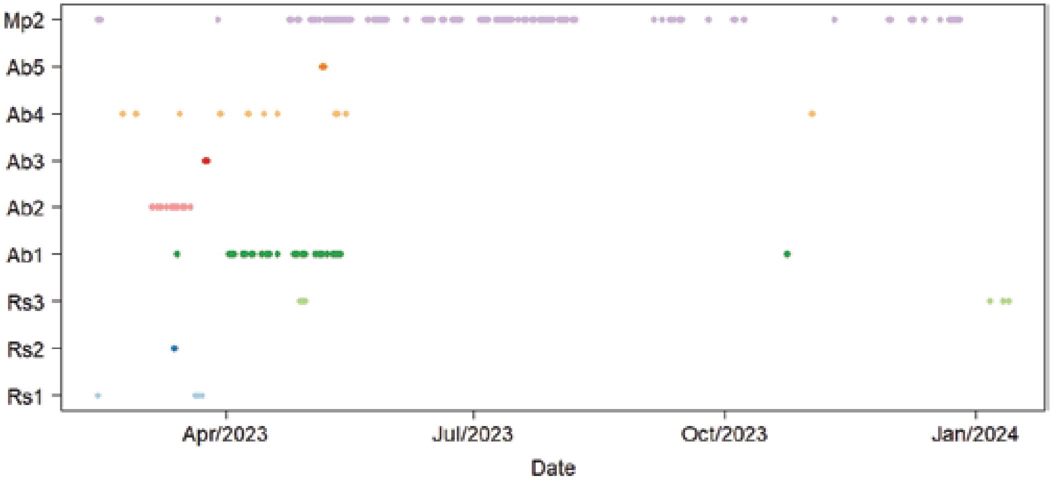

Figure 2: Abacus plot showing detections of each tagged animal on all receivers combined, between the receiver deployment (12/02/2023) and retrieval dates (11/02/2024 for three receivers and 17/02/2024 for one receiver). Mp – Mustelus palumbes*; Ab -* Acroteriobatus blochii*; Rs -* Raja straeleni.

Table 2: Residency indices of each tagged individual, for the whole array. D_d – total number of days detected, D_i – detection interval (number of days between first and last detections), D_t – monitoring interval, IR – residency index, IWR – weighted residency index.

Tagged animal	D_d	D_i	D_t	***IR***	***IWR***
Rs1	4	369	372	0.011	0.011
Rs2	1	341	372	0.003	0.002
Rs3	6	295	372	0.016	0.013
Ab1	25	340	371	0.067	0.062
Ab2	10	349	371	0.027	0.025
Ab3	2	330	371	0.005	0.005
Ab4	11	360	371	0.030	0.029
Ab5	2	287	370	0.005	0.004
Mp2	90	369	370	0.243	0.243

Discussion

This study presents, for the first time, acoustic telemetry data on three species of elasmobranchs and demonstrates the usefulness of this method in an area such as the NIMPA. Of the three species tracked in this study, one (*R. straeleni*) is listed as Near Threatened on the IUCN Red List of Threatened Species, whilst *M. palumbes* and *A. blochii* are listed as Least Concern (Jabado et al. 2021; Pollom et al. 2020; Pollom et al. 2019). *Acroteriobatus blochii* is a regional endemic, occurring only between Western Cape Province (South Africa) and Namibia. All three species are often caught by shore-based recreational anglers and both batoids have, in the past (and in the case of *R. straeleni*, as recently as 2023; R.H. Leeney pers. obs.) been used by anglers as bait for catching larger sharks. *R. straeleni* has also been recorded as a bycatch of the deepwater bottom trawl fishery for hake (R.H. Leeney unpubl. data) and *M. palumbes* may also be an occasional bycatch in Namibian fisheries, as in South Africa it is caught in bottom trawl, line and gillnet fisheries (da Silva et al. 2015). The limited spatial coverage provided by the small receiver array and the short duration of this study precluded the collection of a large dataset, and thus do not allow for any significant conclusions to be made regarding the movements of the tagged animals. Nonetheless, this project has provided useful preliminary data that can be used in the development of future management and monitoring work in the NIMPA.

The consistency of detections for one *M. palumbes* individual throughout the study period suggests a high degree of residency in the area covered by the receivers. Acoustic

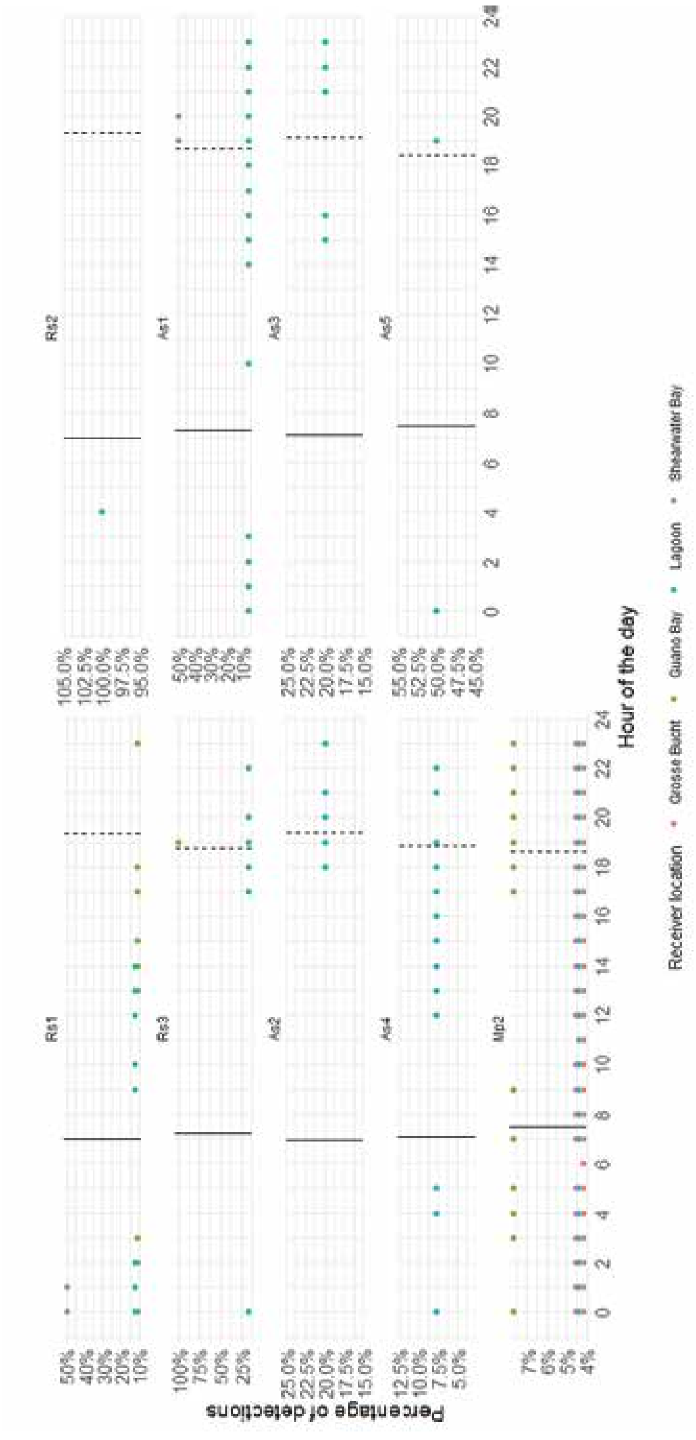

Figure 3: Proportions of all detections for each tagged fish, in each hour of the day. The colour of each point represents the different stations. The solid line indicates the mean sunrise and the dotted line the mean sunset time (estimated using the R package suncalc).

telemetry may thus be an ideal method for tracking the movements of this species. The highest residency index values for this individual were in the lagoon, and the majority of detections for all the other tagged animals also came from the lagoon receiver. This highlights that this habitat may be regularly used by several elasmobranch species, despite its proximity to Lüderitz port and the likely impacts of numerous human activities in the area, including vessel traffic and various aquaculture projects. The presence of large numbers of eggcases from *R. straeleni* and *Rostroraja alba* (spearnose/white skate) on the beach at Griffith Bay (R.H. Leeney, pers. obs. February 2024) suggests that these two species may use an area inside the lagoon as a 'nursery' area for eggcase deposition. This further emphasises the importance of mitigating the impacts of human activities on the lagoons, and ensuring that they are considered as important habitats within the NIMPA.

There are several possible reasons why two of the tagged animals were not detected on the receivers. The most likely reason, given the very limited extent of the receiver array, is that they may have moved beyond the range of any of the receivers, immediately after they were tagged, and during the course of the study simply not returned to an area in which they would have been detected. Their tags may have been faulty and unable to transmit, although this is unlikely as each tag was checked to ensure it was functioning before it was used. The tagged animals may have been caught by fishers and not released alive. Finally, the animals may have been predated after the tagging process or may have died as a result of the surgery. Research has shown that there is high variability amongst shark species in responses to capture and release (Binstock et al. 2023), and likely this is also the case for responses to the tagging process. Since this is, as far as we are aware, the first time that these three species have been tagged using acoustic transmitters inserted surgically, there are no available data on how each species responds to the tagging process.

Light can be a cue for diel or seasonal patterns of activity in elasmobranchs (Carroll and Harvey-Carroll 2023). However, there were no discernible diel patterns to detections of any of the tagged animals. This may have been because the full extent of each animal's daily movements was not captured by the limited spatial coverage provided by our receiver array.

All but one of the elasmobranchs caught and tagged in the NIMPA were female, suggesting that there may be some sexual segregation for one or more of the study species. Sexual segregation has been documented for many shark species (e.g. Braccini and Taylor 2016; Kock et al. 2013; Mucientes et al. 2009) and also for batoids (Simpson et al. 2021). Further research is required to investigate whether there is any spatial segregation of males and females of any of the species tagged in this study.

Data on the movements of aquatic animals can contribute to both fisheries management and marine spatial planning, for example when making evidence-based cases for spatial or temporal protections from activities such as fishing, shipping and marine renewable energy installations (Lennox et al. 2023). The gaps in data on the movement ecology of elasmobranchs in Namibian waters may hinder the effective management of these animals. Previous studies have documented that bronze whalers (*Carcharhinus brachyurus*) regularly travel between South African and Namibian waters (Rogers et al. 2022) and this may also be true for other species. In contrast, broadnose sevengill sharks (*Notorynchus cepedianus*), one of the largest shark species present in the NIMPA, show a high level of site fidelity and do not appear to move regularly between Namibian and South African waters (Engelbrecht et al. 2020). Understanding these patterns in movement and habitat use, for the different focal species in the NIMPA, is essential for the management of elasmobranch species and for understanding the role that MPAs play in protecting species with varying levels of connectivity with other regions. If there is to be any zoning of the NIMPA in the future, to ensure that critical habitats are protected from potentially harmful activities, then having movement data for species of conservation interest will be essential.

This work, although spatially and temporally limited, demonstrates the value of acoustic telemetry data for understanding the movements and patterns in habitat use of species inhabiting an MPA. Establishing an expanded array of receivers to cover the entire NIMPA, and ideally extending into unprotected waters to the north and south, would provide insight into whether the species tracked during this study are adequately protected by the protected area. Future acoustic telemetry studies should perhaps rather focus on threatened chondrichthyan species inhabiting the NIMPA such as tope *Galeorhinus galeus* (listed as Critically Endangered; Walker et al. 2020), bronze whaler shark *Carcharhinus brachyurus* (Vulnerable; Huveneers et al. 2020) and *Rostroraja alba* (Endangered; Dulvy et al. 2006). Tracking the movements of those species would provide insight into the level of protection afforded them by the NIMPA, and whether they are exposed to threats present outside the NIMPA, in particular bycatch in industrial fisheries. Other species of interest, including teleost species that use the waters of the NIMPA and that have value for commercial fisheries and recreational anglers, could also be tagged. Investing in a receiver array and establishing a tracking programme to track multiple species would maximise the value of the required investment in equipment, and result in a wealth of useful data for managers and scientists.

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Appendix 1

Residency indices of each tagged individual at each station. D_d – total number of days detected, D_i – detection interval (number of days between first and last detections), D_t – monitoring interval, IR – residency index, IWR – weighted residency index.

Code	Station	D_d	D_i	D_t	*IR*	*IWR*
Rs1	Guano Bay	2	331	372	0.005	0.005
Rs1	Lagoon	2	333	372	0.005	0.005
Rs1	Shearwater Bay	1	332	372	0.003	0.002
Rs2	Lagoon	1	341	372	0.003	0.002
Rs3	Guano Bay	1	42	372	0.003	0.000
Rs3	Lagoon	5	35	372	0.013	0.001
Ab1	Lagoon	24	280	371	0.065	0.049
Ab1	Shearwater Bay	1	116	371	0.003	0.001
Ab2	Lagoon	10	335	371	0.027	0.024
Ab3	Lagoon	2	329	371	0.005	0.005
Ab4	Lagoon	11	107	371	0.030	0.009
Ab5	Lagoon	2	286	370	0.005	0.004
Mp2	Groβe Bucht	27	165	370	0.073	0.033
Mp2	Guano Bay	7	78	370	0.019	0.004
Mp2	Lagoon	43	53	370	0.116	0.017
Mp2	Shearwater Bay	16	54	370	0.043	0.006

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Assessing the health of lions (*Panthera leo*) in a reserve: A study of Body Condition Score and Stomach Contents Index

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Key Words: Body condition score, Stomach contents index, Animal health, Camera trap, *Panthera leo*, lion, reserve management, Naankuse

Abstract

This research assesses the potential of the body condition score (BCS) and the stomach contents index (SCI) as indicators for monitoring the health status of lions within a fenced-off reserve in central Namibia. BCS is a non-invasive management tool that evaluates an animal's accumulation of fat and muscle, and SCI is the measure reflecting the saturation state of the stomach.

Using 3,700 camera trap pictures from November 2018 to August 2023, we firstly study BCS and SCI of five adult lions (*Panthera leo*), including two males and three females in a 7,500 hectare fenced-off reserve. Then, we investigate the potential correlation between BCS and SCI and analyse whether factors such as sex, moon phase, season, and time of day have an impact on BCS and SCI. Finally, we investigate the influence of BCS and SCI on the drinking behaviour of the lions.

We found that BCS assessments reveal an ideal health status among the lion population in this reserve, while SCI demonstrates a rapid and dynamic response to their feeding behaviour. Analysing the five lions simultaneously reveals a significant positive correlation between BCS and SCI. Concerning the males and females, BCS remains stable across sex but differs between long-term residents and newly introduced lions. In contrast, SCI is unaffected by sex or lion introductions. Our study found no significant variations in BCS and SCI according to the moon phases. While no significant difference in BCS distribution was observed across seasons, SCI varied between dry seasons (dry summer and dry winter) and humid seasons. BCS and SCI showed no differences during dawn, day, and dusk, but we found differences for both between night on the one hand and dawn, dusk, and day on the other. Both BCS and SCI influence their drinking behaviour.

The conclusion is that understanding BCS and SCI enhances the monitoring of lion health status, enabling action to be taken accordingly for the effective management of a fenced-off reserve.

Introduction

The lion (*Panthera leo*) is an iconic apex predator within African ecosystems (Henschel et al. 2016), playing an important role in maintaining the ecological balance by regulating diverse prey species (Funston & Mills 2006; Lima 1998) and influencing other carnivore populations (Périquet, Fritz, & Revilla 2015). Despite occupying the top of the food web, African lion populations almost halved during the last two decades (Abade et al. 2020). This decline can be primarily attributed to factors such as habitat loss and fragmentation, human-wildlife conflict, poaching, and diseases (Bauer et al. 2015; Everatt, Kokes, & Pereira 2019; Sargent et al. 2022; Trinkel 2013; Young 1975).

These essential animals typically live in prides comprising one to three males, several females, and their offspring (Kothe & Taffin-Jouhaud 2018). Being a social predator confers certain advantages, including heightened territorial competition and better prey capture rate (Hopcraft, Sinclair, & Packer 2005; Mosser & Packer 2009). However, this social structure may also entail disadvantages. Indeed, transmission of disease is accelerated among individuals within a group due to proximity, impacting their overall health (Ezenwa et al. 2016).

For reserve management or for conservation efforts it is essential to ascertain the size of the different populations, understand their ecological niche, and assess their health status (Massey, King, & Foufopoulos 2014; Welch & Parker 2016). Every species holds significance, even if some exert a more substantial impact on the ecosystem balance (Ellison & Degrassi 2017). This is particularly true for carnivores, given their role in regulating prey populations (Funston & Mills 2006; Lima 1998). When apex predators are in poor condition, the rest of the food web is more likely to be unbalanced, leading to major deregulation in the ecosystem and significant consequences (Davies et al. 2016; Yugovic 2015). Therefore, it is crucial to monitor and understand the health status of the lion population within a reserve, to recognise the natural cycles of their physical condition influenced by specific environmental factors and their influence on the drinking behaviour of lions.

In this context, the study will assess the potential of body condition score (BCS) and stomach contents index (SCI) as indicators for monitoring the health status of lions. The analysis encompassed BCS and SCI assessments of five adult lions from November 2018 to August 2023 using 3,700 camera trap pictures. The camera traps were distributed across the 7,500 hectare Zannier Reserve (-22.43723° latitude, 17.42623° longitude) in central

Namibia. It is situated in the thornbush shrubland biome with annual rainfall of 250 to 300 mm.

BCS serves as a management tool devised to evaluate an animal's body reserves or fat and muscle accumulation (Coon et al. 2019; Daigle et al. 2015; Teng et al. 2018). SCI is the measure reflecting the saturation state of the stomach (Bertram 1975; Ogden et al. 2008). In the context of this research, BCS was divided into five categories (1 = emaciated / 5 = obese) and SCI into four categories (1 = completely empty stomach / 4 = completely full stomach). BCS functions as an indicator of an animal's health status (Coon et al. 2019; Ezenwa, Jolles, & O'Brien 2009; Teng et al. 2018), whereas SCI indicates length of time since the lion last consumed food, thereby serving as a proxy for feeding intervals (Bertram 1975; Ogden et al. 2008).

Firstly, this study will focus on a detailed elucidation of the body condition score and stomach contents index, providing clarity on their interpretation and significance in the context of reserve management. Subsequently, BCS and SCI values of the studied lions will be presented, facilitating a clear visualisation of their evolution. The next section will focus on the evaluation of a possible correlation between BCS and SCI. Following this, a detailed exploration of the influence of sex on BCS and SCI will be undertaken. Additionally, the impact of environmental factors such as moon phases, seasons, and time of day, will be analysed and interpreted. Finally, the impact of BCS and SCI on the drinking behaviour of lions will be analysed.

Hypothesis

Understanding BCS and SCI enhances the monitoring of lion health status, facilitating the determination of action to be taken for the effective management of a fenced-off reserve.

Research questions

This research addresses the following questions in relation to reserve management:

1. Can the analysis of BCS and SCI through camera trap pictures provide an indication of lion health within a reserve?
2. To what extent do factors such as sex, moon phases, seasons, and time of day have an impact on BCS and SCI?
3. Is the drinking behaviour of the lions influenced by the BCS and SCI?

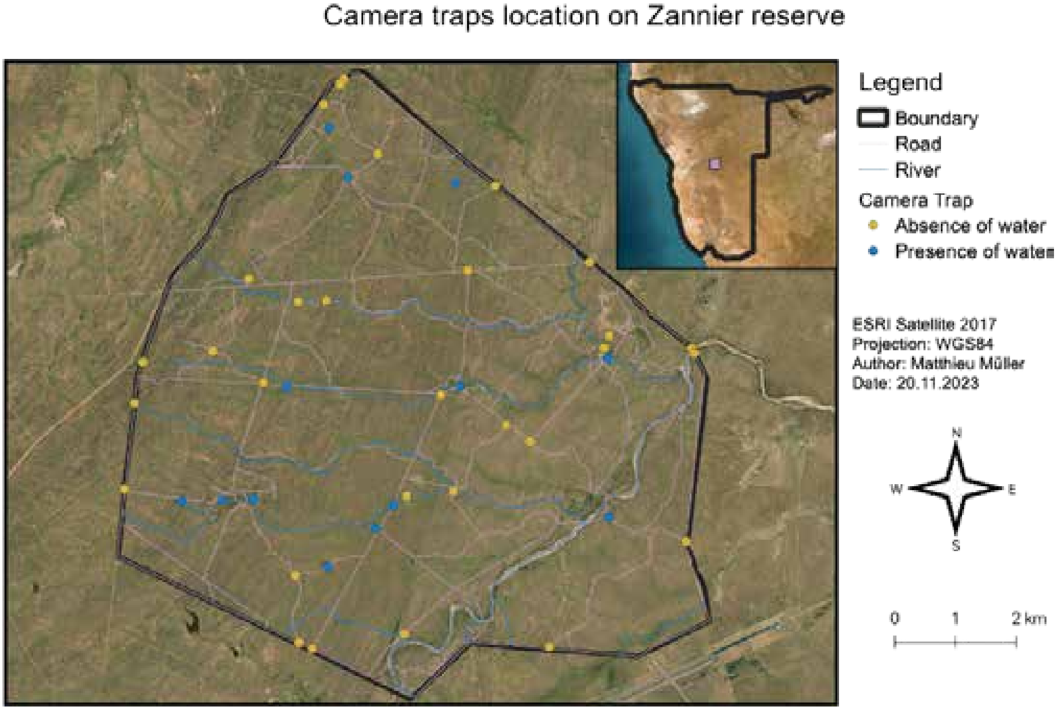

Figure 1: Map presenting the distribution of the camera traps on Zannier reserve

Materials and Methods

Study site: Zannier Reserve

The study site is the Zannier Reserve, managed by the N/a'an ku sê Foundation, located 45 km east of Windhoek (-22.55941° latitude, 17.08323° longitude) in the Khomas region of Namibia. This 7,500 hectare reserve contributes to the conservation and protection of biodiversity by preserving the natural habitat of its diverse wildlife. The reserve serves as a relocation destination for animals involved in human-wildlife conflicts. A research team is working on the reserve to understand the behaviour, movement, and ecological dynamics of the resident wildlife. The anti-poaching unit ensures the security of wildlife. Several camera traps are placed in the reserve for research and monitoring of wildlife (Fig.1). Situated in the savannah habitat with a main river on the south-eastern side, the reserve is home to a wide diversity of animals. This includes but is not limited to primary consumers such as white rhinoceros (*Ceratotherium simum*), common eland (T*aurotragus oryx*), impala (*Aepyceros melampus*), springbok (*Antidorcas marsupialis*), African savanna elephant (*Loxodonta Africana*), plains zebra (*Equus quagga*), and Angolan giraffe (*Giraffa* *angolensis*). Additionally, secondary and tertiary consumers such as leopard (*Panthera pardus*), brown hyena (*Hyaena brunnea*), cheetah (*Acinonyx jubatus*), and lion (*Panthera leo*), contribute to the rich ecological diversity of the reserve.

Population of the study: Lion pride

Considering that lions' home range can vary from 2,000 to 207,500 hectares across study areas (Lehmann et al. 2008), this 7,500 hectare reserve holds a single lion pride. This pride was studied from November 2018 until August 2023 and its composition, that has varied over time as illustrated in Figure 2, differs from a classic lion pride. The inception of the pride dates back to the first sighting on 20 November 2018, when a lion pride was introduced from the Brandberg area to the Zannier Reserve. The pride initially consisted of two female adults and three cubs (one male and two females). In this study, the cubs are considered adults from 17 September 2019, based on observable morphological changes and distinct patterns on their legs and belly. Subsequently, the lion pride evolved to consist of one male and three females, as one of the female cubs did not survive. On 25 March 2022 the initial male, Luke, was relocated to another reserve, resulting in the pride remaining without a male until 23 August 2022. At this point, a new male named Himezembi (also called Himee) was released on the reserve. From this time, the composition remained stable until the end of the observations for the research on 30 August 2023.

Body Condition Score / Stomach Contents Index

The body condition score (BCS) serves as a subjective and non-invasive management tool for evaluating the physical condition of an animal. It considers the quantity of fat and muscle material and the visibility of specific bones, providing insights into the long-term food consumption and overall health status of the animal (Daigle et al. 2015; Teng et al. 2018).

In the context of this study, BCS is divided into five categories, 1 indicating an emaciated lion, 3 an ideal animal and 5 an obese one (Fig. 3). BCS of 1 is characterised by the absence of muscles in the neck, shoulder, and tail base area, prominently visible vertebrae, ribs and pubic bone, and extremely thin limbs. BCS of 2 is identified by a slight presence

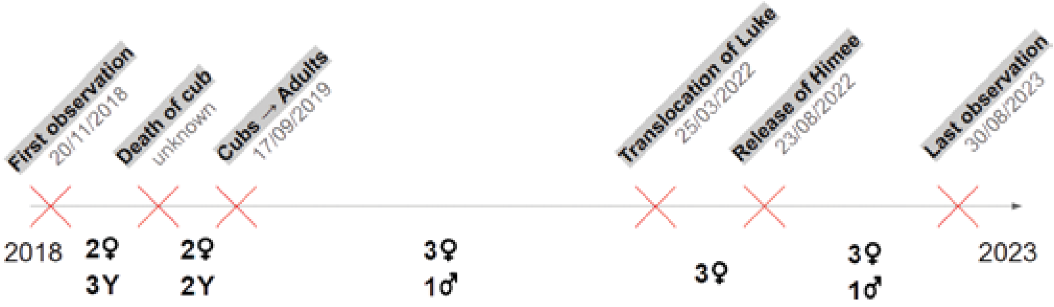

Figure 2: Timeline explaining the changes in the lion pride composition over the years

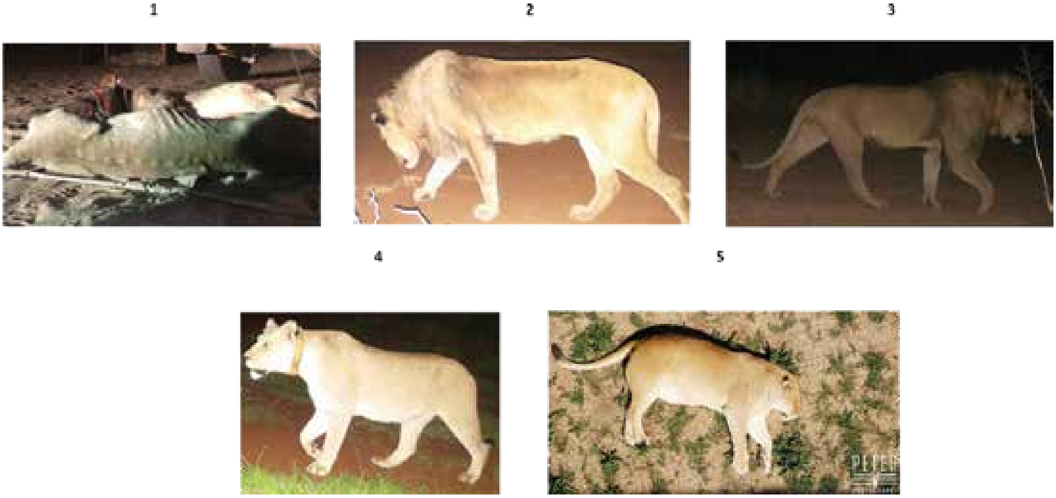

Figure 3: Five different categories of body condition score for the lion. (Pictures 1–4: N/a'an ku sê Foundation; Picture 5: Published with permission of Peter Van, pers. comm.)

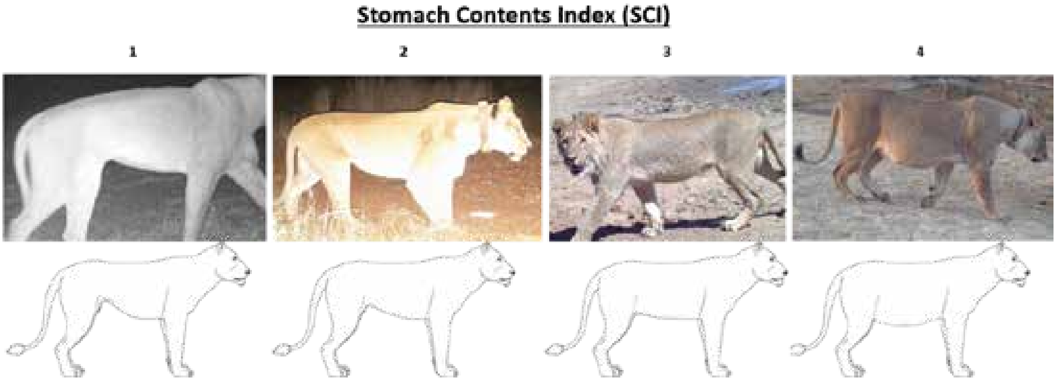

Figure 4: Four different categories of stomach contents index for the lion. (Pictures 1–4: N/a'an ku sê Foundation)

of muscle in the neck, shoulder, and tail base along with slightly visible vertebrae, ribs, and pubic bone, with limbs still being somewhat skinny. BCS of 3 is defined by muscle definition in the neck, shoulder, and tail base, with vertebrae, ribs, and pubic bone mildly visible but not prominent, and strong limbs without excess fat. BCS of 4 is represented by a thick neck, shoulder, and an obscured view of vertebrae, ribs, and pubic bone, with fat limbs and tail base area. BCS of 5 indicates a fat animal on all levels, with rolls sometimes visible on the neck and belly, and layers of fat covering the entire animal.

The stomach contents index (SCI) reflects how full the animal's stomach is (Bertram 1975; Ogden et al. 2008). It is a subjective and non-invasive method and reflects the food consumption over a short period. In the context of this study, SCI is split into four categories, with 1 indicating a completely empty stomach and 4 representing a completely full stomach (Fig. 4). SCI of 1 is characterised by a stomach well above the chest. SCI 2 is identified by a slightly lower position of the stomach, though not completely flat. SCI of 3 is recognised by a flat stomach, aligning with the chest level. SCI of 4 is characterised by the stomach positioned below the level of the rib cage.

Data collection

Camera trap data analysis

3,700 lion pictures were selected from camera trap data, in 44 locations between 20 November 2018 and 30 August 2023. To streamline the analysis, all pictures that were taken by one camera trap within a two-hour timeframe were considered as a single observation. Each lion in every observation was recorded, with a total of 380 observations. The following variables were recorded per observation: camera trap location, date, time, ID of the observation, number of pictures (for each observation), number of lions (for the observation), picture quality for the identification of BCS and SCI (useless; bad quality; medium quality; good quality), sex (Luke; Himee; female; juvenile), BCS (1–5), SCI (1–4).

Quality control for BCS and SCI involved a thorough process. The assessment and verification of all variables, including BCS and SCI, were repeated three times by the researcher. When BCS or SCI identification posed challenges, three additional researchers conducted further reviews. Additionally, 76 randomly selected pictures from different observations, corresponding to 1/5 of the total observations, were discussed with the research team to assess the assigned BCS and SCI categories. The consistency level achieved was 94.3% with differences of only one category, observed both in upward and downward trends.

Environmental factors

Moon phase data, based on the date, was categorised into four main phases: new moon, first quarter, full moon, or last quarter, using the information from the web site "phasesmoon.com" (Moon Phases Today | Lunar Phase n.d.). A full cycle of the moon takes about 29.5 days, and each of these main phases lasts a little over a week (Jongbloet 1983). When the moon was in-between these main phases (waxing crescent, waxing gibbous, waning crescent, waning gibbous), they were divided into halves and attributed to the nearest main phase. In the case where the division resulted in an odd number, the previous phase was selected.

Seasons were divided into dry summer (October, November, December), humid summer (January, February, March, April) and dry winter (May, June, July, August, September).

A similar approach was used for the time of day classification: dawn (05:01 to 07:00), day (07:01 to 18:00), dusk (18:01 to 20:00), and night (20:01 to 05:00).

GPS location and drinking behaviour

The GPS location of each camera trap was recorded with decimal notation (DD.DDDDD°) and plotted on a map of the reserve. Each location was classified based on the presence or absence of a water point, with these water points being permanent. Camera traps in areas with water were focused directly on the water point, showing only animals drinking or staying a few meters from the water point. The camera traps in areas without water were used to monitor lion without a drinking behaviour. This is why areas with or without waterpoints were assumed to be related to their drinking behaviour.

Collar data

Lions' locations were studied using GPS collar data, which recorded their positions approximately every three hours. Unfortunately, technical issues with the collars prevented us from following the movement of an animal, as records were not regular enough. This is why, this data was only used to assess whether the lions were together following the introduction of new individuals.

Data analysis

Data preparation

Using RStudio (R Core Team (2022) v.4.2.0), the data underwent initial cleaning and verification to identify and exclude any mistakes or inconsistencies. The observations of the cubs were excluded from the dataset since only 41 observations were recorded, and no existing literature provided information on BCS and SCI for cubs.

General BCS and SCI

In RStudio, bar charts were generated to analyse the distribution of observations for BCS and SCI using the package ggplot2. A chi-squared goodness of fit test was performed to assess whether the number of observations in each BCS or SCI category differed significantly.

The distribution of BCS and SCI data was examined using a Shapiro-Wilk test. Since this test showed the non-normality of the data, a nonparametric Kendall correlation test was performed to evaluate the correlation between the two variables. The graph of a linear relationship between BCS and SCI and another bar chart showing the number of observations by SCI by BCS were generated. These visualisations were created to show the relation between SCI and BCS.

Sex

The temporal feeding patterns of the lions over the different months were investigated using a scatter plot. BCS and SCI of the males and the females were separately analysed on a timeline and a Chi-Squared test of independence was performed to identify differences of BCS or SCI between the sexes. A nonparametric Kendall correlation test was conducted separately for each sex category.

Environmental factors and drinking behaviour

The relation between BCS or SCI and the environmental factors (moon phase, season, or time of day) as well as their drinking behaviour were explored using a Chi-Square test of independence and illustrated with bar chart graphs. Even with some differences in the length of the three different seasons and four different times of day, the Chi-Square test of independence is adapted as it serves to compare the pattern of BCS and SCI, not considering directly the number of observations, but their proportion (Franke, Ho, & Christina 2012).

Map

A map showing the distribution of the camera traps in the Zannier Reserve was created using QGIS3 (QGIS Development Team (2020) v.3.14).

Results

BCS and SCI

Regarding BCS, no instances of category 1 or 5 were recorded. The distribution of category 2, 3, and 4 was uneven, with BCS of 3 being the most frequently observed assessment and BCS of 2 the least (Fig. 5). Highly significant differences in the number of observations across all BCS categories (χ^2=219.83, *df*=2, p<0.001) were noticed. In the cases where BCS estimations were uncertain due to the picture quality, they were classified as unknown (Unk).

For SCI, all categories (1 to 4) were documented, with the majority of observations belonging to category 3 or 4 (Fig. 6). A notable number of observations were classified as SCI of 2, while only a limited number were assigned as SCI of 1. The difference in the number of observations across SCI categories was highly significant (χ^2=153.62, *df*=3, p<0.001), except for the comparison between SCI of category 3 and 4 (χ^2=1.8113, *df*=1, p=0.1783). The quality of some observations did not allow the precise identification of SCI, which were classified as unknown (Unk).

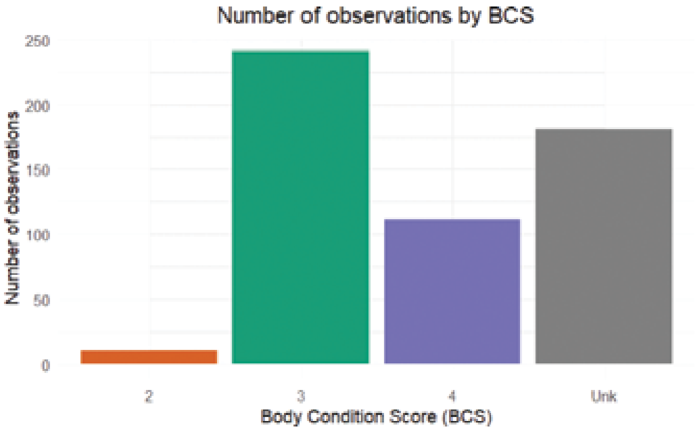

Figure 5: Bar chart showing the number of observations per BCS category

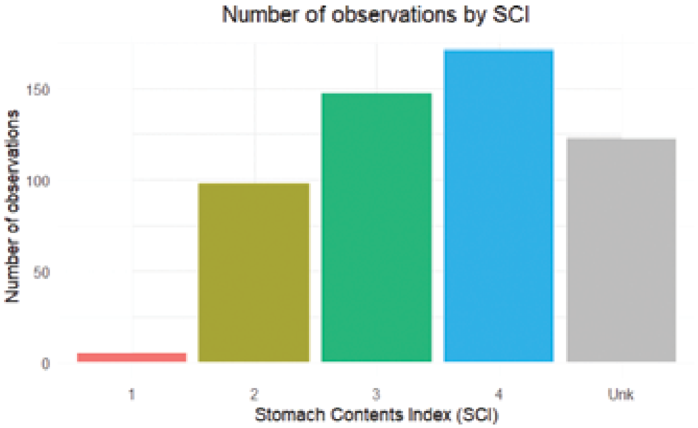

Figure 6: Bar chart showing the number of observations per SCI category

The correlation between BCS and SCI demonstrates high significance, with a *p*-value of 2.264e-11 and a Kendall's tau-b correlation coefficient of 0.3394741, indicating a weak positive correlation (Fig. 7).

The relationship between BCS and SCI is visually depicted in the bar chart in Figure 8. When BCS is 2, SCI is predominantly concentrated around 2. For BCS of 3, SCI is centralised mainly around 2, 3, and 4. In the case of BCS of 4 there is a predominant occurrence of SCI of 4, with fewer instances of SCI of 3.

Sex

Fig. 9 illustrates the temporal progression of BCS for each male and all females. These timelines incorporate information about the individual (only available for the males) and depict the distribution of BCS over time.

Regarding the males, the gap from 25 March 2022 to 23 August 2022 represents the absence of a male in the reserve between the departure of Luke (male 1) and the

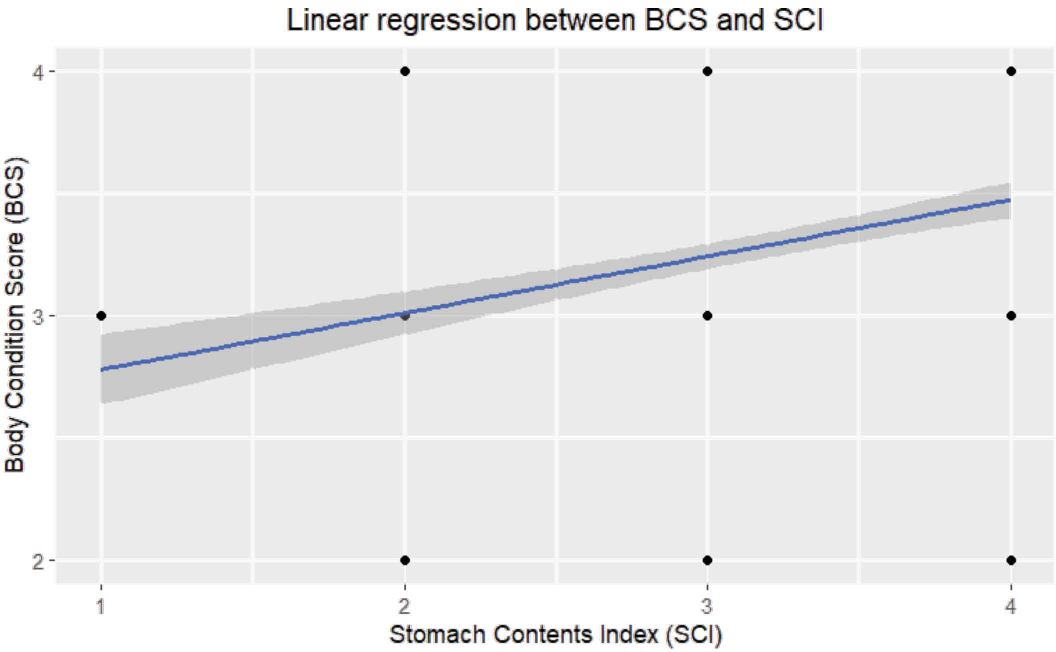

Figure 7: Linear regression between BCS and SCI

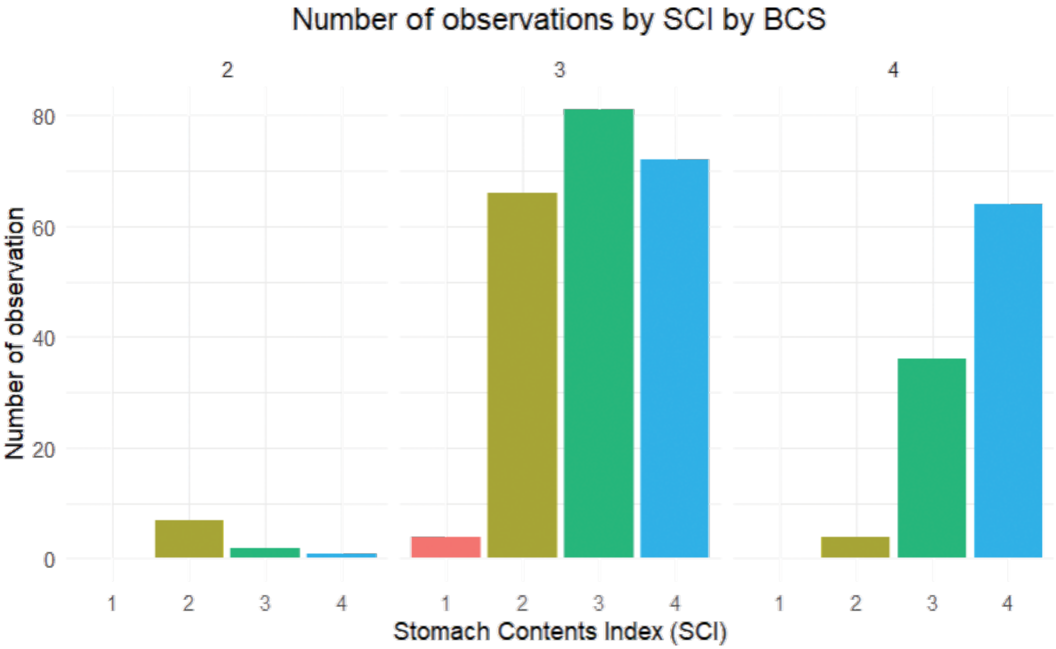

Figure 8: Bar chart showing the number of observations per SCI category and BCS category.

introduction of Himee (male 2). This temporal hiatus can also be viewed in Fig. 10 when analysing the SCI. Examining BCS category for these males reveals that both are primarily around 3, fluctuating between 2 and 4. However, the distribution of observations across categories is significantly different (χ^2=7.7168, *df*=2, *p*<0.05) when comparing these individuals. Specifically, Luke is mainly around BCS 3 and 4 and Himee tends to be more around BCS 2 and 3 in the early stages of his introduction, reaching BCS of 4 just before the end of the observations. Collar data indicates that Himee first joined the females on 02 October 2022 (represented by the orange point in Figures 9 and 10), after a brief period of living alone.

Concerning the females, differentiating them with camera trap pictures is not possible, but an examination of the general trend of BCS is realisable. They exhibit BCS mainly around 3 and 4, with rare fluctuations to 2. The distribution of BCS is significantly similar to that of Luke (χ^2=4.6933, *df*=2, *p*=0.08846) but highly significantly different from Himee (χ^2=27.021, *df*=2, *p*<0.001). In the initial stages of observation corresponding to their release in the reserve, the females were never observed with a BCS of 4. Since July 2019, they have frequently been observed with a BCS of 4 and their distribution by category remained quite similar until the end of the observations in August 2023.

As presented for the BCS, Figure 10 illustrates the timeline of SCI for both males and females.

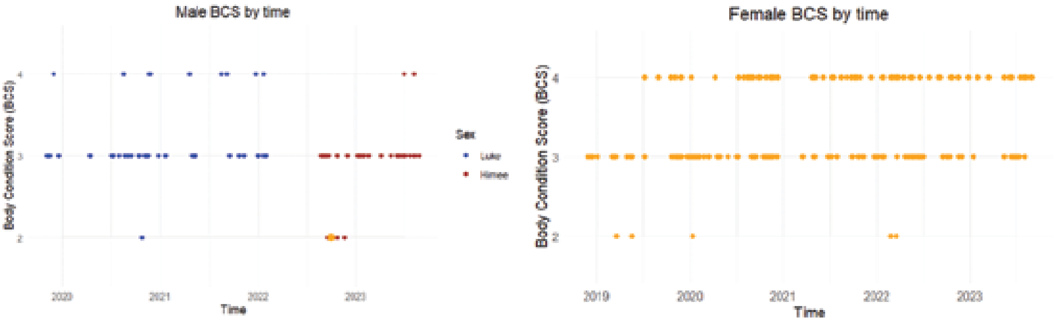

Figure 9: Timeline showing the evolution of BCS of the males and females over time

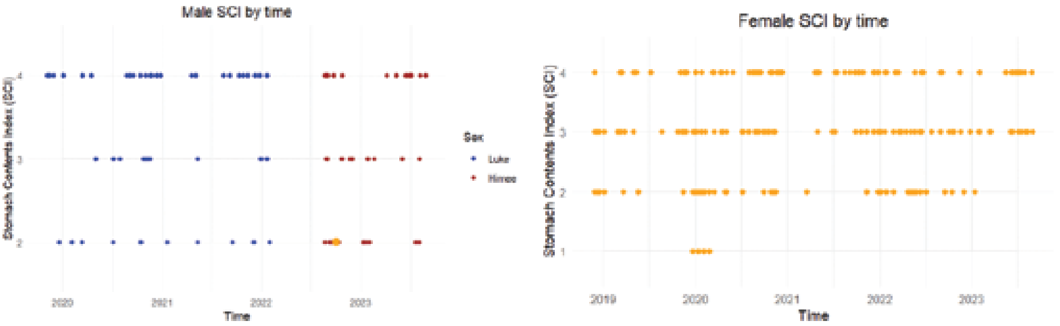

Figure 10: Timeline showing the evolution of SCI of the males and females over time

For both male lions, SCI fluctuates around 2 to 4, and the distribution is more widely spread than for BCS. The number of observations within SCI ranks for these two lions is similar, with no significant differences (χ^2=1.6138, *df*=3, *p*=0.4523).

Examining the females, SCI is mainly around 2 to 4 and fluctuates only for a period in 2020 to the category of 1. No significant variations between Luke or Himee and females were noticed (respectively χ^2=5.2988, *df*=3, *p*=0.1234 and χ^2=3.0465, *df*=3, *p*=0.3728).

Regarding the association between BCS and SCI distinguished by sex, a remarkably strong correlation was observed for the females (*p*<0.001, *tau*=0.3970833), and a significant correlation was noticed for Luke (*p*<0.05, *tau*=0.4085208). However, no significant correlation was found for Himee (*p*=0.2669, *tau*=0.1541067).

Environmental factors

Moon phase

BCS and SCI did not vary significantly according to the phase of the moon (respectively χ^2=6.9318, *df*=6, *p*=0.3278 and χ^2=4.989, *df*=9, *p*=0.8481). Since these results are not significantly different, no graph is presented.

Season

There was no significant difference in BCS distribution between the seasons (χ^2=5.8995, *df*=4, *p*=0.2079). For the SCI, no significant variation between dry summer and dry winter (χ^2=5.8995, *df*=3, *p*=0.2079) was detected. However, there is a significant difference in the distribution of SCI between dry summer and humid summer (χ^2=9.0693, *df*=4, *p*<0.05) and a highly significant difference between dry winter and humid summer (χ^2=18.256, *df*=4, *p*<0.001). SCI varies therefore between dry seasons (dry summer and dry winter) and humid seasons. The data showed a higher SCI during the dry seasons than in the humid seasons, as presented in Figure 11.

Time of day

There were no significant differences in BCS distribution between dawn, day, and dusk (Tab. 1), but a significant difference was observed between night, and dawn and dusk (Tab. 1). A highly significant variation between the night and the day was detected (Tab. 1). Regarding BCS, it is therefore possible to categorise two groups: dawn-day-dusk, and night. The BCS was lower during night when compared with dawn, day, and dusk (Fig. 12), even if it cannot reasonably be expected on a daily timescale. This element is going to be discussed later.

Concerning SCI, similar results were found (Tab. 1). No significant differences were observed in the distribution of SCI between dawn, day, and dusk, but the distribution at

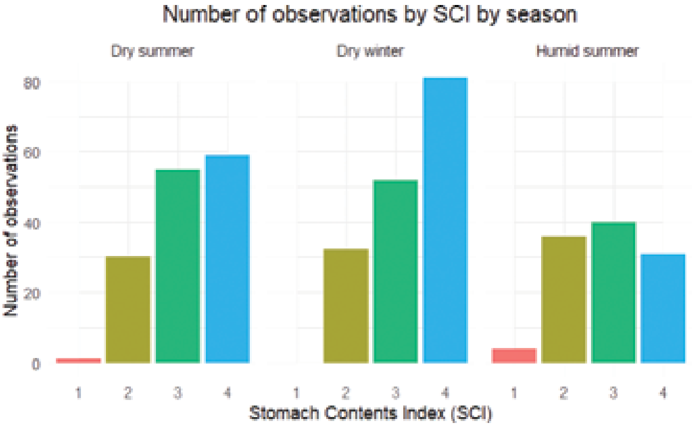

Figure 11: Bar chart showing the number of observations of the relation between SCI and season

Table 1: Results of the Chi-Squared test of independence on the time of day. The significant results are highlighted in grey

BSC Time of the day

	Dawn	Day	Dusk	Night
Dawn	x	χ^2=1.9321, *df*=2, *p*=0.4008	χ^2=1.8632, *df*=2, *p*=0.9245	χ^2=11.088, *df*=2, *p*=0.05
Day	χ^2=1.9321, *df*=2, *p*=0.4008	x	χ^2=2.8593, *df*=2, *p*=0.2034	χ^2=14.675, *df*=2, *p*=0.001
Dusk	χ^2=1.8632, *df*=2, *p*=0.9245	χ^2=2.8593, *df*=2, *p*=0.2034	x	χ^2=12.956, *df*=2, *p*=0.05
Night	χ^2=11.088, *df*=2, *p*<0.05	χ^2=14.675, *df*=2, *p*<0.001	χ^2=12.956, *df*=2, *p*<0.05	x

SCI Time of the day

	Dawn	Day	Dusk	Night
Dawn	x	χ^2=1.9046, *df*=3, *p*=0.6647	χ^2=3.9407, *df*=3, *p*=0.2544	χ^2=21.799, *df*=3, *p*=0.001
Day	χ^2=1.9046, *df*=3, *p*=0.6647	x	χ^2=5.361, *df*=3, *p*=0.07246	χ^2=28.422, *df*=3, *p*=0.001
Dusk	χ^2=3.9407, *df*=3, *p*=0.2544	χ^2=5.361, *df*=3, *p*=0.07246	x	χ^2=21.797, *df*=3, *p*=0.001
Night	χ^2=21.799, *df*=3, *p*<0.001	χ^2=28.422, *df*=3, *p*=0.001	χ^2=21.797, *df*=3, *p*<0.001	x

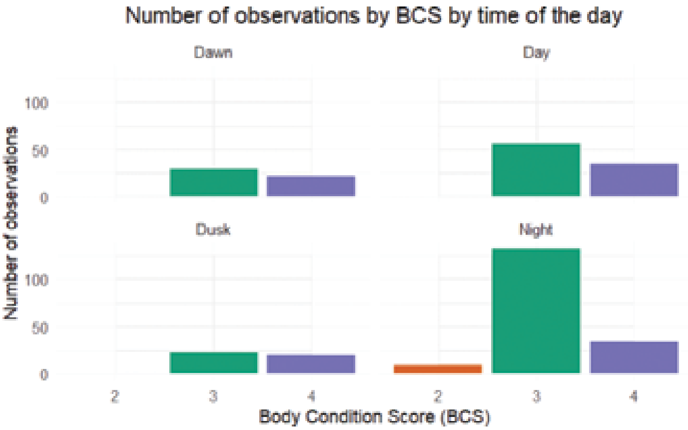

Figure 12: Bar chart showing the number of observations of BCS by time of day

night was highly significantly different from that in dawn, day, and dusk. Regarding SCI, it is therefore possible to categorise two groups: dawn-day-dusk, and night. In the first group, the number of observations with SCI of 3 and 4 is high, and in the second group a SCI score of 2, 3 and 4 are dominant (Fig. 13).

Drinking behaviour

As aforementioned, the drinking behaviour was linked to the presence or absence of water due to the location of the camera traps. Regarding BCS between locations with or without water, a significant difference was noticed (χ^2=7.6723, *df*=2, p<0.05). We found lions with a higher BCS when they were at a water point compared to areas without water, although the distribution of BCS seems almost similar with a higher amount of BCS of 3, followed by a lower proportion of 4 and finally of 2 (Fig. 14).

As shown in Figure 15, the difference in SCI distribution between locations with or without water point is evident. Lions have a higher SCI score when they come to drink.

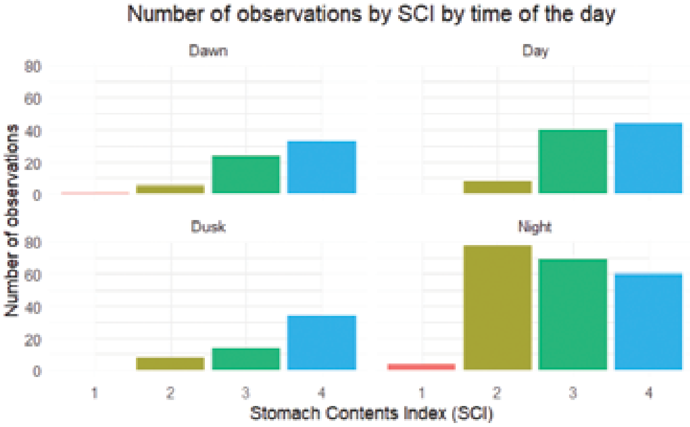

Figure 13: Bar chart showing the number of observations of the relation between SCI and time of day

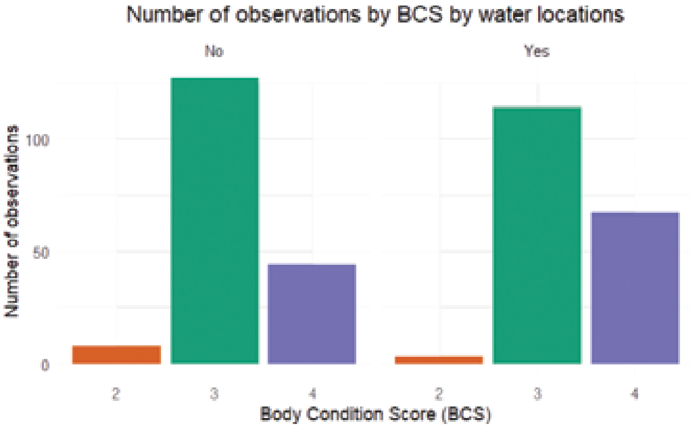

Figure 14: Bar chart showing the number of observations of the relation between BCS and the presence or absence of water

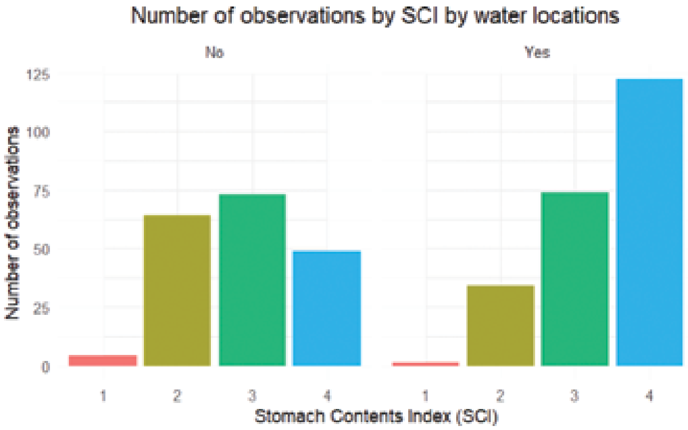

Figure 15: Bar chart showing the number of observations of the relation between SCI and the presence or absence of water

The number of observations for SCI of 4 has more than doubled in locations with water point and SCI of 2 decreased almost twofold. The statistical test confirms this with a highly significant difference (χ^2=38.527, *df*=3, *p*<0.001).

Discussion

BCS and SCI

Body condition score (BCS) assessments conducted on the lion population in the Zannier reserve reveal an ideal health status, with predominant BCS of 3, no observation of 1 (emaciated) or of 5 (obese). We assume that, in the wild, extreme BCS values could signal environmental changes or potential issues in the predator or prey population, such as territorial issues, inadequate number of prey, or disease.

Slight fluctuations (BCS of 2 and 4), observable in this lion population, are considered normal in a healthy population since external factors tend to be unstable, for example, abiotic factors or prey population numbers might vary. Concerning these slight fluctuations, it is recommended to have animals with slightly more fat material as it enhances their resilience (Bright Ross et al. 2021). Lions with a more robust body condition are better prepared during challenging times when competition is intense, and environmental factors undergo rapid changes.

Stomach contents index (SCI) demonstrates a rapid and dynamic response to their feeding behaviour, contrasting with BCS, which is more stable and changes more slowly. Indeed, lions can swiftly shift their SCI from 1 to 4 within a few hours. They consume large quantity of meat, and their digestion is highly efficient, resulting in quick filling or emptying of their stomach (Borstlap 2002). The observation of the four categories of SCI in our study reflects optimal feeding cycles: killing and eating their prey with optimal consumption and digestion. Maintaining a balance between occasionally having an empty stomach and infrequently a full one prevents obesity or emaciation.

Surprisingly, we primarily observed SCI category ratings of 3 and 4, as lions consume meals infrequently but in significant quantities (Borstlap 2002). They can have very full and very empty stomachs, with the latter being more common than the former. SCI values do not necessarily reach 1 between the two kills but decreases towards an SCI of 2. We would, therefore, have expected to find a predominant rate of SCI of 2 or 1 rather than 3 and 4. These unexpected results may be linked to the methodology, specifically the use of camera traps, and will be discussed in detail in the “drinking behaviour” section.

Analysing all lions simultaneously reveals a significant positive correlation between BCS and SCI, indicating the tendency that as SCI increases, BCS also increases. This outcome can be explained by the fact that a high SCI indicates recent feeding, and frequent feeding leads to weight gain due to the caloric content of the meat, stored as fat or muscle (Leaf & Antonio 2017). The same reasoning is valid the other way around. This expected result seems obvious but is essential to monitor in order to confirm that the lions generally live in a balanced, well managed ecosystem and are healthy. Nothing alters the link between eating correctly and being in good physical condition. With the presence of illness and unhealthy stress, the relationship between BCS and SCI would be less obvious because even when eating, the physical condition, and thus BCS, would show a lower category.

This correlation also holds potential for reserve management. When BCS reaches extreme categories, reserve management could strategically target the SCI to influence the BCS, allowing for adjustments to the lion’s health status when necessary. These adjustments could include increasing the number of prey, for instance, or additional feeding. This approach could offer a way to manage and improve the overall well-being of the lion population in the reserve. However, this remains to be proven with future studies since correlations do not establish causality. Indeed, BCS can be explained by many other elements such as diseases, environmental conditions, or natural disasters.

Sex

BCS does not fluctuate significantly because of sex, but significant differences emerge between the lions present for several years (Luke and females) and the more recently released lion (Himee).

Himee’s BCS consistently remained lower than that of Luke or the females, indicating a poorer physical condition. Over time, Himee’s BCS showed improvement, aligning more closely with the established members on the reserve. This change occurred a few months after the first grouping between Himee and the females (see the orange dot in Figure 9), showing that the stabilisation of BCS between 3 and 4 took time. Yet, the latter is not solely attributed to group dynamics but was influenced by various factors.

The impact of introducing Himee into the reserve was noticeable. Himee was living in a pride with three females before being released onto Zannier Reserve. The isolation from its pride and the introduction to a new environment induced significant stress, consumed a lot of energy and modified the lion's behaviour, increasing his tendency to move around to explore and establish his territory. These elements would tend to reduce its BCS.

Although Himee took several months after his first socialisation with females to increase his BCS, living in a group enhances the rate of hunting success and the competitiveness of the individual against other carnivore species. The BCS will therefore tend to decrease when a lion roams around alone rather than in a pride. Another explanation could be that Himee's initial body condition was simply low at the time of his release, and it took time to stabilise. However, this hypothesis was ruled out because Himee was released with an ideal BCS of 3 after being fed in the boma to increase the chances of success. BCS of 3 maintained stability for 23 days after the release before undergoing any deterioration due long-lasting effect of captivity (Skinner, Tuomi, & Mellish 2015) (Fig. 9).

A similar pattern was observed with the females: they did not show a BCS of 4 after their release in the reserve. However, this event is engulfed in the years for the females because this research considered data from the females over five years, while Himee's data covers only one year. The time before reaching a BCS of 4 was a couple of months longer for Himee compared to the females. This may be due to the females' being part of a pride during the release, a situation that did not apply to Himee. This reasoning does not apply to Luke because he was a cub during the release, and these data were excluded. In contrast, the SCI was not influenced by sex or the introduction of a new lion. Himee demonstrated a similar SCI to the other lions, indicating successful hunting, while its lower BCS suggested higher energy expenditure, possibly due to territory establishment, pride integration, and more energy used to kill prey due to his solitary behaviour at the beginning. In other words, there is high calorie usage but normal calorie intake, resulting in a lower BCS despite a good SCI.

When looking at the relationship between BCS and SCI considering sex, we observe a positive correlation between BCS and SCI for the females and Luke, indicating healthy lions with normal caloric intake and caloric usage. The absence of correlation with Himee explains the situation after a release with a good caloric intake but a high caloric usage, disrupting this relationship. SCI is not the only influencing factor for BCS.

To comprehend the dynamics of BCS and SCI in the studied lion population, it is essential to investigate it over several years. This approach enables the capture of the nuances of their feeding behaviour, considering the impact of external factors, which we will discuss in the next section.

Environmental factors

The investigation of the influence of the moon phase on BCS and SCI yields interesting results. Concerning the BCS, which exhibits variations over long periods, it remains unaffected by the relatively rapid changes in the moon phase. On the other hand, the moon phase could have influenced SCI. The very bright or very dark nights might have had impacted on the hunting behaviour and success of the lions and, consequently, on their SCI. This research proves that there is no influence of the moon phase on SCI in the lions within the Zannier Reserve.

The impact of seasons on BCS and SCI also provides interesting insights. Firstly, seasons do not show any effect on the BCS. Lions in the Zannier Reserve maintain a consistent and healthy BCS, indicating that the population resides predominantly in an ideal physical setting irrespective of seasonal variations. Secondly, SCI displays seasonal fluctuations. During dry summer and dry winter, SCI is similar, but differs from humid summer. SCI is higher during dry seasons (dry summer and dry winter) compared to humid summer, indicating better hunting success. This difference can be explained by four elements. Firstly, the prey population increases during the dry season due to the introduction of prey species, that occurs in every year of the study. A higher number of prey may have facilitated hunting. Indeed, more individuals equals increased hunting opportunities, especially considering that some individuals may have been injured or weakened during transportation. Secondly, during the dry season, the scarcity of water concentrates prey near water points, contributing to more successful hunting, as less time is spent looking for prey. Thirdly, the dry season is characterised by the absence of leaves, enhancing visibility. Improved visibility could contribute to the lions' effectiveness in catching prey. Additionally, reduced grazing and browsing opportunities may render prey weaker, further facilitating the lions' predatory success. Lastly, it is important to consider that the use of camera traps might impact the data collected. Indeed, lions tend to drink less at water points during the humid season following a kill, resulting in fewer pictures with high SCI during this period.

The analysis of the influence of the time of day on BCS and SCI reveals intriguing patterns. BCS exhibits fluctuations between daytime (dawn, day, and dusk) and night-time, with lower BCS observed at night. As discussed previously regarding moon phases, the inherent stability of BCS indicates that significant changes cannot occur rapidly, certainly not within a few hours. It is crucial to note that our observations rely on camera traps. This raises the possibility that skinnier lions may exhibit increased activity at night, possibly influenced by prey behaviour or environmental conditions. Another hypothesis would be that the quality of the pictures taken at night makes assessment of BCS less accurate, thus possibly making us underestimate the latter.

Concerning the SCI over the time of day, we observed a similar result: SCI was lower during night-time than daytime. Given the rapid variations in SCI, occurring within hours, this aligns with the nocturnal hunting behaviour of lions. At night, when lions hunt with an empty stomach, camera trap observations reveal lower SCI as they actively search for prey. When they move to drink during dawn, day, or dusk after a successful kill, they have a full stomach, resulting in an increased SCI.

After examining the impact of environmental conditions on BCS and SCI, we will discuss whether the movement in relation to water proximity is influenced by the BCS and SCI.

Drinking behaviour

As previously mentioned, our method employing camera traps presents a bias since we only observe lions as they pass a camera trap. This bias can potentially influence our results and must be considered during interpretation. However, it is also possible to leverage this bias to analyse the impact of BCS and SCI on the drinking behaviour of the lions. Higher BCS near water points were observed because lions in good condition will stay for a longer time at the water points as they can drink easily and have less reason to move than skinnier lions that need to hunt. Lions exhibiting higher SCI are also observed in proximity to water points, and this observation can be attributed to the physiological response of needing water after a recent kill. Our observations reveal that the volume of water consumed by subjects does not appear to exert a significant influence on BCS and SCI as their category remains the same before and after drinking in a same observation.

Limitations

This study is subject to technological constraints that warrant consideration.

Firstly, the identification of BCS and SCI is subjective, leading to potential variations in interpretation and therefore results depending on the researcher. Additionally, the quality of the camera trap pictures was not consistently optimal for precise BCS and SCI assessments, which might lead to miscategorising. The limitations of camera traps become evident under suboptimal lighting conditions, such as weak light or over-exposure, which may compromise the image clarity and do not allow the accurate BCS and SCI assessment. Factors such as the lion's position in the picture and the presence of environmental elements such as vegetation or stones that obscure parts of the lion's body play a critical role in the examination of BCS and SCI. As a result, a significant portion of BCS and SCI observations have been classified as unknown due to various factors. While camera traps offer certain advantages, they present inherent challenges compared to direct observations, even if the animal can run or disappear quickly in the latter case. The use of infrared cameras and artificial intelligence for the identification of BCS and SCI may improve the process of data collection by making it faster, automatic, and perhaps even more accurate.

Secondly, using camera traps introduces an observational bias influenced by factors such as the camera's location, its orientation, the flash emitted at night, and the number of camera traps deployed. These factors might have a significant impact on the study's results.

Thirdly, with the technical issues encountered with the collars, only the location of the individuals at a certain time was usable. For future studies, it would be interesting to add lion movement to the study using fully working and reliable collars.

Fourthly, the inability to identify individuals among the females hindered the analysis of variations within this subgroup. We could imagine a Bluetooth system which would send information on the individual when the collar passes next to the camera trap or simply collars of different colours. Further research on BCS and SCI within female lions could explore factors such as the presence of cubs, which might influence the mother's BCS and SCI during the first months of the study.

Lastly, the small size of the studied population and its atypical composition, compared to the usual structure of lion groups, limit the generalisability of the findings. Future studies should be considered with larger samples sizes to enhance the robustness of conclusions drawn from the research.

Conclusion

The analyses of body condition score (BCS) and stomach contents index (SCI) in lions yield valuable insights into the health and behaviour within a fenced-off reserve.

To address our research questions, firstly, the study of long-term data on BCS and SCI through camera trap pictures can provide information about the health of lions. The findings reveal a stable BCS with no extreme across all lions, with a healthy broad distribution of SCI. The observed correlation between BCS and SCI suggests that the lions inhabit a balanced, well managed ecosystem and maintain good overall health. Secondly, it was observed that BCS is influenced by the lion's past condition rather than by sex differences. Additionally, we observed that seasons influence SCI. The results show significant differences for BCS and SCI depending on the time of day, which is aligned with the rapid changing nature of SCI but not accurate for BCS, which cannot vary so quickly. In the latter case, it is more likely to reveal a change of behaviour depending on BCS. Conversely, any impact of the moon phase on BCS or SCI was noticed. Thirdly, the drinking behaviour is influenced by BCS and SCI, with both exhibiting higher rates closer to water points.

These findings underline the importance of understanding these elements for effective reserve management, especially in the context of regulating prey populations.

Exploring BCS and SCI shows new opportunities for further investigation. Future studies could compare results across different reserves, with different species and/or add, with the help of new methods, injuries, lameness, etc. of animals, providing valuable information for conservation effort. The development of research in this field is crucial for optimizing reserve management practices.

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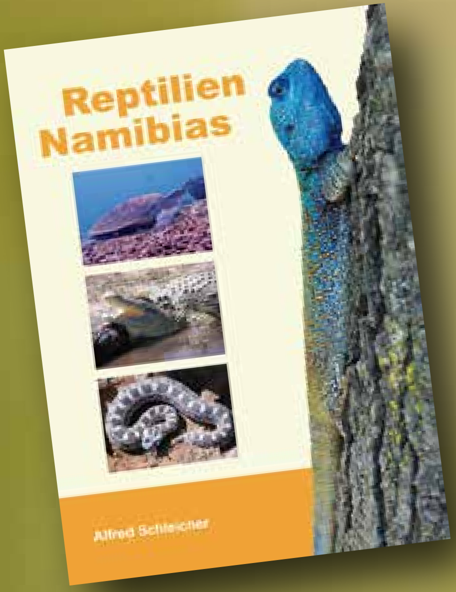
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Beers from malted gluten-free and climate smart pearl millet or sorghum grains: Their physicochemical properties and principal volatile compounds

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Abstract

Omalovu giilya is an opaque beer from Namibia brewed using malts of pearl millet *(mahangu)* or sorghum. There is limited data on physicochemical properties and volatile compounds of *omalovu.* The study investigated the pH, titratable acidity, alcohol, colour, and principal volatile compounds of omalovu brewed using malts of pearl millet varieties (*Okashana 2, Kantana,* and *Kangara*) and sorghum (Macia and a landrace referred to as Red sorghum) varieties. Omalovu was fermented for 9 hours at temperature of 37°C. *Omalovu* pH, alcohol, titratable acidity, and calories were within the reported ranges of other sorghum or pearl millet opaque beers. However, the values of *omalovu* physicochemical properties were generally lower compared to the reference commercial lager beer used. *Omalovu* brewed using the malts of *Okashana 2* pearl millet variety and of *Macia* sorghum variety had significantly higher pH, alcohol, titratable acidity, and calories than all other *omalovu* samples. The compositions of diacetyl, n-propanol, isobutanol, ethyl acetate, amylalcohol, and acetaldehyde in *omalovu* samples were lower or within given range for barley lager beer but were like the values reported for sorghum opaque beer. *Omalovu* brewed using the malts of *Okashana 2* pearl millet variety had a significantly higher 2,3-pentanedione, n-propanol, isobutanol, amylalcohol, and acetaldehyde than other *omalovu* samples. These climate-smart, gluten-free grains can produce beers that with processing optimisation can be of commercial value in the uncertain future battling with climate change effect, and potentially suitable for individuals affected by gluten intolerance and ataxia and celiac issues.

Introduction

Omalovu giilya or omalodu oilya in Oshiwambo, *Chikontini in Sifwe* and *Subia* language in Namibia refers to sorghum or pearl millet malt beers. It is brewed using malts of gluten-free pearl millet (*Pennisetum glaucum* (L.) R.Br.) commonly known as *mahangu* or of sorghum (*Sorghum bicolor* (L.) Moench). It is a heterogeneous, opaque, and unpasteurised low alcoholic beer (Embashu et al. 2019). *Omalovu* is traditionally brewed for cultural occasions such as weddings, birth ceremonies, and thanksgiving (*Oshipe*). Industrial brewing of beers using imported barley malts and other ingredients dominates the Namibian beer market as it does in southern Africa and Africa in general. It is noteworthy that the brewing of sorghum and pearl millet beers hold great significance in the semi-arid and arid regions. This is due to the adaptation of sorghum and pearl millet to growing in dry and hot parts of the earth such as in sub-Saharan Africa. In Africa, some of the countries such as Niger, Nigeria, Mali, Zimbabwe, Ethiopia, Burkina Faso, Cameroon, Mozambique, Angola, South Africa, Botswana, and Namibia produce pearl millet and sorghum (Cruickshank 2016; Taylor 2016). Consequently, these grains hold promise in a future that is faced with climate change. With the threat of elevated temperatures in the future, these cereals can be potentially climate smart as they are able to grow in prevalent semi-arid conditions (Cruickshank 2016; Taylor 2016) and can thus be used industrially in the brewing of beers. Furthermore, they can reduce the importation into Africa of temperate grains such as barley, and the utilisation of locally grown cereals can be diversified in manufacturing value-added products such as beer.

Characteristics of western beers made from especially malted barley have been reasonably well documented (Briggs et al. 2004; Pavsler & Buiatti 2009; Kucharczyk & Tuszyński 2018; Alves et al. 2020). Regarding African beers, most of which are traditionally brewed, there are significant gaps in knowledge although some characteristics such as pH (3.3–4), alcohol (2–4.5% v/v), colour (from pale puff to pink-brown) (Lyumugabe et al. 2012), lactic acid 0.3–0.6%, and solids 4–10% (Rooney 1996) of opaque beer from sorghum have been reported. One of the key gaps in knowledge is on the volatile constituents' fingerprint and characterisation of *omalovu.* For instance, there is limited information on the aroma and flavour compounds in beers brewed using sorghum malt except as reported by Budner et al. (2021) and Lyumugabe et al. (2013) for *ikigage.* Regarding *omalovu* brewed using pearl millet malt, there is little information (Embashu et al. 2019) on the characteristics of this opaque beer and certainly no literature on its aroma and flavour profile and volatile compounds fingerprinting. Therefore, this brief study investigated some physicochemical properties and principal volatile compounds that most likely contribute to the aroma and flavour of *omalovu* brewed using malts of three varieties of pearl millet and two varieties of sorghum.

Material and methods

Grain collection and preparation

Cereal grains (three varieties of pearl millet, namely *Kangara, Kantana,* and *Okashana 2,* and two varieties of sorghum, namely Macia (white) and Red sorghum) were grown and malted as described in Embashu & Nantanga (2019), except that the germination was carried out at 30°C for two days.

Flow process of brewing *omalovu*

Omalovu was brewed following the flow process outlined by Embashu et al. (2019) as shown in Figure 1 with 0.2 % (v/v) *oshikundu* as inoculum.

Physicochemical properties of *omalovu*

The physicochemical properties of *omalovu* from pearl millet and sorghum were determined on fresh and fermented (9 hours) samples. A commercial malted barley lager beer was used as a positive reference.

Determination of titratable acidity and pH

The pH meter (Eutech, Singapore) was used to measure the pH. Titratable acidity was determined following the method reported by Tyl & Sadler (2017).

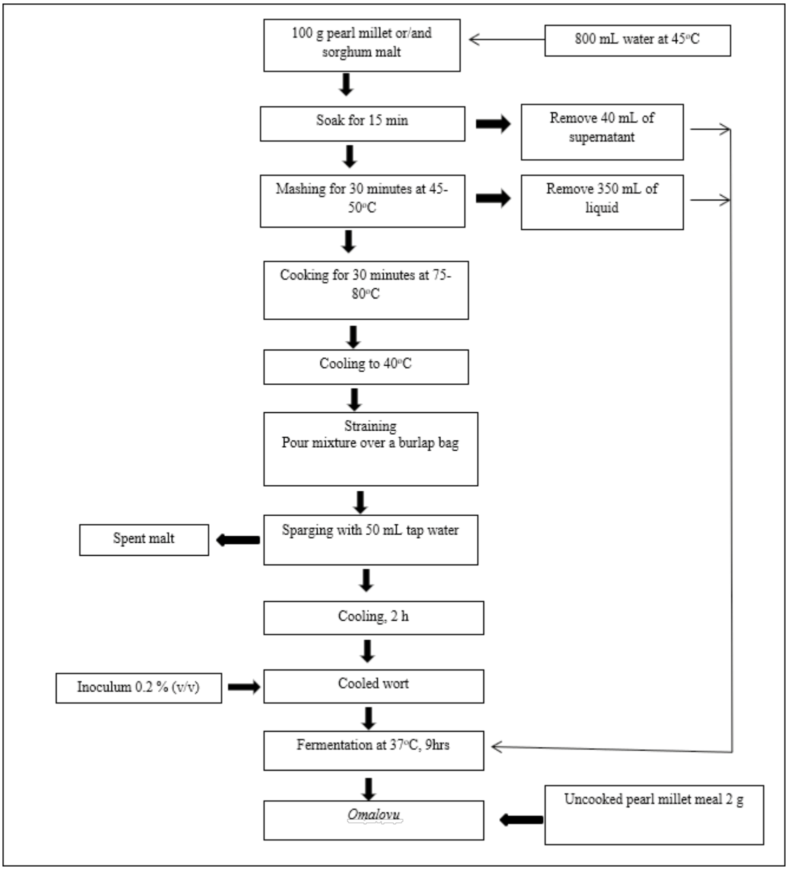

Figure 1: *Flow process of brewing omalovu using pearl millet or sorghum malt*

Determination of alcohol and calories

Alcohol and calories were determined using alcohol analyser (Anton Paar, DMA 4500) by aliquoting 25 mL of *omalovu.*

Determination of colour

The EBC value of *omalovu* was determined according to the standard Analytica-EBC colour measuring method (European Brewery Conversion, 1975). About 3 mL of *omalovu* was transferred by pipette into a cuvette. Absorbance was measured using a UV-Vis spectrophotometer (Thermo Scientific, USA) at 430 nm.

Determination of congeners

Congeners were determined by centrifuging 300 mL of *omalovu.* Internal standards hexanedione, butanol, and heptanone were added and mixed. Then, 2 mL *omalovu* sample was transferred in headspace (Agilent Technology 7697A, China) vials and fractionation was carried out on gas chromatography (Agilent Technology 7890B, China) with flame ion detector (FID) and electron capture detector (ECD). The columns used were DB-wax and DB-5 (Agilent Technology, China) with dimensions 60 m x 530 µm x 1 µL, film 1.00 µm (DB-wax) and 1.50 µm (DB-5).

Statistical Analysis

Grains were malted once and brewing was repeated once (twice replicated brewing) for each of the cereal varieties. All analyses were repeated five times ($n = 6$) except the analyses of congeners which were repeated three times ($n = 4$). The effects of malted pearl millet and malted sorghum on *omalovu* physicochemical properties and congeners were determined using one-way analysis of variance (ANOVA) and Fisher's least significant difference (LSD) test at $p \leq 0.05$ using R software (version 3.5.2, Austria).

Results and Discussion

Physicochemical properties of *omalovu*

Titratable acidity, pH, alcohol content, calories, and colour of *omalovu* are given in Table 1. The pH of wort and *omalovu* differed statistically ($p \leq 0.05$). The pH decreased following fermentation up to 9 hours. The pH values of *omalovu* were within the range of 3.06–4.34 reported by Embashu et al (2019) for sorghum opaque beer. Compared to the reference commercial beer, the pH of *omalovu* was lower. Alcohol was detected in omalovu irrespective of malt cereal used. Among *omalovu,* the samples made using the malt of *Okashana 2* displayed significantly higher alcohol content ($p \leq 0.05$) than all the others. Furthermore, there was a significant difference ($p \leq 0.05$) in the alcohol content of *omalovu* brewed using the pearl millet varieties. These alcohol content findings were within the range of 0.18–5.0% (v/v) reported by Lyumugabe et al. (2012) and Embashu et al. (2019) for sorghum beer. There was no significant difference ($p > 0.05$) in the titratable acidity expressed as lactic acid in wort irrespective of the malted cereals used. However, titratable acidity increased following fermentation. The titratable acidity was in the following order: malted *Kantana omalovu* = malted *Macia omalovu* > malted *Okashana 2 omalovu* = malted *Kangara omalovu* = malted Red Sorghum *omalovu.* These *omalovu* had lower titratable acidity than the reported 1.8% (Quin1959; Taylor & Emmambux 2008) for *bjalwa bja leotsa,* a pearl millet opaque beer. Nevertheless, this study's titratable acidity

Table 1: The pH, alcohol, titratable acidity, calories and colour of wort and omalovu from pearl millet and sorghum malt varieties.

Sample	pH	Alcohol (% v/v)	Titratable acidity (%)	Calories (kJ/100 mL)	Colour (EBC units)
Pearl millet wort					
Malted *Okashana 2*	5.5 ±0.1^{b}	ND	0.1 ±0.0^{c}	88.0 ±8.1^{a}	10.0 ±1.2^{h}
Malted *Kantana*	5.9 ±0.1^{a}	ND	0.1 ±0.0^{c}	69.9 ±0.7^{cd}	17.4 ±1.9^{f}
Malted *Kangara*	5.9 ±0.0^{a}	ND	0.1 ±0.0^{c}	76.7 ±3.4^{bcd}	14.6 ±0.7^{g}
Sorghum wort					
Malted *Macia*	5.6 ±0.1^{b}	ND	0.1 ±0.0^{c}	76.4 ±0.9^{bcd}	27.7 ±0.7^{d}
Malted Red Sorghum	6.0 ±0.1^{a}	ND	0.1 ±0.0^{c}	55.7 ±13.2^{e}	15.0 ±3.4^{g}
Pearl millet beer *(omalovu)*					
Malted *Okashana 2*	3.9 ±0.2^{cd}	0.5 ±0.0^{a}	0.3 ±0.1^{b}	81.7 ±9.3^{ab}	39.6 ±0.1^{b}
Malted *Kantana*	3.9 ±0.01^{de}	0.4 ±0.0^{b}	0.5 ±0.1^{a}	67.5 ±0.7^{d}	52.1 ±0.4^{a}
Malted *Kangara*	4.0 ±0.0^{c}	0.3 ±0.0^{c}	0.3 ±0.0^{b}	80.6 ±1.9^{ab}	34.2 ±2.5^{c}
Sorghum beer *(omalovu)*					
Malted *Macia*	3.8 ±0.1^{e}	0.1 ±0.0^{d}	0.5 ±0.1^{a}	78.5 ±1.1^{abc}	28.9 ±0.9^{d}
Malted Red Sorghum	3.9 ±0.1^{de}	0.1 ±0.0^{d}	0.3 ±0.1^{b}	56.6 ±13.6^{e}	19.3 ±0.8^{e}
Commercial beer	4.2–4.34	4.9			6.80–7.30

Note: values are mean ± standard deviation; values with the same letter in a column are not significantly different ($p > 0.05$); ND, not detected; n = 6.

findings were within the range of 0.3–0.6% reported by Rooney (1996) for sorghum opaque beer. Compared to a commercial lager beer, *omalovu* calories were lower than the range 85–125 kJ/100 mL reported by Briggs et al. (2004) but were within the broader range of 31.1–466.6 kJ/100 mL reported by Hlangwani et al. (2021) for sorghum opaque beer. Malted *Kantana omalovu* had significantly higher ($p \leq 0.05$) EBC values compared to other *omalovu* samples. *Omalovu* had significantly darker ($p \leq 0.05$) colours than their respective worts. The reference commercial beer had a lighter colour compared to all the *omalovu* samples. Perhaps the difference in colour can be attributed to the microfiltration process applied during the processing of the reference commercial beer, which was not applied during the processing of *omalovu.*

Congeners in *Omalovu*

Congeners of the wort and *omalovu* are given in Table 2. All the congeners found in *omalovu* in this study have been reported in malted barley lager beer (Baxter & Hughes 2001; Briggs et al. 2004) and sorghum beer *ikigage* (Lyumugabe et al. 2013). The diacetyl

Table 2: *Congeners of wort and omalovu from pearl millet and sorghum malt varieties.*

Samples	**Diacetyl (µg/L)**	**2,3-Pentanedione (mg/L)**	**DMS (µg/L)**	**n-Propanol (mg/L)**	**Isobutanol (mg/L)**	**Amylalcohol (mg/L)**	**Ethyl acetate (mg/L)**	**Acetaldehyde (mg/L)**
Pearl millet wort								
Malted *Okashana 2*	12.2 ±0.6^{f}	3.6 ±0.4^{c}	ND	ND	6.4 ±0.12^{cd}	ND	ND	ND
Malted *Kantana*	55.5 ±0.8^{a}	3.5 ±0.1^{c}	ND	ND	6.3 ±0.0^{cde}	ND	ND	ND
Malted *Kangara*	43.6 ±1.5^{c}	4.0 ±0.1^{ab}	ND	ND	6.2 ±0.0^{def}	ND	ND	ND
Sorghum wort								
Malted *Macia* (white)	47.2 ±0.8^{b}	4.3 ±0.1^{a}	ND	ND	6.1 ±0.5^{f}	ND	ND	ND
Malted Red Sorghum	47.0 ±0.4^{b}	3.6 ±0.2^{bc}	ND	ND	5.9 ±0.0^{g}	ND	ND	ND
Pearl millet beer *(omalovu)*								
Malted *Okashana 2*	22.0 ±0.8^{e}	2.7 ±0.17^{d}	322.2 ±9.9^{d}	2.3 ±0.5^{a}	7.1 ±0.1^{a}	1.2 ±0.2^{a}	0.08 ±0.1^{b}	2.3 ±0.6^{a}
Malted *Kantana*	56.2 ±1.8^{a}	ND	430.3 ±15.8^{c}	0.5 ±0.8^{b}	6.7 ±0.2^{b}	1.4 ±0.3^{a}	0.2 ±0.1^{a}	ND
Malted *Kangara*	56.9 ±0.1^{a}	3.1 ±0.45^{d}	477.8 ±6.8^{b}	ND	6.4 ±0.1^{c}	0.4 ±0.7^{b}	0.07 ±0.1^{b}	ND
Sorghum beer *(omalovu)*								
Malted *Macia* (white)	8.5 ±1.8^{g}	1.8 ±0.0^{f}	454.9 ±17.7^{b}	ND	6.2 ±0.1^{ef}	ND	ND	ND
Malted Red Sorghum	29.0 ±1.8^{d}	2.3 ±0.1^{e}	561.3 ±21.0^{a}	ND	6.3 ±0.0^{cdef}	0.4 ±0.6^{b}	ND	ND

Note: values are mean ± standard deviation; values with the same letter in a column are not significantly different ($p > 0.05$); DMS, Dimethyl sulfide; ND, not detected; n = 4.

content statistically differed ($p \leq 0.05$) between wort and *omalovu* except that those of malted *Kantana omalovu* remained statistically unchanged ($p > 0.05$) following fermentation. Malted *Kantana* and *Kangara omalovu* had a significantly higher ($p \leq 0.05$) diacetyl content than all the other *omalovu* samples. Diacetyl is attributed to the butterscotch aroma in beers (Krogerus & Gibson 2013). The diacetyl contents of *omalovu* were within the range of 20–80 µg/L reported by Briggs et al. (2004) for malted barley lager beer. However, the diacetyl content of malted *Macia omalovu* was lower than the same reported range by Briggs et al. (2004) for malted barley lager beer following fermentation. The diacetyl content of *omalovu* was lower than 16.3 µ/L reported by Lyumugabe et al. (2013) for *ikigage,* a sorghum opaque beer. Krogerus & Gibson (2013) attributed a toffee-like flavour to 2,3-pentanedione in malted barley lager beer. In this study, fermentation of wort into *omalovu* significantly ($p \leq 0.05$) decreased the content of 2,3-pentanedione regardless of malted cereal used. The 2,3-pentanedione contents were in the following order: malted *Okashana 2 omalovu* = malted *Kangara omalovu* > malted Red sorghum *omalovu* > malted *Macia omalovu* > malted *Kantana omalovu.* The 2,3-pentanedione contents in this study were higher than those reported by Briggs et al (2004) for malted barley lager beer, which ranged between 0.01 and 0.5 mg/L. The contents of diacetyl and 2,3-pentanedione in beers can be attributed to the concentration of wort free amino nitrogen and the amino acids as they influence the formation of acetohydroxy acid that is converted into vicinal dekitones (Briggs et al. 2004). Dimethyl sulfide (DMS) was not detected from wort irrespective of malted cereal used. The DMS content of *omalovu* differed significantly ($p \leq 0.05$), except those of malted *Kangara* and malted *Macia omalovu.* Malted Red sorghum *omalovu* had the highest DMS content. The *omalovu* DMS contents were relatively higher than the range of 30–100 µg/L reported by Briggs et al. (2004) for malted barley lager beer and were also higher than 3.2 µg/L reported by Lyumugabe et al (2013) for *ikigage,* a sorghum beer. DMS content in beers can be influenced by conditions used during malting as they influence the amount of DMS and DMSO formation, conversion of S-methylmethionine (SMM) to DMS during fermentation and temperature during wort boiling and wort stand time (Briggs et al. 2004). The DMS contributes sweetcorn flavour or can smell like cooked cabbage in lager beers, as reported by Briggs et al. (2004). The n-propanol was not detected in any of the worts and in *omalovu* samples produced using malted Red sorghum, malted *Macia,* and malted *Kangara.* N-propanol was detected in malted *Okashana 2* and malted *Kantana omalovu* samples. These samples had lower n-propanol contents than the 5–10 mg/L reported by Briggs et al. (2004) as well as the 114.5–212 mg/L reported by Lyumugabe et al. (2013) for malted barley lager and *ikigage* a sorghum beer, respectively. Isobutanol (2-methylpropoanol) content significantly ($p \leq 0.05$) increased following fermentation. Malted *Okashana 2 omalovu* had a significantly higher ($p \leq 0.05$) isobutanol content than all the other *omalovu* samples. These study findings were within the reported range of 6–11 mg/L (Briggs et al. 2004) for malted barley lager beer. However, these study findings were lower than 24.8 mg/L isobutanol reported by Lyumugabe et al. (2013) and higher than the isobutanol content of 3.1 mg/L reported by Coulibaly et al. (2021) for similar malted sorghum opaque beers *ikigage* and *tchapalo,* respectively. Amylalcohol (3-methylbutanol) was not detected in wort samples and in malted *Macia omalovu.* Coulibaly et al. (2021) also reported similar observation where amylalcohol was not detected in wort of malted sorghum opaque beer *tchapalo.* Amylalcohol contents of *omalovu* were in this order: *Okashana 2 = Kantana > Kangara* = Red sorghum. The amylalcohol content of *omalovu* was lower than 32–85.2 mg/L reported by Briggs et al. (2004) for malted barley lager beer and by Lyumugabe et al. (2013) for a similar malted sorghum opaque beer, *ikigage.* These higher alcohols (n-propanol, isobutanol, and amylalcohol) are common and contribute to the general flowery or solvent-like and alcohol-like aromas in beers. Ethyl acetate was not detected in worts or in malted sorghum varieties *omalovu,* but was detected in malted pearl millet varieties *omalovu* as follows: *Kantana > Okashana 2 = Kangara.* These study findings were lower than 8–14 mg/L reported by Briggs et al. (2004) for malted barley lager beer and 0.7 mg/L reported by Lyumugabe et al. (2014) for similar malted sorghum opaque beer, *ikigage.* The ethyl acetate is generally responsible for fruity aroma or rum-like off-flavours in beers. Acetaldehyde was only detected in malted *Okashana 2 omalovu.* Its content in this study was within the 0–13 mg/L reported by reported by Briggs et al. (2004) for malted barley lager beer and was close to the 0.076 mg/L reported by Lyumugabe et al. (2014) for malted sorghum opaque beer, *ikigage.* Generally, acetaldehyde imparts sourness and unripe apple flavours to beers.

Conclusions

Omalovu pH, alcohol, titratable acidity, and calories were within the reported ranges of other sorghum or pearl millet opaque beers. However, the values of *omalovu* physicochemical properties were generally lower compared to the reference commercial lager beer used. *Omalovu* brewed using the malts of *Okashana 2* pearl millet variety and of *Macia* sorghum variety had significantly higher pH, alcohol, titratable acidity, and calories than all other *omalovu* samples. The compositions of diacetyl, n-propanol, isobutanol, ethyl acetate, amylalcohol, and acetaldehyde in *omalovu* samples were lower or within given range for barley lager beer but were similar to values reported for sorghum opaque beer. *Omalovu* brewed using the malts of *Okashana 2* pearl millet variety had a significantly higher 2.3-pentanedione, n-propanol, isobutanol, amylalcohol, and acetaldehyde than other *omalovu* samples. These climate-smart grains can produce beers that with processing optimisation can be of commercial value in the uncertain future battling with climate change effect.

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About the Author

Sarah N.P. Nengola is a pharmaceutical marketing and sales representative at Erongomed. Her position focuses on bringing awareness to affordable medication from which different communities can benefit. Sarah received a distinction in her undergraduate research project on molecular identification of lactic acid bacteria from sorghum and pearl millet beer. She graduated with a BSc (Hons) Biomedical in Applied Biochemistry from the University of Namibia.

Annastasia K. Ekandjo is a Senior Technologist and PhD candidate in the Department of Biochemistry, Microbiology, and Biotechnology at the University of Namibia. Her PhD research utilises Omics technology to conduct a comprehensive molecular characterisation of drought-tolerant plants. Focusing on transcriptomic and metabolomic analyses, her study aims to uncover underlying mechanisms of drought tolerance. Annastasia holds an honours degree in Biochemistry and Chemistry and a Master of Science degree in Industrial Biochemistry, both from the University of Namibia.

Werner Embashu is a senior researcher at the Multidisciplinary Research Services unit of the University of Namibia. His research focuses on improving nutritional, functional, and sensory qualities of food. Werner received a PhD from the University of Namibia.

Komeine K M Nantanga, who holds a PhD from the University of Guelph, Canada, is an Associate Professor of Food Chemistry and Processing Engineering at the University of Namibia. He is a member of the South African Association for Food Science and Technology, and of the Cereals & Grains Association (formerly the American Association of Cereal Chemists (AACC International)).

His research interests include connecting community diets to their underlying scientific and technological principles to improve the quality of life through intelligent consumption of foods. His key focus on food security is directed at understanding the safety of nutritious foods, especially those that are indigenous, in order to develop shelf-stable varieties for consumers from different socio-economic sectors.

Technical and research services rendered to some of the major food industries and laboratories in SADC, Canada, Croatia, and the USA have provided him with experience in dealing with diverse audiences. He has encouraged the development of learners by sponsoring floating trophies in Mathematics, English, and the Sciences in several education circuits and schools in the Oshana and Oshikoto regions of Namibia.

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