CORRELATING RELATIVE ABUNDANCE AND RAINFALL: A TIME-SERIES ANALYSIS OF CHECKLISTS

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Summary

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Time series checklist data (1982/1983-1990/1991) collected for a region of South Africa were correlated with total annual rainfall. The analysis used standard techniques for time-series analyses. Of the 104 species analyzed, 20 showed significant correlations with rainfall in the same year but lag effects were detected for only 1 species. This study shows that reporting rates derived from simple presence/absence checklist data can provide useful results when analyzed by sophisticated statistical procedures.

Key words: atlases, time-series analysis, reporting rate, rainfall, Orange Free State, South Africa

Introduction

Amateur ornithologists are avid compilers of lists. The Southern African Bird Atlas Project (SABAP) and its predecessors have exploited this enthusiasm by making the "checklist" the basic data sample unit (Cyrus and Robson 1980, Earlé and Grobler 1987, Tarboton *et al* 1987, Hockey *et al* 1989). Southern African bird clubs have encouraged compilation of checklists and have amassed collections of data spanning several years or even decades.

This invaluable historical data, built up by thousands of observers, awaits detailed analysis and doubtless holds much important information. As a first step in exploiting this resource, the SABAP has accessed most of the data sets and computerized each checklist. The potential now exists to analyze time series of checklists which incorporate both the historical and the recent SABAP data.

The value of a time series of checklists is the opportunity provided to detect changes in populations of species. To go beyond a mere statement of appearance or disappearance of species based on presence or absence on checklists, an index of relative abundance must be developed, based on the frequency at which species are reported.

This paper shows that:

* reporting rates are subject to variation due to factors other than changes in abundance and must be corrected before being used as an index of relative abundance;
* the reporting rate index varies over time in a manner consistent with its use as an index of relative abundance; and
* the potential exists to relate the reporting rate index to environmental variables, such as rainfall, thus providing insights into species ecology.

Study area

The study area is part of the province of the Orange Free State (OFS) in South Africa (Figure 1). The area was chosen for its 11-yr series of checklists collected for the atlas project of the OFS Ornithological Society, 1982-1986 (Earlé and Grobler 1987) and for SABAP, 1987-1991 (Harrison 1987). Coincidence with a period of dramatically fluctuating rainfall also influenced the choice of area. Boundaries were set to include a relatively homogeneous ecological area falling entirely in the grassland biome (Rutherford and Westfall 1986).

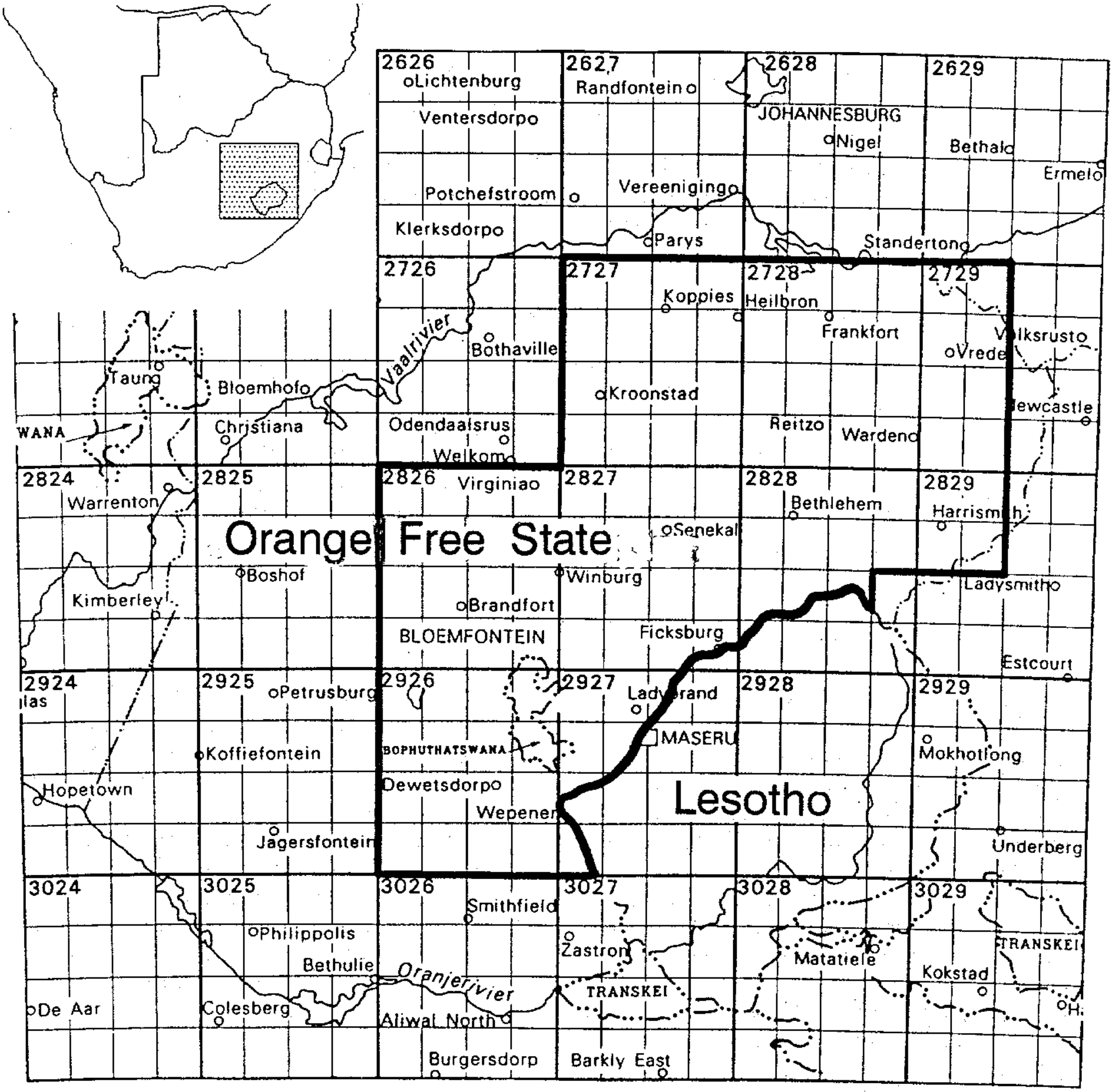

Figure 1 The Orange Free State study area, part of the Southern African Bird Atlas Project

Materials and methods

Reporting rate

The checklists were collected at the spatial and temporal resolutions of the ¼° grid square (15'x 15') and calendar month (Earlé and Grobler 1987, Harrison 1992). Since there was no control of the amount of time, effort, or observer skill when data were collected, a statistical standardization was applied to the data). In this study, all checklists from the study area for a "rainfall year" were combined to provide reporting rates at this particular scale of geographical and temporal resolution. The rainfall year is the 12 mo September-August, designed to include the whole of 1 rainy season. Rainfall years 1981/1982 and 1991/1992 were excluded because of insufficient data, leaving 9 yr from 1982/1983 to 1990/91 inclusive. Checklists used in each rainfall year numbered 171, 463, 555, 410, 569, 844, 864, 559, and 349: mean checklist length (= number of species) was 33, 30, 35, 41, 38, 37, 47, 59, and 61.

In its most basic form, reporting rate for a particular species, for a unit of time and space, is obtained by calculating the proportion or percentage of all checklists which record that species. The reporting rate is used as an index of relative abundance when comparisons are made between time periods and/or between geographical areas (Harrison 1989).

Rainfall
Rainfall data were obtained from the Computer Centre for Water Research, Pietermaritzburg. Totals were obtained from as many stations as possible and averaged over the study area. Rainfall for 1980/1981 and 1981/1982 is included as these years were used to test lagged responses in 1982/1983 and 1983/1984. Drought persisted from 1982/1983 to 1986/1987 while 1987/1988 was a wet year in which floods occurred in many parts of the OFS. Mean rainfall for the study area is 600-700 mm per annum.

Analysis
In order to assess validly the relationship between reporting rate (or some quantity derived from it) with rainfall (or any other variable) it is necessary to "prewhiten" (Chatfield 1989 p. 139, Peach *et al* 1991) each of the time series being related. Unless this is done, spurious correlations between the 2 series can arise. The use of much longer data sets has shown that total annual rainfall in the OFS is not serially correlated (Zucchini and Adamson 1984) and consequently requires no prewhitening. The reporting rates do exhibit serial correlation structure, however, and therefore do need prewhitening. To do this, the autoregression-moving average family of models (Box and Jenkins 1976, Chatfield 1989) was used to identify and then fit the appropriate model to each reporting rate series and then compute the residual series. These residuals were then related to rainfall. A series of steps was carried out for each species analyzed:

* a simple linear regression between reporting rate and checklist length was applied to remove the trend resulting from increased mean checklist length over time by isolating the residual reporting rate -- index *R*, which can be interpreted as a reporting rate corrected for checklist length;
* *R* was checked for serial correlation structure to avoid artifacts caused by spurious regression and, if significant, the residuals from the appropriate model (autoregressive or moving average) were estimated (Box and Jenkins 1976, Chatfield 1989);
* the time series of *R* values exhibits, or does not exhibit serial correlation structure and if the former was the case the residuals from the model fitted to the *R* series were related to rainfall, whereas in the latter case the *R* series itself was related to rainfall but whichever option was applied, the corresponding series was cross-correlated with rainfall to search for correlations with rainfall in the same year (no lag), rainfall in the previous year (1-yr lag) and rainfall 2 yr previously (2-yr lag).

This procedure was applied to 104 species, including all having reporting rates in excess of 10% in most of the rainfall years. The rarer species, for which reporting rates are unlikely to provide a reliable index of relative abundance, were excluded as were species likely to have been greatly affected by improved observer skills in identification over time. All cisticolas (Sylviidae, *Cisticola* spp.), pipits (Motacillidae, *Anthus* spp.) and most larks (Alaudidae) were excluded. Swallows and martins (Hirundinidae) and corvids (Corvidae) were also excluded as these groups had been the subject of intensive investigations during parts of the study period which may have affected reporting rates relative to the remainder of the period.

Results

A total of 21 of the 104 species analyzed showed significant ($p < 0.05$) or near-significant ($p < 0.1$) correlations with rainfall (Table 1): 18 of these species showed a significant correlation ($p < 0.05$) with mean checklist length (Table 1, Figure 2) and therefore required correction. After correction, 15 species showed a significant positive correlation between R and rainfall in the same year (Table 1, Figure 3a) while 5 showed a significant negative correlation (Table 1, Figure 3b). The Hamerkop *Scopus umbretta* was the only species to show near-significant ($p < 0.1$) positive correlation with a 1-yr lag on rainfall (Table 1). Corrected reporting rates for 4 species known or suspected to be increasing in range and abundance showed positive correlations with rainfall in the same year (Table 1 Figure 4).

Discussion

Avian responses to variations in rainfall

It is emphasized that the aim of this paper is to present a method of analyzing checklist data to help detect changes in relative abundance over time in relation to environmental variables. No *a priori* hypotheses with regard to the response of birds to rainfall were tested and the results cannot therefore be taken as proof of any such phenomenon. To do this we need to analyze the avian community as a whole and check the results for each species in the light of information about its movements, feeding habits and breeding biology. Despite this important caveat and bearing in mind the inadequate length of the time series, the results obtained, are sufficiently consistent with expected results to give us confidence that reporting rates can be analyzed usefully in this manner.

Table 1 Correlation coefficients (*r*) between bird data series and card length, and between corrected reporting rate and rainfall

Species		Correlation coefficient[a]			
Common name	Scientific name	Card length	Same year	1-yr lag	2-yr lag
Long-tailed Cormorant[b]	*Phalacrocorax africanus*	0.94^{**}	0.63^{+}	0.61	0.13
Grey Heron	*Ardea cinerea*	0.97^{**}	0.76^{*}	0.08	-0.08
Cattle Egret	*Bubulcus ibis*	0.74^{*}	0.81^{**}	0.46	-0.13
Hamerkop	*Scopus umbretta*	0.93^{**}	0.48	0.63^{+}	-0.02
Hadada	*Bostrychia hagedash*	0.91^{**}	0.82^{**}	0.03	-0.20
Red-billed Teal	*Anas erythrorhyncha*	0.96^{**}	0.65^{+}	0.59	0.11
South African Shelduck	*Tadorna cana*	0.56	-0.74^{*}	-0.49	-0.04
Secretary Bird	*Sagittarius serpentarius*	0.60^{+}	-0.66^{*}	-0.36	0.21
Lesser Kestrel	*Falco naumanni*	0.65^{+}	-0.70^{*}	-0.60	0.04
Swainson's Francolin	*Francolinus swainsonii*	0.98^{**}	0.79^{*}	0.23	-0.16
Helmeted Guineafowl	*Numida meleagris*	0.98^{**}	0.61^{+}	0.07	-0.17
Speckled Pigeon	*Columba guinea*	0.95^{**}	0.81^{**}	0.41	-0.35
Laughing Dove	*Streptopelia senegalensis*	0.86^{**}	0.60^{+}	0.20	-0.16
Speckled Mousebird	*Colius striatus*	0.98^{**}	0.70^{*}	0.45	-0.10
Crested Barbet	*Trachyphonus vaillantii*	0.91^{**}	0.82^{**}	0.14	-0.12
Spike-heeled Lark	*Chersomanes albofasciata*	0.94^{**}	-0.73^{*}	-0.32	-0.03
Red-capped Lark	*Calandrella cinerea*	0.91^{**}	-0.60^{+}	-0.43	-0.01
African Red-eyed Bulbul	*Pycnonotus nigricans*	0.87^{**}	0.65^{+}	0.28	0.01
Bokmakierie	*Telophorus zeylonus*	0.96^{**}	0.61^{+}	0.18	-0.39
Indian Myna	*Acridotheres tristis*	0.87^{**}	0.66^{*}	0.37	-0.35
White-browed Sparrow-weaver	*Plocepasser mahali*	0.85^{**}	0.59^{+}	0.41	-0.34

Note: a) d.f. = 7, 6, and 5 for same year, 1-yr lag and 2-yr lag
b) corrected for autocorrelation
$^{+}$ $p < 0.1$; * $p < 0.05$; ** $p < 0.01$

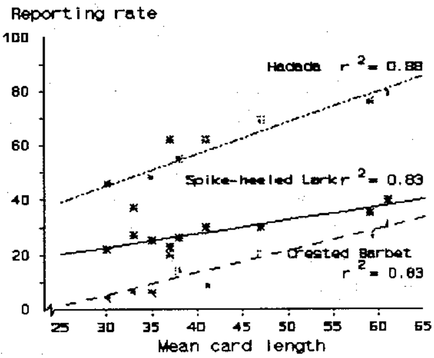

Figure 2 Sample relationships between species reporting rate and checklist length

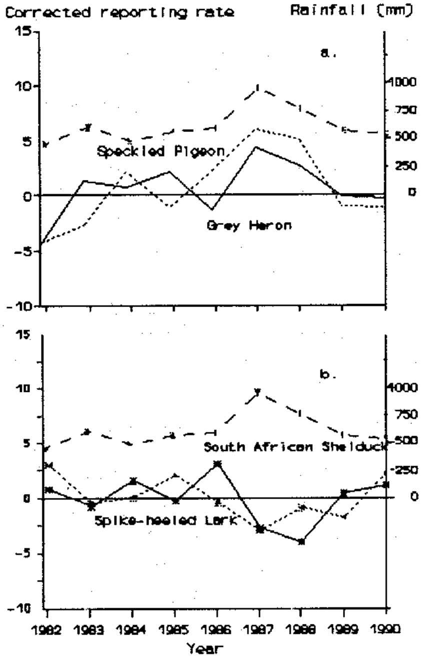

Figure 3 Corrected reporting rates for two species each with: a. positive; and b. negative correlation with rainfall in the same year

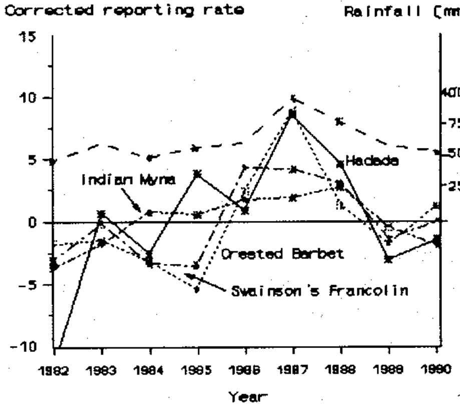

Figure 4 Corrected reporting rate for four species known or suspected to be increasing in distribution and abundance in the study area and showing positive correlations with rainfall in the same year

The importance of rain, or lack of it, as a determinater of local movements (Maclean 1970, 1974, Cunningham-van Someren 1984, Martin *et al* 1986), timing of breeding (Skead 1975, Martin *et al* 1986) and breeding success (Grobler 1988, Kemp 1991) in Africa is well known, although seldom quantified. That reporting rates do not display a significant lagged response to precipitation suggests that rainfall events in grassland areas result in relatively short term responses by birds, although these events may be prolonged and extend over subsequent years. Lagged effects on breeding in southern Africa appear to have been described only for woodland birds, where tree leaf and fruit production is suggested as the mediating factor (Kemp 1973, Vernon 1978, Earlé 1981).

Significant immediate responses to variations in rainfall might have been expected to be evident in a larger proportion of species than was found in this study. Changes in reporting rates associated with rainfall variation could result from fluctuations in population density due to breeding productivity or movement in to or out of the area, changes in conspicuousness due to breeding activity, or a combination of these factors. Many birds are known to exploit wetter conditions by increasing breeding productivity (Grant and Grant 1987, Grobler 1988). Water birds, in particular, colonize temporary water bodies after rain (Geldenhuys 1976a) so a higher proportion of these species could be expected to show a significant immediate rise in reporting rate.

The expectation of increased reporting rates after increased precipitation in species which benefit from more mesic conditions, due to increased density from immigration and/or enhanced breeding success, and increased conspicuousness due to breeding displays by males, may not be met. This is because these factors might be balanced by lush vegetation growth and secretiveness in breeding females, that reduce conspicuousness in some species.

Reporting rate is a relatively inelastic measure of abundance (Underhill and Hockey 1988). This means that large changes in abundance may result in small changes in reporting rate. The amount of flooding after the heavy rains of 1987/1988 may have created conditions that were so unusual that many species did not show the short-term positive responses ordinarily expected after a more normal increase in rainfall (Grobler 1988). It is possible that the results of the present analysis are influenced by this extreme rainfall (Figures 3 and 4). A longer time series would be needed to control for such unusual events and to cover several consecutive wet/dry precipitation cycles.

Aquatic species

Positive response to rainfall

Only 4 of the 20 species showing significant immediate responses to variations in rainfall are water birds. Positive correlations between Long-tailed Cormorant *Phalacrocorax africanus*, Grey Heron *Ardea cinerea* and Red-billed Teal *Anas erythrorhyncha* and rainfall are predictable, as increased precipitation would lead to more aquatic habitat. The increased reporting rate of these species cannot, however, automatically be interpreted as an increase in total population size. During dry periods, the populations may be concentrated at the relatively few large, permanent water bodies and populations could be expected to disperse to numerous seasonal wetlands following rain, thus affecting reporting rate. The impact of changes in patterns of dispersal on reporting rates is poorly known but needs to be considered when interpreting the latter.

The Hamerkop was the only species to show a 1-yr lagged response to rainfall. As an aquatic species, a positive response to increased rainfall is predictable but why it should be lagged by 1 yr is not clear. The Hamerkop is characterized by 3 unusual features: solitary habits while feeding and breeding; specialized diet of *Xenopus* adults and tadpoles; and high visibility (Siegfried 1975). Observers may have recorded this species from nests seen, in addition to actual sightings of the birds, and some factor(s) associated with these features may be responsible for the lagged response.

Negative response to rainfall

The immediate negative response to increased rainfall shown by the South African Shelduck *Tadorna cana*, is rather surprising although it has been shown that it avoids areas with rainfall in excess of 600 mm (Geldenhuys 1981). A major reduction in reporting rate occurred in the 2 years with rainfall above 600 mm (Figure 3). Avoidance of high rainfall may be due to wetlands under these conditions supporting luxuriant emergents and dense littoral hydrophytes which are habitats unsuitable for this species (Geldenhuys 1976b). Flooding of the underground breeding sites of this species (L. van Erck pers.comm.) and changes in population dispersal patterns within the study area could also play a role. The OFS grasslands may serve as a drought refuge for the shelduck which may disperse into the Karoo, its major distribution area, following widespread rains there (SABAP, unpublished data).

Terrestrial species

Positive response to rainfall

Only the Cattle Egret *Bubulcus ibis* (Tarboton *et al.* 1987) and Laughing Dove *Streptopelia senegalensis* (Rowan 1983) of the 12 terrestrial species showing immediate positive responses to rainfall are known to undertake widespread movements, although the Speckled Pigeon may also be nomadic (Rowan 1983). This suggests that immigration was responsible for the observed increases in these species.

The implication is that increases in reporting rates of the other species are due to previously unsuspected movements, to enhanced breeding success, to increased conspicuousness, or to a combination of these factors. Increased conspicuousness is thought possibly relevant in only 4 species.

All of Swainson's Francolin *Francolinus swainsonii*, Helmeted Guineafowl *Numida meleagris* and Bokmakierie *Telophorus zeylonus* have distinctive and far-carrying advertising calls which may be more frequent during higher rainfall periods. White-browed Sparrow-weavers *Plocepasser mahali*, like Hamerkops, build conspicuous nests and it is also possible that this species appears on checklists from nests seen, in addition to sightings of the birds. If increased rainfall results in increased nest production the increased reporting rate may reflect more nests, rather than more sparrow-weavers.

Swainson's Francolin, Helmeted Guineafowl, Speckled Pigeon, Laughing Dove, and White-browed Sparrow-weaver, all of which were subject to increased reporting, are strongly associated with maize fields, where they feed on fallen seeds and other food (Grafton 1969, Ferguson 1983, Rowan 1983, Maclean 1985). Increased rainfall resulting in good maize production would probably benefit these species.

A feature of the list of terrestrial species which showed a positive response to rainfall, is that no less than 4 are known to be rapidly expanding in range and abundance in the OFS and elsewhere (Figure 4). These are Hadada *Bostrychia hagedash* (Macdonald *et al* 1986), Swainson's Francolin (Clancey 1965), Crested Barbet *Trachyphonus vaillantii* (Earlé and Grobler 1987, Heroldt and Earlé 1987, du Plessis 1989) and Indian Myna *Acridotheres tristis* (Earlé and Grobler 1987). Why these species in particular should display such fine-tuned responses to variations in rainfall is unclear and warrants further investigation.

Negative response to rainfall

The Secretary Bird *Sagittarius serpentarius*, Spike-heeled *Chersomanes albofasciata*, and Red-capped *Calandrella cinerea* Larks showed immediate negative responses to rainfall. This is not wholly unexpected as all 3 are known to be nomadic to some extent and to avoid the dense grasslands resulting from increased rainfall (Steyn 1982, Maclean 1985). The Spike-heeled Lark is always rare or absent in the highest rainfall, sour grasslands of eastern South Africa (SABAP, unpublished data). Changes in conspicuousness of these ground-dwelling species due to the masking effect of taller grass resulting from increased rainfall cannot, however, be ruled out as a contributory factor to changes in reporting rates.

The reasons for the negative response shown by the Lesser Kestrel *Falco naumanni* are unclear. Changes in conspicuousness due to vegetation cover or breeding activity can be ruled out for this obvious and non-breeding migrant which hunts from elevated perches and by hovering. It is possible the study area serves as a drought refuge for the species, which may spread into the adjacent Karoo following widespread rain. The Lesser Kestrel is reported to be undergoing a decrease in overall population size (Collar and Andrew 1988) but the current data show no obvious negative trend in the study area, probably due to the relatively inelastic nature of reporting rates for a conspicuous species and the short study period.

It is the results for these species which lend credence to the positive responses displayed by others, strongly suggesting that artifacts of unknown bias in data collection or analysis are not involved.

Reporting rate

Some limitations are inherent in the use of reporting rates as an index of relative abundance:

- they confound abundance/density with conspicuousness and identifiability (Temple and Temple 1984, Underhill *et al* 1992); and
- the relationship between reporting rate and absolute abundance/density is monotonic but not linear (Underhill *et al* 1992);

The implications of these limitations are, in the first case, that while the models can be compared qualitatively, it is not legitimate to do so in quantitative terms for different species unless they are equally observable and identifiable at all times and under all conditions. In the second case, simple multiples of reporting rates do not necessarily imply simple multiples in population size, although increases or decreases in reporting rates do indicate population changes in the same direction (Temple and Temple 1986b, Bruderer and Bruderer 1993).

An upward trend in checklist length with time -- an increase in the number of species recorded per list -- has been noted elsewhere (Temple and Temple 1976, Underhill and Hockey 1988) and is an obvious phenomenon in the SABAP databank. It is easily understood in terms of 3 observer-related trends:

* observers' skill at observing and identifying birds improves with time;
* many recruits fall out of large-scale projects, leaving a smaller body of enthusiastic and serious participants who produce relatively long lists; and
* as a project such as the SABAP progresses a more serious and goal-oriented attitude develops, leading to increased effort to produce lists of high quality (Underhill and Hockey 1988).

These factors tend to have a marked effect where there is no control for skill or effort employed in the compilation of checklists, as was the case in the SABAP. As reporting rate increases with increasing checklist length, a spurious upward trend in relative abundance tends to appear, requiring a correction/standardization procedure (Temple and Temple 1976). The effect of this phenomenon is not likely to be the same on different species and depends on relative observability and identifiability. Standardization was therefore based on a regression calculated separately for each species.

The reporting rate as an index of relative abundance has a long history but it has been under-rated and under-utilized as a technique for measuring relative abundance. The properties of reporting rates or "frequency of occurrence" were discussed, and an example of their application provided, a long time ago (Linsdale 1928, 1932) and their use strongly advocated. A search of the literature has, however, yielded few additional examples. It has been recognized that most bird census methods yield little more than a relative measure of abundance/density (Dawson 1981, Temple 1981) but there still appears to be resistance to using techniques which do not involve actual counts of individuals.

Some workers have employed the reporting rate index using "Timed Species Counts" to provide indices of relative abundance at different sites (Pomeroy and Tengecho 1986a, 1986b). These have then been used to interpret distributions in terms of habitat preferences. Reporting rates have been used in North America (Temple and Cary 1987) and used effectively to show spatial variation and seasonal changes in relative abundance within a species' range by plotting reporting rates against time of year (Temple and Temple 1986a). Comparison of such plots for 2 ecological regions of Wisconsin helped to elucidate the direction and timing of avian seasonal movements (Temple and Temple 1984).

Of particular relevance to this study is work in which reporting rates have been used to analyze time series, such as the checklists used to detect changes in relative abundance of 35 species in New York State (Temple and Temple 1976). Reporting rates have also been to describe year-to-year variations in migration phenology (Temple and Cary 1987) and to study nomadism in the Gull-billed Tern *Sterna nilotica* over a 5-yr period (Davies 1984) using reporting rates derived from checklists compiled for the Australian atlas (Blakers *et al* 1984). Population trends in rare birds have been described based on reporting rates in British county records (Mason 1990) although the study did not involve checklists as such.

The results in this paper would not be evident from presence/absence mapping alone as all species occur in all years but at different levels of relative abundance. The phenomena are relative and not absolute by nature and therefore a measure of abundance to detect and describe them. Ironically this need can be satisfied by simple presence/absence data compiled to produce reporting rates.

Conclusions

The body of work using reporting rates is small but the approach has repeatedly shown its usefulness in describing, and detecting trends in time in, relative abundance. A recurring theme in analyses of this type is the use of checklists and reporting rates as simple but useful tools in monitoring bird populations over large geographical areas and for a broad spectrum of species. More rigorous census techniques tend to be more limited in scope.

In this paper a method whereby a time series of reporting rate indices can be statistically correlated with an explanatory variable, namely rainfall, has been demonstrated.

In a North American context it has been suggested that "... checklist records can be of great value in elucidating long-term trends in bird populations..." (Temple and Temple 1976), and their collection in other regions advocated. The results presented in this paper support others (Macdonald 1992, Underhill *et al* 1992) which show that checklist-based projects are an appropriate technique for population monitoring in an African context.

The developing nations have a great need to monitor their wildlife populations in these times of rapid environmental change. In many cases, this has to be done in the absence of the basic information that is usually available in the developed world. It is therefore appropriate that data-collection protocols encourage the broadest geographic and taxonomic scope, while allowing sophisticated analysis of the data to monitor changes in relative abundance. The checklist and the reporting rate statistic appear eminently suited to this purpose, particularly if there is control for observer-related effects.

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