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CLIMATIC CONDITIONS IN THE MARINE PARK OF SILBA

Klimatski uvjeti u morskom parku Silba

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Abstract: As part of the project *Preservation of biological diversity in the Adriatic sea* the climatic conditions and climatic variability in the marine park Silba in the period 1964–1993 have been analysed. As amount of precipitation, evaporation and soil moisture greatly affect the island flora, the mean annual values of water balance components (potential and actual evapotranspiration and moisture loss from the soil) have been calculated by the Palmer method. According to linear trend analyses and the nonparametric Mann–Kendall test, the existence of a significant trend of potential evapotranspiration (decreasing chronology) and relative air humidity (increasing chronology) has been established during the last 30 years. A tendency towards decrease in precipitation amount and actual evapotranspiration has also been observed, but the linear trends are not significant at the 0.05 level. Significant linear trends in air temperature and soil moisture loss do not occur.

***Key words*:** Silba, climatic conditions, Palmer method, water balance components, linear trend

Sažetak: U sklopu projekta *Očuvanje bioraznolikosti u Jadranskom moru* analizirani su klimatski uvjeti i varijacije u morskom parku Silba u razdoblju 1964–1993. Budući da količina oborine, isparavanja i vlage u tlu znatno djeluje na otočku floru, izračunate su i srednje godišnje vrijednosti komponenata vodne ravnoteže (potencijalna i stvarna evapotranspiracija te gubitak vode iz tla) po Palmerovoj metodi. Prema analizi linearnog trenda i neparametarskog Mann–Kendallova testa utvrđeno je postojanje signifikantnog trenda potencijalne evapotranspiracije (kronološko smanjivanje) i relativne vlažnosti zraka (kronološko povećavanje) posljednjih 30 godina. Primijećene su i tendencije smanjenja količine oborine i stvarne evapotranspiracije, ali linearni trendovi nisu signifikantni na razini 0.05. Kod temperature zraka i gubitka vode iz tla nije se pojavio signifikantni linearni trend.

***Ključne riječi*:** Silba, klimatski uvjeti, Palmerova metoda, komponente vodne ravnoteže, linearni trend

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* was started in Croatia in order to protect some special areas along the Adriatic coast. In one of these areas — the marine park of Silba — the water balance components have been researched to estimate possible climatic variability. To determine the climatological standards, meteorological data such as air temperature, precipitation, relative humidity, cloudiness, wind and the occurrence 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 coast.

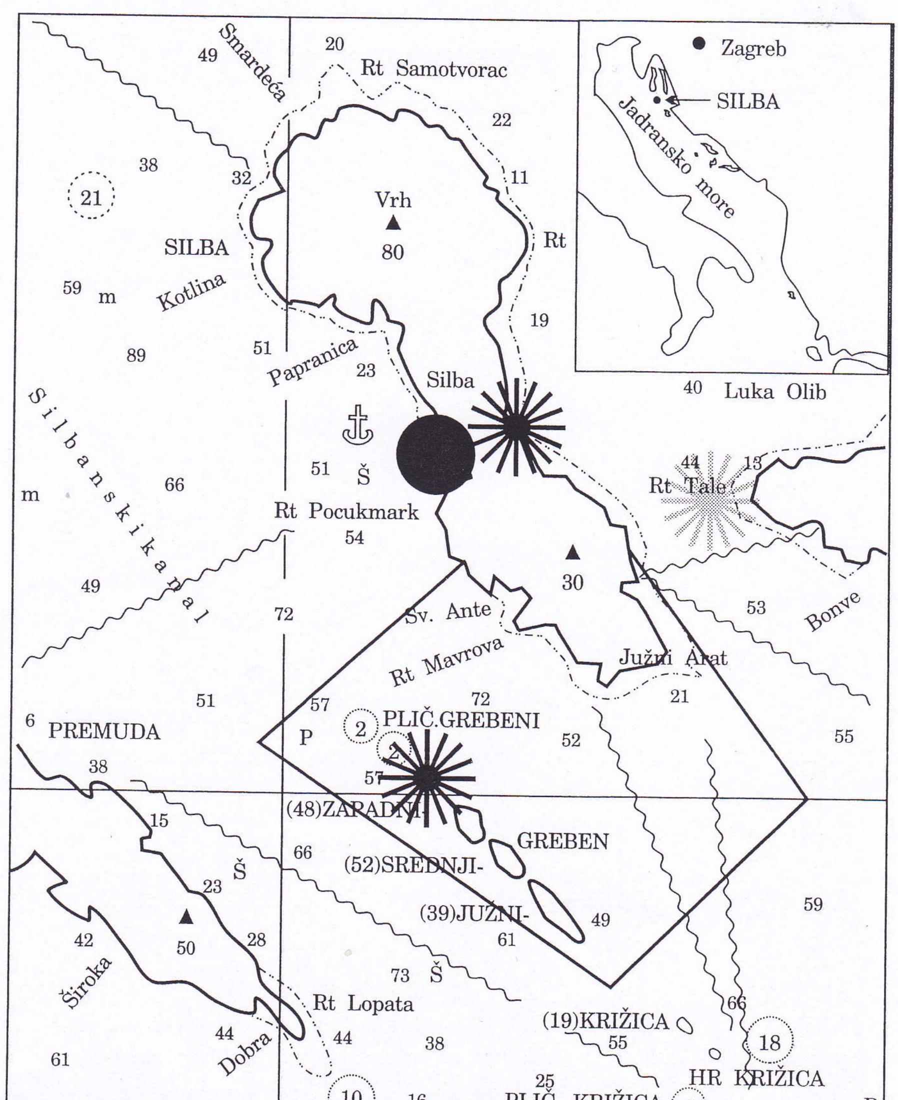

Figure 1 Map of the marine park of Silba and the location of meteorological station

Slika 1. Karta morskog parka Silba i položaj meteorološke postaje

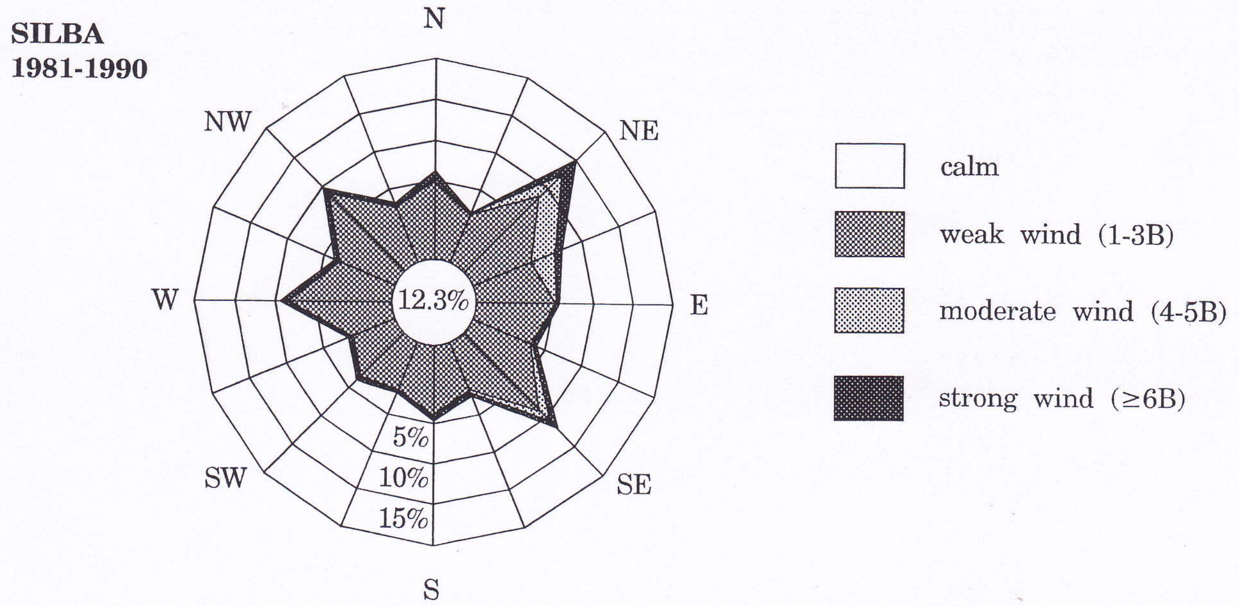

Figure 2. The wind rose for Silba during the period 1981–1990

Slika 2. Ruža vjetra za Silbu za razdoblje 1981–1990

As there is no instrument for wind speed measurements at the Silba station, its strength is determined by its effect 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. 2). 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* wind is a dry, cold and gusty wind and intensifies the feeling of cold (Penzar and Makjanić, 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* wind 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* blows 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 relatively frequent on Silba (12.3%). Strong winds (6 B) are most frequent in the winter season with 5–6 days per month and they are mainly *bura* or *jugo* winds. 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. Vučetić, 1991, 1993)

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

Tablica 1. Statistički pregled meteoroloških parametara za Silbu u razdoblju 1964–1993

months	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

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 montlhy 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]
$N_{P\geq 0}$	mean monthly number of days with precipitation amount 0.1 mm
$N_{P\geq 10}$	mean monthly number of days with precipitation amount 10.0 mm
$N_{P\geq 20}$	mean monthly number of days with precipitation amount 20.0 mm
$N_{P\geq 50}$	mean monthly number of days with precipitation amount 50.0 mm
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]

3. THERMAL, HUMIDITY 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 the 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 days with air temperatures above 30°C (hot days) occurred from June to September (16.8 days in average) and most of them were in August. A day with warm night is a day when the minimum daily temperature exceeds 20°C. In July and August this is a very frequent phenomenon in Dalmatia (M. Vučetić and V. Vučetić, 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 on Silba is relatively rich with humidity. 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 Makjanić, 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 (cyclones and fronts) 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 is often connected with thunderstorm. 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, the 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 consideration. In the next chapter, one of methods for the calculation of water balance components is described.

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 Pandžić (1985) were the first to apply the Palmer method to the meteorological data of Zagreb and the Adriatic coast area. After that, Pandžić and M. Vučetić (1995, 1996, 1997); M. Vučetić and V. Vučetić (1993, 1994a, 1994b, 1996), V. Vučetić and M. Vučetić (1993, 1996), Štambuk and M. Vučetić (1993) and Gajić–Čapka and Zaninović (1998) applied this method to different parts of Croatia.

The Palmer method assumes that precipitation amount is distributed between evapotranspiration and soil drenching, 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:

$$P+L=ET+R+RO \qquad (1)$$

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 runoff (Palmer 1965, Penzar 1976 and Pandžić, 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 according to the relations:

$$\begin{aligned} P-PTE>0 &\Rightarrow ET=PTE \\ P-PTE<0 &\Rightarrow ET=P+L \end{aligned} \qquad (2)$$

where PTE is potential evapotranspiration. Potential evapotranspiration is computed by the Eagleman relation (Eagleman, 1967, Pandžić, 1985, V. Vučetić and M. Vučetić, 1996).

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 moisture loss from the surface layer is calculated by:

$$\begin{aligned} &S_1' > PET-P \quad \& \quad PET-P>0 \Rightarrow \\ &\qquad \Rightarrow L_1 = PET-P \\ &S_1' < PET-P \quad \& \quad PET-P>0 \Rightarrow \\ &\qquad \Rightarrow L_1 = S_1' \\ &S_1' = 0 \Rightarrow L_1 = 0 \\ &PET-P<0 \Rightarrow L_1 = 0 \end{aligned} \qquad (3)$$

The moisture loss from the underlying layer is calculated by:

$$\begin{aligned} &L_2 = PET-P-L_1 \frac{S_2'}{S_m} \\ &S_m = S_{m1}+S_{m2} \\ &L_2<0 \Rightarrow L_2=0 \\ &L_2>S_2' \Rightarrow L_2=S_2' \end{aligned} \qquad (4)$$

The moisture loss from the surface and underlying layers is obtained by:

$$L=L_1+L_2 \qquad (5)$$

L_1 and L_2 are the monthly moisture loss from the surface and underlying layer. S'_1 and S'_2 are the monthly capacity of moisture in the surface and underlying layer. S_m is the maximum capacity of moisture in the soil. S_{m1} and S_{m2} are the maximum capacity of moisture in the surface and underlying layer.

The Palmer method was applied to the climatological data from the Silba station during the period 1964–1993. The annual courses of poten-

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

Tablica 2. Srednje mjesečne i godišnje vrijednosti potencijalne *PET*, mm i stvarne evapotranspiracije *ET*, mm te gubitak vode iz tla *L*, mm za Silbu u razdoblju 1964–1993

months	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

tial and actual evapotranspiration are similar in the cold season (Tab. 2). The greatest differences between potential and actual evapotranspiration (64–71 mm) were in July and August. The maximum 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.

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 estimation of the existence of a linear trend is the non–parametric Mann–Kendall 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 τ and the significant level . The closer the τ–values are to zero, the higher is the level of significance i. e. the analysed values do not increase or decrease chronologically.

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 eliminated, 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 a minimal value of 70%. A particularly high precipitation amount was noticed in the

Table 3 Linear trends °C,% or mm/10 years, the Kendall coefficients (τ) and the corresponding significant levels (α) 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

Tablica 3. Linearni trendovi °C,% or mm/10 god, Kendallovi koeficijenti (τ) i odgovarajuće razine signifikantnosti (α) za vremenske nizove srednje godišnje temperature zraka *t*, °C, relativne vlažnosti *RH*, %, količine oborine *P*, mm, potencijalne *PET*, mm i stvarne *ET*, mm evapotranspiracije te gubitka vode iz tla za Silbu u razdoblju 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

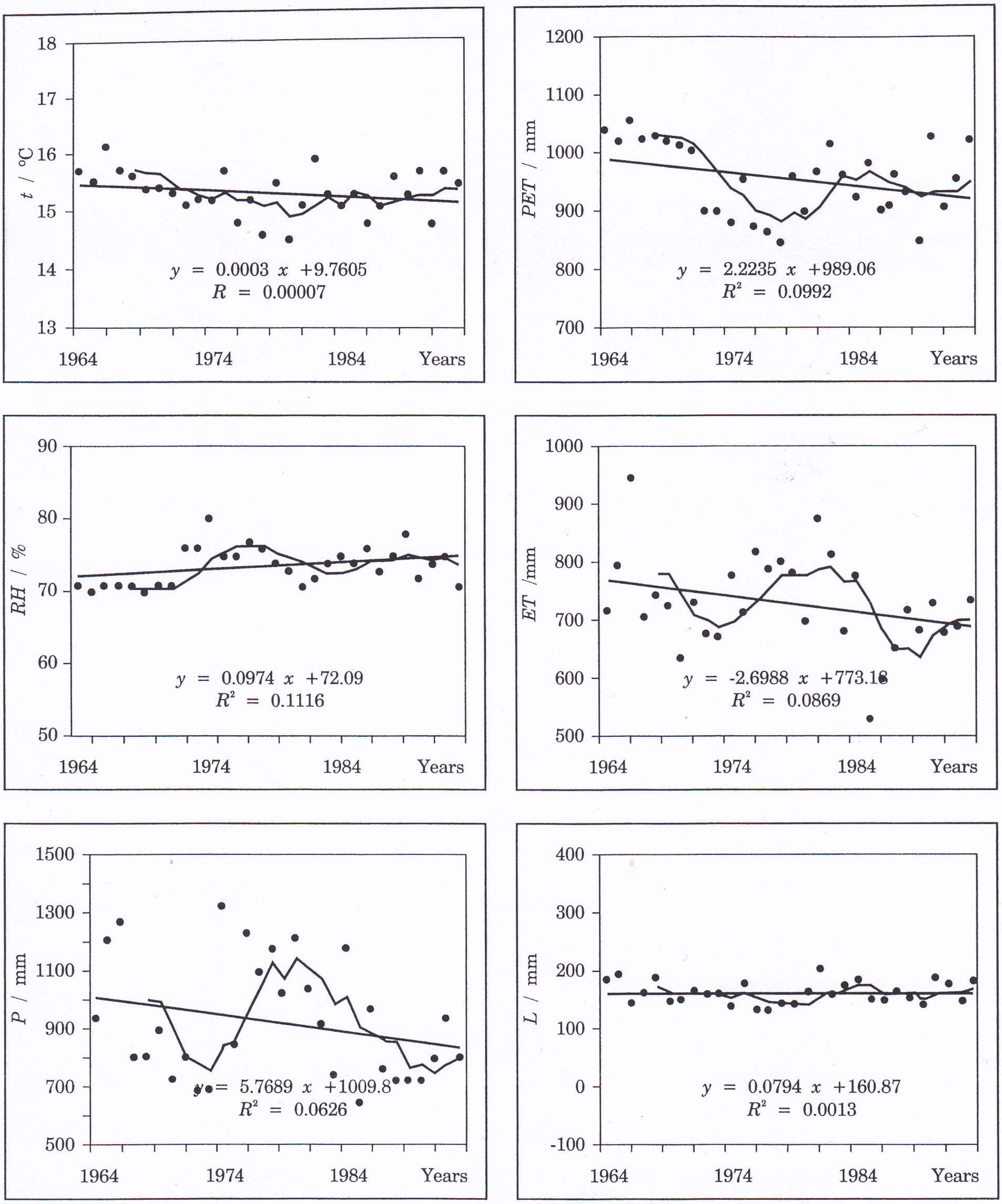

Figure 3 The time series (dots) of mean annual air temperature t [°C], relative humidity RH [%], annual precipitation amount P [mm], potential PET [mm] and actual ET [mm] evapotranspiration, moisture loss from soil L [mm], the 5-year moving average and the linear trends for Silba during the period 1964–1993. x is the number of years (1,2..30)

Slika 3. Vremenski nizovi (točke) srednje godišnje temperature zraka t [°C], relativne vlažnosti zraka RH [%], godišnje količine oborine P [mm], potencijalne PET [mm] i stvarne ET [mm] evapotranspiracije, gubitka vode iz tla L [mm], nizovi 5-godišnjih kliznih srednjaka i linearni trendovi za Silbu u razdoblju 1964–1993. x je broj godina (1,2..30) seventies. Two periods of deficient precipitation amount were recorded in the previous and following decades. The maximum of 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 in precipitation amount (–55.8 mm in 10 years) causes a decrease in evapotranspiration (–21.5 mm in 10 years for potential and –26.1 mm in 10 years 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 Pandžić et al (1993) and Gajić–Čapka and Zaninović (1998), a significant secular trend of precipitation exists, but an 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 in the marine park of Silba could be faster than the decrease in annual evapotranspiration.

6. CONCLUSION

Knoweledge 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 the variability have been analysed in the marine park 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, fauna and environment on the whole can only be protected by further cooperation among meteorologists, biologists, zoologists, oceanologist, geologists, geophysicists and other scientists of close profiles.

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