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# Detection and understanding of changes in biodiversity in response to changes in environmental drivers and pressures in the Mediterranean area, an example from Egypt

**Abstract**

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El Omayed 'ROSELT' Observatory adopted a thematic procedure of evaluating and monitoring changes in natural resources. Data from previous studies was reworked to fit into the concerned themes. The trends of temporal change in the different variables were evaluated using polynomial curve fitting confirmed by statistical analyses. The extracted trends indicate a steady increase in air temperature, relative humidity and annual rainfall, while wind speed is declining. The standardized seasonal rainfall results in an autumn trend that approximates annual trend with amplitude of five years, while that during winter season is declining and that of spring is inclining above the long-term average starting mid nineties. Concurrently, sodium, sulfate and chloride contents increased rapidly late in the nineties joined with increasing the very fine sand fraction that reflects the active erosion and deposition processes associating recent human interference in the area. The temporal changes in the soil properties define the inland ridges as having the most stable conditions. The long-term records report 122 perennials and 104 annuals of plant species residing in the observatory. Except for the inland plateau, there is a process of recharging the species diversity late in the nineties after experiencing a former sizable decline. Also detected is a change in the life-form spectrum towards larger woody component. Moreover and at the closing of the decade, the perennial species exhibit less reproductive effort coupled with a decline in the annual reproduction of both perennials and annuals. It is evident that 26 species can be considered in jeopardy in terms of declining density and spatial occupation. With 54 % of these are ligneous, there is high risk imposed on the structure and function of the concerned ecosystems. Some of these species are transient with a trend of a five years cycle of species replacement. The values of alpha and beta diversity indices argue that the habitats most abet to plant diversity are inland ridges and inland plateau; hosting the highest species diversity and specificity and larger positive value of species turnover.The change in the diversity of perennial species is allied to changes in rainfall, temperature and wind speed of the climatic, and salinity, bicarbonate, calcium, and sulfate of the edaphic variables. This applies also to the endangered species with especially air temperature and soil sulfates as the most determinant driving factors. Further is the shift of the rainfall above the long-term average from winter to spring that elucidates the trend of change detected in the diversity at the close of the decade. It is concluded that, the diversity of biotops (spatial heterogeneity in habitats) in the area is the influential base for the biodiversity and is greatly affected by human impacts. Concurrently, the changes in the climate and the associated environmental degradation of notably soil resources, are more of cyclic (recurring) phenomena, which reflects specific feedback effects on biodiversity in the region.

## Introduction

The need for the detection and understanding of environmental change is evolving especially with the increasing rate and extent it is happening. This increased the interest in long-term monitoring of the impacts of global environmental changes.

The questions if biodiversity is a property that can be measured and what is the most appropriate form for it to take? (cf. Harper & Hawksworth 1995) are resolved by several workers. In this respect and from an ecological perspective, studies on biodiversity (alpha diversity) cover local samples of the community in limited areas to determine the degree of dominance, equity, or the number of rare species as basis for estimating the structure and function of these communities (Halffter 1998). Complementarily, The landscape scale, mesoscale perspective as called by Ricklefs & Schluter (1993), uses a study unit that varies in size between the local and regional spatial scales with time scale ranging from decades to centuries.

Dominant ecological effects at the local level and historical effects, biogeographical or evolutionary, on broader levels are registered at the landscape scale where the consequences of human impacts are most evident (Halffter 1998). Thus, species diversity from landscape perspective could be analyzed as a function of the heterogeneity of the physical and biological environment at the one hand and as a function of human activity at the other hand (Noss 1983; Franklin 1993).

In the conventional perspective, all anthropogenic modifications to pristine communities result in a loss of species richness. Halffter (1998) argue that this can occur at the local level (alpha diversity) but may produce the opposite effect over a landscape (gamma diversity). Fjeldsa & Lovett (1997) referred also to the very little attention given to study the impacts of the cyclic changes of the global climate on local and regional turnover rates of species of erratic changes.

The present work concerns El Omayed area, which had suffered for the last two decades some major changes attributed to human impacts that are interacting with natural causes, notably climate change, leading to degradation of natural habitats. This area was recently labeled as El Omayed ROSELT Observatory* (established in 1996) and hence paved the way for setting a thematic procedure for monitoring natural resources and elaborating ecological indicators. This article exposes some of the work conducted in the Observatory and demonstrates examples of the analyses and interpretation undertaken for the detection of change in biodiversity in disturbed and natural systems, at local and regional scales, in relation to contemporary and future environmental issues.

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* El Omayed Observatory (Egypt) is a unit of the program of 'Long-term Ecological Monitoring Observatories Network (ROSELT)' of the Sahara and Sahel Observatories (OSS), which conducts the monitoring of the basic environmental drivers, pressures and responses to environmental change with the aim of combating desertification and for implementing sustainable development plans. It has a programme that links field data, remote sensing data and modeling approach for detection and understanding of long-term change in natural and disturbed areas.

## Material and Methods

Marked physiographic heterogeneity and different types of habitats characterize the Omayed area, in the western Mediterranean region of Egypt, which lead to distinct local variations in the distribution of vegetation and hence variable plant diversity and relatively high fauna richness for such a low rainfall desert.

One major theme involved in the program of the observatory is to use the climatic and edaphic data to explain the trends of change in species diversity, and to evaluate species turnover (beta diversity) under the influence of land-cover conversion (human impacts). Including identification and mapping of habitats (and of land-use types) most apt to affect biodiversity (biotops). Changes in the diversity and types of flying arthropods are also used as indicators of the intensity and extent of expansion in human population in the area.

The Observatory has twelve permanent sampling plots representing the different habitats and/or ecosystems, and seventeen pilot areas along a fixed transect layout (25 km, North-south) which cover the variations at the landscape scale. The plots are intensively studied and monitored on a seasonal bases, while transect is extensively sampled on an annual bases (during spring).

The habitats covered in the program are inland plateau (plots 1 and 2), inland ridges (plots 3), non-saline depression (plots 4), cultivated areas (plot 5), saline depression (plots 6) and coastal dunes (plots 7). A, B and C designates representative plots within a habitat. Concurrentally, there are 16 microhabitats (T1-16) represented by 24 micro-sites (designated by a,b and c) that came across the sampling transect.

The concerned monitoring themes include recording and analyzing climate variables, soil status, plant abundance and species diversity. The database is included in the Annual Reports of El Omayed ROSELT Observatory (1996 through 2000). The trends of temporal change in the different measures and variables were evaluated using polynomial curve fitting methods. In this respect, statistical and numerical analyses are used to confirm the degree of these associations.

Data from previous studies in the area (along 20 years) was reworked to fit into the concerned theme. The method adopted to overcome the problem of inconsistent units and procedures in collecting data by different researchers was simply applying independent ranking of measures into classes (pseudo-values). These are then used for detecting the trends of change using curve-fitting technique.

Species diversity indices (or genetic diversity) are evaluated at the levels of habitat (alpha), community (beta), and the whole area of observatory (gamma) (refer to Whittaker 1972; Pielou 1975; Magurran 1988; Ricklefs & Schluter 1993).

## Results

The general trends of change in climatic variables on a long-term temporal scale indicates a steady increase in the mean daily temperature, relative humidity and the annual rainfall (by about 2-3 °C, 10-15 % and 20-30 mm respectively), while that of the wind speed is declining (Fig. 1). The standardized rainfall measures over the annual and the seasonal long-term temporal scale results in a trend during autumn which approximates, by far, that of the annual trend (a "sin" curve around a long-term mean) with amplitudes of

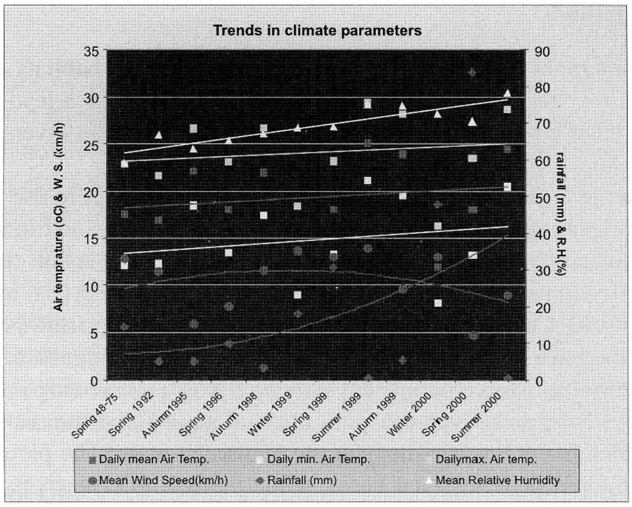



Fig. 1. Trends of change in the climatic measures on the long-term temporal scale.

five years period (Fig. 2). Concurrently, the trend of rainfall during winter seasons is declining below the long-term average starting mid nineties while shifting into a continuous incline above the average during spring.

Soil trends assigned the largest variation to sodium, sulfate and chloride contents (salinity), which increased rapidly late in the nineties associated with similar trends, but to much less extent, for both calcium and bicarbonate contents (Fig. 3). These trends correspond to a remarkable change in the soil texture during the same period with incorporating larger component of the very fine sand fraction.

The temporal changes in the soil properties of the different habitats define the inland ridges as having the most stable conditions (least differences among years) with an obvious increase in its soil finer particles (Fig. 4). All habitats exhibit increases in soil contents of especially calcium and bicarbonates. On the other hand, the inland plateau is experiencing a sharp change in its soil texture associated with the increase of sulfate content. However, this trend was lately reversed with declining sodium and sulfate and increasing calcium and bicarbonate contents associating the increase in sand coarse and fine fractions.

The long-term records in the observatory area assign species richness values to 122 perennials and 104 annuals at the landscape scale of which the sampling plots account for about 77 % (106 perennials and 67 annuals). Some species have common occurrences in several habitats (12 species) and others have a restricted distribution to a single habitat (total of 72 species). On a national scale, many of the species recorded in Omayed area have a narrow geographical distribution allover Egypt and have high ratio of rare and very rare ones.

The trends of change in the richness of perennial species at both the spatial (habitats) and the temporal scales demonstrate two general findings (Fig. 5). The first is that inland ridges support the highest plant diversity (plots 3A and 3B; about 18 species are habitat

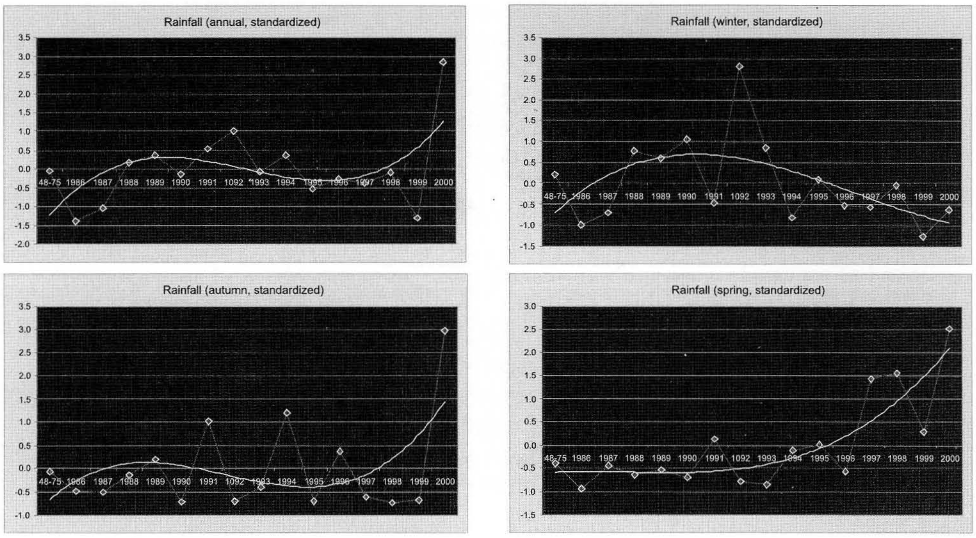



Fig. 2. Trends of change in the standardized values of rainfall over the annual and seasonal long term temporal scale.

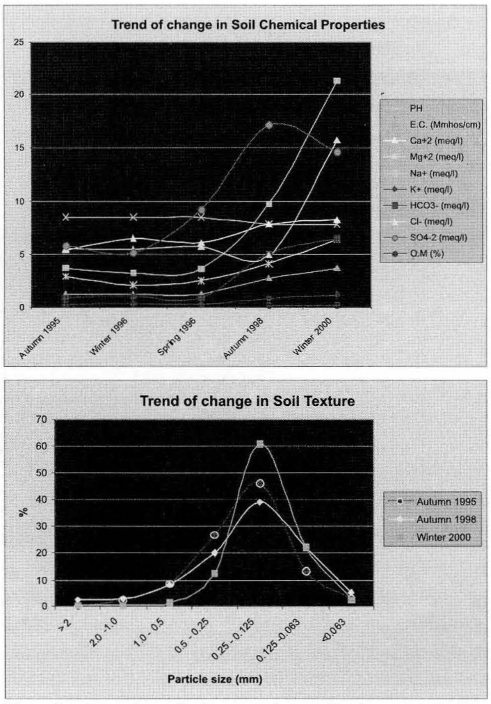



Fig. 3. Trends of change in soil characteristics within five years period.

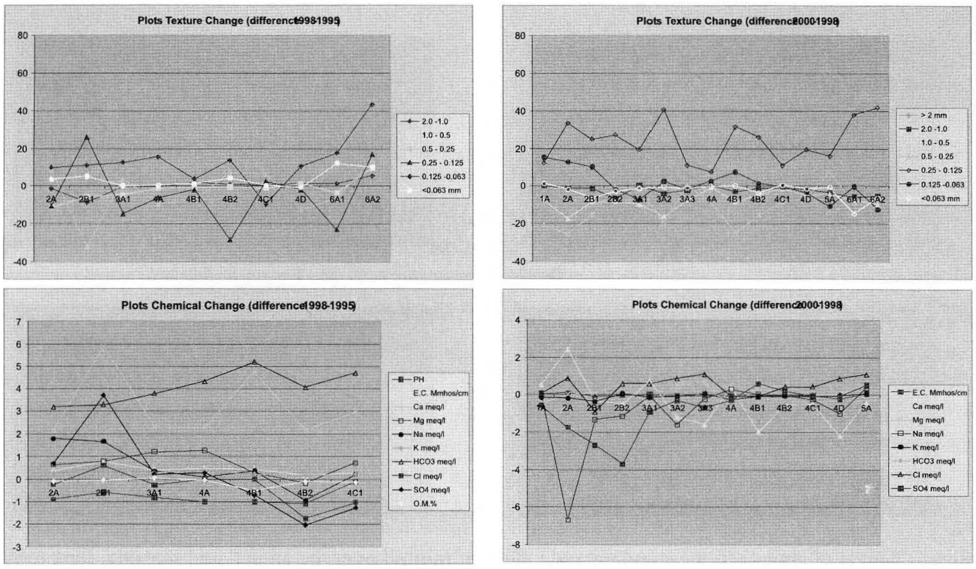



Fig. 4. Variations in soil characteristics of the different habitats among years 1995 - 1998 (left) and years 1998 - 2000 (right).

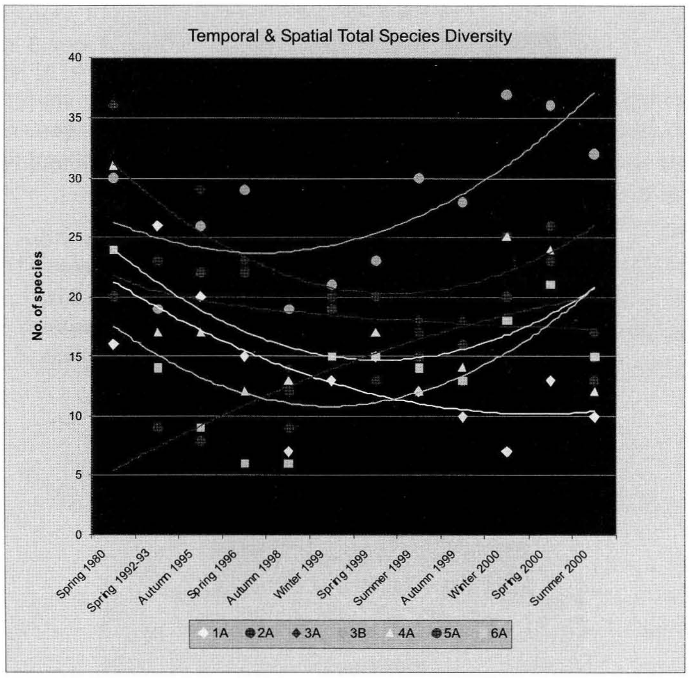



Fig. 5. Trends of change in species richness at both the spatial (habitats) and temporal (years) scales.

specific) with its peak values towards the northern slopes and foots of the ridges (3B). The second finding highlights the issue that except for the inland plateau (1A and 2A; 14 species are habitat specific), where the trend of plant diversity is declining, there is a process of rapid recharge of species diversity starting the year 1999 after a sizable decline along the preceding time period. However, extremes of maxima and/or minima in the number of species did occur in some habitats during specific years. The source data also reveals that the change in the density of the various plant species is indifferent among habitats while changing with time as imposed by the acting driving factors.

The trend of change in the perennial species richness tends to slightly increase along the temporal scale with a trend's average of about 60 species. This trend differs with life form; notably the chaemephytes and phanerophytes (ligneous component of plant communities) are continuously inclining at the expense of the hemicryptophytes and geophytes (Fig. 6). That of annuals started to increase early in the year 1999 after a continuous decline in the preceding years. Chaemephytes is the dominant component of the life-form spectrum in the observatory.

The trend of temporal change relating the perennial species richness to the climatic variables (Fig. 7) clearly indicates that the number of species is increasing subject to increasing rainfall and decreases with increasing mean daily air temperature, while is decreasing at intermediate level of wind speed. Similarly, relating the species richness to the soil properties indicates that the number of species drops to a minimum level at intermediate levels of salinity, calcium and bicarbonate contents, while it is a maximum at the intermediate level of sulfate content. Moreover, the phenology trends of perennial species at the closing of the decade (Fig. 8) indicate that the vegetative phase is expanding at the

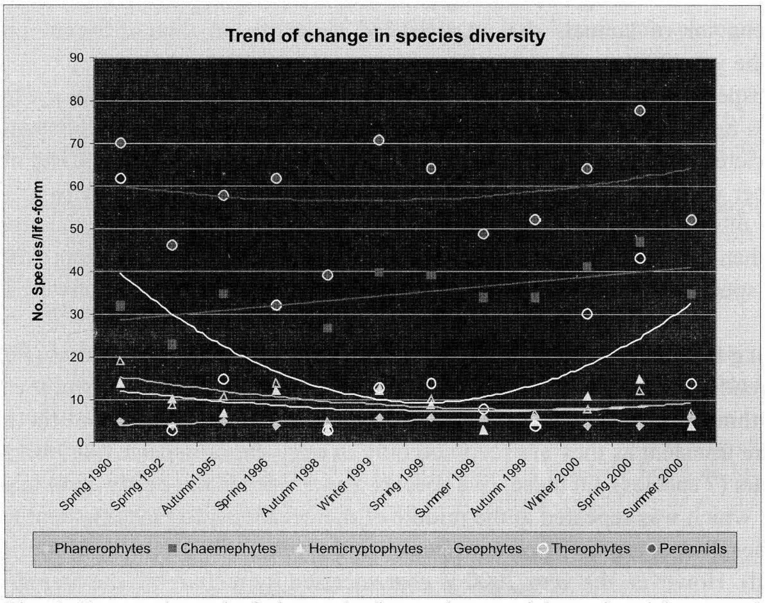



Fig. 6. Temporal trend of change in the total perennial species richness and within life forms at the landscape scale.

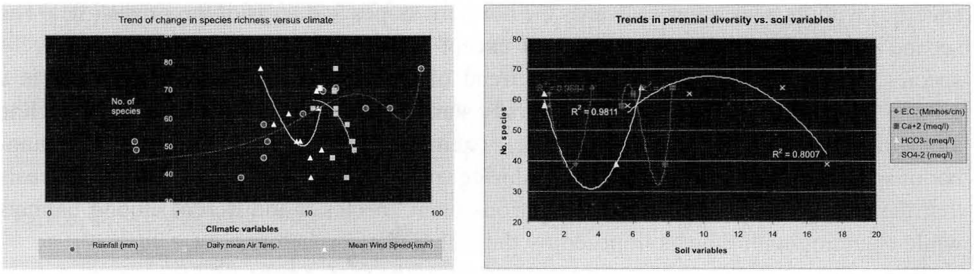



Fig. 7. Trends of the relationship between species richness and selected climate variables (left) and soil measures (right).

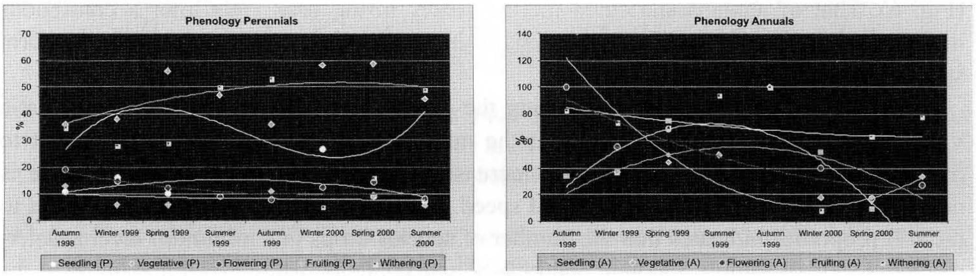



Fig. 8. Trends of change in the average phenological behavior of plants with time.

expense of both flowering and fruiting phases. The seedling phase is, more or less, similar to the behavior of annuals that experienced a decline in their different phenophases towards the year 2000.

The inspection of the temporal variability in the measures of perennial species residing in the area testifies that 26 species exhibit a great decline in density and in spatial occupation (restricted niche) as they are mostly linked to specific habitats. The trend of change in the number of these species during the last decade was slightly increasing while their measures of density and presence percentage were decreasing towards the closing of the decade when they started to increase (Fig. 9). The ligneous component approximates 54 % of these species (2 phanerophytes, 12 chaemephytes, 6 hemicryptophytes and 6 geophytes).

Relating the number of endangered species to climatic and soil measures (Fig. 10) indicates a trend of temporal change similar to that of the other species, while calcium had more rhythmical influence at its different levels. Concurrently, many of the endangered species are transient as they are recorded only in one year (23 species) or only in two different years (7 species). Of these, five species were recorded once only early in the nineties (Fig. 11), which was repeated at the middle of the decade and again at its end followed by even higher disappearance of certain species in the year 2000 (up to eight species of a single record). However, the year 2000 is characterized by recharging the area of the observatory by other species that were previously recorded in one year only during the last decade (six species).

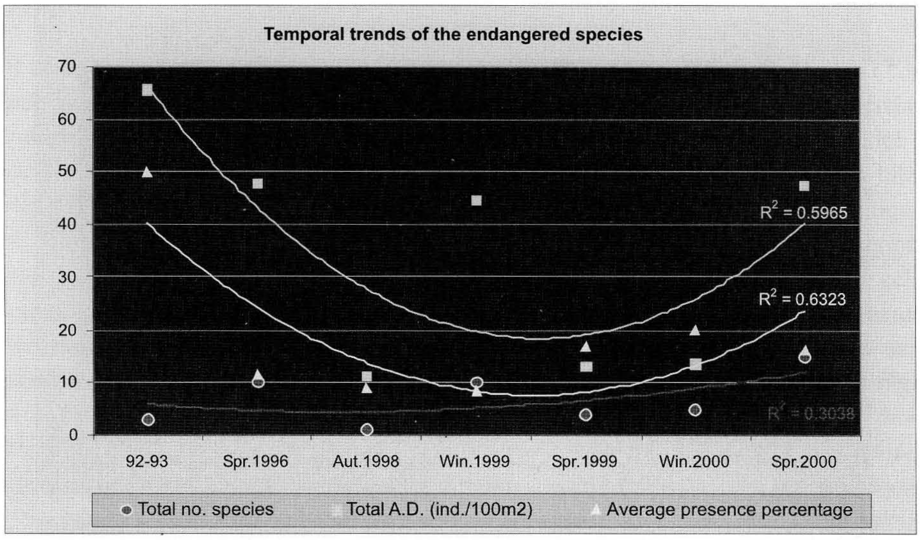
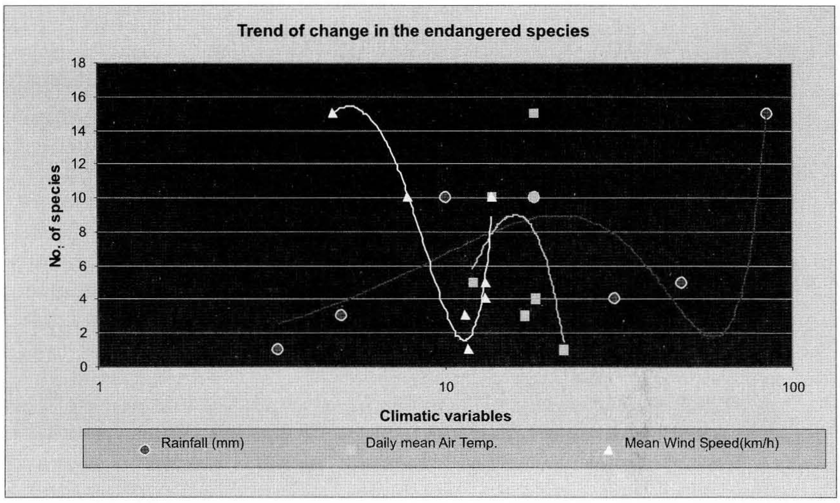



Fig. 9. Trends of change in the number of endangered species, their density and occurrence at the landscape level.

The general trend of local species diversity, within the source database, shows a remarkable decrease in alpha diversity and evenness by increased disturbance level coinciding with the increase in dominance of few species (only one strong dominant species in many plots), which are adapted to live in disturbed environment. On the other hand, less disturbed sites are characterized by having larger number of frequent and most frequent species as measured by Hill's number N1 and N2.

Alpha and gamma diversity indices are used, herein, to detect variations at both the spatial and the temporal scales with further measures of species turnover among habitats. The habitats of inland ridges and inland plateau, which exhibited the highest values of alpha diversity (richness) possessed also a larger positive value of species turnover. The temporal variations in species diversity of sampling plots at both the local (habitats) and the landscape scales (Fig. 12) indicate coincident trends of both species replacement along years (beta values) and overall diversity (gamma values). Examining the computed gamma diversity at different years indicates the occurrence of detectable temporal variability at the landscape level that is linked to temporal variations in both alpha and beta diversity values.

The alpha diversity indices of species recorded in pilot areas along the transect shows great variability representing the different intersected microhabitats with higher values during the year 2000 compared to the year 1999 (Fig. 13). Similar variability is detected for beta diversity and species turnovers of these microhabitats. While at the landscape scale, the value of gamma diversity, is higher for the year 2000 as the result of higher alpha and beta diversity indices.



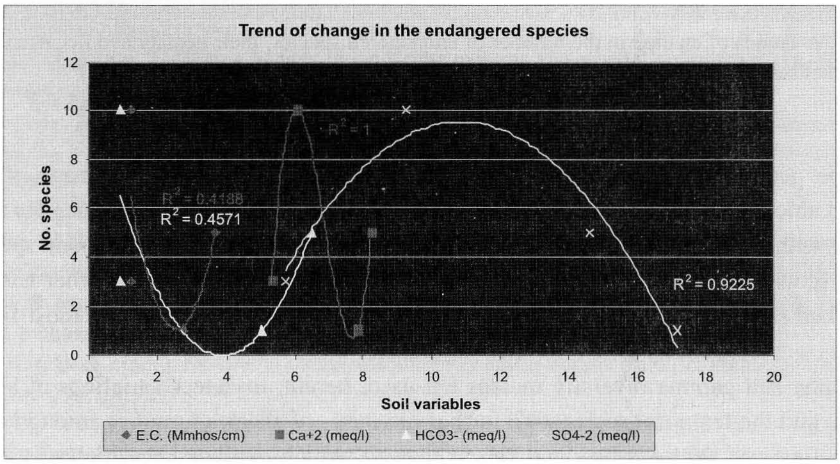
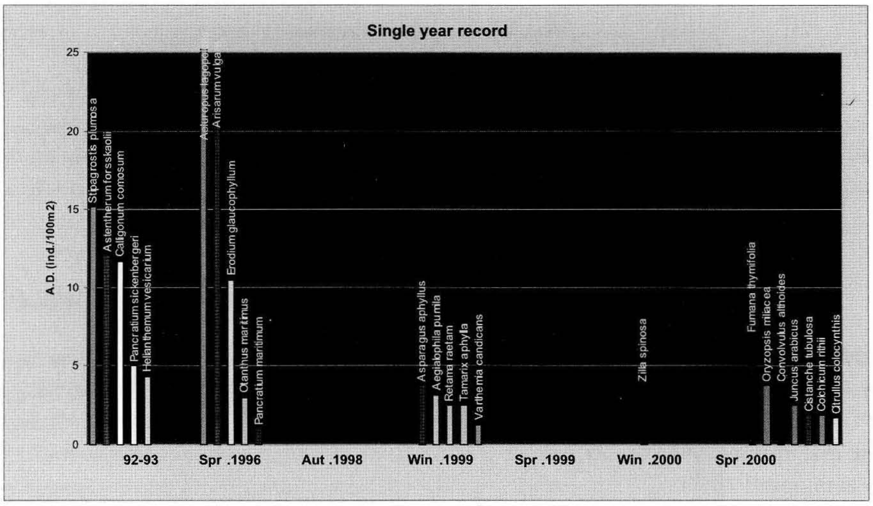




Fig. 10. Trends of relationship between number of endangered species and selected climate variables (top) and soil measures (bottom).

## Discussion

Although long term temporal trends of climate variables are steadily increasing, except for the wind velocity, the trend of a calculated moving average (three years) are, more or less, constant for temperature and relative humidity, while is bimodal for rainfall and highly irregular for wind speed at the closing of the decade. This would designate a prospected effect of the change in rainfall and wind speed as components of the environmental driving forces, leaning on the specifications of a stable climate (cf. Fjeldsa & Lovett 1997).

Rainfall regimes based on standardization by season, as a climatic driver, reveal a shift of the rainfall incline above the long-term average from winter to spring, which elucidates the detected trend of change for species richness. Further is a support of earlier initiation



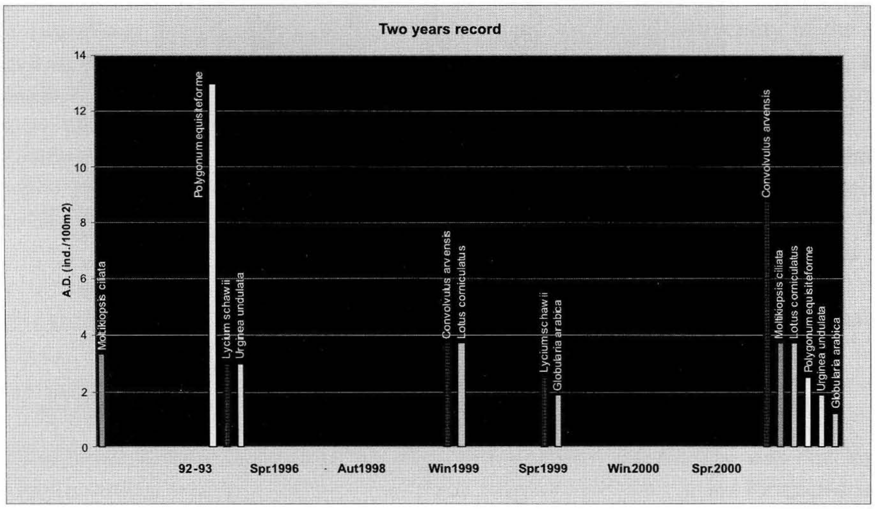




Fig. 11. Changes in transient species with time.

of the plant active growth period backed by the recent increase in the rainfall above average during autumn. Changes on seasonal aspect were also detected in southern Africa with species richness associating the variation in rainfall regimes between seasons (Lovett & al. 2000). Moreover, expanding the vegetative phase of perennials at the closing of the decade at the expense of reproductive phases indicates less reproductive effort, while the decline in the seedling phase of perennials and in establishment of annuals highlights a less annual reproduction capacity. Accordingly, if those species were habitat specific, an increase in the number of threatened species would be expected when experiencing erratic hazard.

The detected increase in the contents of especially calcium and bicarbonates in all habitats would reflect the active erosion and deposition processes resulting from erratic winds

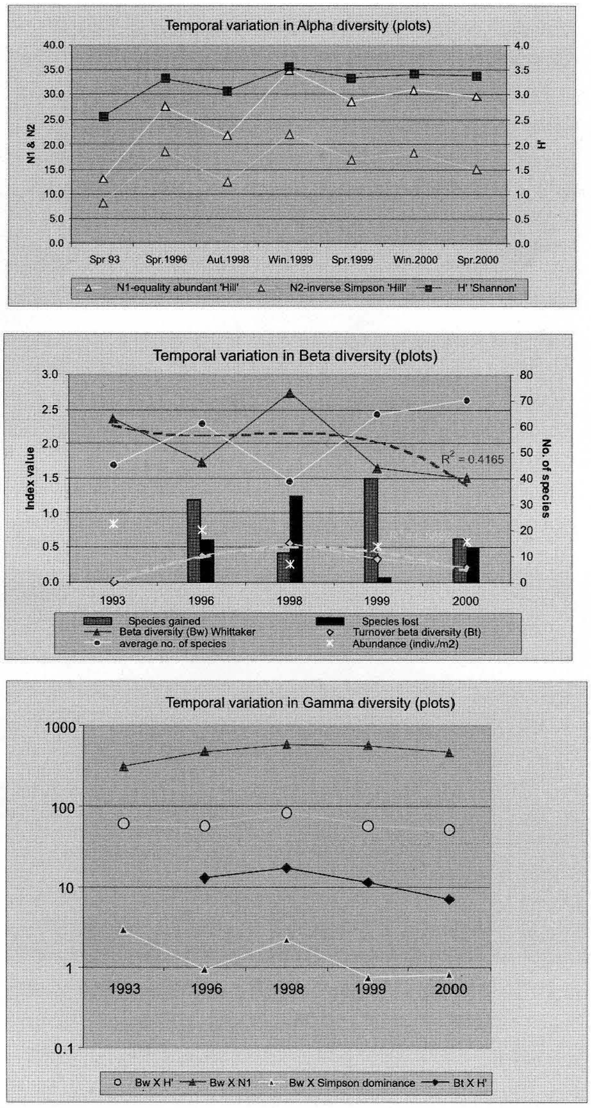



Figure 12. Temporal variability in diversity indices at local and landscape scales (plots).

(defined as a climatic driver) coupled with recent human interference in the area. Concurrently, the largest variations in soil measures contributed by the salinity components associating the remarkable change in the soil texture would define the edaphic drivers affecting biodiversity, considering disturbance as a major factor affecting populations and modifying interactions among species in communities (Connell 1978; Sousa 1984; Pickett & White 1985).

The ascertain of the inland ridges as having the most stable soil physical and chemical

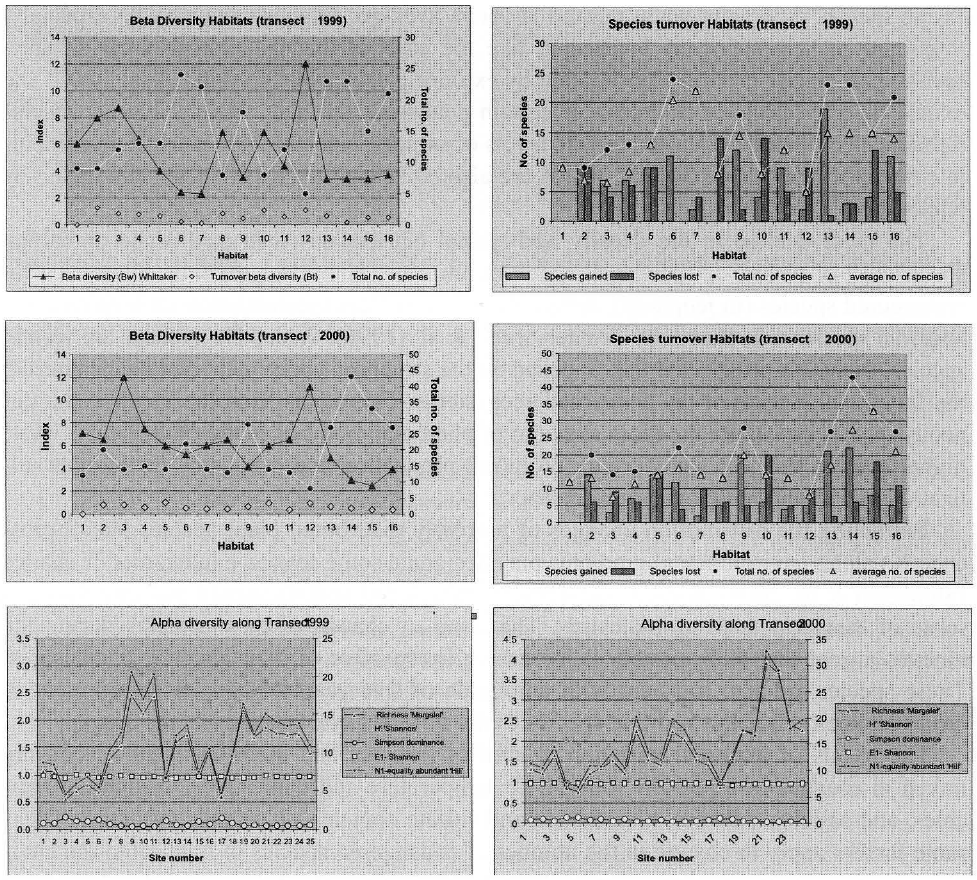



Fig. 13. Temporal variability in diversity indices at local and landscape scales (transect).

conditions along with increasing its soil finer particles content can advocate its highest rank of species richness; acting as a refuge site for several species. However, the plant community of this ecosystem is considered fragile (cf. Danielsen 1997) and as man-made perturbations would have their most detrimental effects in such areas (Bagon & al. 1986). This would declare the high risk imposed on inland ridges and explains why the ongoing active change of soil characteristics on the inland plateau of the observatory, resulting from the acknowledged climatic and edaphic drivers, is associated with a local detectable decline in species richness.

The association of the temporal change in species richness, at the landscape scale, positively with rainfall and negatively with higher air temperature is obvious, however its decrease at intermediate level of wind speed is interesting. It seems that the years with below average wind speed afford stable soils surface condition that support the growth of especially herbs and the increase in plant cover parallel to low habitat perturbations. In contrast, above average wind speed results in creating new micro-sites at the landscape scale, which combined with human disturbance could promote reintroducing rare and/or exotic species especially when rainfall is above average. This process may be especially important in heterogeneous landscape, like the case of the observatory area, as plant species can greatly expand their domain by exploring ecotones (Stohlgren & al. 2000) and extend the physiological tolerance of certain genotypes (Bazzaz 1996). Notably, species richness also decreases at intermediate levels of salinity, calcium and bicarbonate contents in contrast to the sulfate content, which are also connected to soil erosion / deposition by winds.

The great decline in the density and spatial occupation (restricted niche or habitat specificity) of twenty-six perennial species with time, nominates them as candidates for endangered species (in jeopardy). A high degree of habitat specialization on both rare and endemic species was shown by Trinder-Smith & al. (1996). With 54% of these are woody species, there is a prospected risk imposed on the structural component and hence altering the functional aspects of the concerned ecosystems. This stems from the fact that the ligneous species constitute the main skeleton of plant communities in the observatory, while higher species richness significantly promotes production and efficiency in resource utilization and retention (Tilman & al. 1996).

Extracting the distribution changes of narrowly distributed plant species (small presence %) along environmental gradients may designate some sensitive indicators of change (Stohlgren & al. 2000). Indeed, the defined endangered species satisfy this criterion and some of them can hold as indicators. The trend of change of these species during the nineties argues that their number is increasing irrespective of their abundance measures. These species are also transient with amplitude of five years of species replacement or turnover when related to additive species to the different communities in the area.

The trends of temporal variation in species richness and their life-form spectra are linked to changes in especially rainfall, air temperature and wind speed of climatic variables, and salinity, calcium, bicarbonate and sulfate contents of edaphic variables. These same factors apply to change in the number of endangered species in relation to the environmental drivers but with further soil texture effect. Each of these variables has its specific action on changes in species richness, with especially air temperature and soil sulfates as the most determinant driving factors. Extremes of maxima and/or minima in species richness that occur in some habitats during specific years can thus be attributed to erratic climate variability in the first place.

The habitats (biotops) most abet to plant diversity are inland ridges and inland plateau, which have the highest alpha diversity and species specificity (bio-indicators) and a larger positive value of species turnover (beta diversity) compared to other habitats. Several studies attributed the high species diversity of ridges' communities to their spatial heterogeneity (cf. Puerto & al. 1990; Tilman & Pacala 1993; Cowling & al. 1996), jointly with the presence of different trends associating diversity-altitude relationships (e.g. Whittaker 1970 & 1977; Hamilton & Perrott 1981; Ghazanfar 1991; Stohlgen & al. 2000).

Comparing the diversity indices at landscape scale indicates that the replacement of species along the transect (beta diversity) exceeds by far that of plots representing the major habitats. This supports the idea that superimposed on broad scale climatic gradients are smaller gradients of micro-sites with diverse edaphic features that influence the species richness (cf. Stohlgren & al. 2000). The transect comes across different levels of topographic and human interventions in the area that lead to habitat fragmentation with transition areas resulting in the change of species richness and turnover rates at smaller distance scales. Accordingly, the suggestion of Oliviera & Mori (1999) that high species richness is the result of a combination of habitat heterogeneity and geological history is applicable herewith. While high species exchange along the sampling transect can be justified by considering the physiological adaptation to different edaphic conditions as the principle determinant of species turnover (cf. Simmons & Cowling 1996). In this respect, it is possible to select appropriate indicator species for specific, anticipated environmental changes using the changes in the distribution frequency of selected species linked to associating soil characteristics along the transect (cf. Stohlgren & al. 2000).

Halffter (1998) speculated that species diversity has also to be examined at the landscape (or mesoscale "gamma diversity") level where the consequences of human activities are most evident. Adopting this strategy at the temporal scale declares that the gamma values calculated for the major habitats are slightly decreasing with time corresponding to decreasing beta diversity among them (intrinsic complexity of the dominant ecosystems). In contrast, those calculated for microhabitats along the sampled transect increased with time attributed mainly to increasing beta diversity (species exchange); as larger homogeneous patches of micro-sites are developing along with expanding land conversion (landscape heterogeneity).

It is concluded that, the diversity of biotops (spatial variability in microhabitats) has large influence on the biodiversity at the landscape scale. This is greatly affected by human impacts detected through change detection in land cover using mapping technique and processing of remote sensing images reflecting the land-use/land conversion practices (defined in the database of the observatory). While the global environmental changes, among which the change in the climate and the associated environmental degradation of notably soil resources, are more of a cyclic (recurring) phenomena, which has its feedback intermingling effects on biodiversity in the region. Moreover, climate change should also be treated on a seasonal basis to enable extracting climatic drivers acting upon local species diversity and functioning.

Finally, the occurrence of a high degree of species exchange (high beta diversity) at the landscape scale as a function of distance and representing the principle component of gamma diversity question the appropriate protected area for conserving global diversity at the landscape scale.

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