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Sediments as tracers for transport and deposition processes in peri-alpine lakes: A case study

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SUMMARY

The benthic sediment fingerprint is analysed in the small peri-alpine lake Levico (Trentino, Italy) to identify the causes of recurrent phenomena of turbidity peaks, particularly evident in a littoral region of the water body. In order to study the sediment transport processes, we exploit the fact that the sediment supply from the major tributary has a specific chemical composition, which differs from that of the nearby lake basin. Three elements (Fe, Al, K) have been used as tracers to identify the source and the deposition patterns of tributary sediments, and another typical element, Si, has been critically analysed because of its dual (allochthonous and autochthonous) origin. Several samples of the benthic material have been analysed using SEM–EDS, and the results of the sedimentological characterisation have been compared with the patterns of sediment accumulation at the bed of the lake obtained using a three-dimensional numerical model, in response to the tributary supply under different external forcing and stratification conditions. The coupled use of field measurements and numerical results suggests that the turbidity phenomena are strongly related to the deposition of the sediments supplied by the tributary stream, and shows that it is possible to reconstruct the process of local transport when the tributary inflow is chemically specific.

1. Introduction

Benthic sediment composition is strongly interrelated with the physical, chemical and biological characteristics of lakes and their catchment characteristics. The distribution of the sediments and the spatial variation of their chemical composition is a function of many factors, like the type and position of external inputs, the internal production and the currents within the lake. Depending on their origin, sediments can be classified in allogenic, endogenic and authigenic (Hakanson and Jansson, 1983). For example, the endogenic fraction of benthic sediments usually increases with water depth, as the result of the dominantly biochemical processes taking place in the water column, while the littoral zones are usually dominated by the allogenic materials (Hakanson, 1995; Peinerud et al., 2001). The sediments in the superficial layer can be considered outstanding archives of the recent history of the lake. If the geological features of the surrounding catchment are distinctive, the allogenic fraction can be distinguished from the endogenic and a sediment fingerprint technique can be applied to evaluate sediment source type. This technique is widely applied in river and catchment studies (e.g. Collins et al., 1997; Walling and Woodward, 1992, 1995; Collins and Walling, 2003). The sedimentological peculiarities of the benthic detritus can be used to infer the fate of sediments supplied by the tributary and transported by lake hydrodynamics as a response to wind shear stress, thermal stratification and other external physical forcing.

Several processes affect the transport and the deposition of suspended sediments within a lake. The main driving force for current development is typically the wind acting on the lake surface. Thus the sediments released by the tributary are transported by currents and slowly deposit with a sinking velocity which depends on the apparent grain size and relative density (Boudreau and Jorgensen, 2001). When considering the discharge from the tributary in the near field, buoyancy can play an important role as well. In fact, if the stream temperature is different from that of the lake, as almost always occurs, the (positively or negatively) buoyant character of the thermal plume affects the trajectories of the transported particles (e.g. Rueda and MacIntyre, 2010).

In this paper we examine a peculiar case study, the lake Levico in Trentino (northern Italy, see Fig 1), where significant turbidity phenomena were noted after 2002 in the southern region of the lake, in the neighbourhood of the main tributary entrance. Since beaches and tourist facilities are located in the area, occasional high turbidity events compromised the recreational use of the lake. For this reason a detailed field survey was conducted in 2004–2005. It followed from the analysis that, among the various possible explanations (e.g. sediment resuspension by wind action,

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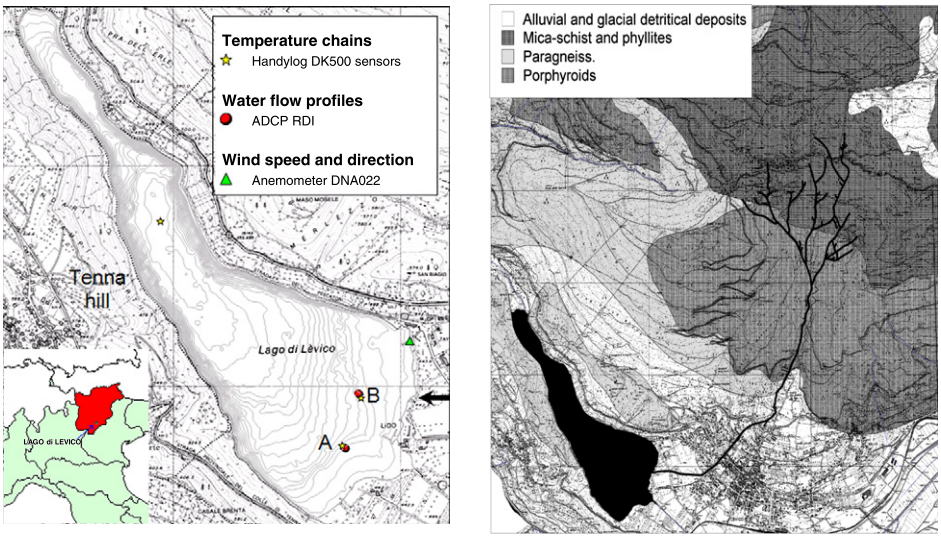

Fig. 1. Lake Levico: (a) bathymetry and position of the instruments installed during the field campaign (May–October 2005); the main tributary (Rio Maggiore) is shown with an arrow and (b) geological map of the lake and of the Rio Maggiore catchment.

increased local productivity, etc.), turbidity events were to be associated with the sediments transported by the tributary and recently deposited and not yet consolidated. As it will be shown later, this explanation was confirmed by the analysis of the benthic sediments. Indeed, motivated by these results, the River Monitoring Office of the Autonomous Province of Trento found that a bank collapse had occurred along the tributary in its upper catchment (further stabilized in 2006), leading to an unusual sediment supply to the lake.

In general, the deposition area of the sediment transported by the tributary cannot be easily determined for intermittent events like floods, also because the fate of tributary sediments is strongly affected by the seasonal variations of the temperature difference between the inflow and the water body. Nevertheless the peculiar chemical composition of the stream material, coming from an upstream catchment with distinct geological features, allowed us to use the recently deposited sediments as a signature of naturally transported tracers.

In order to verify whether the sediment accumulation area was compatible with the wind-induced circulation and consequent transport of sinking material, a set of numerical simulations were performed. Three-dimensional numerical models are able to give detailed indications about the trajectories of sediments transported by wind-driven circulations, but they need a large number parameters to be calibrated. In particular, complete seasonal simulations are prohibitive for complex models both for computational costs and for the need of long series of many input data. Therefore, we have decided to choose a few representative conditions considering different characteristic and prevalent scenarios. As we will show in the following of the paper, the results of the two most relevant scenarios show a qualitative agreement with the deposition pattern yielded by the sedimentological analysis.

2. Study site

Lake Levico (Fig 1) is a dimictic, mesotrophic alpine lake (440 m a.s.l.) in the north-eastern part of Italy (Trentino region). The lake is 2840 m long, has a maximum width of 950 m and a maximum depth of 38 m. The basin is narrow in the northern part, where shores are steeper and greater depths are reached. The wider, shallower part of the lake in the south region is characterised by the presence of the only outflow (Brentella di Levico) and the main inflow (Rio Maggiore, see Figs. 1a and 2). Except for the eastern side, the shorelines are covered by a thick vegetation consisting of broadleaf (mainly alders and willows) and reed. On the western side, lake Levico is separated from the lake Caldonazzo by Tenna hill, which represents an obstacle for western winds.

The main tributary of lake Levico is Rio Maggiore. It flows along the southern slope of the Mount Fronte, drains a 5 km^2 basin and carries arsenicate–ferrous rich waters into the lake. In fact, the geological map (Fig. 1b) shows that the lake basin is mainly constituted by paragneiss and alluvial deposits, while the Rio Maggiore basin is characterised by porphyric rocks. The chemical features of the sediments transported by the tributary reflect the particular nature of its catchment.

Rio Maggiore is not gauged, so precise data about the amount of water entering into the lake do not exist. Nevertheless, based on the geometrical and hydraulic features of the final reach, we have estimate a reference discharge of about 1 m^3/s during floods. The same reference discharge has been assumed for the outlet. Most of the sediment supply occurs during flooding events, typical of late spring (during the formation of stratification) and prevalently of middle autumn, but important storm events are common also during summer due to the small dimensions of the catchment basin. No data are available about the water temperature of tributary, but reasonable values can be assumed by analogy with similar situations. In particular, we refer to the tributaries of lake Caldonazzo (which is only 400 m far from lake Levico, separated by the Tenna hill), which where monitored during 2005.

3. Materials and methods

3.1. Field measurements

Field surveys were performed during the period May–October 2005 with the purpose of studying the hydro-thermodynamics of the lake and the characteristics of bottom sediments. Three chains of thermistors Handylog DK500 were deployed (one in the centre of the lake and two in the south-east shore at a depth of 8 m, Fig. 1a) for a total of 26 probes, measuring water temperature every 10 min. Such acquisition frequency was high enough to monitor the internal seiches, typically of the order of few hours. An acoustic Doppler current profiler (RDI-ADCP) was placed alternatively in correspondence of the two thermal chains in the