



# AOT40 as preliminary indicator for ozone induced forest injury on Mountain Medvednica near Zagreb

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## Abstract

*The phytotoxic effect of ozone has been known for decades and accumulated exposure to ozone above a threshold (AOT) is an attempt to assess the risk of forest injuries due to ozone attack. Ozone levels have been monitored for 16 years at Puntijarka site and AOT values are calculated for each growing season. Recent research performed by Forest Institute Jastrebarsko shows that forest damage at Medvednica is more severe than that in other parts of Croatia and even larger than the European mean. Air quality and boundary layer ozone are a possible cause for the observed damage. According to measurements the AOT40 values at Puntijarka in the period from 1988 to 2006 every year exceeded the critical limit of 5 ppm·h and even the critical value for more resistant trees has been exceeded as well.*

## INTRODUCTION

There is no doubt that forests within the temperate zone of the Northern hemisphere experience severe damage and progressive dying over the last decades (1, 2). The reasons are much less clear, the presumed culprits are changing over the years from sulfur dioxide, acid rain, soil and water acidification, industrial and photochemical smog to, recently, ozone toxicity. Indeed, after the discovery of ozone in the 19<sup>th</sup> century (Schönbein) and recognition that it is a rather constant microconstituent of the air, during the last hundred years its volume fraction in the troposphere is increasing and is nowadays higher than ever (3, 4). Although the stratospheric ozone by absorption of Sun's UV-radiation enables life on Earth's surface the increased surface ozone concentrations i.e. that in direct contact with life forms are toxic and represent a hazard to them.

The phytotoxic nature of ozone has been known for decades (5). Accumulated ozone time or accumulated exposure to ozone above a threshold (AOT) (6, 7) was the first and simplest concept which was developed in the 1990s for assessment of risk for forest injuries due to boundary layer ozone attack on tree leaves or needles. AOT40 is defined as the integral over time of ozone fractions in excess of 40 ppb during a relevant growing season and daily light. Although new assessment methods like flux concept of cumulative ozone uptake into the leaves are developed (7, 8), the AOT concept, due to its simplicity, is still useful at least as a preliminary tool for prediction of risk of forest injuries. Presently, flux based critical levels have been established for certain plant species but AOT based critical levels are still in use for forests. Of course, in the AOT concept many assumptions need to be

taken like that ozone induced injuries are invariant with respect to species and region and can be set to zero below the 40-ppb level as well as during the night.

Elevated ozone concentrations, due to oxidative stress, frequently induces changes in growth pattern and physiology of trees (9).

Recent experiments (8) proposed that ozone critical level represented with AOT40 should be 5 ppm h for sensitive conifers (Norway spruce) and sensitive broad-leaf trees (birch) and 18 ppm h for less sensitive species (oak). The critical level of 5 ppm h was exceeded at the most majority (80 – 95%) of remote forest sites (10).

## EXPERIMENTAL

Ozone monitoring at the Puntijarka site (located on the Medvednica mountain) started in 1988 within the EUREKA environmental project EUROTRAC on tropospheric ozone research (subprojects TOR (1988 – 1996) and TOR-2 (1996 – 2002)) (11, 12). The station is located about 10 km north of the city of Zagreb on the ridge of mountain Medvednica (45.90° N; 15.97° E, 980 m a.s.l.). To the north of the mountain there is an agricultural area with no significant industry.

Ozone has been monitored with commercial Dasibi and Environment monitors, which have been regularly checked and calibrated against primary ozone standard instruments.

## RESULTS

Mountain Medvednica region is rich forested, mainly by beech, but significant chestnut, oak and fir regions are also found. According to recent research performed by the Forest Institute Jastrebarsko at Medvednica beech trees are damaged by 70%, chestnut 74%, oak 64% and spruce 60%. The damage of beech trees is more severe than that in other parts of Croatia and even greater than the European mean (Vjesnik, 23. 2. 2005.). Since the quality of soil and nourishment of trees is good other possible causes for mentioned damages need to be identified to protect the Medvednica forest.

Air quality and boundary layer ozone are a possible cause for the observed damage. According to measurements the AOT40 values at Puntijarka in the period from 1988 to 2006 every year exceeded the critical level of 5 ppm·h and even the critical level for more resistant trees (18 ppm·h) (7, 8) has been exceeded as well (Table 1).

There are indications that Mediterranean trees, because of adaptation to hot and dry summer conditions (13), are more resistant and better adapted to the oxidant stress because of more frequent exposure to higher ozone levels. That could, to some extent, hold for trees in the Croatian continental area as well. The key role in the mechanism of oxidant stress is held by RuBisCO (ribulose-1,5-bisphosphate carboxylase) the enzyme which catalyzes the first major step of carbon fixation i.e. the addition of gaseous carbon dioxide to ribulose-1,5-bisphos-

**Table 1**

AOT40 / ppm·h valued for 16 consecutive years at Puntijarka site on Medvednica mountain. Values are calculated for daylight times during the growing season April to September. Values are normalised for missing hourly values.

Year	AOT40 / ppm * h
1990	49
1991	29
1992	72
1993	36
1994	34
1995	35
1996	13
1997	8
1998	20
1999	12
2000	34
2001	27
2002	24
2003	34
2004	16
2005	18
2006	17

phate (RuBP). RuBisCO is apparently the most abundant protein in leaves and is only active during the daylight because RuBP is not produced in the dark.

Measurements or modeling of ozone deposition onto the surface and ozone uptake into leaves are needed for a more precise determination of ozone impact on the forest trees.

A high spatial resolution ozone flux model has been recently developed in Hungary (Lagzi *et al.*, 2004). Based on that, dealing with ozone exposure of border forest areas among the three neighboring countries, a trilateral project (Ozone Research for Forests, ORFF) within the Neighbourhood Programme Slovenia-Hungary-Croatia 2004–2006, INTERREG IIIA has been proposed. This project has not been accepted yet due to some technical objections to the Hungarian contribution which is rather unfortunate.

## CONCLUSION

Obtained AOT40 values for the last 16 years on Medvednica could be an possible explanation for reported unusually high forest injuries in Nature park of Medvednica. There is a need for more detailed research including ozone flux measurements, cumulative ozone uptake and modelling.

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