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Sustainable use of the Predjama Cave (Slovenia) and possible scenarios related to anticipated major increases in tourist numbers

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ABSTRACT

In August 2009 a continuous cave-air temperature monitoring programme was initiated to help improve the understanding of natural microclimate conditions in Predjama Cave one of 10,700 karst caves in Slovenia. Whereas Predjama Castle, which is build partly in the shelter of one of the cave's entrances, is among the most popular and spectacular tourist destinations in Slovenia, Predjama Cave currently attracts fewer visitors. Studies of the cave microclimate are being conducted to help determine the potential impact of increased tourist visits on the natural cave environment. Recently recorded visitor numbers create no notable impact on the natural cave microclimate. However, increased tourist traffic and additional heat generated by proposed electrical installations could elevate air temperature in the cave. Provision of sustainable precautions to minimize such anthropogenic effects on the cave microclimate and cave fauna must be considered in any future planning for the development of Predjama Cave as a show cave.

1. Introduction

Predjama Cave, Slovenia's fourth-longest karst cave at 13,092 m, is listed as an asset of national importance in the country's Register of Natural Assets. The cave is managed by the *Postojnska jama d.d.* company, under a concession contract that runs until 2028. This private company also manages tourism at the better known and more heavily visited Postojna Cave (Gregorič, Vaupotič, & Šebela, 2013; Šebela & Turk, 2011a, 2014).

Karst landscapes cover some 12% of the Earth's terrain and provide 25% of the world's drinking water (van Beynen, 2011). Karst land is a type of important and unique terrain on the Earth's surface because of its extensive distribution, impressive landforms, and high ecological fragility. Recently, more and more researchers have realized that irrational land-use practices are leading to a series of alarming environmental issues on karst (van Beynen & Townsend, 2005). Karst occupies 43% of Slovenia's land area and provides more than 50% of the country's drinking water (Knez, Petrič, & Slabe, 2011). The Slovenian Cave Register currently includes details of 10,700 caves. Slovene words such as doline, polje, ponor, etc., are used internationally to designate specific karst landforms that were first described in the Classical Karst area of southwestern Slovenia. Recreational use of caves in a modern sense dates from the early Seventeenth Century, when the Vilenica Cave in Slovenia was opened for visits by paying tourists (Gillieson, 2011). Karst landscapes, as typified in Slovenia, have become important internationally, not only geomorphologically but also as popular tourist destinations (Day & Hall, 2012). Nowadays, more than 600 show caves are operating worldwide (Gillieson, 2011).

Regular climatic and partial biological monitoring at selected locations in Predjama Cave have been undertaken since 2009 by staff members of the Karst Research Institute ZRC SAZU, who also act as karstology consultants and cave advisers in matters relating to the implementation of the concession contract. Thus the state of the cave is monitored professionally, with an emphasis on the impact of the use of the cave as a natural asset (Culver et al., 2012; Gabrovšek et al., 2011; Šebela & Turk, 2011a, 2011b; Šebela et al., 2013). The cave adviser role within the Short-Term Programme of the use of the natural asset of Predjama Cave (2009–2013) includes various important tasks. As well as climatic and biological monitoring, it is vital to maintain regular communication with the Nova Gorica Regional Unit of the Institute of the Republic of Slovenia for Nature Conservation (ZRSVN OE Nova Gorica) regarding the implementation of the concession and the condition of the cave. Additionally the role involves implementation of a rehabilitation program to eliminate impacts caused by the use of the natural asset, drawing attention to any external factors that put the cave at risk, recording results of research, drawing up an inventory of infringements, and maintaining records of the cave system's cultural heritage.

Within the broad framework covered by the cave adviser tasks, the Long-Term Programme for the exploitation of a natural asset (2009–2028) anticipates the needs for natural protection precautions, based on the five-year monitoring of the cave's climate and fauna. This program proposes joint marketing of Predjama Castle and Predjama Cave, improved presentation of the archeological site in the cave, development of a prehistoric display in the cave, reconstruction of the

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historical electrical fittings in the cave, new electrical systems along the tourist route and expansion of monitoring in areas that are not currently visited by tourists. Overall therefore, the mission of those involved in the cave adviser role is to provide professional supervision and management consultancy services that will ensure the sustainable development of the cave system, to develop and implement guidelines for the continuing use of the cave system as a natural asset, and to carry out climatic and biological monitoring of the cave.

The plan for climatic monitoring includes routine recording of basic parameters (air temperature, air pressure, CO_2, wind and humidity) but also places emphasis on the need to analyze the impact of outside climate on the cave interior. Because the cave has multiple entrances, the effects of climate changes and inflow of cold air into the cave can be felt deep inside. The aim of climatic monitoring is to analyze the changes in cave microclimate related to increased use of the cave for tourism.

Issues related to climate change and clearer understanding of underground climates worldwide are becoming ever more important (Baker & Genty, 1998; Calaforra, Fernández-Cortés, Sánchez-Martos, Gisbert, & Pulido-Bosch, 2003; de Freitas, 2010; Faimon, Ličbinská, Zajíček, & Sracek, 2012; Faimon, Troppová, Baldik, & Novotny, 2012; Gregorič, Vaupotič, & Gabrovšek, 2013). This is emphasized on consideration that massive increases in tourism internationally are a major driver of global climate change (Dwyer, Knežević Cvelbar, Edwards, & Mihalic, 2012).

Plans for biological monitoring in Predjama Cave draw attention to the importance of providing protection for the rich underground fauna and keeping records of their existing state. As a result, a side passage in Fiženca is closed to visitors every year during the period of bat hibernation. Annual counting of individuals occupying bat colonies is currently undertaken at four monitoring sites in Predjama Cave. In recent years there have been about 1000 bats hibernating in the cave during winter. Wider aims are to learn more about the current population status, and to make an inventory of other animals, including animals that occasionally live in the cave. Routine observation and recording of the fauna found in percolating waters are also included within the biological monitoring plan.

Predjama is a major tourist attraction partly because of the spectacular position and appearance of its medieval castle (Fig. 1). A hydrological connection between the River Lokva sinking into Predjama Cave and the Vipava karst springs some 14 km to the northwest was first inferred by the eminent Slovene scientist Valvasor (1689).

Tourists in Predjama Cave follow a route that is about 700 m long, with a vertical range of 50.74 m. Cave tours are organized between 01 May and 30 September, with individual trips lasting about 45 min. There is no electric lighting installed along the route; visitors are equipped with battery-powered lamps. A typical tour group comprises a maximum of 55 to 60 visitors accompanied by two cave guides.

Reflecting the complex geometry of its passages and its several entrances at different altitudes, Predjama Cave presents a particularly interesting site for cave meteorology studies. Results of early meteorological recording in Predjama Cave were published by Schmidl (1854). Anelli (1941–44) provided clear descriptions of the winter and summer ventilation regimes of Predjama Cave and air temperature measurements. Some years later Habe (1970) produced temperature graphs, covering the February 1956 to February 1957 period, for almost the whole cave system. Measurements of air temperature and humidity for entrance zones were obtained by Kranjc (1983) between 09 January 1980 and 31 March 1981.

In recent years the microclimatic characteristics of the Predjama Cave have been studied with the aim of recognizing the potential influences of tourist use on the cave (Šebela & Turk, 2011b).

As part of the environmental and sustainable tourism research reported here, basic cave microclimate characteristics are presented based upon a cave-air temperature dataset collected at hourly and 10-minute intervals. Details of periodic measurements of wind speed and direction, and of summer and winter ventilation regimes, are also presented. Comparative analyses between cave-air temperatures and air temperatures outside the cave are provided to illustrate the influence of external climatic conditions on the cave microclimate. Predictive analyses covering potential cases of tourism growth in Predjama Cave and its influence on the cave's microclimate are considered in the context of sustainable tourism development, and can be used worldwide at similar sites in the context of the international significance of sustainable management of karst caves.

2. Site description

Predjama Cave lies about 10 km northwest of the better-known tourist site of Postojna Cave. Cave passages extend from entrances within a 164 m-high, sub-vertical, limestone cliff (Fig. 1a). The medieval Predjama Castle is built partly inside a natural shelter-type cave.

To improve understanding of the natural meteorological conditions inside the cave, two cave-air temperature monitoring sites were established on 06 August 2009 in parts of the cave that lie on the tourist path (Fig. 2). One monitoring site is in Konjski Hlev (Fig. 1b) at 488 m above sea level (asl), where the air temperature outside the cave retains a strong influence. Instrumentation is installed about 0.7 m above the cave floor and about 3 m away from the tourist path, close to the cave wall. The cross-sectional area of the cave passage at Konjski Hlev is about 18 m^2. Site number 2 (Fig. 1c) is in Velika Dvorana chamber (at 492.5 m asl), with the instrumentation 2 m south of the tourist path that leads to Fiženca, and about 1 m above the cave floor. Velika Dvorana has a volume of some 84,000 m^3, and the monitoring site lies between the biggest collapsed chambers in the cave system.

The monitoring site at Velika Dvorana is separated from the higher (Fiženca) cave entrance (at 541 m asl) by 49 m vertically and 35 m horizontally. There is a vertical separation of 79 m between the ponor sink of the river Lokva into the cave (at 462 m asl) and the higher Fiženca passage. On 07 October 2009 a third air-temperature monitoring site was set up outside the cave, in the forest near Postojna Cave, at 545 m asl. Whereas this monitoring site lies some 9 km from Predjama Cave, the data it provides are sufficiently representative of local surface conditions to support meaningful comparisons of cave and outside air temperatures.

Wind speed and direction in the cave were measured occasionally to help determine details of winter and summer ventilation regimes (Fig. 2). One monitoring site is located at Imenski Rov and another at Vetrovna Luknja.

3. Methodology

Air temperature readings were measured and recorded automatically using *Diver* instruments (produced by Van Essen Instruments) with a claimed accuracy of ± 0.1 °C. A continuous series of air temperature measurements at hourly or 10-minute intervals has been recorded at two sites in the cave since 06 August 2009. Basic statistical analysis was employed to compare cave-air temperatures measured at the two monitoring sites with temperatures measured outside the cave.

Occasional wind speed and direction values were measured in the cave using a manual anemometer with an accuracy of 0.5 m/s.

Details of visitor numbers per year to Predjama Castle and Predjama Cave are also recorded. These are presented specifically in the context of the possible influence of tourism on cave microclimate and to help predict future trends of tourism growth and its potential impact on the cave environment.

4. Results and discussion

Although it is commonly stated that caves operate at or near a constant temperature, detailed examination indicates that cave temperatures are neither static nor constant. Air temperature and humidity