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BORA REGIONS ON THE ADRIATIC COAST OF YUGOSLAVIA AND IN TRIESTE

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In order to make clear the local distrubution of bora, an attempt was made to observe the wind-shaped trees at 380 points on the Adriatic coast from Trieste to Dubrovnik, on the five islands, on the slopes of Dinar Alps, and in some inland basins. The monthly mean wind frequency and force at the 76 climatological stations were calculated also. We came to the following conclusion: 1) The strongest bora region is located near Senj. The monthly mean wind force of NE wind is 6.0 and its frequency is 25.8% at Senj in January. 2) The ENE wind flows out from the Vratnik Pass and reaches to Cres and Lošinj islands as NE-NNE winds. 3) The strongest bora reaches as far as 50—60 km from the coast. On the north and south of this region, the bora is strong as far as 20 km from the coast. 4) The macro-topography conditions are peculiar at the strongest part. Namely, width of the Dinar Alps with the other parallel mountain ranges is narrowest, their height is relatively low, and the ridge of the Velebit Mts. runs quite near the coast 5). The strong NE wind appears only in small parts south of Zadar. On the contrary, E—SE winds, Jugo, become to prevail. 6) On the slopes of the Dinar Alps facing to the Adriatic Sea, the NE winds are strong up to 800 m above sea level and become weak suddenly at a height of 1,000 m. At the pass topography with a height of 700—800 m, the wind is very strong locally.

1. Introduction

From the standpoint of climatology, meteorology, and geography, the local wind bora and the related phenomena on the Adriatic coast from Trieste, Italy, to Dubrovnik, Yugoslavia, have been studied extensively by Japanese scientists in cooperation with Yugoslav scientists since 1968. One of our main purposes is to make clear the bora regions in detail. As has been shown in an annotated bibliography on bora (Yoshino 1972 a), there are articles and descriptions more than one hundred since 1866. However, there are few studies on the bora regions in microand meso-scale.

The present paper describes the distrubution of bora on the coast and islands, on the slopes of the Velebit Mountains and in some inland basins and

valleys. The complete results of our group studies will be published in 1976 in a monograph entitled »Local wind, bora« edited by M. M. Yoshino.

2. Study Region

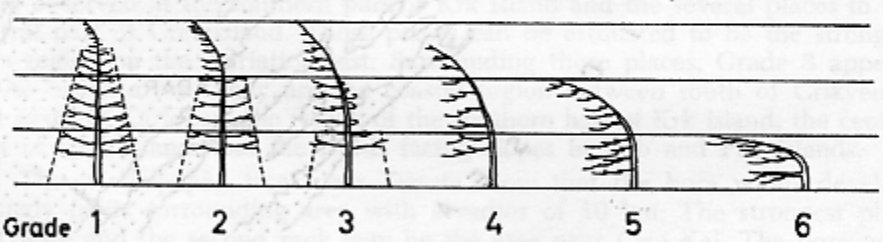
The study region is the Adriatic coast from Trieste, Italy, to Dubrovnik. Yugoslavia. Especially, an extensive observation was made (i) in the region between Rijeka and Zadar along the coast, (ii) on the five islands of Krk, Cres, Lošinj, Rab and Pag, (iii) on the slopes at right angle to the coastal line at Crikvenica, Senj, Jurjevo, Jablanac, and Karlobag, (iv) along the cross-section from Senj to Otočac, and (v) in the inland basins and valleys.

Distance from Trieste to Zadar is about 200 km by an airline and that from Zadar to Dubrovnik is about 280 km. The Velebit Mountains have peaks higher than 1,200 m above sea level and even 1,600 m in some places. There are several passes lower than 1,000 m among the mountains. The ridge of the Velebit Mountains runs quite near coast in some parts it is located within 2 km distance from the coast.

3. Study Method

In order to make clear the detail distribution bora region, we observed the wind-shaped trees as an indicator of wind direction of wind velocity. The significance and classification of the wind-shaped trees are discussed elsewhere (Yoshino 1973 a). Kinds of trees observed are **Pinus nigra, P. helepensis, Ostrya carpinifolia, Fraxinus ornus, Quercus pubescens, Juniperus oxycedrus, Acer monspesslanum, Phellyrea latifolia, Carpinus orientalis, Salix** sp., **Populus** sp., Olive trees, etc. Among these, **Ostrya, Fraxinus** and **Quercus** are dominant as decidious broadleaved trees in the northern part of the study region and **Pinus** prevails in the southern half of the study area. The grade applied in this study is shown in Fig. 1. The grade and the direction at one point is a mean value of several trees.

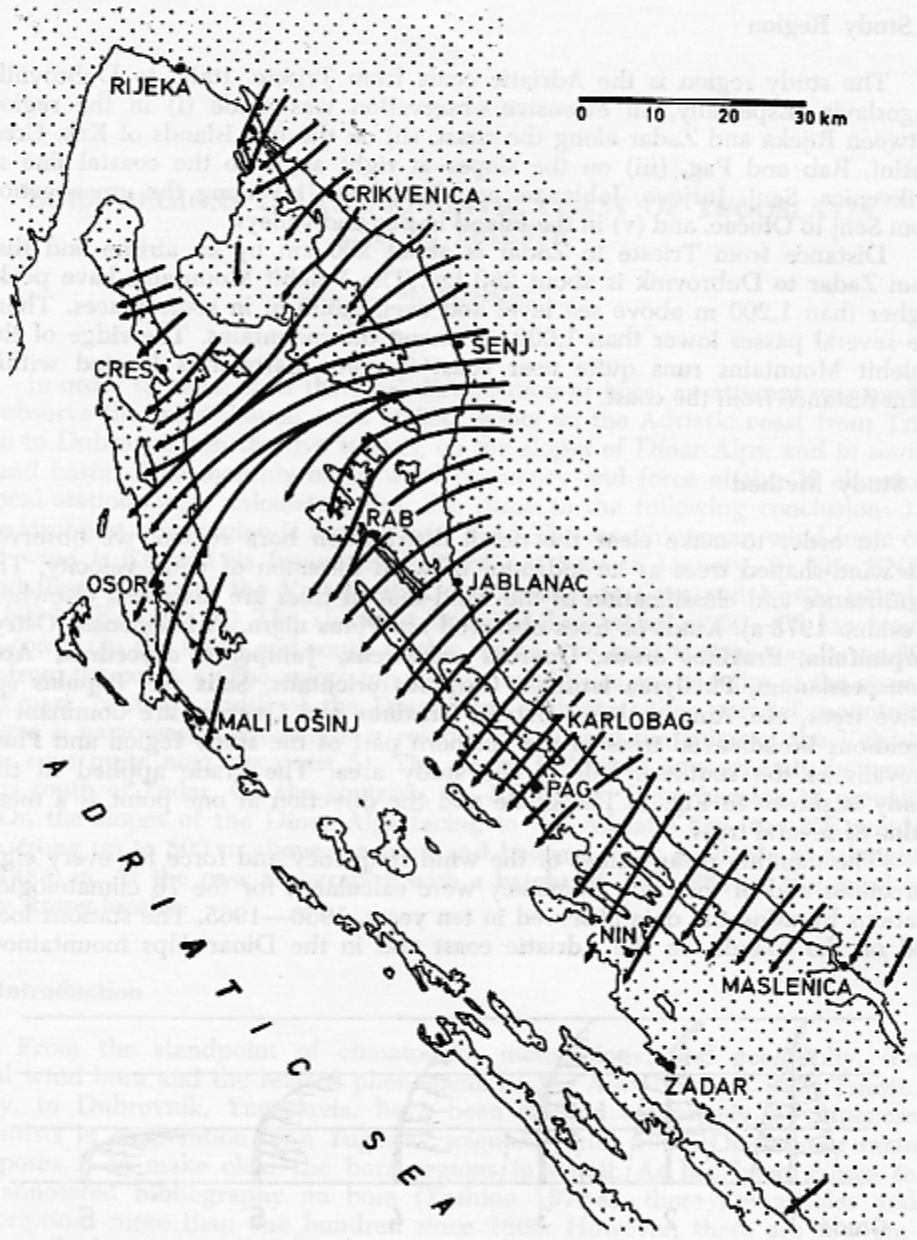
The monthly mean values of the wind frequency and force for every eight directions and of the calm frequency were calculated for the 76 climatological stations by using the data observed in ten years, 1956—1965. The stations located on the islands, on the Adriatic coast and in the Dinar Alps mountainous



Sl. 1. Stupanj vjetrom oblikovanog drveća primjenjen u ovom radu

Fig. 1. Grade of the wind-shaped trees applied in this study

region were taken. The results are given in the tables in the previous report (Yoshino 1972 b). In this paper, the distributions of the monthly mean wind force are shown in the figures, using the results.



Sl. 2. Pravac strujanja prevladavajučeg sjeveroistočnog vjetra određen na temelju oblika krošanja drveća

Fig. 2. Stream line of the prevailing NE winds as revealed by the wind-shaped trees

4. Results

(A) By the Wind-shaped Trees

The stream lines according to the distribution of direction of the wind-shaped trees are shown in Fig 2. In this figure, it is clearly seen that, in general, the NE winds prevail within a distance of 20 km from the coast. The ENE winds, however, flow out around Senj and they change gradually the direction as the NE winds and finally, NNE winds on the southern part of Cres island and Lošinj island. This means that the bora develops most striklingly in this part of the Adriatic coast reaching 50—60 km off shore.

In the northern part of Cres island, the strong ENE wind area appears at the col topography 10 km NNW of the town Cres. This strong wind area can be attributed to the microtopographical situation of the col at a narrow ridge. The strong NE winds are obervable at the central part of Cres island. From the central part to the southern part of Cres island, the NE-NNE winds, which flow out over the Vratnik pass behind Senj as the E-ENE winds and blow over the southern part of Krk island as the ENE-NE winds, are prevailing.

Rab island, especially its southern part, is directly affected by the NE winds from the main land. Within the area of Pag island 12—15 km from the coast of main land, the NE winds prevail also.

The NE winds do not dominate from Zadar to Dubrovnik as a whole, but they appear in the areas around Šibenik, where the winds flow out along the Krka Valley, north of Split, where the winds come over the Klis pass, and around Makarska (the Dubci pass).

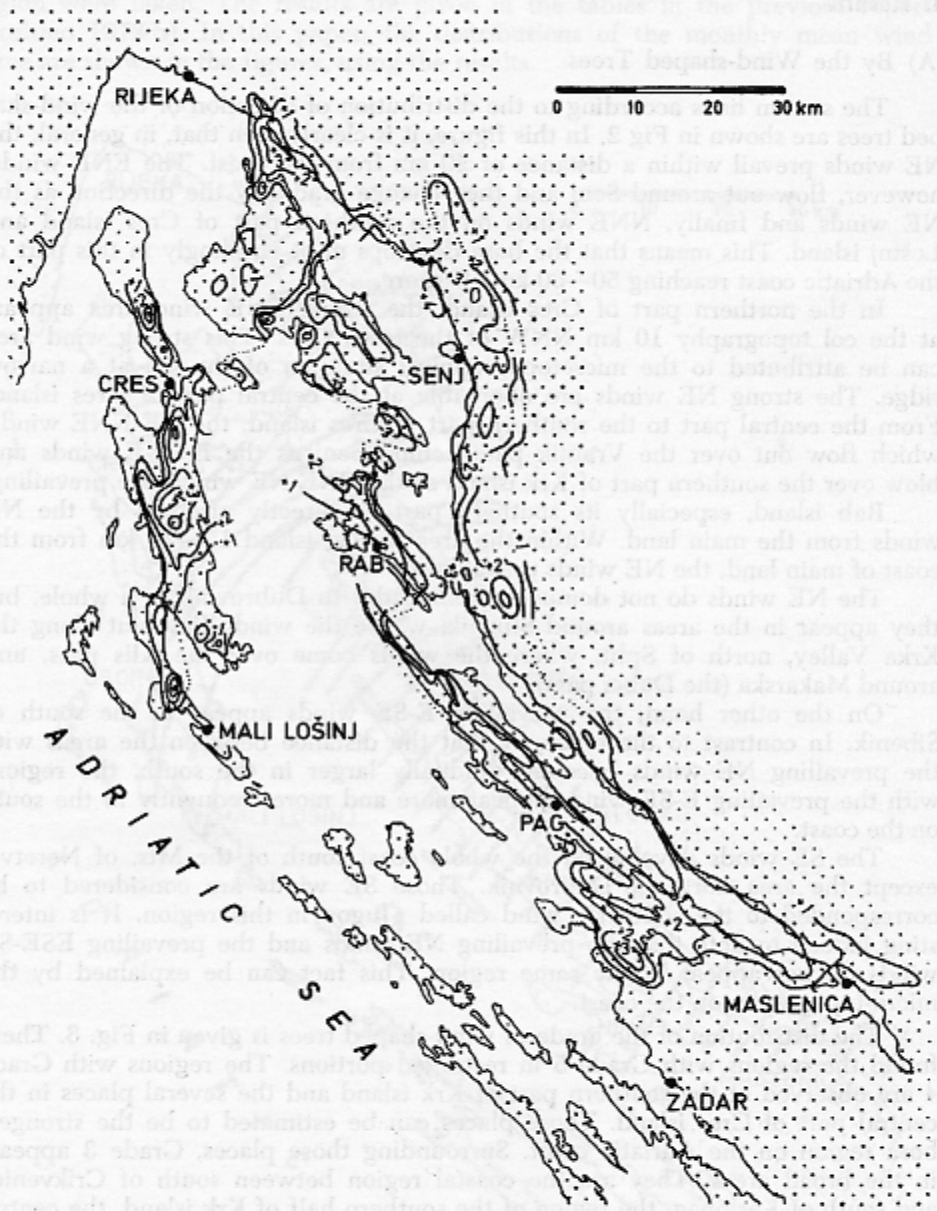
On the other hand, the prevailing E-SE winds appear in the south of Šibenik. In contrast to the tendency that the distance between the areas with the prevailing NE winds becomes gradually larger in the south, the regions with the prevailing E-SE winds appear more and more frequently in the south on the coast.

The SE winds develop on the whole coast south of the Mts. of Neretva, except the area north of Dubrovnik. Those SE winds are considered to be corresponded to the southerly wind called »Jugo« in this region. It is interesting indeed to note that the prevailing NE winds and the prevailing ESE-SE winds do not appear in the same region. This fact can be explained by the micro-topography on the coast.

The distribution of the grade of wind-shaped trees is given in Fig. 3. There found the regions with Grade 5 in restricted portions. The regions with Grade 4 are observed at the southern part of Krk island and the several places in the central part of Cres island. Those places can be estimated to be the strongest bora region on the Adriatic coast. Surrounding those places, Grade 3 appears in the broad areas. They are the coastal region between south of Crikvenica and south of Karlobag, the region of the southern half of Krk island, the central part of Cres island, and the NE-E facing slopes in Rab and Pag islands.

The wind-shaped trees near Trieste show that the bora winds develops strongly in its surrounding area with a radius of 10 km. The strongest place is Trieste and the second rank may be the area near Črni Kal. The bora wind develops along the line from Ljubljana, to Trieste via Postojna.

According to a detail investigation on the mountain slopes faced to the Adriatic Sea in the Senj region, the wind is quite strong not only on the coast,



Sl. 3. Stupanj vjetrom oblikovanih drveća

Fig. 3. Distribution of grade of the wind-shaped trees

but also on the slope up to 800 m above sea level. At an altitude higher than 800 m, the winds become weak suddenly, excepting at the pass or col topography. That is, the grade changes from 2 to 1 sharply at an altitude of about

1,000 m above sea level and Grade 0 appears immediately at the inland side of the isolines of Grade 1. In the inland region, there appears Grade 0—1, except the regions near Kompolje and 2—4 km east of Otočac, where Grade is 1—1.5. On the contrary to such tendency of the winds, a yellow lichen, **Xanthoria parietina,** develop in the inland regions. It is considered that these lichen is an indicator of the cold, humid environment, which develops in the basins.

The distribution of wind conditions was observed at 80 points through the observation of grades of wind-shaped trees in the Ajdovščina bacin, Slovenia. The distribution map revealed that the axis of wind maximum is located along the foot of mountains, which resulted from the NE wind or the bora. The horizontal distance between the axis and the mountain ridge is 3—4 km. Another region with a wind maximum appears also about 3 km further leeward of this axis (Yoshino 1973 b).

B) By the Data at the Climatological Stations

The monthly mean wind frequency and force for each eight directions and calm frequency were calculated for the 76 climatological stations from the data observed in 1956—1965. The distribution maps of monthly mean wind force were made for each direction for each month. Among them, the distribution of the monthly mean wind force of NE wind in January is most conspicuous; that is 6.0 at Senj, 5.0 at Sinj and Titog.ad, 4.9 at Mosor-Ljuvač, and 4.7 at Šibenik and Ajdovščina. There are many other stations with the monthly mean wind force greater than 3.0. The frequency of these NE winds is also high.

These stations with the greater values are located not only on the coast, but also in the inland basins or valleys. From this fact, we can conclude that the bora occurs also in the inland regions. In particular, the basins along the River Krka and River Cetina.

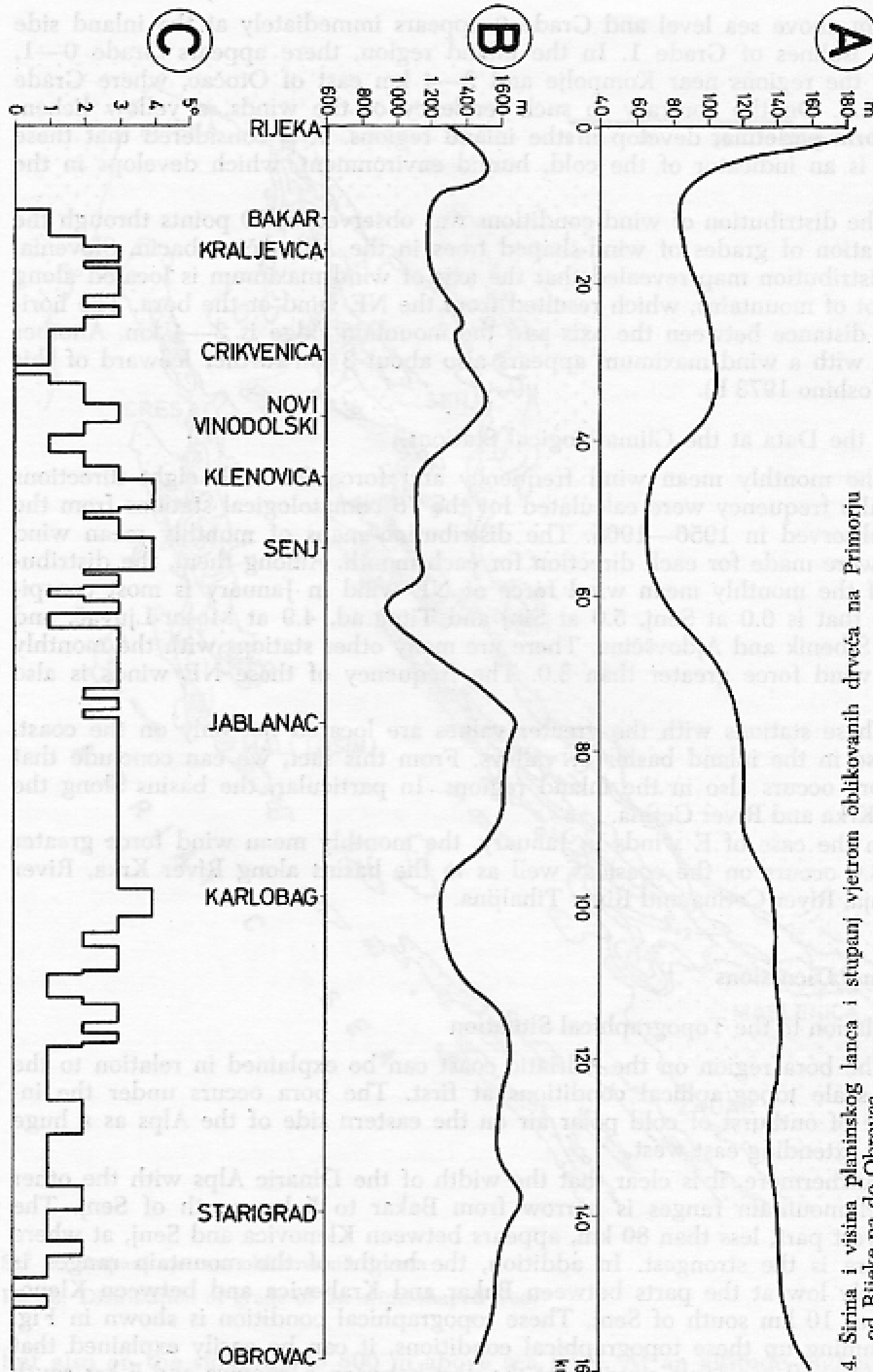
In the case of E winds in January, the monthly mean wind force greater than 3.0 occurs on the coast as well as in the basins along River Krka, River Zrmanja, River Cetina and River Tihaljina.

5. Some Dicussions

A) Relation to the Topographical Situation

The bora region on the Adriatic coast can be explained in relation to the macro-scale topographical conditions at first. The bora occurs under the influence of outburst of cold polar air on the eastern side of the Alps as a huge barrier extending east-west.

Furthermore, it is clear that the width of the Dinaric Alps with the other parallel mountain ranges is narrow from Bakar to 5 km south of Senj. The narrowest part, less than 80 km, appears between Klenovica and Senj, at where the bora is the strongest. In addition, the height of the mountain ranges is relatively low at the parts between Bakar and Kraljevica and between Klenovica and 10 km south of Senj. These topographical condition is shown in Fig. 4. Summing up these topographical conditions, it can be easily explained that the cold air flows down strongly at the part between Klenovica and 5 km south of Senj where the width is narrow and the height is low.



Sl. 4. Sirina i visina planinskog lanca i stupanj vjetrom oblikovanih drvca na Primorju od Rijeke pa do Obrovca

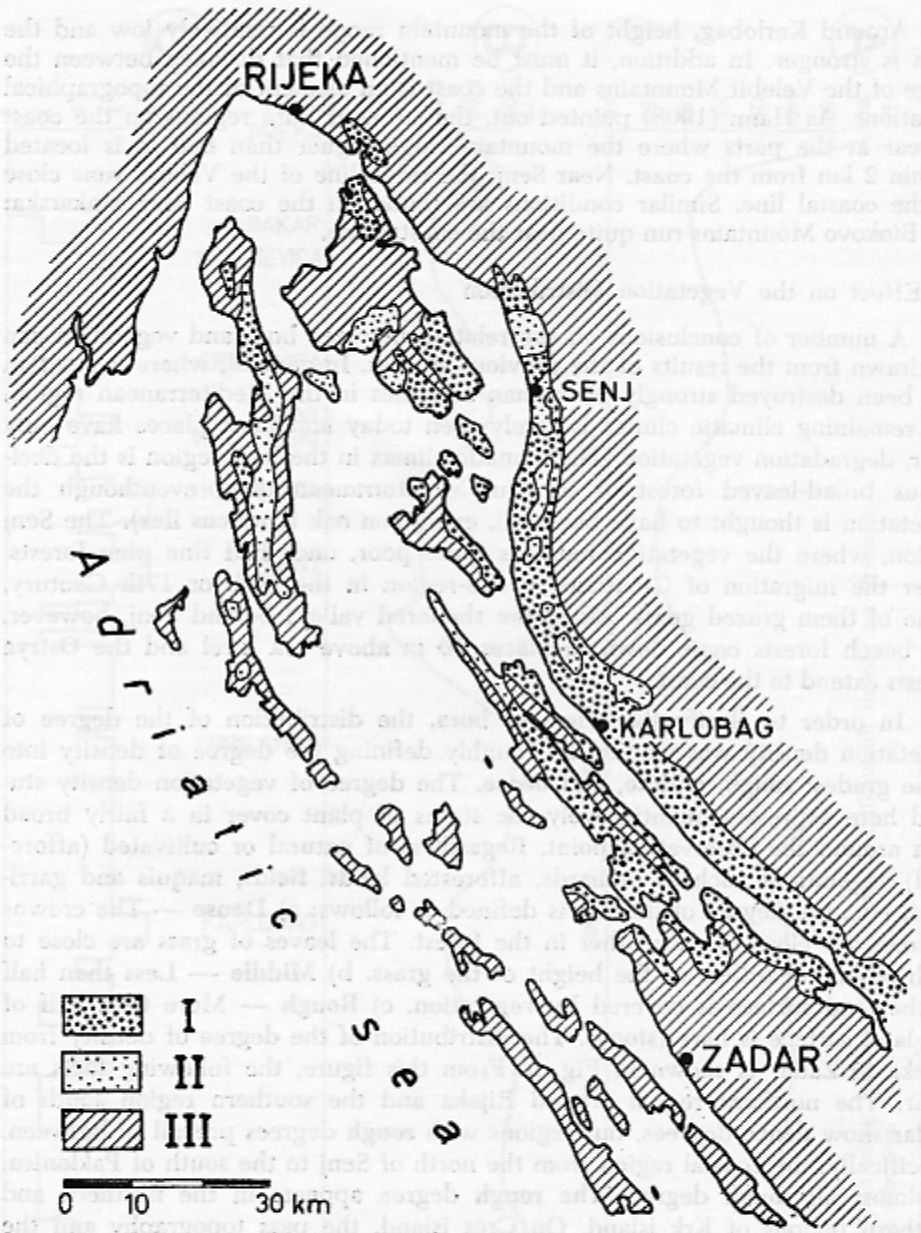
Fig. 4. Width of mountain range, height of mountain range and the grade of wind-shaped trees on the coast from Rijeka to Obrovac

Around Karlobag, height of the mountain range is relatively low and the bora is stronger. In addition, it must be mentioned that distance between the ridge of the Velebit Mountains and the coast is an element of the topographical situations. As Hann (1908) pointed out, the stronger bora regions on the coast appear at the parts where the mountain ridge higher than 800 m is located within 2 km from the coast. Near Senj, the ridge line of the Velebit runs close to the coastal line. Similar conditions are found on the coast near Makarska: the Biokovo Mountains run quite near the coastal line.

B) Effect on the Vegetation Distribution

A number of conclusions on the relation between bora and vegetation can be drawn from the results of the previous studies. In general, where vegetation has been destroyed strongly by human activities in the Mediterranean region, the remaining climatic climax is rarely seen today and most places have only poor, degradation vegetation. The climatic climax in the Senj region is the deciduous broad-leaved forest of the Sub-Mediterranean type, eventhough the vegetation is thought to have been tall, evergreen oak **(Quercus ilex).** The Senj region, where the vegetation today is quite poor, once had fine pine forests. After the migration of Croatians to this-region in the 16th or 17th Century, some of them grazed goats. Along the sheltered valleys behind Senj, however, the beech forests come down to places 50 m above sea level and the **Ostrya** forests extend to the coast.

In order to clarify the effect of bora, the distribution of the degree of vegetation density was studied by roughly defining the degree of density into three grades: **rough, middle,** and **dense.** The degree of vegetation density studied here expresses quantitatively the status of plant cover in a fairly broad area around the observation point. Regardless of natural or cultivated (afforested) vegetations such as orchards, afforested lands, fields, maquis and garriques, etc., the degree of density is defined as follows: a) **Dense** — The crowns of trees are close to each other in the forest. The leaves of grass are close to each other, regardless of the height of the grass. b) **Middle** — Less than half of the land surface is covered by vegetation. c) **Rough** — More than half of the land surface is bare (stony). The distribution of the degree of density from Rijeka to Zadar is shown in Fig. 5. From this figure, the following facts are clear: The northern region around Rijeka and the southern region south of Zadar show **dence** degrees, but regions with **rough** degrees prevail in between. Specifically, the coastal region from the north of Senj to the south of Paklenica, is almost all **rough** degree. **The rough** degree appears in the northern and southern regions of Krk island. On Cres island, the pass topography and the mountain peak areas are of **rough** degree, but the tableland, the main part of the island, has a middle degree. On the whole, the distribution of the density of vegetation shown in Fig. 5 coincides quite well with the distribution of the grade of windshaped trees shown in Fig. 3. The regions where the grade of wind-shaped trees is more than grade 3 are found to be mostly **rough** degree regions. In other words, the regions with the strong NE winds coincide with the regions having the rough degree of vegetation.



Sl. 5. Raspored gustoće vegetacije. Definicija burnosti (surovosti), sredine i gustine dat je u tekstu.

Fig. 5. Distribution of the density of vegetation. Definition of I: rough, II: middle and III: dense is given in the text

Summarizing these facts and results of the studies, it can be said that the regions from the Adriatic coast to the mountains were covered by dense

vegetation. The trees were almost deciduous broad-leaved trees with some pine **(Pinus nigra)** trees. In the period around the 17th century, the forests were cut down and the people grazed goats extensively. As a result, the secondary vegetation did not grow. Afforestration attempts were made, and succeeded in some parts of the upper slopes facing the sea, but not in some parts of the lower part of the slopes and the areas around Senj. The areas where the afforestration was not successful are the most windy places facing the bora.

Since destruction, the secondary forests have been recovering in the regions with weak bora winds, even though they are regression vegetation with either dense degree or great cover degree. However, the thin soils between the blocks were blown off after the destruction of vegetation and the growth of young trees was hindered by the mechanical injury and physiological desiccation caused by strong bora winds. Furthermore, the grazing of goat and sheep and the felling of trees for firewood have been continued until recent times and this intensified the hinderance effect of the winds. Therefore, the present vegetations, whether low trees, bushes, or grass, are very poor and the landscape is desolate in the bora regions.

The results mentioned above are described in detail in another paper (Yoshino, 1976).

C) Some Considerations on the Standing Point of Towns and Air Port

Northern limit of the strong NE winds is located from Bakar to the northern most part of Krk island. As the stream lines in Fig. 2 points out, the prevailing wind direction is crosswind for the direction (NNW—SSE) of runway of air port there, suggesting danger in landing and takeoff of the airplanes. If this air port is located slightly southwest, the prevailing winds might be far more weak.

The towns of Krk and Cres, old capitals, were located roughly on the northern border of this strongest bora region. It can be said that, in old times, the strong wind region played a role like an »invisible wall« against enemies from the sea. In addition, the towns themselves are located at a sheltered place microtopographically. Therefore, it must be concluded that the standing point of the towns were the best from the viewpoint of wind conditions in the old times.

On the other hand, Mali Lošinj and Veli Lošinj at the Lošinj island are located roughly on the southern border of this strong bora region. The same things can be said to the situation of these towns.

In the area south of Šibenik, the NE wind is generally weak but strong at some places, as described above. However, it is interesting to note that fairly large cities as Šibenik, Split, Makarska, and Dubrovnik are located in the places of locally strong NE winds. It is thought that the city locations had some relation to the navigation of earlier periods. It may be said that the NE winds in the area south of Zadar had at least positive meaning.

Acknowledgements

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Summary

PODRUČJA BURE NA JUGOSLAVENSKOM PRIMORJU

M. M. Yoshino

U cilju jasnije spoznaje prostornog raširenja pojave bure na jadranskom primorju, vršena su istraživanja od Istre do Dubrovnika i na 5 otoka (Krk, Cres, Lošinj, Rab i Pag). Područje s najjačom burom nalazi se blizu Senja. ENE vjetar puše kroz vratničko sedlo. On postepeno skreće u smjer NE na moru i zahvaća Cres i Lošinj kao NE-NNE strujanje. Najjača bura dosiže udaljenost od 50—60 km od obale. Sjeverno i južno od tog područja jaka bura zadržava svoja svojstva samo do 20 km od obale. Jaki NE vjetar se pojavljuje samo u ograničenim područjima južno od Zadra, gdje inače dominiraju E-SE vjetrovi. Na primorskim padinama Dinarida NE vjetrovi su jaki do 800 m aps. visine, a slabe osjetno na oko 1000 m apsolutne visine. U zoni planinskih prevoja od 700—800 m bura može lokalno biti vrlo jaka. Na otocima, kontrast između padina zavjetrine i privjetrine je osobito izražen. U radu su prikazani uvjeti razvoja bure u području oko Trsta i u unutrašnjim krajevima prvenstveno Vipovskom.

Preveo V. Rogić