CLIMATIC CONDITIONS ON THE ISLAND OF SILBA

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1. INTRODUCTION

The atmosphere plays a prominent role in the management of natural resources. One of the preconditions for the reasonable management of natural resources is a profound knowledge of biological processes depending on climatic conditions because the spatial distribution of plant and animal species depends on climatic elements as radiation, light, warmth, humidity, the amount of soil water and other meteorological occurrences. As climate is one of the key factors, we have to understand it, to use its advantages and to protect ourselves from its negative influences. For example, a prolonged precipitation deficiency, high air temperatures and reinforced evapotranspiration can cause drought, with possible catastrophic consequences for both plants and the economy. Therefore, some meteorological parameters as evapotranspiration and moisture loss from the soil significantly influence the land and island flora.

The project *Preservation of biological diversity in the Adriatic sea* in order to protect some special areas along the Adriatic coast was started in Croatia. In one of these areas – the island of Silba - the water balance components have been researched, to estimate possible climatic variability. To determine climatological standards, meteorological data such as air temperature, precipitation, relative humidity, cloudiness, wind and occurrences of dew, fog, hail and thunder have also been analysed. The island of Silba is situated in the northern Adriatic and meteorological observations have been performed since 1964. Meteorological data and water balance components have been studied for the period 1964-1993, except for wind strength and direction in the period 1981-1990.

2. WIND REGIME

The wind regime on the Adriatic coast is one of the decisive factors affecting the land-island flora and fauna with its characteristic winds, known as *bura*, *jugo* and *maestral* blowing along the Adriatic coast.

As there is no instrument for wind speed measurements at the Silba station, its strength is determined by its effects on objects in nature. Wind strength is evaluated according to the 12 degree Beaufort scale. Wind direction is determined visually by means of a wind vane. These wind data are observed three times a day (7, 14 and 21 h).

To show the flow regime on Silba it was necessary to analyse the probabilities of a simultaneous occurrence of different wind strengths and directions (Fig. 1). At the Silba station, the most frequent wind is the *bura* blowing from NE (14.5%), then the SE wind known as *jugo* (11.9%) and a NW wind (9.3%). The *bura* is a dry, cold and gusty wind and intensifies the feeling of cold (Penzar and Makjanic, 1978). A strong *bura* wind over the sea tears the crests of the waves and causes marine spray. The coast exposed to the *bura* is sprinkled with salt from evaporated seawater brought there by the *bura* with sea spray. Plants hardly grow on such areas and the soil is bare. In contrast to the *bura* the *jugo* blows uniformly and causes high waves. In the southern wind regime warm air penetrates the Adriatic sea from North Africa adopting maritime characteristics and thus rain falls. Closer to the mainland the *maestral* occurs in summer. The etesian winds (seasonal winds from the NW direction) superpone with the sea breeze (a day wind from the same direction in accordance with coastal circulation) and the *maestral* occurs. The *maestral* is refreshing in summer and is always followed by bright and dry weather. The negative influence of strong wind on the island plants is wind erosion. In the areas where a frequent wind from the same direction is observed, trees are bent but their crowns develop into the side opposite to the wind direction.

If wind strength is considered independently from direction, then it can be noticed that winds from 1 to 3 B prevail (from light breeze to weak wind) in 69.4% of cases. The relative frequency of moderately strong winds (4-5 B) is 14.0% and that of winds stronger than 6 B is 4.3%. Calm is relative frequent on Silba (12.3%). Strong wind (? 6 B) is most frequent in the winter season with 5-6 days per month and it is mainly *bura* or *jugo*. The mean annual number of strong and severe wind days is 37.8 days and 4.9 days, respectively. It can be concluded that severe wind on Silba is a rare phenomenon in comparison to the northern and mid-Adriatic coast (V. Vucetic, 1991, 1993)

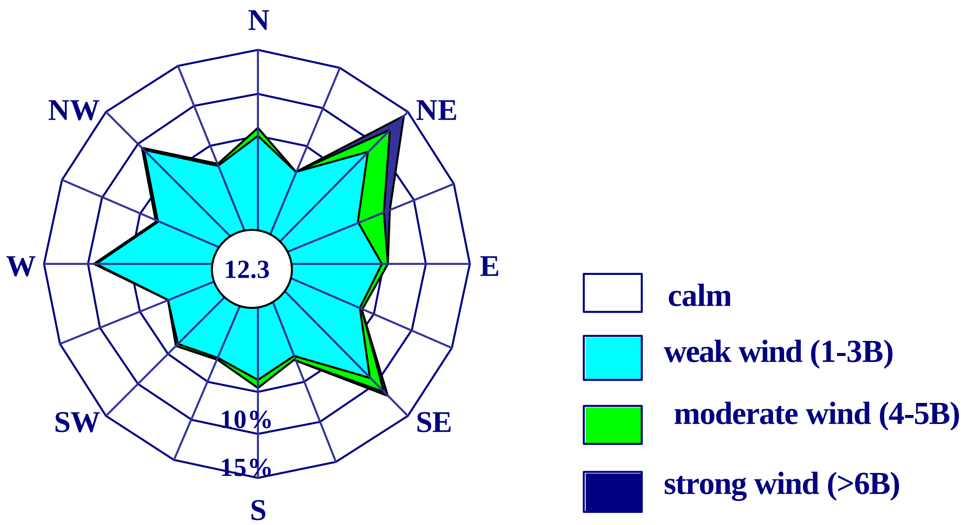

Figure 1 The annual wind rose for Silba during the period 1981-1990.

3. THERMAL AND PRECIPITATION CONDITIONS

Air temperature is a meteorological parameter that is most frequently used as a climatic indicator. The greatest temperature changes take place in the lowest air layer. In this layer near the ground it can be very warm during the day and very cold during the night, when the weather is clear and calm. However, standard temperature measurements are taken at 2 m above the ground, where the daily temperature fluctuation of air is smaller. Temperature conditions on Silba have been analysed taking into account the mean and extreme monthly and annual air temperature and the number of days with different temperature characteristics.

The annual course of air temperature resembles a simple wave with its lowest temperature in January and its highest in July. The mean annual air temperature is 15.1?C (Tab. 1). The absolute maximum was 35.2?C and absolute minimum -5.9?C. Negative air temperatures may occur from December to March, but only very rarely (in average 3.8 days). The maximum number of with days air temperature above 30?C (hot days) occurred from June to September (16.8 days in average) and most of them were in August. A warm night is a day when the minimum daily temperature exceeds 20?C. In July and August this is a very frequent phenomenon on the Adriatic coast (M. Vucetic and V. Vucetic, 1995, 1995a, 1995b) and also on Silba (32.8 days in average).

Relative air humidity has an annual course opposite to that of air temperature. In average, a maximum relative humidity occurs in January (76%) and a minimum in July (68%), which indicates that the air is relatively rich with humidity on Silba. Such annual courses of relative humidity are characteristic for the maritime climate where the difference between the maximum and minimum mean monthly relative humidity is usually small.

The next meteorological parameter defining the climate of a certain area is precipitation. The annual course of precipitation at Silba can be defined as maritime (Penzar and Makjanic, 1978). A minimum precipitation falls in July (37.6 mm) and a maximum in November (127.7 mm). Such distribution of precipitation is caused by different kinds of paths of atmospheric disturbances (cyclone and front) in which humid air rise and cools, resulting in clouds and precipitation. Because of a general atmospheric circulation in winter, numerous cyclones pass over the Mediterranean and the Adriatic sea. With the maritime type of annual course, the maximum amount of precipitation and the maximum number of overcast days (about 10 days per month) occur at that time. In summer, the cyclone paths are further to the north, the Adriatic is under the influence of the Azores anticyclone, which causes a minimum amount of precipitation, and a maximum number of clear days (about 15 days per month). In the 30-year period the maximum daily precipitation amount was 144.7 mm. However, days with a large amount of rain are rare, the annual mean is 1.5 days with an amount exceeding 50 mm.

The meteorological phenomena, which mostly influence the land and island flora, are dew, fog and hail, which are often connected with thunderstorms. Dew covering the soil, can be of great importance for the plants on the Adriatic islands during the dry season. In some areas, it appears in quite a large amount and it may be the only source of humidity for plants. Fog, on the contrary, may have negative impacts on the flora, preventing transpiration and triggering plant diseases. Because of insufficient air turbulence during fog, an amount of dangerous components in the air increases and so does pollution, which can have a negative effect on plants. Although hail is a rare phenomenon along the Adriatic - just one situation with heavy hail and strong wind might already cause significant damage to plants. On Silba thunder (37.8 days in average), fog (7.0 days) and hail (1.8 days) are neither very frequent nor very rare phenomena, but dew is frequent (86.3 days). All these analyses contribute to a better knowledge of climatic conditions. However, the wet and dry conditions in a certain area can not be determined only by precipitation amount and air temperature. The necessary water amount for evaporation and transpiration must be also taken into to consideration. In the next chapter one of methods for the calculation of water balance components is applied.

The list of symbols

t mean monthly air temperature ??C?

t_{max} maximum monthly air temperature ??C?

t_{min} minimum monthly air temperature ??C?

N_{cd} mean monthly number of cold days ? t_{min} < 0?C?

N_{wd} mean monthly number of warm days ?t_{max} ? 25?C?

N_{hd} mean monthly number of hot days ?t_{max} ? 30?C?

N_{wn} mean monthly number of days with warm nights ? t_{min} ? 20?C?

RH mean monthly relative humidity ?%?

RH_{min} minimum monthly relative humidity ?%?

$N_{RH?30\%}$ mean monthly number of days with relative humidity ? 30 %

$N_{RH?80\%}$ mean monthly number of days with relative humidity ? 80 %

P mean monthly precipitation amount ?mm?

P_{max} maximum monthly precipitation amount ?mm?

$N_{P?0.1}$ mean monthly number of days with precipitation amount ? 0.1mm

$N_{P?10}$ mean monthly number of days with precipitation amount ? 10.0mm

$N_{P?20}$ mean monthly number of days with precipitation amount ? 20.0mm

$N_{P?50}$ mean monthly number of days with precipitation amount ? 50.0mm

C mean monthly cloudiness ?1/10?

N_{oc} mean monthly number of overcast days ?C < 2/10?

N_{cl} mean monthly number of clear days ?C > 8/10?

N_h mean monthly number of hail days

N_f mean monthly number of fog days

N_d mean monthly number of dew days

N_t mean monthly number of thunder days

N_{stw} mean monthly number of days with strong wind ?? 6 Beaufort?

N_{sew} mean monthly number of days with severe wind ?? 8 Beaufort?

Table 1 A statistical review of meteorological parameters for Silba during the period 1964-1993.

	1	2	3	4	5	6	7	8	9	10	11	12	year
t	8.1	8.1	10.0	12.9	17.1	21.1	24.0	23.8	20.4	16.3	12.1	9.3	15.1
t_{max}	16.6	20.0	21.5	25.2	29.4	32.7	35.1	35.2	30.5	30.1	21.7	18.8	35.2
t_{min}	-5.9	-3.7	-4.4	3.8	5.7	10.2	12.9	12.7	1.4	5.8	0.1	-1.5	-5.9
N_{cd}	1.2	1.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	3.8
N_{wd}	0.0	0.0	0.0	0.1	2.7	15.8	28.8	27.6	15.0	1.2	0.0	0.0	87.4
N_{hd}	0.0	0.0	0.0	0.0	0.0	1.3	7.9	8.2	0.3	0.0	0.0	0.0	16.8
N_{wn}	0.0	0.0	0.0	0.0	0.0	3.2	14.1	14.8	2.3	0.0	0.0	0.0	32.8
RH	76	74	75	73	75	72	68	70	75	75	75	75	74
RH_{min}	25	21	24	22	23	30	23	25	25	21	25	28	21
$N_{RH?30}$	0.3	0.4	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.3	0.2	0.1	2.4
$N_{RH?80}$	9.8	6.9	5.7	3.5	3.1	2.1	0.8	1.0	2.9	4.2	7.1	8.2	52.9
P	84.5	72.1	68.9	65.2	61.8	57.2	36.8	68.3	91.5	98.6	130.2	89.6	893.8
P_{max}	144.7	73.8	44.6	48.5	58.0	83.0	119.5	94.1	71.1	106.0	84.8	71.7	144.7
$N_{P?0.1}$	8.7	7.7	8.6	8.7	7.8	6.9	3.9	5.1	7.1	7.8	10.1	8.9	88.2
$N_{P?10}$	2.8	2.4	2.7	2.1	2.2	1.9	1.2	2.1	3.2	3.3	4.7	3.0	30.7
$N_{P?20}$	1.1	1.0	0.7	0.8	0.6	0.8	0.4	1.3	1.5	1.7	2.1	1.3	12.9
$N_{P?50}$	0.1	0.1	0.0	0.0	0.03	0.1	0.1	0.2	0.2	0.2	0.3	0.1	1.4
C	5.7	5.3	5.2	4.9	4.5	3.9	2.8	2.9	3.6	4.6	5.7	5.8	4.6
N_{oc}	10.9	7.8	8.5	7.1	5.1	3.2	1.6	2.1	3.6	6.4	9.7	10.6	70.4
N_{cl}	6.3	6.8	7.5	7.5	8.5	9.6	15.1	15.5	12.7	9.2	5.9	6.3	104.0
N_h	0.2	0.3	0.2	0.1	0.2	0.3	0.03	0.1	0.1	0.1	0.1	0.1	1.9
N_f	0.7	1.2	1.3	0.6	0.4	0.1	0.3	0.4	1.3	1.0	0.2	0.5	7.7
N_t	1.6	1.9	1.7	2.4	2.7	4.9	4.0	5.2	4.8	4.0	3.9	2.2	37.8
N_d	5.7	3.9	8.0	7.8	9.3	6.2	4.5	6.8	10.6	8.6	6.6	5.9	80.2
N_{stw}	4.4	4.3	4.2	3.1	1.3	1.2	1.6	1.4	2.7	4.7	4.9	5.8	37.8

N_{sew}	0.6	0.6	0.4	0.4	0.2	0.03	0.2	0.2	0.3	0.5	0.9	0.9	4.9

4. APPLICATION OF THE PALMER METHOD

The Palmer method (Palmer, 1965) is one of methods for the calculation of the mean monthly values of water balance components (potential and actual evapotranspiration, moisture loss from the soil, recharge and runoff). Penzar (1976) and Pandžic (1985) were the first to apply the Palmer method to the meteorological data of Zagreb and the Adriatic coast area. After that, Pandžic and M. Vucetic (1995, 1996, 1997); M. Vucetic and V. Vucetic (1993, 1994a, 1994b, 1996a), V. Vucetic and M. Vucetic (1993, 1996), Štambuk and M. Vucetic (1993) and Gajic-Capka and Zaninovic (1998) applied this method to different parts of Croatia.

The Palmer method assumes that precipitation amount is distributed between the evapotranspiration and drenching soil with the excess water running off. If the precipitation amount is insufficient, the soil water storage evaporates and there is no runoff. The mathematical expression is the following:

$$P + L = ET + R + RO$$

P is the amount of precipitation, L is the moisture loss from the soil, ET is the actual evapotranspiration, R is the recharge (soil water storage) and RO is the run off (Palmer 1965, Penzar 1976 and Pandžic, 1985). Using the climatological data of mean monthly air temperature and relative humidity, the monthly amount of precipitation as well as the pedological data of soil moisture capacity it is possible to calculate the actual evapotranspiration. Potential evapotranspiration is computed by the Eagleman relation (Eagleman, 1967, Pandžic, 1985, V. Vucetic and M. Vucetic, 1996a). Palmer assumed that the soil consists of two layers. The upper layer is called surface layer and is roughly equivalent to the plow layer (approximate depth 20 cm). This is the layer onto which the rain falls and from which evapotranspiration takes place until all the available moisture in the layer has been removed. There is no recharge to the underlying layer of the root zone (approximate depth from 20 cm to 100 cm) until the surface layer has been brought to field capacity. The loss from the underlying layer depends on its initial moisture content as well as on the computed potential evapotranspiration and the available capacity of the soil system.

The Palmer method was applied to the climatological data from the Silba station during the period 1964-1993. The annual courses of potential and actual evapotranspiration are similar in the cold season (Tab. 2). The greatest differences between potential and actual evapotranspiratiomn (64-71 mm) were in July and August. The maximum of mean monthly moisture loss from soil (55.7 mm) occurred in July. After that, the moisture loss from soil abruptly decreased because the soil water storage was very small.

Table 2 The mean monthly and annual values of potential [PET, mm] and actual evapotranspiration [ET, mm] and moisture loss from soil [L, mm] for Silba during the period 1964-1993.

	1	2	3	4	5	6	7	8	9	10	11	12	year
PET	34.3	36.5	42.6	57.8	84.6	120.8	153.7	145.4	107.9	78.9	53.2	38.9	945.6
ET	34.3	36.2	42.4	57.1	79.5	101.0	89.6	74.8	69.1	58.7	49.9	38.8	731.3
L	3.1	3.9	3.5	8.5	28.0	41.9	55.7	7.5	2.6	5.5	0.3	1.6	162.1

5. LINEAR TRENDS OF THE PALMER INPUT AND OUTPUT VARIABLES

In order to establish the kind of climatic variability in the marine park of Silba, the linear trends for the input and output variables of the Palmer method have been analysed. One of the methods making possible the estimation of statistically significant changes of the level around which the terms of the time series are distributed i. e. the n estimation of the existence of a linear trend is the non-parametric Mann-Kendal rank test (Mitchell et al, 1966). This test is based on the value of the individual term in the series and the position of this term in the series. Namely, if a linear trend exists, then the values ought to be chronologically more or less increasing or decreasing. This test is defined by two parameters: the Kendall coefficient ? and the significant level ? . The closer the ?-values are to zero, the higher is the level of significance i. e. the analysed values do not increase or decrease chronologically.

Table 3 Linear trends ??C, % or mm/10 years?, the Kendall coefficients (?) and the corresponding significant levels (?) for the time series of mean annual air temperature ?t, ?C?, relative humidity ?RH, %?, precipitation amount ?P, mm?, potential ?PET, mm? and actual ?ET, mm? evapotranspiration and moisture loss from soil ?L, mm? for Silba during the period 1964-1993**.**

	trend	??	? ?
t [?C]	0.002	-0.0103	0.4173
RH [%]	0.94	0.2924	0.0208
P [mm]	-55.8	0.2244	0.0762
PET [mm]	-21.5	0.2817	0.0260
ET [mm]	-26.1	0.2067	0.1024
L [mm]	0.80	0.1170	0.3551

The changes in annual values of air temperature, relative humidity and precipitation amount for Silba are presented from year to year in Figure 3. According to the curve of a 5-year series of air temperature moving average, from which very short-term fluctuations were eleminated, the warmest period was noticed in the mid-sixties and the coldest in the transition period from the seventies to the eighties. During the warmest period the mean annual air temperature deviation from the long-term mean reached a maximal value of 0.8?C. In the same period, the mean annual relative humidity reached the minimal value of 70%.A particularly high precipitation amount was noticed in the seventies. Two periods of deficient precipitation amount were recorded in the previous and following decade. The maximum positive anomaly in annual precipitation amount was 394.6 mm (1974) and the maximum negative anomaly -270.4 mm (1985).

The greatest probability of not finding a linear trend is in the series of air temperature and moisture loss from the soil (Tab. 3 and Fig. 3). A significant linear trend at the 0.05 level occurs in the time series of relative humidity and potential evapotranspiration. However, a great probability of a linear trend is also noticed in the series of precipitation amount and actual evapotranspiration. A tendency towards a decrease of precipitation amount (-55.8 mm/10 years) causes a decrease in evapotranspiration (-21.5 mm/10 years for potential and –26.1 mm for actual evapotranspiration). In spite of that a decrease in evapotranspiration may have a positive influence on plants, while a decrease in annual precipitation amount has a negative effect on the island vegetation. In order to establish which effect will dominate we should have longer time series. According to Pandžic et al (1993) and Gajic-Capka and Zaninovic (1998), a significant secular trend of precipitation exists, but an actual evapotranspiration trend was not experienced in the last hundred years at Crikvenica, which is the nearest meteorological station to the marine park of Silba. Therefore, it can be expected that the decrease in annual precipitation amount on the island of Silba could be faster than the decrease in annual actual evapotranspiration.

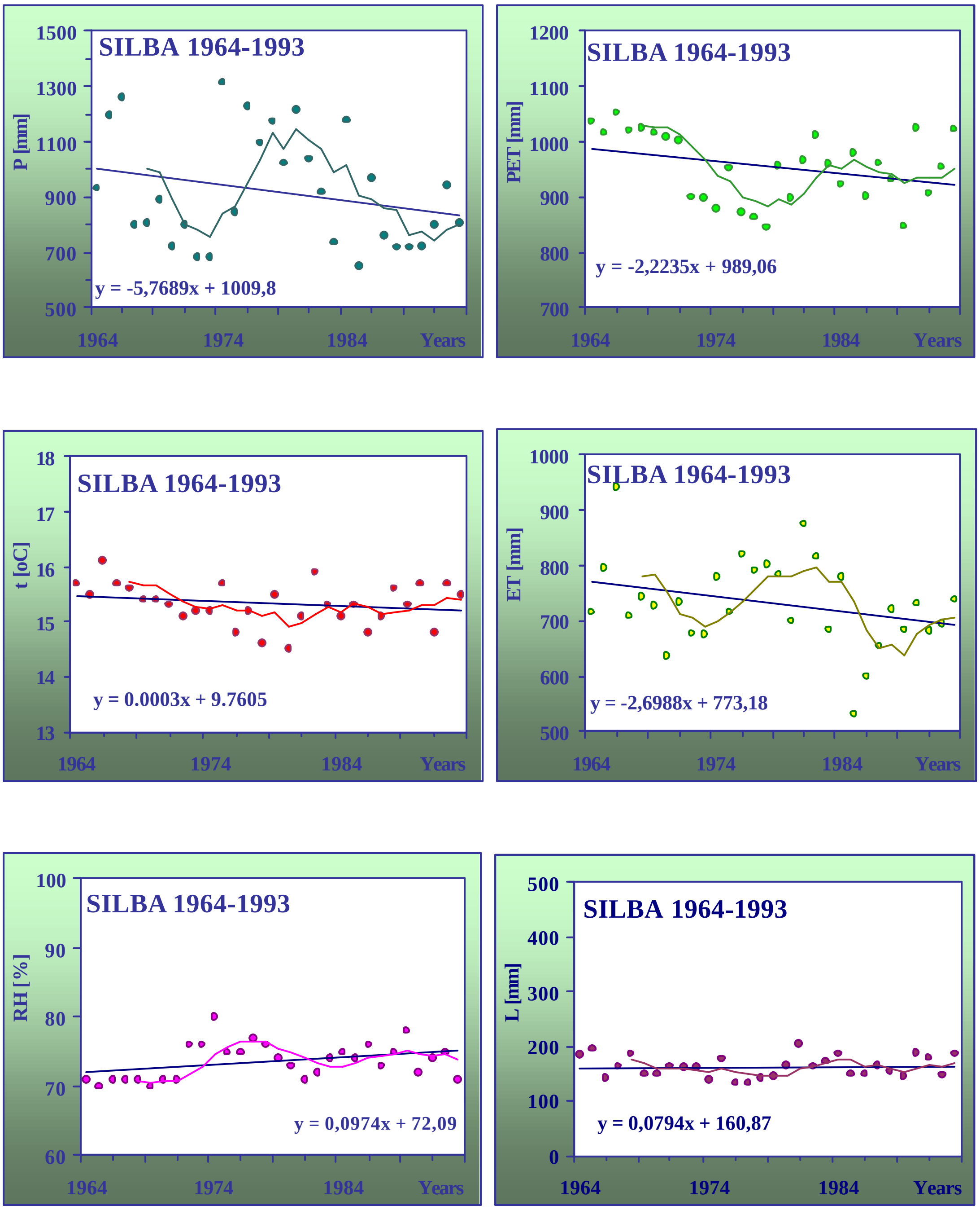

Fig. 2 The time series (dots) of mean annual air temperature t [^{o}C], relative humidity RH [%], annual precipitation amount P [mm], potential PET [mm] and actual ET [mm] evapotranspiration, moisture loss from soil L [mm] the 5-year moving average and the linear trends for Silba during the period 1964-1993. x is the number of years (1,2…30).

6. CONCLUSION

Knowledge of the development of biological processes depending on climatic conditions is the basic precondition for the effective management of natural resources. This is the reason why the climatic conditions and their variability have been analysed on the island of Silba. The analysis of linear trends has shown that a significant decrease in potential evapotranspiration and an increase in relative air humidity occurred during the period 1964-1993. A decreasing tendency in precipitation amount and actual evapotranspiration has also been established but it is not statistically significant. A further decrease in precipitation amount could have a negative influence on the island flora.

Finally it should be mentioned that the flora and fauna and the environment on the whole can only be protected by further co-operation among meteorologists, biologists, zoologists, oceanologist, geologists, geophysicists and other scientists of close profiles.

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