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Citizen Science

The Virtual Museum: an African biodiversity database holding more than two million records

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Abstract

This paper describes the history of the Virtual Museum, originally developed in 2005 for the Southern African Reptile Conservation Assessment (SARCA), which was sponsored by the South African National Biodiversity Institute (SANBI). The Virtual Museum grew to encompass 17 sections and the associated database, in 2023, contained 2.2 million biodiversity records from Africa. We summarize the major outputs of this initiative, and discuss potential future uses of the database.

Introduction

In a nutshell, the Virtual Museum is a database containing a collection of photographs with metadata for each record. Boxes 1 and 2 contain a sample of Virtual Museum records. The core components of the metadata for each record consist of the date of observation, the coordinates of the observation, the species and the observer. Each record has up to three photographs. This contrasts with a real museum, where the photographs for a record are replaced with a specimen, a preserved form of a real animal. The records in the Virtual Museum do not lose colour nor shrink, as museum specimens do, but photographs cannot be used for DNA samples. Thus, photographic records do not replace the value of historical specimens, but rather complement them by capturing additional context such as habitat and behaviour.

The purpose of this paper is to describe the origins of the Virtual Museum, and to track some of its history and achievements.

History

The Virtual Museum is the outcome of four factors: (1) SANBI's requirement for the Steering Committee of the Southern African Reptile Conservation Assessment (SARCA) that the project needed to have a "citizen science" component; (2) The development of the digital camera; (3) The availability of GPS units to citizens; (4) Domestic access to the internet.

In 2005, James Harrison was project coordinator for SARCA in the Animal Demography Unit at the University of Cape Town. He had to solve the problem of involving citizen scientists in a project with a big snake component. Together with Graham Alexander at the University of the Witwatersrand, they grasped that factors (2), (3) and (4) combined could meet his need for a solution to factor (1). Rene Navarro, coauthor of this paper, turned the concept into a computer system, and has continued to maintain the software, upgrading it at intervals to new platforms.

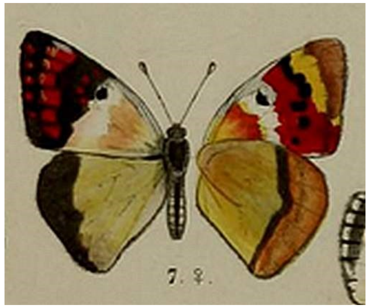
When SARCA started in 2005, both GPS units and digital cameras were expensive. Additionally, early digital cameras had relatively poor resolution and were regarded as substandard relative to film

BOX 1

Pieter Cronje's photograph of the Somali Lilac Tip, Magadishu, Somalia, 5 December 2017. LepiMAP record 635642.

In December 2017, citizen scientist Pieter Cronje, in his official capacity as a human rights lawyer, was training members of the Somali Civilian Oversight Board, people who visit police detention facilities to monitor police behaviour and human rights violations. He was based within the Green Zone near the international airport in Mogadishu, Somalia. As a citizen scientist, he was frustrated to be confined to this high-security area, but made the most of the opportunity. He managed to photograph this butterfly on Zinnea flowers – there were few flowers – and submitted it to LepiMAP. Fanie Rautenbach identified it as the Somali Lilac Tip *Colotis praeclarus*.

It seems that this is the first photographic record of this butterfly. The only other image is in the paper with the original description of the species (Butler 1885). Arthur Butler was based at the British Museum in London and was reporting on a collection of butterfly species received from a plateau south of Berbera on the Gulf of Aden. He was greatly excited by this new species: "This is one of the most distinct, beautiful, and at the same time interesting species yet discovered." Pieter Cronje's record at Magadishu is c. 900 km south of the original record. We paraphrase Arthur Butler's excitement to state: "This is one of the most remarkable records in the Virtual Museum." This butterfly is safely archived in LepiMAP; there are two more photos here.



The only other image of Somali Lilac Tip, an illustration in the original description of the species (Butler 1885).

cameras. The Virtual Museum established for SARCA in 2005 was, globally, the first project of its genre (de Villiers et al. 2008, see Figure 1). The prototypes of both iSpot and iNaturalist were launched in 2008 (Clow & Makriyannis 2011, Mesaglio & Callaghan 2021).

In 2005, when the Virtual Museum commenced, home access to the internet in southern African was still in its infancy, and for those who were connected, internet access was cumbersome, expensive, and extremely slow via a system popularly known as "dial-up". ADSL connection to the internet started to become available to domestic users from about 2007 and was widespread by about 2010. However, the ADSL system used the standard copper cables of landline phones, and thus was relatively slow. It was not until about 2018 that optical fibre connections started to become commonplace in the suburbs of South African cities.

The reptile atlas, SARCA, was the trigger that got the Virtual Museum started; Virtual Museum records comprised 5% of the 136,000 records on which the reptile atlas distribution maps were based (Bates et al. 2014). However, the contribution made to SARCA cannot be measured simply in terms of the percentage of records in the database that came from the Virtual Museum. 55% of the specimen records which the reptile atlas was based on had been collected by 1960 and were therefore half a century out of date. By contrast, the Virtual Museum records were made during the period of the project (2005–2009) and presented reliable evidence that a species was still present in an area. Most of the Virtual Museum records were either the first records for a species in a grid cell, or "refreshed" previous specimen records, many of which, as noted above, were decades old.

Two years after the start of SARCA, the reptile alas, SANBI initiated a parallel project for butterflies, the Southern African Butterfly Conservation Assessment, known as SABCA. For this butterfly atlas, a duplicate of the Virtual Museum software was created in 2007 to consolidate and curate all available data, including the citizen science component. This created the challenge of needing to change both sets of software as developments were added; the solution was to write a single piece of software that could maintain datasets for as many taxa

BOX 2

Spesbona (previously known as the Ceres Streamjack) *Spesbona angusta* was described in 1863; it was first discovered along streams near Ceres, Western Cape. It was last recorded there in 1920. When it was next searched for in this area, it was found that it had been radically transformed and many of the streams no longer flowed due to over-extraction of water for the fruit industry. So for the next eight decades it was considered to be extinct Then, in November 2003, a population was found along the Dutoitsrivier, which flows into the Theewaterskloof Dam, near Villiersdorp. This locality is 60 km distant from the original Ceres locality. From 2003 onwards the OdonataMAP database contains multiple sightings in this new area. For more than a decade, it was believed that this was the only locality where the species occurred.

Then, on 10 October 2017, citizen scientist Jean Hirons caused a massive surprise when she submitted this photograph to OdonataMAP, quickly identified as Spesbona. This record was from a locality near Sedgefield, 330 km due east of the Theewaterskloof site. This was an astonishing range extension. Since the locality has been discovered, Spesbona has been found there annually. This raises the question: does Spesbona occur at a series of intermediate localities, in suitable habitats along the mountain ranges between Ceres and Sedgefield? The likely answer is yes; in fact Spesbona has subsequently been discovered at a several intermediate locations, with the most recent being on 29 September 2023 near Somerset West, Western Cape (OdonataMAP record 141749).

Jean Hiron's 330-km range extension of the distribution of Spesbona is one of the most fascinating records in OdonataMAP.

Virtually First: An Online Museum of Reptiles of South Africa, Lesotho and Swaziland

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South Africa, Lesotho and Swaziland have an extraordinary diversity of reptiles: approximately five times the number of species expected on the basis of land area, with over 1/3 of species endemic to the region. Yet reptiles are traditionally overlooked in conservation plans. This is partly due to a shortage of resources for adequate monitoring, but also due to the poor public image of this faunal group. The Southern African Reptile Conservation Assessment (SARCA) has addressed these issues through the creation of a novel tool – an online Virtual Museum (VM). This makes use of open source software - mySQL provides the database backend, and the front end was written entirely in PHP. Photographs of reptiles are submitted by the public via email, along with basic information in a simple format. Submissions are processed, locality information verified and photos edited, before uploading onto the project's website (http//:sarca.adu.org.za). Species identifications are then made by a panel of experts. VM records feed into a larger database of reptile distribution records, compiled from museum and other collections and from published literature. Real-time distribution maps are available online. In the three years since its launch, SARCA's VM has received 5000 submissions (comprising 4.3% of the distribution database) from about 400 contributors. Results of a questionnaire indicated that wildlife enthusiasts submitted most records, and amateur naturalists were most responsible for promoting the VM to other people. A moderate to considerable increase in knowledge or appreciation of reptiles as a result of the VM was indicated by most respondents (57% and 72%, respectively). Submissions include new distribution records, including records of seldom seen fossorial species; records of rare or threatened species; records of species' range extensions; and records of unusual colour morphs. Map coverage by VM records is fair, and concentrations of VM records correspond with those received from other sources (e.g. museum collections). SARCA's VM has been so successful that it has been adopted by the Southern African Butterfly Conservation Assessment and the concept has also been adapted for the South African National Survey of Arachnida. However, the future of these VM's beyond the projects of which they are a part has yet to be resolved. If they are continued, then consideration should be given to advances in technology (such as cell phone technology) that would further automate the sending, processing and uploading of submissions.

Figure 1: Abstract of presentation by de Villers et al. (2008) at 6th World Conference on Herpetology. Extracted from https://www.worldcongressofherpetology.org/_files/ugd/924435_509218d2d04342c7873e9efee6bc8d45.pdf

as would need atlas projects. Ultimately, 17 sections were developed (Table 1).

The same general data pattern observed for the reptile atlas also occurred for the butterfly atlas (Mecenero et al. 2013); 4% of the 337,000 records on which the butterfly atlas maps were based were Virtual Museum records. 30% of the atlas records had been collected

Table 1: The 17 sections within the Virtual Museum, the year in which they started, the number of photographic records uploaded to each section by September 2023. The other records include specimen records from museums, records from private collections (LepiMAP), literature records, and, in the case of PHOWN, information on date and place of breeding digitized from nest record cards (Underhill et al. 1991).

Section	Start	Photographic Records	Other Records	Total
ReptileMAP	2005	54,438	136,290	190,728
LepiMAP[1]	2007	289,868	335,196	625,064
OdonataMAP	2010	138,302	121,120	259,422
PHOWN[2]	2010	25,605	6,088	31,693
MammalMAP	2010	45,549	551,775	597,324
FrogMAP	2010	14,361	42,462	56,823
TreeMAP	2010	33,112	316	3,3428
BirdPix[3]	2012	256,036	2	256,038
EchinoMAP[4]	2012	2,184	44	2,228
BOP[5]	2012	638	0	638
SpiderMAP	2013	18,685	778	19,463
ScorpionMAP	2013	5,510	0	5,510
LacewingMAP	2014	5,450	12,898	18,348
MushroomMAP	2014	14,786	0	14,786
OrchidMAP	2014	9,672	1	9,673
DungbeetleMAP	2015	3,966	24,216	28,182
FishMAP	2015	1,811	0	1,811
Total		919,973	1,231,186	2,151,159

[1].LepiMAP includes the Lepidoptera as a whole, both butterflies and moths
[2].PHOWN is the acronym for PHOtos of Weaver Nests
[3].BirdPix contains photographs of African birds
[4].EchinoMAP includes all the Echinoderms, i.e. the starfish, sea-urchins, brittle-stars, etc.
[5].BOP is the acronym for Birds with Odd Plumages

prior to 1960. This percentage is less than the 55% for the reptile atlas because members of the Lepidopterists' Society of Africa (LepSoc), which was founded in 1983, contributed 121,000 records (36%), mostly from personal specimen collections assembled since the formation of LepSoc. These records were digitized as part of the butterfly atlas project.

The first taxon to be added to the unified Virtual Museum software platform was for the Odonata (dragonflies and damselflies) in 2010 (Table 1). This was created as an informal and internal project with the purpose of demonstrating the software's capability to handle more than two taxa. This was followed by a project with the acronym PHOWN (PHOtos of Weaver Nests), under the leadership of Dieter Oschadleus, also in 2010. The innovation of this section of the Virtual Museum was that it contained records of structures created by animals—in this case, the nests built by weavers—rather than the animals themselves.

The next section to be added was a mammal atlas project for Africa, sponsored by USAID and led by Dr Tali Hoffman, who coined the term MammalMAP. MammalMAP was subsequently subsumed into the mammal Red List project undertaken by SANBI and the Endangered Wildlife Trust, where it was responsible for contributing distribution maps to the Red Listing effort. More than 551,775 records of mammal distribution in southern Africa were uploaded into the database from a variety of sources. In addition, 45,549 photographic records have been added to the MammalMAP database (Table 1).

The invention of the portmanteau word "MammalMAP" led to the abandonment of acronyms to name projects, so that SARCA evolved into ReptileMAP, and SABCA to LepiMAP (which included all lepidoptera, including moths). The project for dragonflies and damselflies was given the name OdonataMAP.

A frog atlas had been compiled over the period 1996 to 2003, based on both historical records (mainly from museums and the literature), and on contemporary fieldwork (Minter et al. 2004). The assembled database of 42,536 records was uploaded in 2010 to a section of the Virtual Museum called FrogMAP. This enabled the ongoing collection of photographic records of frogs in anticipation of a second frog atlas (Underhill et al 2013). By September 2023, a total of 14,361 photographic records had been added to this database, an increase of 34%.

BirdPix, a collection of bird photos, was launched in 2012. It was planned as a service to SABAP2 (Second Southern African Bird Atlas Project) (Brook et al 2022, Lee et al. 2022), with the primary motivation of providing a repository for the photographs submitted by atlas observers to confirm the identify of submitted records for which an algorithm had generated "Out of Range Forms" (i.e. the species listed by the observer had not previous been recorded at the place, and confirmation of identification was required). However, BirdPix quickly grew into a photographic atlas of bird distribution records. By September 2023, it contained 256,000 records (Table 1), with most countries in Africa represented.

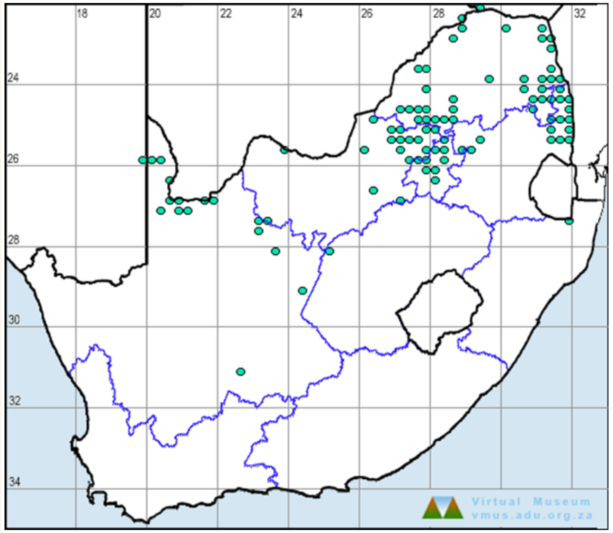
Subsequently, the Virtual Museum hosted initiatives for a variety of taxa, mostly instigated by societies or individuals (Table 1). Projects that produced summaries included OdonataMAP (Underhill et al. 2016, Loftie-Eaton et al. 2018) and LacewingMAP (Underhill et al. 2019).

The Virtual Museum database for dragonflies and damselflies, OdonataMAP, received funding from the JRS Biodiversity Foundation. Among its achievements are the production of an online atlas of the dragonflies and damselflies of South Africa (including Lesotho and Eswatini) (Tippett et al. 2023). Each of the species texts has sections on identification, habitat, behaviour, status, distribution and phenology. The advantage of the online format is that text and especially the distribution maps can be updated to include incoming data.

The online atlas of the dragonflies and damselflies contained two innovations. One was an interpolated map based on the actual distribution records, which suggested the grid cells in which the species might be present, provided those grid cells contained suitable habitat. The mapping algorithm, which lacks a published description, took ac-

BOX 3

Birds have wings and fly, so vagrancy is commonplace. But, at face value, we would not anticipate an African Grey Hornbill *Tockus nasutus* in the arid Karoo; it is a species whose preferred habitat is tall savanna woodland (Herremans 1997). But, as Herremans (1997) also points out, "It is mobile and becomes gregarious and nomadic in the dry season." Citizen scientist Sybrand Venter, a farmer near Carnarvon, found this species on his farm on 6 June 2023. There was not just one bird, but a small group. They were not totally out of appropriate habitat, because the farmyard area where they were found is a typical Karoo farm, with a garden and many trees This spot is about 200 km south of the nearest record of African Grey Hornbill. Potentially, the habitat around Karoo farmhouses provides stepping stones for birds to cross otherwise inhospitable habitat.



https://vmus.adu.org.za/?vm=BirdPix-256051

count of the number of records of all species of dragonflies and damselflies in neighbouring grid cells on a distance-weighted basis. In well covered areas, there was little or no interpolation; in poorly covered areas with few records, the interpolation was more liberal. The algorithm took no account of habitat. As an extreme example, the actual records for Spesbona *Spesbona angusta* are sparsely distributed (Figure 2). However, as a consequence of the relatively small number of records in OdonataMAP for parts of the Western Cape coastal plain, the adjoining mountain ranges and the southern Karoo, the algorithm generates Figure 3 as the interpolated distribution map for Spesbona. Much of this estimated range can be trimmed away on habitat considerations, but it also indicates that searches in suitable habitat (for example, along the mountain chains) would be valuable. As the algorithm suggests, the occurrence of Spesbona in these areas cannot be dismissed. A general increase in sample sizes in the entire region will reduce the tendency for the algorithm to extend into inappropriate areas.

The second innovation in the dragonfly and damselfly atlas is an attempt to generate phenologies of species flight periods. The 59 records of Spesbona in the Virtual Museum were classified into number of records per pentade (five-day periods starting 1 July (Figure 4)). The smoothed line through these points suggests that the bulk of the flight period is in the months September to December, with a peak in late October. This provides guidance on the best period for fieldwork in search of this species.

Contributions

This section discusses some of the applications of the data within various sections of the Virtual Museum, beyond those of the funding mandates.

Of all the sections of the Virtual Museum, it is PHOWN that has generated the largest number of publications and products (Table 2). Of the 30 papers listed in Table 2, 10 make contributions to understanding the biology of weavers, and 16 discuss weavers as ecological engineers. This term was first used in the context of weaver nests by

Table 2: References to the PHOWN project of the Virtual Museum in the literature. The papers are classified into four focus categories: W=biology of weavers; EE=ecological engineering, i.e. other species gaining benefits from weaver nests; P=project promotion and report back; R=external recommendation.

Title	Category	Reference
Make a PHOWN call	P	Underhill 2010
Trapped! Weaver nests as death traps	W	Oschadleus 2012a
Variation in colony sizes and nest sites in weavers.	W	Oschadleus 2012b
Photos of Weaver Nests: PHOWN progress report to December 2012	P	Oschadleus & Underhill 2013
Bird nests in museum collections: a rich resource for research	W&R	Russell et al. 2013
Weavers: Africa’s awesome research opportunity	W&P	Underhill & Oschadleus 2012
PHOtos of Weaver Nests. Why PHOWN?	P	Oschaeleus 2014
Roadside densities and variation in nest size and structure of Sociable Weaver colonies near Prieska, Northern Cape, South Africa	W	Oschadleus & Harebottle 2014
Spotted Eagle-Owl nesting on top of Sociable Weaver nest	EE	De Swardt 2014
Not so friendly neighbours: Pygmy Falcon eating Sociable Weaver nestling	EE	Spiby 2014
Breeding data on the birds of Namibia: laying months, colony and clutch sizes and egg measurements	EE	Brown et al. 2015
Weaver nests as a resting site for frogs	EE	Oschadleus 2015a
Range limits of the Sociable Weaver	W	Oschadleus 2015
Southern Masked Weavers nest earlier in suburban than rural areas	W	Oschadleus et al. 2015
Cape Sparrows using weaver nests	EE	Oschadleus & McCarthy 2015
Number of nests owned by individual Cape Weaver males	W	Oschadleus & Werner 2015
Cape Weaver nesting association and interactions with waterbirds	EE	Krochuk & Oschadleus 2016

Table 2 (continued): References to the PHOWN project of the Virtual Museum in the literature. The papers are classified into four focus categories: W=biology of weavers; EE=ecological engineering, i.e. other species gaining benefits from weaver nests; P=project promotion and report back; R=external recommendation.

Title	Category	Reference
Nesting association between weavers and warblers	EE	Oschadleus 2016a
Nesting associations between vultures and weavers	EE	Oschadleus 2016b
Brant's Climbing Mice using weaver nests	EE	Oscadleus 2016c
Weaver nests as novel food sources for birds	EE	Engelbrecht 2017
Cheetahs utilising Sociable Weaver structures at Tswalu Kalahari Reserve	EE	Lowney & Charlton 2017
Birds and animals using weavers' nests	EE	Oschadleus 2017
Cape Sparrows roosting in Cape Weaver nests in Cape Town.	EE	Oschadleus et al. 2017
Common Fiscal pecking Cape Weaver nest	EE	Schultz 2017
Birds adopting weaver nests for breeding in Africa	EE	Oschadleus 2018
Raptors breeding on weaver nests in trees and on man-made structures	EE	Oschadleus 2019
Editorial. The value of citizen science projects to African ornithology	R	Harebottle 2020
Variation in colony sizes of weavers from a citizen science project	W	Oschadleus 2020
History and biology of the reassigned Ruvu Weaver *Ploceus holoxanthus*	W	Oschadleus et al. 2021
Convergent evolution of elaborate nests as structural defences in birds	R	Street et al. 2022

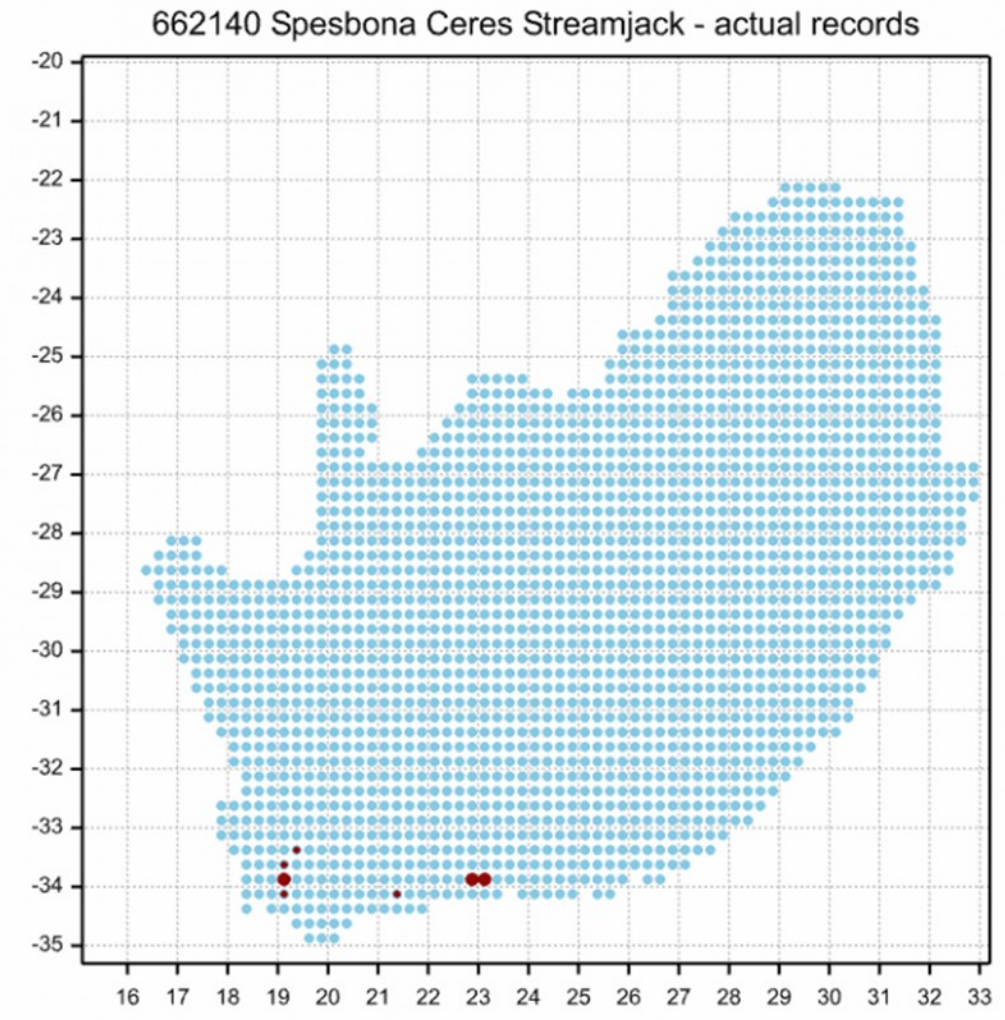


Figure 2: Actual distribution of Spesbona (Tippett et al. 2020).

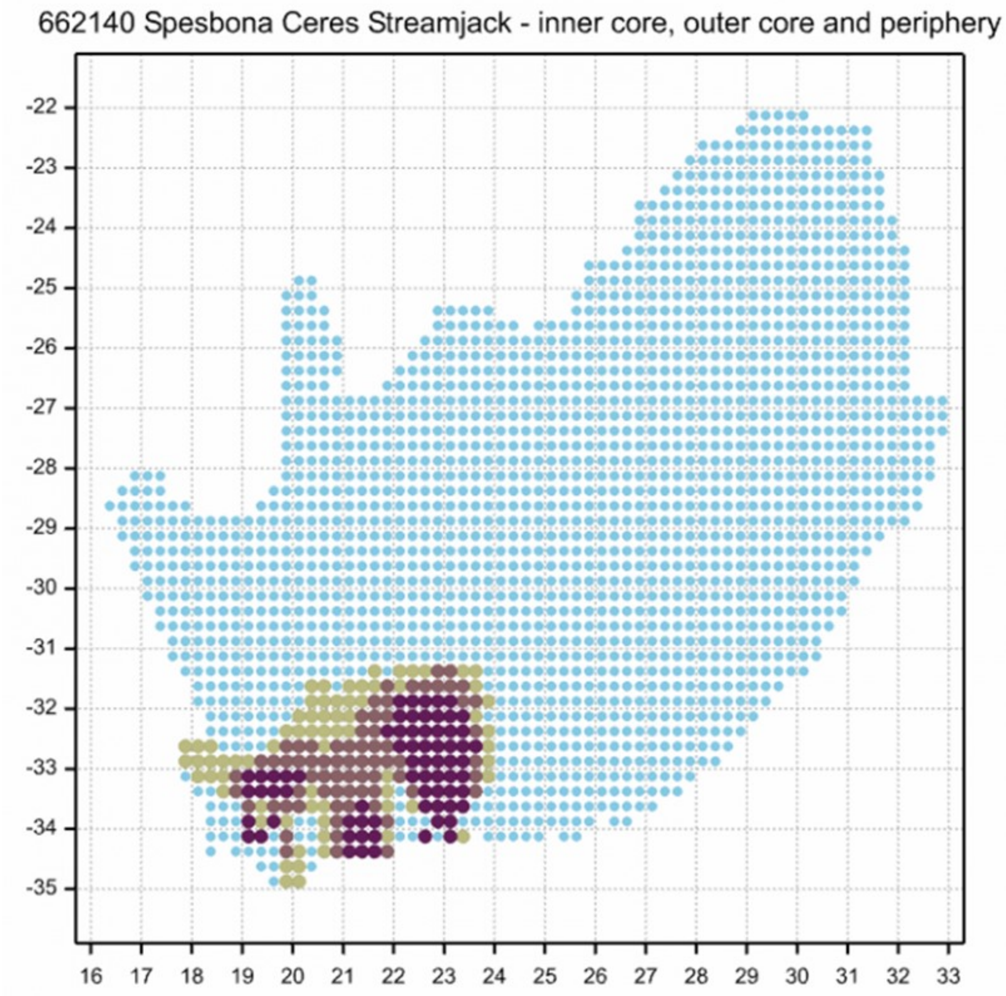


Figure 3: The interpolated distribution of Spesbona (Tippett et al. 2020).

Lowney & Thomson (2021); the concept includes the beneficial use of the nests of multiple weaver species by mammals, reptiles, insects and other bird species. The remaining papers in Table 2 either promote citizen scientist contributions to the project or recommend it as a valuable data resource.

Species lists for regions and localities have been compiled using data from LepiMAP (butterflies and moths of Robben Island, Loftie-Eaton et al. 2016), and OdonataMAP (Table 3). A biodiversity survey of the Hans Hoheisen Wildlife Research Station near the Orpen Gate of the Kruger National Part used data from 15 of the 17 sections of the Virtual Museum (Oschadleus 2016d). The photographic records in BirdPix have been extensively used in bird identification guides. Daniel &

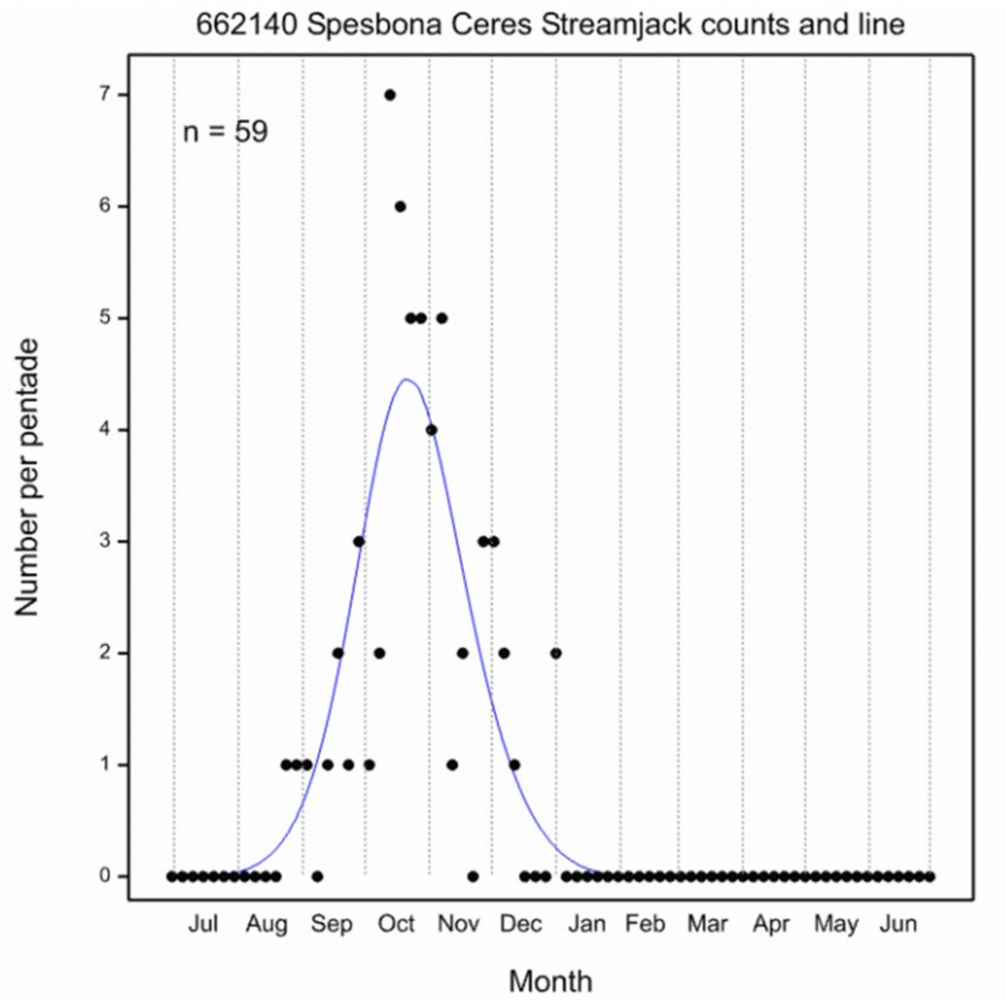


Figure 4: The number of records of Sesbona per pentade (defined as five-day periods starting 1 July. There are 73 pentades in the year. The blue curve is generated by an algorithm which performs local smoothing (adapted from Summers et al. 1992) (Tippett et al. 2020).

Loftie-Eaton (2023) developed an identification guide for the birds of suburban gardens in Cape Town, and the format used in this guide is being steadily extended on the website of the Biodiversity and Development Institute (BDI Admin 2023). BirdPix also played a key role in documenting the period during which an out-of-range Red-billed Oxpecker *Buphagus erythrorhynchus* remained at a site (Meléndez-Arteaga et al. 2023). EchinoMAP provided distribution records for a monograph on the brittle stars and basket stars of South Africa (Olbers et al. 2019). Records from Nigeria within BirdPix and LepiMAP have been summarized by Ringim et al. (2020) and Ringim et al. (2022) respectively.

Various sections of the Virtual Museum have been recommended and acknowledged in field guides: OdonataMAP by the dragonfly and damselfly guide (Tarboton & Tarboton 2019), which also made extensive use of the photographs in OdonataMAP, MushroomMAP by the mushroom guide (Goldman & Gryzenhout 2019), LepiMAP by the butterfly guide (Woodhall 2020) and the moth guide (Staude et al. 2023), and ScorpionMAP by the field guide to the scorpions (Engelbrecht 2023).

Discussion

Table 3: Species list for regions and localities, compiled from the OdonataMAP database.

Title	Reference
A dragonfly and a damselfly on Robben Island: preliminary results from OdonataMAP	Underhill 2016
Kenyan dragonflies: Past, present and future	Njoroge et al. 2017
Dragonflies and damselflies of the Western Cape – OdonataMAP report, August 2018	Underhill et al. 2018a
Odonata of the Kruger National Park	Underhill et al. 2018b
Dragonflies and damselflies of the KhoiSan Karoo Conservancy	Tippett & Underhill 2022
Dragonflies and damselflies of the Lower Olifants River Valley: Citrusdal to the sea.	Tippett et al 2022

Gamification

Although the Virtual Museum aims to curate accurate coordinates for records, it operates on the traditional quarter degree grid system in use over much of southern Africa. This facilitates gamification (Ainsley & Underhill 2117), a built-in motivation to achieve an objective. One of the best examples of gamification is the "frequent flyer" programmes of airlines. The objective of the airline is passenger loyalty, and the frequent flyer programme achieves this by awarding free flights to people who have completed a pre-determined number of paid-for flights on the airline. The strategy is to play mind games with people: "Should I stick with the airline of my frequent flyer programme, or should I take a flight on a cheaper airline?" Once an individual has paid money to be loyal to the airline, it increases their determination to take more flights with the same airline in order to get the free ticket. In the case of the Virtual Museum, the objective is coverage, obtaining data from as many regions as possible. Thus, grid-based coverage maps provide motivation to citizen scientists to visit grid cells with no records, or only a small number of records.

Additionally, there is a second category of gamification employed by the Virtual Museum. For each species in each grid cell, the data of the most recent record is provided. As this date recedes into the past, it provides a motivation for observers to "refresh" the species in the grid cell. The observer's challenge becomes trying to rediscover the species in the grid cell. This element of gamification adds value by keeping the data up-to-date. If a species has been searched for and not recorded, the possibility of local extinction needs to be considered.

The long-term value of photographic records in relation to climate change

Many of the Virtual Museum images show not only the object of interest, but also the context. This contrasts with a specimen museum, where the specimen is entirely removed from its habitat. In the face of climate change, it is likely that, ultimately, one of the Virtual Museum's biggest contributions to science will be the habitat in the background of species photographs. In this respect, it is important to encourage participants in the Virtual Museum to include an element of the habitat in which a species was recorded when they crop and submit their images.

Mapping scales

The fundamental spatial scale underpinning the Virtual Museum data has been the 15-minute grid widely used for mapping biodiversity in southern Africa. This generates the so-called quarter degree grid scale, with 16 cells per degree. The bonus of georeferencing observations as accurately as possible is that it becomes feasible to produce maps at alternative scales.

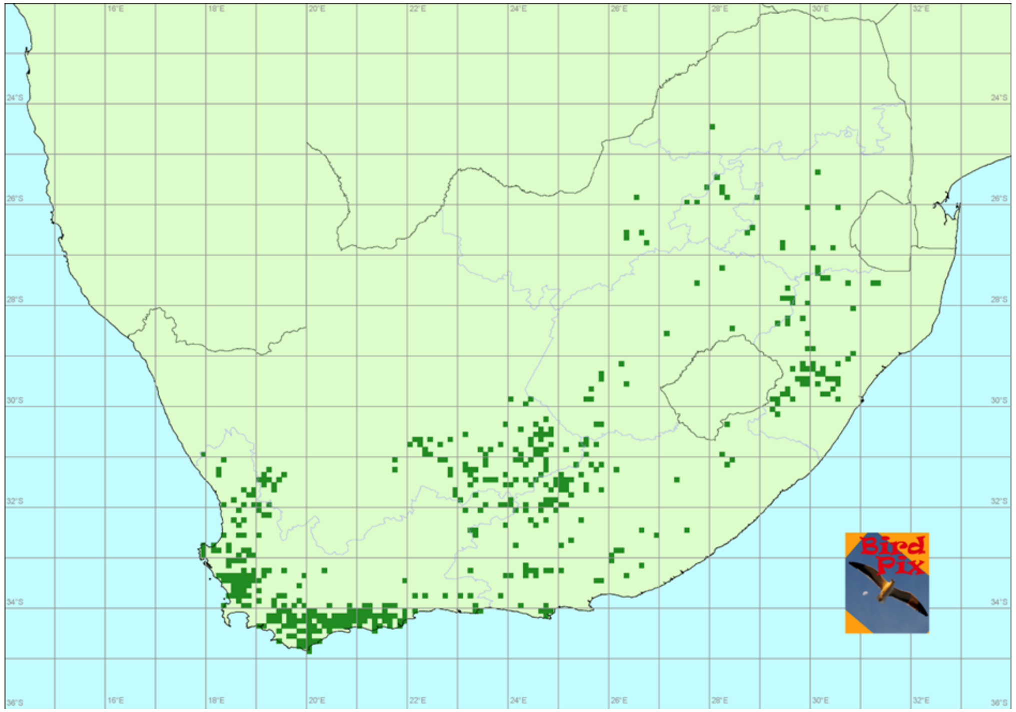


Figure 5: Presence-absence distribution map for Blue Crane on one-tenth degree grid scale, based on 949 records in the BirdPix section of the Virtual Museum.

BOX 4

This is record 15379 from LacewingMAP. The photograph was taken by Jessica Kemper, a citizen scientist from Lüderitz, in southwestern Namibia on 24 July 2018. It was on the edge of a patch of *Gazania jurineifoliais* in flower on the Lüderitz Peninsula in the Namib Desert.

Merwyn Mansell, for whom the lacewings have been a career, stated that it belongs to the genus *Palmipenna* (Underhill et al. 2019). He went on to comment: "This is doubtless an undescribed species, remarkable for its early appearance (July) and its close proximity to the sea. This record was a total surprise. It is the farthest north that this genus has ever been recorded, and the second record of this genus from Namibia. Previous records of this genus were almost exclusively from the Western Cape, South Africa. It resembles *Palmipenna palmulata*, but this species is only known from two populations in Western Cape. This is a fantastic record!"

In September 2023, the LacewingMAP database contained 18,348 records; 12,898 specimen records built up by Mervyn Mansell from museum collections worldwide, and 5,450 photographic records, submitted since LacewingMAP started nine years ago. That is 610 records per year, about three times faster than the rate of growth of the specimen database. LacewingMAP has made a huge contribution to our knowledge of the distributions of this important group of insects (Underhill et al. 2019).

The Second Southern African Bird Atlas Project chose to use a five-minute grid; this was constrained by the need to be compatible with the first atlas. This scale generated nine grid cells (called pentads) per quarter degree grid cell, and 144 pentads per degree cell.

If we could start afresh, a sensible choice would be a one-tenth degree grid, or six minutes. This generates 100 grid cells per degree cell. The georeferencing of the Virtual Museum data enables such maps to be made. An example is provided in Figure 5, which shows the presence-absence distribution of the Blue Crane *Anthropoides paradiseus* on the one-tenth degree grid scale. The map is based on 949 records and successfully portrays the current distribution of this species.

Additional uses of the Virtual Museum database

These paragraphs suggest three ways in which the Virtual Museum can be used. The first is a potential strategy to supplement the database of a different project. The second and third are examples of ways in which the information contained in the images can be used in research projects.

Bird atlas projects are traditionally built on sight records, with citizen scientists submitting checklists of birds seen and identified. Participation is effectively restricted to people who are able to identify the birds of their region in the field. The African Bird Atlas Project (ABAP) follows this pattern (Brooks et al. 2022). In many parts of Africa, there are relatively few observers with sufficient confidence in their bird identification skills to submit checklists to the ABAP. There is the potential to broaden participation by enabling people to contribute to the project through uploading photographs of birds to the BirdPix section of the Virtual Museum (Underhill & Brooks 2016). These can be cell phone photographs; for a photographic submission to be included in the Virtual Museum, the only criterion is that the species can be identified. This identification is done by expert panels. The Virtual Museum, through BirdPix, provides a potentially valuable strategy for additional observers to make a substantial contribution to the bird atlas project.

The Birds with Odd Plumage (BOP) section of the Virtual Museum was conceived as an archive of birds with atypical plumage; it was not anticipated to generate scientific results. This idea is challenged by two recent papers: Zbyryt et al. (2021) attempted an analysis of internet-mined photographs of birds with plumage colour aberrations in Poland, and Aguillon & Shultz (2023) have suggested that studies of such birds could improve our understanding of the evolution of the colours and patterning of birds. The 638 records in BOP (Table 1) provide a curated resource for such studies.

Leighton et al. (2016) used internet-mined photographs to examine geographical patterns in colour morphs; one of their case studies was the distribution of dark and light morphs of the Black Sparrowhawk *Accipiter melanoleucus*. At that point in time, the BirdPix section would have contributed only 38 records to their database of 139 usable images sourced from the internet. In 2023, there were 366 photographic records of this species in BirdPix. Future studies of colour morphs of African bird species are likely to find that the Virtual Museum provides a useful starting point.

Conclusion

The Virtual Museum was the first project of its genre. The information it has collected has made a substantive contribution to our understanding of biodiversity in Africa. It provides a platform which enables citizen scientists, members of the public, to contribute to biodiversity mapping projects. It has built in systems which help direct people to areas where the database is weakest, and where records are most in need of being updated.

We cannot conserve Africa's biodiversity effectively if we do not know where species occur. Up to date distribution maps are key for species conservation. The realm of biodiversity conservation is no longer only the responsibility of professional scientists and game rangers; everybody has their part to play. The Virtual Museum enables people to participate.

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