CITIZEN SCIENCE:
THEORY AND PRACTICE

Temporal Dimensions of Data Quality in Bird Atlases: the Case of the Second Southern African Bird Atlas Project

COLLECTION:
CONTRIBUTIONS OF CITIZEN SCIENCE TO THE UN SDGS

RESEARCH PAPER

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ABSTRACT

Halting biodiversity loss on land (Sustainable Development Goal [SDG] 15) is an unfolding problem, and as such, requires novel solutions. Citizen science (CS) promises large quantities of data, but introduces the challenge of ensuring these are valuable to conservation research and can inform meaningful action. This paper contributes to this endeavour, examining the impact of systematic as opposed to unstructured fieldwork on the biodiversity monitoring value of data from the Second Southern African Bird Atlas Project (SABAP2). SABAP2 "atlasers" work within a fine-scale grid system to generate avian species checklists that are comprehensive at the time of fieldwork. Though valuable, unstructured fieldwork efforts paint an incomplete picture; effective conservation action requires monitoring—keeping a finger on the pulse of local biodiversity through consistent and systematic data collection. Systematic collection allows for the detection of nuanced biological patterns such as seasonal population trends and movements, rapidly alerting scientists to anomalies and galvanizing swift response. It is, however, a demanding protocol, and implementation requires careful consideration of participant impact and motivations. Here, we used a newly developed approach for measuring temporal data quality to examine the systematic atlasing efforts of a CS community in the Hessequa Atlasing Area, South Africa, assessing the biodiversity monitoring value of structured data collection versus opportunistic checklists. We found that structured data collection increased the temporal resolution of atlas data, and thus its monitoring quality. We discuss challenges in maintaining achievable fieldwork goals for participants, and examine Hessequa's project structure and participant motivations to provide recommendations for future project management.

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KEYWORDS:
Data quality; temporal proximity; biodiversity monitoring; systematic fieldwork; social impact

TO CITE THIS ARTICLE:
Daniel, KA and Underhill, LG. 2023. Temporal Dimensions of Data Quality in Bird Atlases: the Case of the Second Southern African Bird Atlas Project. *Citizen Science: Theory and Practice,* 8(1): 31, pp. 1–17. DOI: https://doi.org/10.5334/cstp.578

INTRODUCTION

Conservation is context-dependent; novel problems require novel solutions, and the analysis of citizen science (CS) data is no exception. As technological advancements rapidly expand the field of CS, scientists are faced with previously unmatched quantities of raw data at unprecedented scale, and are tasked with learning how to utilise these to maximise their potential conservation impact. While the scientific value of CS data rests in whether they are amenable to statistical analysis and able to generate defendable scientific outputs, it is equally important to consider the sociocultural value of CS and the impact of a CS initiative on its participants. In this study, we seek to further discussions on both concepts.

CITIZEN SCIENCE AND CONFRONTING BIODIVERSITY LOSS

Among the 17 Sustainable Development Goals (SDGs) outlined by the United Nations (UN), SDG 15 sets a target of halting biodiversity loss. Recent outputs from The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biolgocial Diversity (CBD) Kunming-Montreal Global Biodiversity Framework draw attention to a widespread need for the involvement of "the whole of government and the whole of society" in combatting the global biodiversity crisis and achieving SDGs (CBD 2022). This spotlight on collective action arrives at an opportune moment, corresponding with a rise in scientific understanding and implementation of CS initiatives (Follett and Strezov 2015). CS as a discipline serves at least two purposes: It opens the door for public participation in scientific research (Bonney et al. 2009b) and amasses data in quantities and over spatial and temporal scales not achievable by scientists alone (Dickinson, Zuckerberg, and Bonter 2010; Chandler et al. 2017). CS has already contributed towards the monitoring needed for achieving SDG targets (Fraisl et al. 2020); however, beyond data output, a collective action approach requires an equal consideration of the personal and social dimensions of CS participation (Bonney et al. 2009a,b; Phillips et al. 2019). What motivates citizen scientists to participate, and how can scientists support these motivations to ensure project sustainability? Such questions mark a movement away from viewing CS as crowdsourcing and towards exploring its broader potential; no longer only data collectors, citizen scientists are included as co-creators in project design, data analysis, and even policy implementation (Thornhill et al. 2019; Hidalgo et al. 2021). Targets identified in the Kunming-Montreal Global Biodiversity Framework also emphasize a need to understand the social and cultural implications of collective action; within the context of CS, we ask, what are the personal and community-level impacts of participation, and how do these contribute to social change?

CITIZEN SCIENCE IN SOUTHERN AFRICA: SABAP2

Within southern Africa, long-standing contributory CS projects such as the Second Southern African Bird Atlas Project (SABAP2, http://sabap2.birdmap.africa) have generated vast quantities of valuable species distribution data and have served as subjects for an extensive body of research (Harrison et al. 2008; Hofmeyr, Symes, and Underhill 2014; Underhill 2016; Burman et al. 2018; Lee et al. 2022). SABAP2 utilises a systematic, protocol-based collection methodology in which citizen scientists operate within a grid system to compile species checklists that are comprehensive at the time of fieldwork. Many aspects of the atlas are designed for ease of statistical analysis: It operates on a pentad scale (144 pentads per 1-degree square), a spatial unit which is five minutes north to south and five minutes east to west (roughly 9 km × 8 km) (Underhill 2016). This scale was carefully selected to balance manageable spatial coverage within a minimum two-hour protocol while producing fine-scale knowledge of species presence (Underhill 2016). Participants are encouraged to explore each pentad as thoroughly as they can, searching for bird species in as many habitat types as possible.

Once a pentad is populated with a small number of seasonal bird atlas checklists, all species that are regularly part of its avifauna are likely to be detected, and by default, the remainder of the world's avifauna are listed as "not occurring" regularly in the pentad. Hence, once data collection coverage is comprehensive, distribution maps produced by bird atlas data can be regarded as accurate.

Traditionally, bird atlas projects for a region have had time frames measured in years, with the goal of obtaining as complete coverage as possible within the project time period, which is frequently five years, as for the First Southern African Bird Atlas Project (SABAP1; 1986–1990) (Harrison et al. 2008). SABAP1 provided a snapshot of bird distributions for this time period. The Second Southern African Bird Atlas Project (SABAP2) launched in July 2007 and was initially intended to provide a similar snapshot that could be used for comparison with SABAP1. However, SABAP2 ultimately morphed into a long-term monitoring project, ongoing in 2022. At 15 years, it is the longest-running atlas project in the world; however, SABAP2 cannot be classed as a monitoring project because it does not employ the repetitive and regular fieldwork necessary for detecting trends through time (Tulloch et al. 2013). Paired with systematic fieldwork efforts, SABAP2 offers an opportunity to undertake long-term spatial monitoring at a sub-continental scale, providing critical baseline data necessary for understanding changes in local avian biodiversity (Boakes et al. 2010; Pocock et al. 2018; Altwegg and Nichols 2019). This paper describes a fieldwork strategy that has already been trialed, and discusses this strategy from two perspectives: (1) the quality of data it generates, and (2) sustainability in terms of human resource management, leadership, and motivation.

TEMPORAL PROXIMITY AS A MEASURE OF CONSERVATION RELEVANCE

Though fine-scale species lists are excellent resources, their value to applied conservation is mediated by recency. Biodiversity monitoring requires constant database refreshing to ensure that any action taken will be relevant at the time of implementation (Tessarolo et al. 2017); high-resolution temporal data are necessary for detecting population trends (Dennis et al. 2017; Horns, Adler, and Şekercioğlu 2018; Fink et al. 2020), analysing phenology (Mayer 2010; La Sorte, Tingley and Hurlbert 2014; Supp et al. 2015; Bison et al. 2019), detecting invasive species (Pocock et al. 2017; Grason et al. 2018; Moulin 2020), and examining detection probability (de Solla et al. 2005). In this regard, SABAP2 pentads with recent checklists are of greater value than pentads with old checklists (Callaghan et al. 2019). SABAP2 checklists, however, remain opportunistic, since pentads are not necessarily atlased with regularity, and the relevance of data from a given region corresponds directly to the collection efforts of local citizen scientists. This poses the challenge of obtaining data of monitoring value from a semi-structured CS protocol; along with other dimensions of sampling bias (Courter et al. 2013; Bird et al. 2014; Isaac et al. 2014; August et al. 2020; Di Cecco et al. 2021; Bowler et al. 2022), consistency of sampling effort remains a critical component in generating early warnings (Kamp et al. 2016; Brown and Williams 2019). We examine the potential for systematic fieldwork to address this challenge and improve the temporal resolution of regional SABAP2 data.

MATERIALS AND METHODS

ATLASING AREAS

Eleven atlasing regions were selected for comparison with the region of interest, Hessequa, on the basis of geography, comparable size, and atlasing effort (Table 1). Eight of these regions (GG1-8) fall within Greater Gauteng; an area defined as four one-degree grid cells that cover Gauteng Province as well as parts of Limpopo, North West, Mpumalanga, and the Free State (Ainsley 2016). The remaining three regions, Western Overberg, Garden Route, and Northern Swartland, are within the Western Cape. All eleven regions are roughly equivalent in size to Hessequa (75 pentads): each of the eight Greater Gauteng regions contains 72 pentads, Western Overberg contains 79 pentads, Northern Swartland contains 77 pentads, and Garden Route is the largest, containing 99 pentads.

It is important to note that additional data such as the number of atlasers and consistency of atlasing effort are not easily estimated for all of the eleven regions selected for comparison. Because Hessequa and the eight Greater Gauteng regions were part of intentional data collection challenges, we have a clearer knowledge of participation and effort in those regions during those challenges. However, apart from Hessequa, data collection efforts in all other regions remain largely uncoordinated, with no consistent motivational strategy in place (Table 1). In all regions with periods of intentional data collection, opportunistic checklists (i.e., full-protocol checklists completed by visitors and ad-hoc species records) were also accepted.

Hessequa Atlasing Area

The 75 pentads of the Hessequa Atlasing Area (Hessequa) closely follow the boundary of the Hessequa Municipality on the western edge of the Garden Route. The northern pentads of Hessequa are bordered by the Langeberg mountain range, and the southernmost pentads reach the sea. Though pentads in the north and south contain natural vegetation, the majority of Hessequa consists of

ATLASING REGIONS AND FIELDWORK STRATEGIES.

REGION	PENTADS	FIELDWORK STRATEGY
Hessequa	75	Systematic atlasing, community and scientific leadership
Greater Gauteng (GG1–8)	72	Sporadic atlasing challenges, scientific leadership
Northern Swartland	77	No coordinated atlasing
Garden Route	99	No coordinated atlasing
Western Overberg	79	No coordinated atlasing

Table 1 Note no official coordination or systematic data collection strategies were used in the Northern Swartland, Garden Route, or Western Overberg regions.

agriculturally transformed land, used for both crops (barley, canola, wheat) and livestock farming (cattle and sheep).

Fieldwork efforts in Hessequa were erratic from the launch of SABAP2 in 2007 until 2014, when local atlasers began pursuing seasonal monitoring targets across two-year cycles (van Rooyen and Underhill 2020). The monitoring strategy began with a chessboard pattern for the region, dividing the atlasing year into four austral seasons: Summer (December—February), Autumn (March—May), Winter (June—August) and Spring (September—November). Over a two-year period, the black pentads of the chessboard received fieldwork in summer and winter during the first year and autumn and spring during the second year, and vice versa for the white pentads. In this way, every pentad was scheduled to produce a checklist in every season by the end of a two-year atlasing cycle, with structure to the patterning of the seasonality.

Efforts were coordinated by Johan van Rooyen, leader of the local U3A Stilbaai Bird Group. van Rooyen, a keen atlaser, introduced the idea of an atlasing project by hosting a trial atlasing day, dividing participants into six groups and sending each out with at least one experienced birder to compile a bird checklist in different parts of the same pentad (van Rooyen, personal communication). van Rooyen explains the four groups together compiled a list of more than 100 species, and those who enjoyed the experience committed to atlasing a certain number of pentads each year, while those who wished to participate but lacked sufficient bird identification skills were encouraged to join with experienced birders and work towards atlasing independently. A core group of 17 atlasers formed, along with several occasional participants. van Rooyen communicated extensively with core members, detailing which pentads needed to be surveyed each month. Atlasers then selected and volunteered to survey pentads in each season and were updated continuously on progress towards achieving monitoring targets. Participation remained voluntary and locally organised, and participants were free to back out if or when desired (van Rooyen, personal communication).

Greater Gauteng Regions

The four-degree area containing the eight Greater Gauteng regions (25°S 27°E northwest corner; 27°S 29°E southwest corner) has been extensively atlased since the launch of SABAP2 in 2007. The four degrees are centred around the cities of Johannesburg and Pretoria and encompass a range of urban and peri-urban habitats. Regional atlasing efforts can be largely attributed to a collection of CS challenges initiated in the area; these included goals of atlasing each pentad in the four degrees once every year, and even once every month (Ainsley 2016). In 2016, focus shifted to a seasonal timescale, attempting to atlas every pentad twice in both summer and winter of each year (Ainsley and Underhill 2017). Though the eight regions continue to generate large quantities of data, coordination of atlasing effort was and remains minimal, and data collection cannot be considered systematic.

Northern Swartland

The Northern Swartland is a block of 77 pentads with 33°S 18°E in the northwest corner and 33°30′S 19°E in the southeast corner. Moorreesburg and Hopefield are the largest towns within the boundaries, and most of the land in the region is transformed to arable agriculture, with wheat and canola as primary crops. The western edge of the region contains the natural vegetation of the West Coast National Park. No coordinated atlasing or systematic data collection efforts have been implemented in the region.

Garden Route

The Garden Route consists of 99 pentads with 33°40′S 22°E in the northwest corner and 34°15′S 23°30′E in the southeast corner. It contains the land south of the Outeniqua mountain range, with Mossel Bay, George, and Knysna as its main population centres. Land cover varies from natural vegetation (ranging from Mountain Fynbos to indigenous forests) to commercial plantations and both arable and pastoral agriculture. No coordinated atlasing or systematic data collection efforts have been implemented in the region.

Western Overberg

The Western Overberg contains 79 pentads with 34°S 19°E in its northwest corner and 34°35′S 20°E in its southeast corner. The main towns within the boundaries are Caledon, Hermanus, and Gansbaai. The region is mostly transformed for agriculture, more arable than pastoral, with some tracts of natural vegetation (mountain fynbos and renosterveld). No coordinated atlasing or systematic data collection efforts have been implemented in the region.

DIMENSIONS OF DATA QUALITY

The focus of this paper is a comparison of systematic fieldwork and non-systematic fieldwork, specifically in what ways the systematic fieldwork in Hessequa differs from non-systematic fieldwork elsewhere. While not all are explicitly discussed here, it is necessary to acknowledge some of the significant factors impacting CS data quality. Among others, these include four biases identified by Isaac et al. (2014): (1) uneven temporal intensity of records, (2) uneven spatial coverage, (3) uneven sampling effort per visit, and (4) variation in volunteer ability to detect species. Here, we examine only the temporal intensity, or "recentness" and spatial coverage of SABAP2 data in each of the eleven selected regions. Several studies have stressed the importance of structuring and monitoring a CS initiative's data collection process to limit potential bias (Hugo and Altwegg 2017; Kelling et al. 2019; August et al. 2020; Di Cecco et al. 2021); the design of SABAP2 is intended to minimise uneven spatial and sampling bias as well as species misidentification. Gamification encourages atlasers to regularly visit both new and "home" pentads (Ainsley and Underhill 2017), and the strict collection protocol standardises fieldwork effort and limits participation to birders with strong identification skills. Though no dataset can be considered watertight, it is assumed that these elements of project design reduce potential variation in SABAP2 data (Bird et al. 2014; Kelling et al. 2019). Though the SABAP2 protocol addresses spatial, sampling, and detection biases, it does not fully address the problem of temporal quality; citizen scientists are under no obligation to refresh species lists in specific pentads (though this is encouraged). Thus, we limit the focus of our analysis to temporal quality.

MEASURING TEMPORAL QUALITY

Advocates of systematic fieldwork may reasonably expect that, across all pentads in a region, species occurrence records are, on average, more recent than with non-systematic fieldwork. For any one species recorded in a pentad, the critical date is its most recent record (Callaghan et al. 2019); as that date recedes farther into the past, the less likely it is that the species persists in that pentad. We first calculate the date of the most recent record for each species recorded in the pentad. This information is then summarized by calculating the median of these dates of the most recent record (we use the median date in preference to the mean date because it is a robust measure of the central point of the dates). This median date provides a simple summary of the recency of the species records for the pentad. Finally, we calculate the median of the median dates for all the pentads in the region. This date provides us with an estimate of the overall temporal quality of the bird atlas data for the region (Underhill, unpublished).

This final date is then compared with the date on which the calculations were undertaken. This difference in dates, measured in days, is small if, overall, the records for species in the region are recent, and it is large if, overall, the records are old. We coin the term "temporal proximity" to describe this quantity. Thus, small values of temporal proximity indicate good data quality, and large values indicate poor quality. Again, it is important to note that these characterizations refer only to the temporal quality of data.

For each region described above, we calculated temporal proximity at the end of each year from 2009 to 2021, using the SABAP2 data collected up to that point in time. Using the ggplot2 package (Wickham 2016) in R (R Core Team 2020), we plotted the values of this time series as a line graph for each region. Additionally, we calculated the number of checklists submitted to the project in each year from 2009 to 2021 for each region; we plotted these as a histogram, with the colour intensity of the bars describing the percentage of pentads within the region visited in that year.

RESULTS

In the Hessequa region, fewer than 80 checklists per year were submitted between the years 2009 and 2014 (Figure 1). At the end of 2012, the year with the smallest number of checklists, the temporal proximity was 730 days (Table 2). In other words, on 31 December 2012, the median of the 75 temporal proximities of the pentads within the Hessequa region was 730 days.

From 2015 to 2021, the number of checklists for the region increased to between 200 and 300 per year (Figure 1), and the overall temporal proximity for the region improved to periods of between 127 and 244 days. The motivational strategy used by the leadership of the Stilbaai Bird Group resulted in every pentad being surveyed in every quarter; there were no gaps in the data. We discuss this aspect of project sustainability below.

By contrast, the Western Overberg, for example, mostly received between 200 and 300 checklists per year between 2009 and 2021; the temporal proximity shows a long-term deterioration from 113 days in 2009 to 967 days in 2021 (Table 2, Figures 1 and 2). Similar patterns of gradual deterioration in temporal proximity over the full 12-year span are apparent when comparing the remaining 10 regions with Hessequa (Table 2, Figures 2 and 3).

The same pattern emerges when this analysis is performed on checklists for the austral spring (September to November) (Table 3, Figures 4, 5 and 6). At the end of 2021, of the 10 regions compared with Hessequa, only Greater Gauteng Region 4 (GG4) had a temporal proximity comparable with Hessequa (473 versus 403 days) (Table 3, Figures 7 and 8), even though the number of spring checklists submitted for GG4 far exceeded the number submitted for Hessequa (390 versus 59; Figure 5).

The inescapable conclusion is that systematic atlasing in Hessequa significantly impacted the temporal proximity of data when compared with eleven thoroughly—but non-systematically—atlased regions (Tables 2 and 3). Additionally, the improvement in temporal proximity through systematic atlasing is achieved with far smaller amounts of fieldwork than in the other eleven regions (Figures 1, 4, 5 and 8).

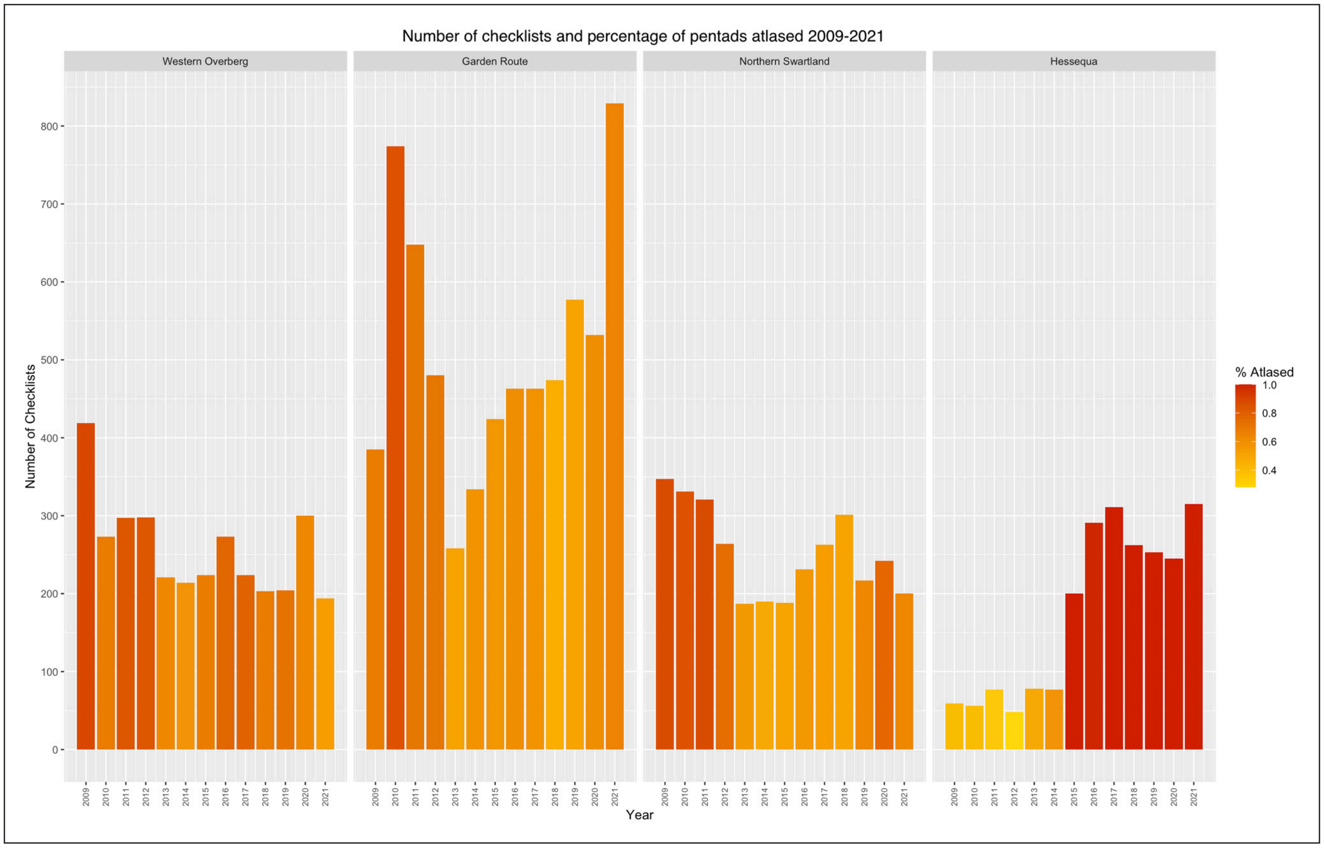

Figure 1 Atlasing effort (number of checklists) and regional coverage (percentage of pentads atlased) in Hessequa and three Western Cape regions between 2009 and 2021. Darker colour indicates more complete coverage.

ANNUAL TEMPORAL QUALITY FOR SABAP2 DATA FROM 2009–2021.

YEAR	HESSEQUA	WESTERN OVERBERG	GARDEN ROUTE	NORTHERN SWARTLAND	GG1	GG2	GG3	GG4	GG5	GG6	GG7	GG8
2009	271	113	69	96	150	138	207	103	188	196	82	198
2010	375	336	96	145	124	83	120	299	132	84	160	195
2011	471	244	222	180	247	340	267	328	91	232	172	135
2012	730	253	343	310	422	376	370	302	270	301	228	317
2013	386	451	506	458	464	304	376	276	386	438	364	390
2014	359	755	557	666	609	334	388	227	324	334	275	325
2015	146	591	507	743	443	372	358	175	404	404	249	394
2016	127	493	586	545	368	482	484	214	613	400	346	586
2017	139	470	645	674	646	592	652	246	623	500	380	623
2018	232	679	1003	772	928	652	753	297	692	674	365	688
2019	221	735	1208	822	774	585	666	359	441	684	349	751
2020	244	847	1264	455	827	502	680	334	663	729	500	760
2021	228	967	368	697	852	476	741	442	824	765	557	950

Table 2 Note units are days prior to 31 December of the year in the row (see text). Large values represent poor temporal quality.

Notes: SABAP2: Second Southern African Bird Atlas Project.

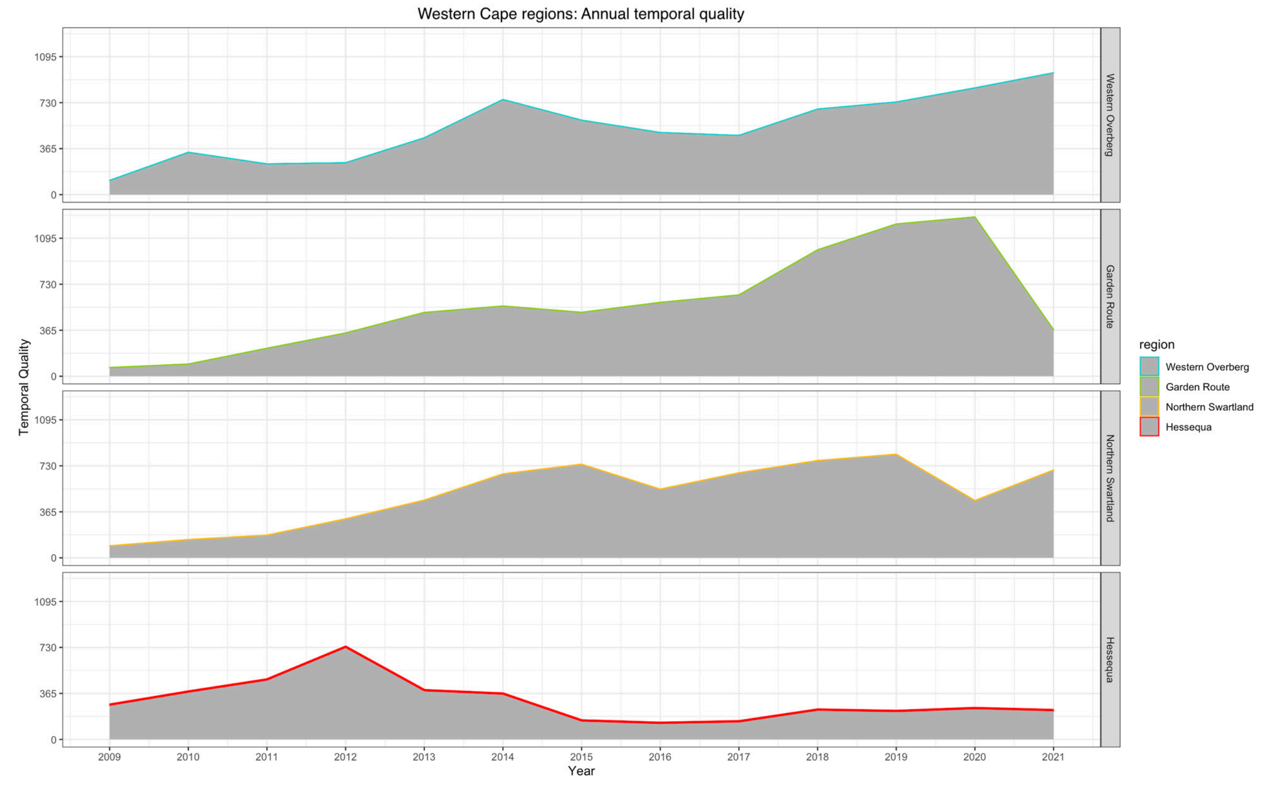

Figure 2 Temporal proximity for Hessequa and three Western Cape regions between 2009 and 2021 (see also Table 2).

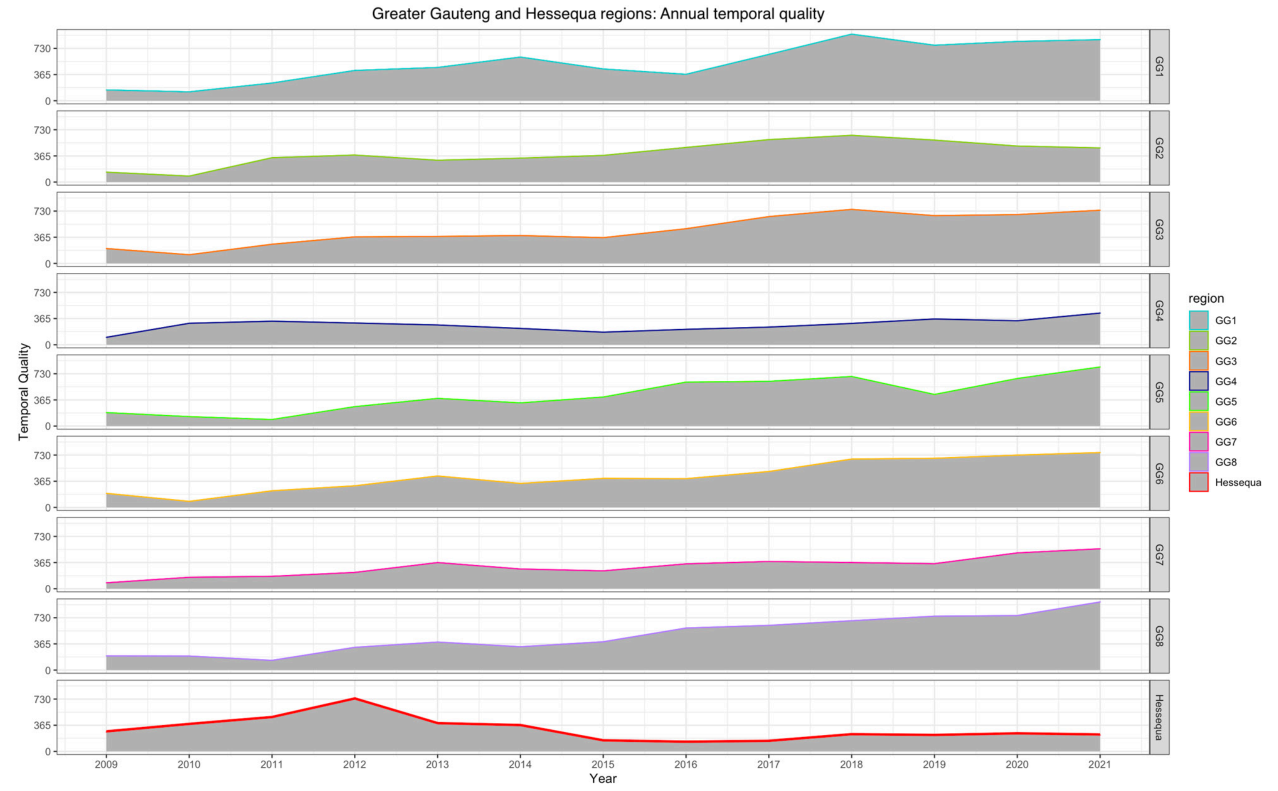

Figure 3 Temporal proximity for Hessequa and eight Greater Gauteng regions between 2009 and 2021 (see also Table 2).

SPRING TEMPORAL QUALITY FOR SABAP2 DATA FROM 2009–2021.

YEAR	HESSEQUA	WESTERN OVERBERG	GARDEN ROUTE	NORTHERN SWARTLAND	GG1	GG2	GG3	GG4	GG5	GG6	GG7	GG8
2009	111	73	61	79	85	94	89	82	82	89	58	110
2010	468	409	68	397	75	85	75	405	69	68	258	114
2011	467	182	411	260	399	408	427	763	91	56	400	84
2012	833	421	444	428	418	766	766	113	428	412	95	408
2013	843	455	783	465	465	413	479	408	432	480	415	764
2014	1184	802	1133	824	774	463	428	115	480	436	407	816
2015	106	1162	1168	1166	810	775	452	96	625	446	436	1146
2016	400	1206	1202	1502	833	816	766	111	769	766	722	1203
2017	233	778	1548	1135	1184	1155	784	401	812	768	836	1501
2018	409	824	1582	1199	1209	1180	841	401	840	806	820	1528
2019	407	1150	1864	1528	1544	1506	1129	451	814	781	477	1530
2020	406	1186	1537	1130	829	1132	814	444	798	820	770	1515
2021	403	1536	817	848	1153	776	1158	473	1140	825	818	1216

Table 3 Note units are days prior to 31 December of the year in the row (see text). Large values represent poor temporal quality.
Notes: SABAP2: Second Southern African Bird Atlas Project.

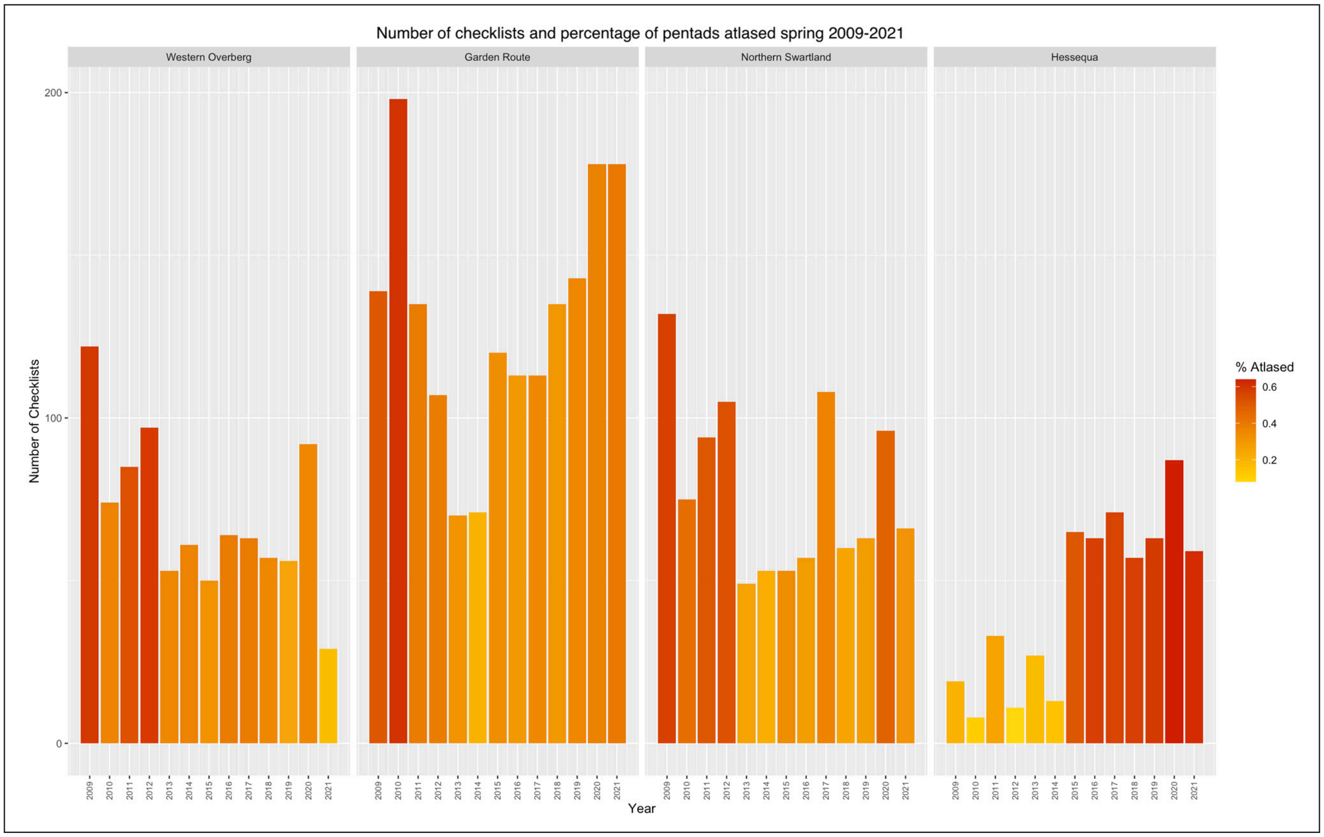

Figure 4 Atlasing effort (number of checklists) and regional coverage (percentage of pentads atlased) in Hessequa and three Western Cape regions during austral spring, between 2009 and 2021. Darker colour indicates more complete coverage.

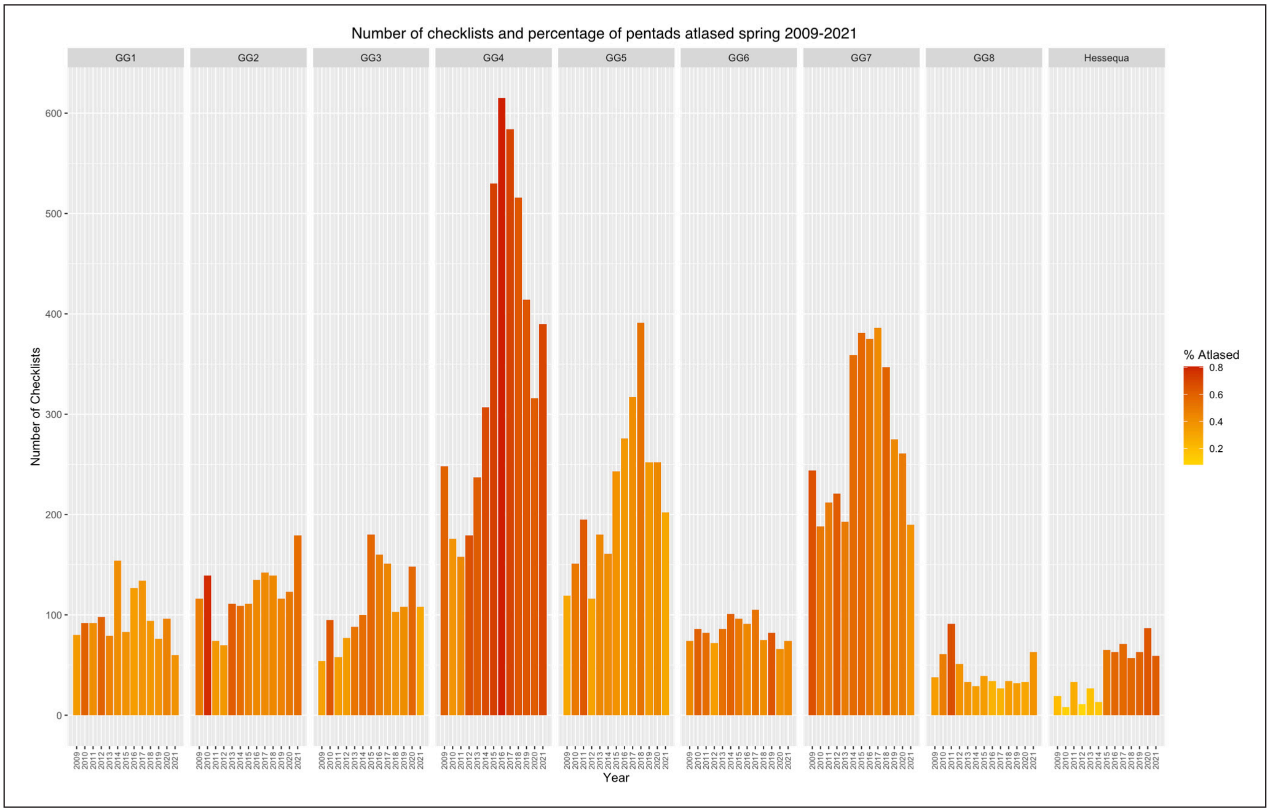

Figure 5 Atlasing effort (number of checklists) and regional coverage (percentage of pentads atlased) in Hessequa and eight Greater Gauteng regions during austral spring, between 2009 and 2021. Darker colour indicates more complete coverage.

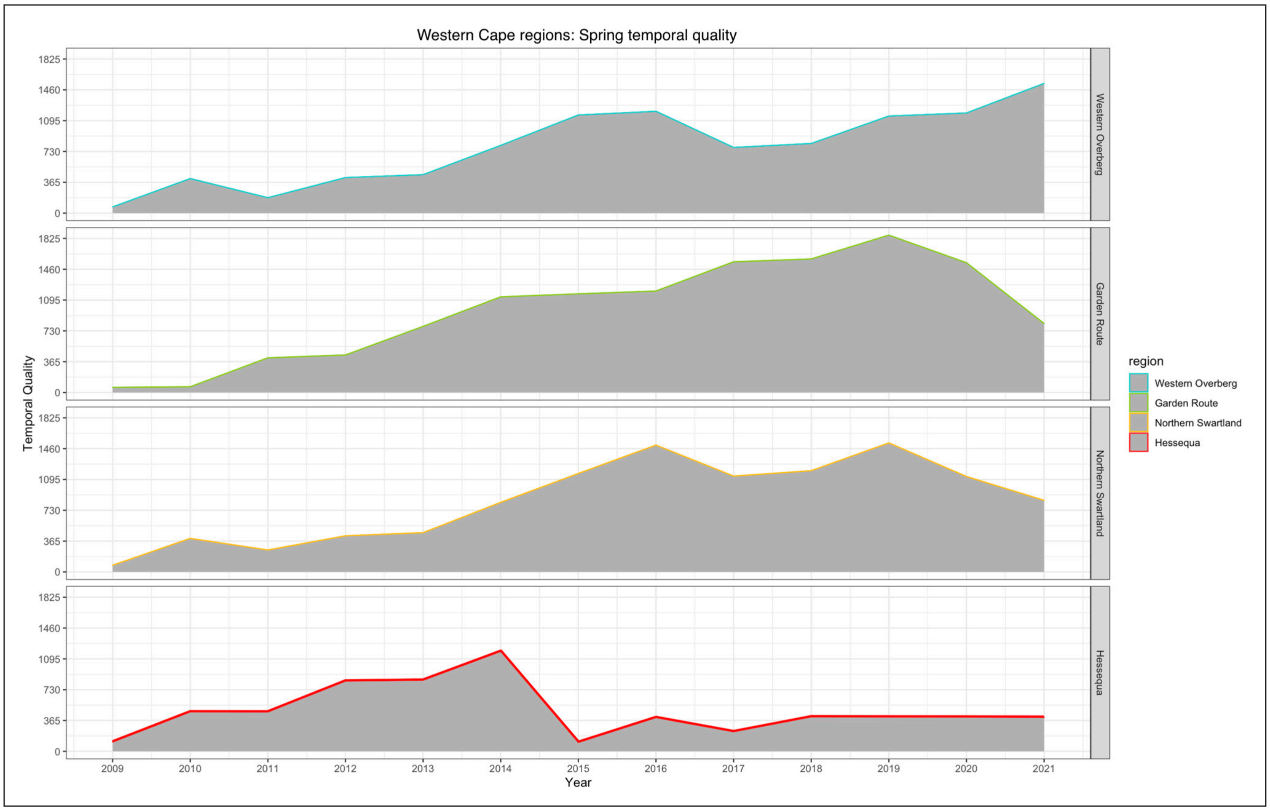

Figure 6 Temporal proximity for Hessequa and three Western Cape regions during austral spring, between 2009 and 2021 (see also Table 3).

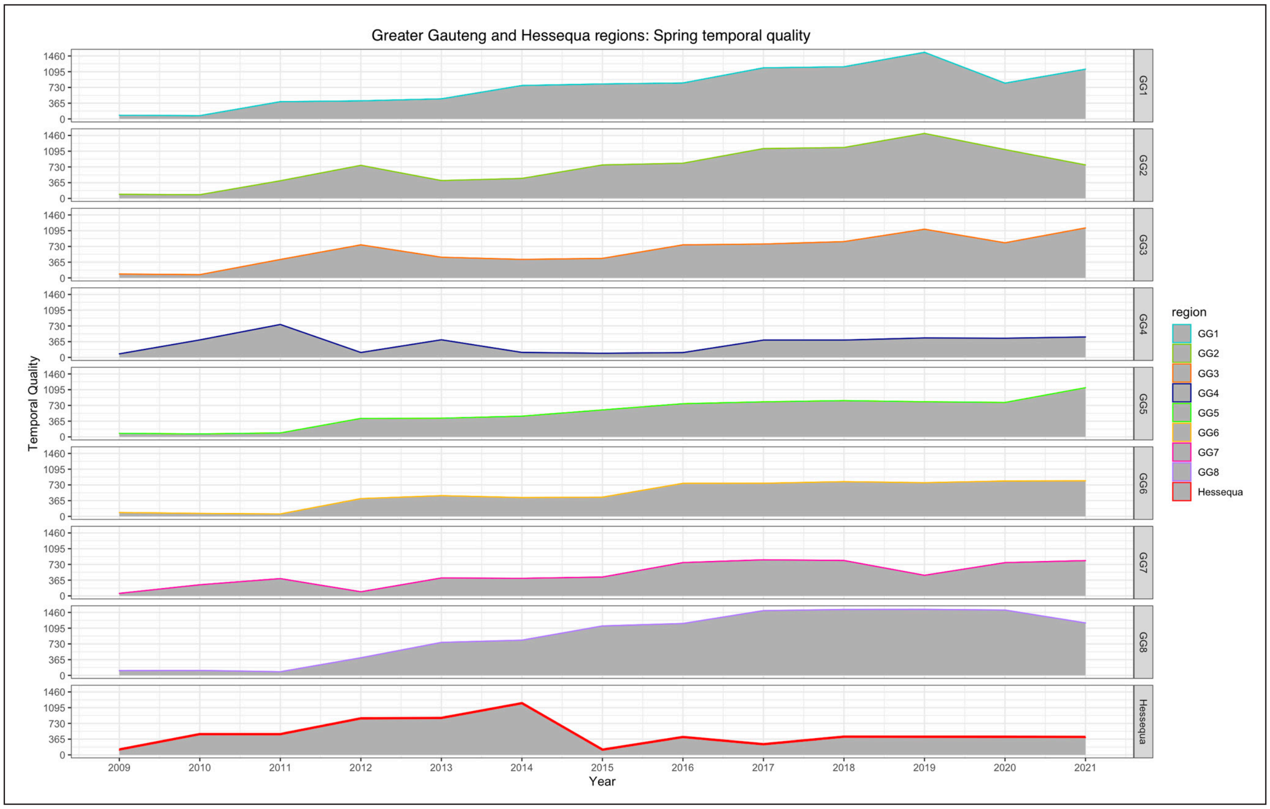

Figure 7 Temporal proximity for Hessequa and eight Greater Gauteng regions during austral spring, between 2009 and 2021 (see also Table 3).

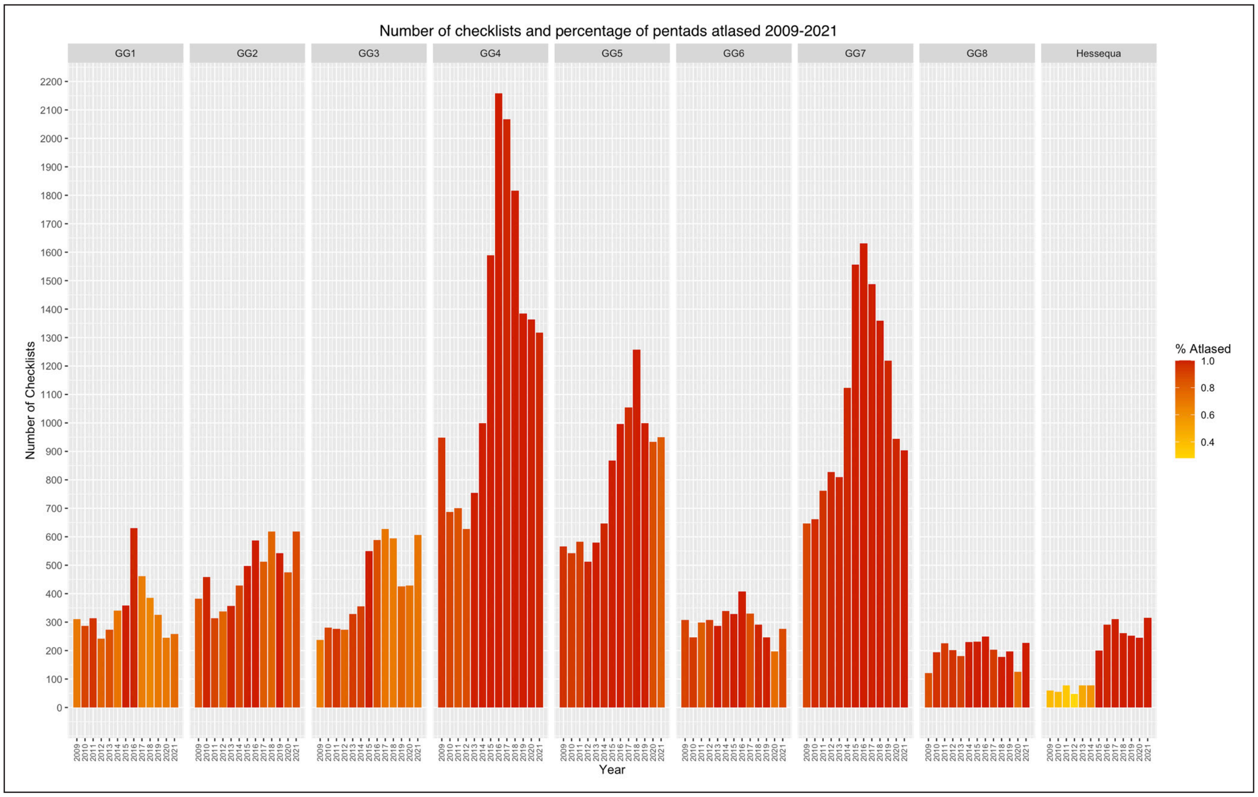

Figure 8 Atlasing effort (number of checklists) and regional coverage (percentage of pentads atlased) in Hessequa and eight Greater Gauteng regions between 2009 and 2021. Darker colour indicates more complete coverage.

DISCUSSION

TEMPORAL PROXIMITY AS A MEASURE OF DATA QUALITY

Apart from the illustrative examples in Underhill (unpublished), this is the first large-scale application of this method for quantifying the temporal proximity of a biodiversity database. Its behaviour in this application needs to be assessed.

By design, temporal proximities are small when every pentad is visited regularly, as in the systematic fieldwork used in Hessequa. Our interest focused on the extent to which the algorithm would show large temporal proximities in the eleven areas where atlasing was non-systematic. It clearly achieved this (Tables 2 and 3, Figures 1–4). At face value, the large quantities of checklists (frequency exceeding 1,000 per year) submitted for the Greater Gauteng regions (Figure 5) would suggest that these regions have the best data; however, this is not necessarily the case. The approach of quantifying temporal proximity provides a more nuanced measure of the quality of biodiversity data than number of checklists alone.

SABAP2 started in July 2007, and the earliest date for which temporal proximity was calculated was 31 December 2009, 30 months later. At the start of a project, all records are recent, and the numbers of species per pentad is still increasing. Thus, temporal proximities in the early years will always be good, in spite of small volumes of data (Tables 2 and 3, Figures 1–4).

A further consideration is that, in computing the temporal proximity at the end of each calendar year (Tables 2 and 3), the algorithm included all checklists submitted since the commencement of the project. The total species lists for each pentad slowly increased through time with the occurrence of vagrant species; thus, the temporal proximity for each pentad was computed across a steadily increasing number of species, at least some of which are unlikely to be observed again. To a large extent, the use of the median rather than the mean to compute the temporal proximity eliminates this problem, but it is important to acknowledge that temporal proximity will become larger over time, even with uniform amounts of fieldwork. This could be overcome by eliminating vagrant species from the calculations, but introduces subjectivity and arbitrariness into the measure. In Hessequa, by 2021, this appears to be a theoretical concern rather than a practical one; for the final four years, 2018 to 2021, the temporal proximity remained stable (Tables 2 and 3).

EXPLORING EFFECTIVE TIMESCALES

As well as maintaining temporal proximity, the Hessequa protocol was also designed around the capacity of atlasers to sustainably achieve the required level of fieldwork. In other areas with sufficient human resources available to undertake systematic atlasing, it would be worthwhile to test alternative strategies. Strategies that are less intense than the Hessequa protocol can be tested for their potential impact on temporal proximity by simulation. This would involve subsampling, in accordance with the proposed strategy, from the Hessequa database.

GENERATING MEANINGFUL DATA

A key challenge for biodiversity monitoring data is their ability to generate alerts while mitigation is still possible (Pocock et al. 2018; Altwegg and Nichols 2019). Early warning systems are necessary not only for detecting problems, but also informing response. Many comparisons of CS data are made over extended time periods, and within these timeframes, new and potentially irreversible threats may establish themselves. Examples include comparisons of changes in range and abundance between bird atlas projects, which typically take place at decadal intervals or longer. To date, the only study to consider trends within the timescale of the SABAP2 project rather than to make comparisons between SABAP1 and SABAP2 is Quintana et al. (unpublished); the authors describe a range expansion of the African Red-eyed Bulbul since 2007, when SABAP2 started. Though the authors present important insights, their trend comparisons are weakened by the reality that the atlasing protocol in place was non-systematic, and the pentads atlased in a given year were essentially random. In contrast, van Rooyen et al. (unpublished data) demonstrated that the systematic data collected in Hessequa could be used to estimate trends in the abundance of 139 species in the Hessequa region in the six-year period 2015–2020. Crucially, these data revealed that as a group, waterbirds were experiencing the largest short-term decreases in abundance. These trends can now be closely followed to understand the severity and nature of declines.

The ability to follow these fine-scale changes reflects important progress towards current targets in global policy; in particular, SDG 15, and the Kunming-Montreal Global Biodiversity Framework (CBD 2022). Halting biodiversity loss begins with understanding the current state of systems (Mehring et al. 2017; Hochkirch et al. 2021), and monitoring species at a regional scale generates a nuanced and up-to-date picture of population trends, seasonal changes, and shifts in distribution. Systematic data collection initiatives not only address critical data deficiencies, but also generate data that are capable of telling a long-term story.

PARTICIPANT BENEFIT AND THE SUCCESS OF THE HESSEQUA ATLASING PROJECT

Our results demonstrate the feasibility of maintaining up-to-date and comprehensive atlas coverage with relatively few checklists. This realization is especially significant in light of recent dialogue regarding participant benefits in CS (Kimura and Kinchy 2016; Adler et al. 2020); as CS becomes increasingly relevant to conservation work, scientists are met with the double-edged challenge of ensuring that participants are not exploited as free labour while also encouraging a level of fieldwork effort that will produce meaningful quantities of data (e.g., Robinson et al. 2018). Taken as a case study, the Hessequa initiative may offer insights into achieving sustainable fieldwork goals. Though numerous factors undoubtedly influence the project's success, here we discuss three: local leadership, communication/dissemination of scientific results, and community-structured protocol.

As part of a separate study, 17 atlasers in Hessequa participated in conversational interviews. Comparison of citizen scientist motivations was not the focus of the study; thus, interviews were not carried out in any of the other eleven regions. The interview insights presented here are intended to enrich ongoing conversations around citizen scientist motivation and project impact, and are not intended for comparison with other atlasing regions or CS initiatives. In interviews, Hessequa atlasers were asked to discuss their motivations for participating in SABAP2. Though personal motivations varied between individuals, nearly all interviewees emphasized the role of their local project leader in maintaining their interest and motivation in the atlas project (Daniel et al. unpublished data).

While participation in the Hessequa atlas project was voluntary, local project leader Johan van Rooyen (see van Rooyen 2018) used a variety of techniques to keep participants engaged and motivated. Atlasers were consistently updated via email on their collective progress towards achieving monitoring targets and were provided with detailed maps of the Hessequa Atlasing Area for use in the field. As an additional resource, van Rooyen maintained a list with names and contact details of local landowners, which atlasers used to alert landowners when they atlased in the area, or to ask permission to atlas on private land. During national lockdowns resulting from the COVID-19 pandemic in 2020, van Rooyen introduced a "lockdown challenge," encouraging atlasers to keep lists of the birds in their gardens and submit photographs to another CS initiative, the Virtual Museum. Several interviewees emphasized the role of van Rooyen's enthusiasm and knowledge in maintaining their own interest in the project:

> *"My motivation…that was Johan van Rooyen, without a doubt. He's not only [an] enthusiastic person, but he's got the knowledge, also. He's an absolutely wonderful coordinator as well."*

> *"Johan has maps; they put exactly where you should go, and we know from 'there' to 'there' is about so many kilometres…with our project, the huge input from Johan van Rooyen—I think he keeps us going."*

> *"We really appreciate him. Over the lockdown, it was really difficult to still keep going, and he had ideas. We couldn't move out of our house[s], [but] we were still able to get most of the birds that you see from your house. So we did that!"*

Bonney et al. (2009a) specified three categories for public participation in scientific research: contributory, collaborative, and co-created. Though SABAP2 was designed as a contributory initiative, the community-led atlasing in Hessequa marks a shift towards collaborative or community-based participation (Danielsen et al. 2014; Kennett et al. 2015; Chandler et al. 2017), with community members contributing to data collection, analysis, and project design. The role of local leadership in Hessequa's atlasing success raises questions around the sustainability of purely contributory biological CS initiatives. For the institutions driving such initiatives, our observations in Hessequa suggest that it may be worthwhile to invest in training CS leaders to coordinate fieldwork efforts in specific geographic regions, equipping local enthusiasts with skills in project management and interpersonal communication. While this coordination arose independently in Hessequa, this will almost certainly not be the case in every community. Investing in training CS leaders may positively influence project longevity.

Although it is often contended that CS requires adaptive management in order to balance the continuous fluctuation in volunteer participation and effort, we offer that this is perhaps only characteristic of CS viewed solely as a tool for data collection (Eitzel et al. 2017; Phillips et al. 2019). In Hessequa, we observed a community of citizen scientists self-organising and initiating collaboration with scientists in order to set and reach self-identified targets. This observation illuminates the possibility of CS as not only a form of resource management, but also as a tool for social transformation (Sullivan et al. 2014; Jørgensen and Jørgensen 2021). Though the project significantly increased the demands of participation on time and travel costs, Hessequa atlasers were not offered monetary compensation—participation remained voluntary with no consequences for dropping out. This seems an unlikely result; as Fraisl et al. (2022) highlight, projects that demand a great deal of time may not be ideally suited for CS data collection. What, then, might motivate the consistent contributions of Hessequa atlasers?

Conversations with participants highlight critical differences between external (incentivised) and internal (personal) motivation: atlasers continued to participate in demanding and perhaps costly ways because participation held personal or relational meaning (Everett and Geoghegan 2016; Richter et al. 2018).

Atlasers described the significance of making a meaningful contribution to science in motivating their participation, shared their enjoyment of giving purpose to their hobby (birdwatching or twitching), and expressed the importance of seeing their data in use:

> *"I've been a birder for a long time...when we got involved with the SABAP programme through Johan, it gave a totally different connection to our hobby of birdwatching. All of a sudden, my hobby is purposeful. It's not just for my pleasure; I'm doing it with something bigger in mind."*

Such statements are consistent with findings from Hidalgo et al. (2021) and Adler, Green, and Sekercioglu (2020) who conclude that CS initiatives are more likely to succeed when participants are involved as coresearchers rather than data collectors. Furthermore, a sense of meaningful contribution may play a critical role in generating social change. Meaningful contribution has been linked to increased likelihood of personal intention to engage in conservation behaviour (Day et al. 2022). In Hessequa, participants expressed that their experiences of meaningful contribution were largely enabled by the clear and continuous feedback streams maintained between scientists, local leadership, and atlasers; these statements align with responses in recent studies on participant motivation (e.g., Richter et al. 2018; Kuehn et al. 2022).

Finally, the success of the Hessequa monitoring project may be partially attributed to its community focus. Participants meet in person at regular intervals to connect with one another and discuss and divide fieldwork responsibilities. Many are also part of local group messaging streams or email lists, which members use to discuss species identification and share noteworthy observations throughout the year.

In interviews, several participants described the interpersonal connections experienced through atlasing as motivations for participation. These connections were diverse, including a sense of community found with like-minded individuals, enjoying quality time with a spouse or friend while atlasing together, and a sense of communal learning through birding as part of a group. These responses are supported by Kaplan Mintz, Arazy, and Malkinson (2023), who found that for 89 citizen scientists, the primary motivation for participation was learning through social interactions.

The significance of community in this context extends beyond benefit into the realm of values—a collective that is gaining increased recognition in socioecological research for its importance in leveraging long-term behavioural change (e.g., Mattijssen et al. 2020). Even contemporary CS initiatives seldom consider the social significance of project participation beyond personal motivations. Our conversations with atlasers suggest that the social community created through project involvement is not only a strong motivator for participation, but also generates awareness and conversation surrounding local conservation issues, which may ultimately spill over into the wider community. This is reflected in the findings of Day et al. (2022), who offer that both social engagement and a sense of meaningful contribution are necessary components of social change for citizen scientists. In light of the potential broader social impact of citizen scientists as a community, it may be worthwhile for CS project managers to consider ways to connect local citizen scientists with one another and to create opportunities for meaningful interpersonal interactions between participants.

Together, the leadership, communication, and community in Hessequa create a strong foundation for project longevity and continued participant motivation. In the future, we suggest this foundation may be adapted as a model for jointly pursuing sustainable CS fieldwork and maximizing conservation and social impact. The framework is flexible for adaptation in diverse contexts; leadership and communication style may be tailored to fit local needs. Additionally, we recommend that CS project leaders consider taking inventory not only of participant motivations, but also values; i.e., asking what lies beneath motivations. Understanding the deep-seated personal decision-making systems driving participant behaviour may prove valuable in structuring projects to maximise their social impact.

CONCLUSION

Mitigating biodiversity loss requires a nuanced understanding of species populations and trends at a regional level. As CS initiatives offer potential solutions to data collection challenges, it becomes necessary to both verify the quality of data collected and ensure that collection protocol remains sustainable. Temporal proximity provides a useful measure for determining the monitoring value of semi-structured CS data to applied conservation, and systematic data collection effort (such as that employed in Hessequa) supports sustainable fieldwork objectives. In the case of Hessequa, project success is also heavily influenced by local leadership, communication, and the community of citizen scientists. Approaching CS as a tool for informing meaningful action involves consideration of not only its scientific impact, but also its social impact. This study seeks to embrace the twofold implications of a CS initiative in South Africa, and we hope that the questions raised here will enable further research in a similar vein moving forward.

DATA ACCESSIBILITY STATEMENT

The checklist data used in our analyses were downloaded from the SABAP2 website. SABAP2 data are freely available upon request from the project team.

ETHICS AND CONSENT

The interviews quoted in the discussion section of this paper were conducted with the approval of the University of Cape Town Faculty of Science Research Ethics Committee, approval code FSREC 049 – 2021. All interviewees provided informed consent to participate.

ACKNOWLEDGEMENTS

We are deeply grateful to the contributions of the Stilbaai U3A Bird Group, whose data and commitment to the Hessequa monitoring initiative give us a story to tell. In particular, we wish to acknowledge the contributions of Johan and Estelle van Rooyen in coordinating local atlasing efforts and establishing a citizen scientist community in Hessequa. Johan also provided valuable comments during the revision process for this paper. Michael Brooks downloaded the datasets used in the analyses from the SABAP2 website.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Karis Daniel wrote the introduction, results, discussion, and conclusion, and produced the figures. Les Underhill assisted with data analysis and writing the methods and results, and provided revisions and feedback throughout the writing process.

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TO CITE THIS ARTICLE:
Daniel, KA and Underhill, LG. 2023. Temporal Dimensions of Data Quality in Bird Atlases: the Case of the Second Southern African Bird Atlas Project. *Citizen Science: Theory and Practice,* 8(1): 31, pp. 1–17. DOI: https://doi.org/10.5334/cstp.578

Submitted: 30 September 2022 **Accepted:** 15 March 2023 **Published:** 27 June 2023

Citizen Science: Theory and Practice is a peer-reviewed open access journal published by Ubiquity Press.