Beiträge zur Hydrogeologie / 53 / Seiten 73–82 / Graz 2002

Herbicides in the Sediments of the Tovel Lake (Trento Province, Italy) – An Example of Long Distance Wind Transport of Phytochemicals

Herbizide in den Sedimenten des Tovel Sees (Provinz Trento, Italien) – Ein Beispiel für den Ferntransport von Phytochemikalien durch Wind

G. MORTEANI[1]), A. FUGANTI[2]) & L. EICHINGER[3])

Inhalt

1. Introduction and problem

The explosive growth of red alga *Glenodinium Sanguineum* March. and the subsequent reddening of the Tovel lake (Val di Non, Trento province, NE Italy) observed in the warm days between June and August completely disappeared during the period 1964 to 1965. Reddening of the lake in summer attracted crowds of tourists producing a very positive effect on the economy of the area.

Hydrobiology of Tovel lake is studied comprehensively by E. BALDI (1941). He summarized in his paper all previous investigations, too. The life cycle of the alga *Glenodinium Sanguineum* March. was studied in detail by V. MARCHESONI (1941, 1959).

Reasons for the disappearance of the reddening of the water of the Tovel lake are discussed in many papers, e. g. A. ARRIGHETTI (1972), C. BONI et al. (1983), J. D. DODGE et al. (1987), A. FUGANTI (1994), V. GEROSA (1970), P. GUILIZZONI et al. (1992), A. PAGA-

[1]) Prof. Dr.-Ing. Giulio MORTEANI, Geoexpert International, Via Zara 3, I-38100 Trento, Italia. E-mail: gmorteani@gmx.de
[2]) Prof. dott. Andrea FUGANTI, Dipartimento di Ingegneria dei Materiali, Università di Trento, Via Mesiano 77, I-38100 Trento, Italia. E-mail: afuganti@tin.it
[3]) Dr. Lorenz EICHINGER, Hydroisotop GmbH, Woelkestr. 9, D-65301 Schweitenkirchen, Deutschland. E-mail: hydroisotop@t-online.de

NELLI (1985, 1992), A. PAGANELLI et al. (1981), G. TOMASI (1989), A. VITTORI (1972, 1973), A. FUGANTI & G. MORTEANI (1999).

The present paper discusses the results of geochemical analyses, including pesticides and herbicides, and of lake sediments aimed at determining the history of the Tovel lake and the reasons for the disappearance of the reddening.

2. Geography, geology and climate

The Tovel lake (Lago di Tovel) is found in the Brenta Dolomites (Trento province, NE Italy) at an altitude of 1,178 m a.s.l. (Fig. 1). The lake covers an area of 384.45 sq. m and its volume is 7,367,610 m^3.

Surface water temperature of Tovel lake reaches 0.9 °C in winter and 17.0 °C in summer. Below 30 meters the temperature is always below 5.4 °C (A. PAGANELLI et. al., 1988).

The lake is divided into a northern basin with a depth of 38.5 m and a southern one, the Red Bay (Baia Rossa) that is only 4–5 m deep (Fig. 2). Small creeks, often dry in summer months, are tributaries of the lake. The lake is drained to the N by the Tresenga river, which joins in the Noce river.

The forested Tovel valley and the Tovel lake are shown in the aerophotograph which looks from the Val di Non to the S (Fig. 3).

The lake is embedded in Mesozoic dolomite and limestone. In the lake water is up to at least 5 m below the surface oxidizing, whereas at the bottom it is reducing (see A. PAGANELLI et al., 1988).

From ^{14}C age determination of wood fragments, recovered from the sediments, the landslide which generated the lake happened around 1000 AD. Tree trunks lying in the Red Bay on the ground fell according to ^{14}C age determinations at the beginning of the 15^{th} century (A. FUGANTI & G. MORTEANI, 1999).

Orchards with a very intensive apple farming area are found in the Val di Non about 5 km east from the lake (Fig. 1). According to most recent data, published by the PROVINCIA AUTONOMA DI TRENTO (1990, 1997), the predominant summer winds blow in the Val di Non area towards W. These winds hit on their way to the W the N–S trending ridge formed by the mountains Peller (2,319 m), Pietra Grande (2,936 m) and Cima Brenta (3,150 m) which limits the valley, where the Tovel lake lies, in the W. The difference in elevation between the Tovel lake and the mountain ridge is between 1,200 and 2,000 m. As already described by V. MARCHESONI (1959) and shown schematically in Fig. 1 this high ridge deviates the winds incoming from the Val di Non into the valley of the Tovel lake.

Intensive fruit farming in the Val di Non requires, like in other similar areas, the use of phytochemicals. Phytochemicals are sprayed onto the apple trees by high pressure pumps which produce a very fine aerosol. Such a fine aerosol is needed in order to distribute homogeneously the phytochemicals onto the trees. The extensive use of phytochemicals started in the sixties (A. FUGANTI, 1994).

Reddening of the Tovel lake was produced by the alga *Glenodinium Sanguineum* March. that turns red under the summer sunshine due to the production of carotenoids (V. GEROSA, 1959, 1961, 1966, 1970). Reddening was particularly intense in the Red Bay where the algae were accumulated by the wind blowing from NE. Reddening occurred on calm peaceful days in the months from June to August. Optimum water temperatures for rapid growth and reddening of the alga *Glenodinium Sanguineum* March. were between 15 °C and 18 °C, but in the case of a cold summer

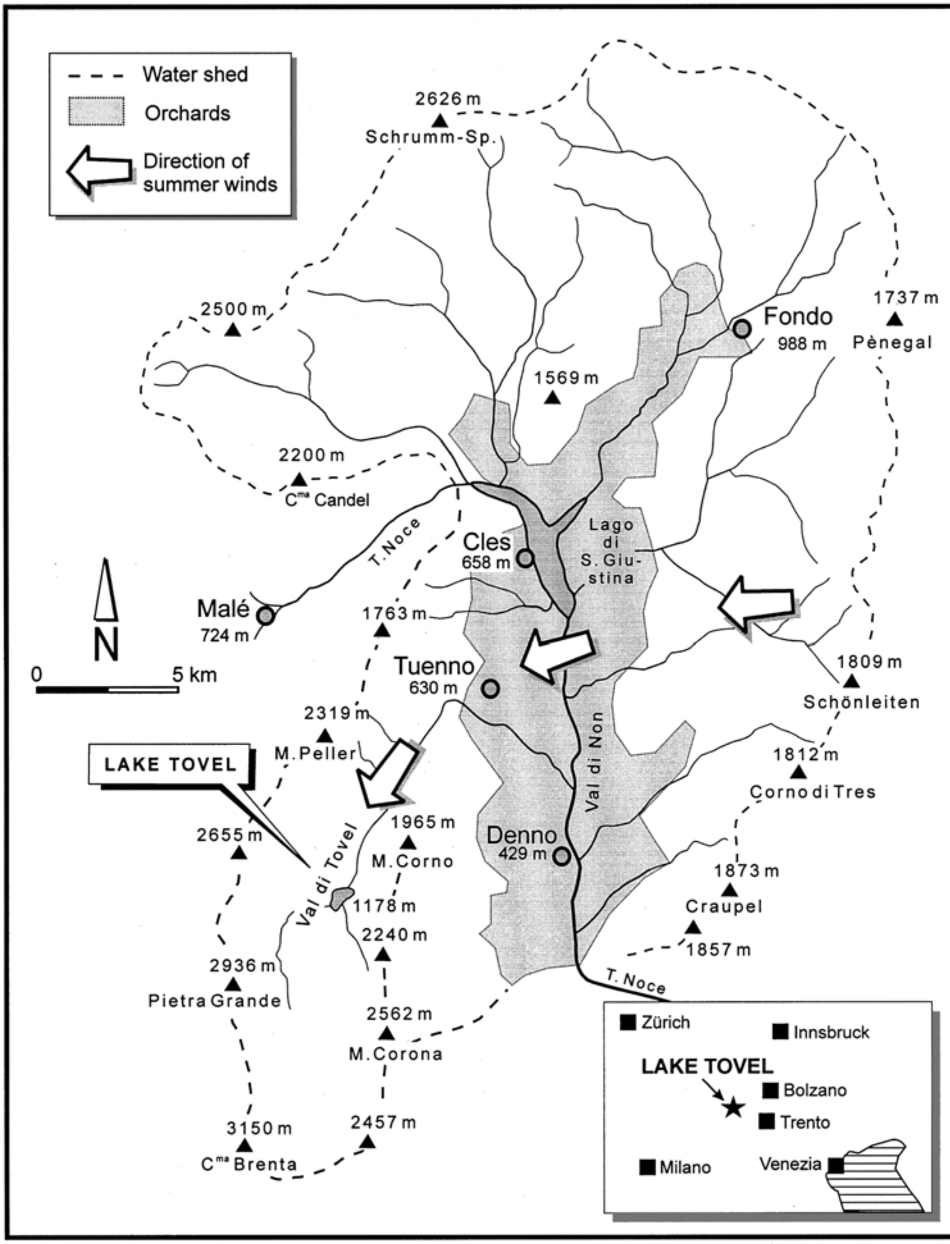

Fig. 1: Sketch map showing Tovel lake, the main mountain ridges and wind direction as well as the area cultivated with orchards in the Val di Non.
Lageplan des Tovel Sees mit Hauptgebirgskämmen, Windrichtung und Obstanbaugebiet in der Val di Non.

temperatures of 11–12 °C were also sufficient (V. MARCHESONI, 1959). Since 1964 the phenomenon practically has vanished, although it reappears sporadically in a weak and very limited form.

The most accepted reason for the disappearance of the reddening to date is a change in climate. The authors A. ARRIGHETTI (1972) and E. CORONA (1973a, 1973b, 1976) refer the climatic changes in the Tovel valley to the construction of the Santa Giustina dam and increasing irrigation in the Val di Non both supplying humidity to the winds entering the Tovel valley. The authors A. PAGANELLI (1985, 1992), A. PAGANELLI et al. (1982, 1988) and P. GUILIZZONI et al. (1992) have observed a change in phytoplancton since 1964. A. PAGANELLI (1992) and A. PAGANELLI et al. (1982, 1988) refer these to changes in the regional climate, mainly to an increase in precipitation and cooling of the lake

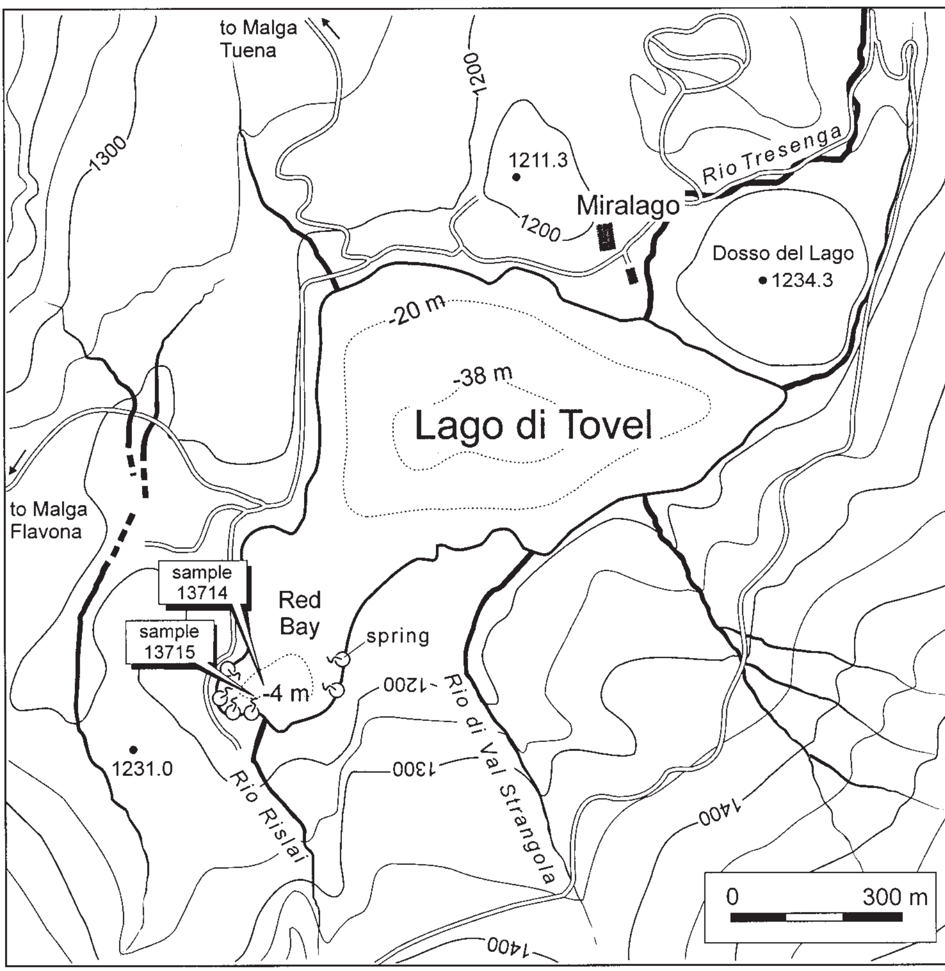

Fig. 2: Topographic sketch of Tovel lake with the Red Bay (Baia Rossa), the tributaries, the draining river Tresenga and the two sample localities.
Topographische Karte des Tovel Sees mit „Roter Bucht“ (Baia Rossa), den Zuflüssen, dem Abfluss Tresenga und den beiden Probenahmestellen.

water. In Fig. 4, the three years backwards running mean and the correlation line of the temperatures recorded north of the Alps at Hohenpeissenberg in Southern Germany and south of the Alps at Cles in the Val di Non are shown. From both curves it can be seen that the temperatures show on average an increase, whereas the rainfall, as determined at Cles, decreases. The given data demonstrate for the whole Eastern Alps a continuous temperature increase of about 1 °C since 1964, the time where the

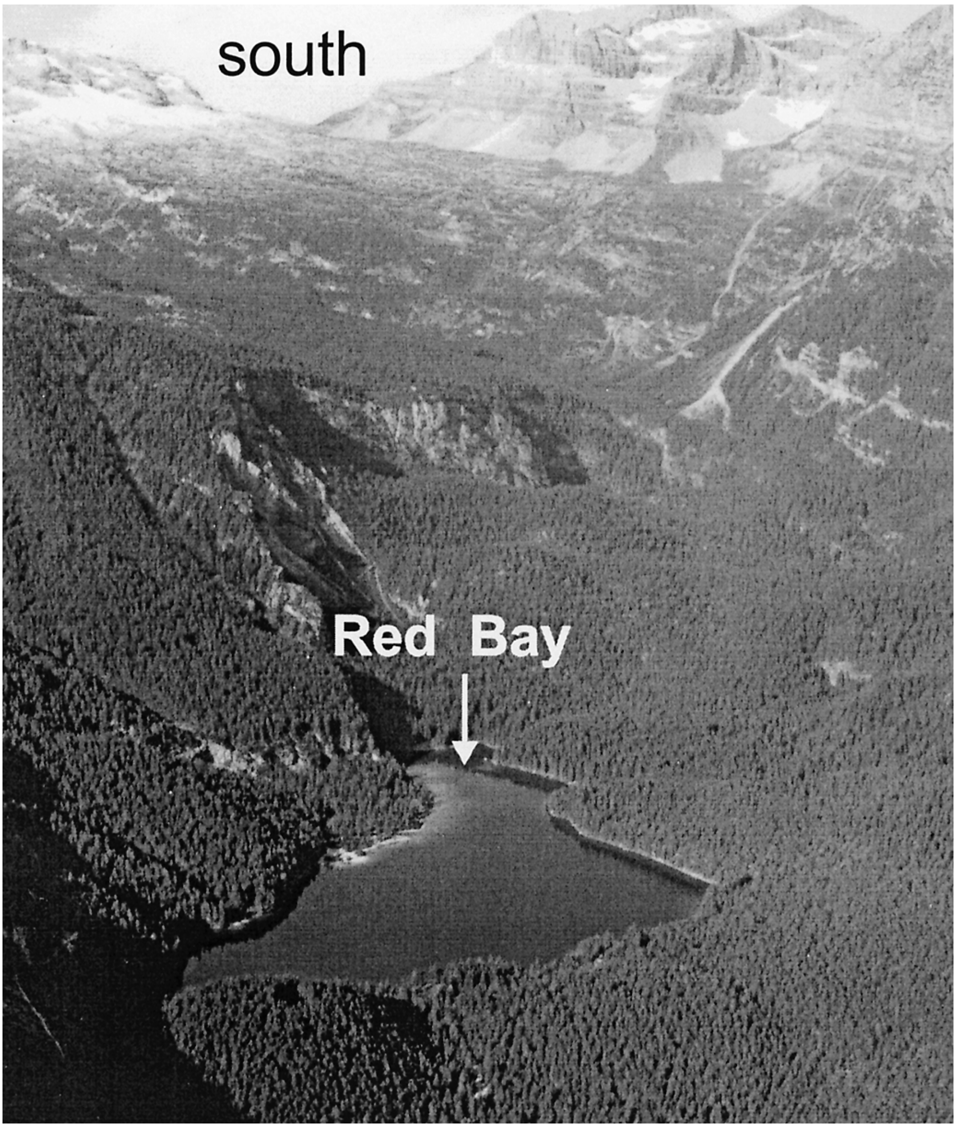

Fig. 3: Aerophotograph showing the Tovel valley, the Red Bay (Baia Rossa) and the thick forest surrounding the lake.
Luftbildaufnahme vom Tovel Tal mit „Roter Bucht" (Baia Rossa) und dichtem, den See umgebenden Waldgürtel.

reddening disappeared from the Tovel lake. In the Val di Non area the rainfall decreased in the same time span by about 100 mm/a.

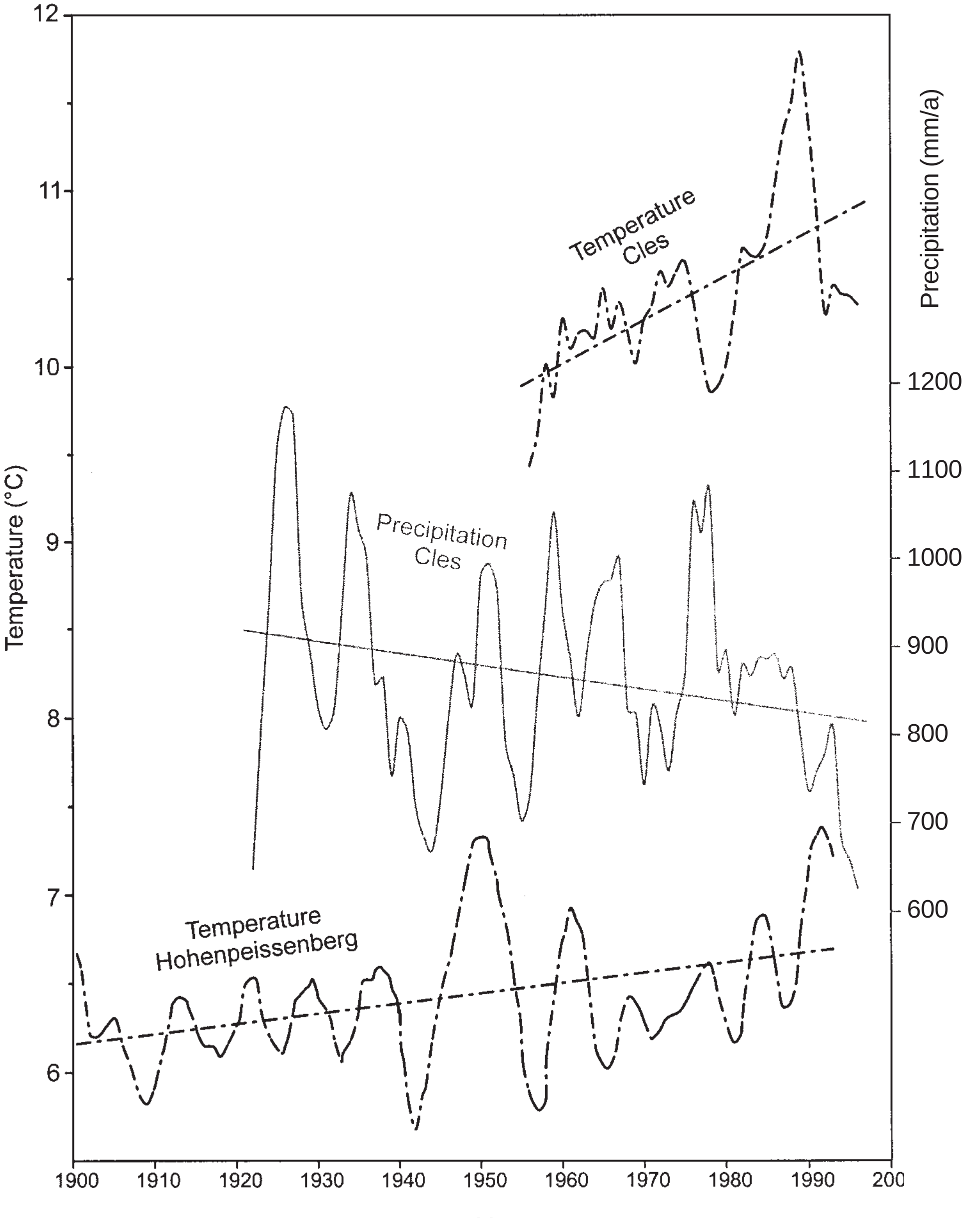

Fig. 4: Temperatures and rainfall determined north and south of the Eastern Alps at Hohenpeissenberg (Germany) and at Cles (Italy), respectively.
Temperatur und Niederschlag an der Nord- und Südseite der Ostalpen am Beispiel Hohenpeissenberg (Deutschland) bzw. Cles (Italien).

3. Lake sediments

In their content of fossils and mineralogical, chemical and isotopic composition lake sediments give an excellent record of the changes in chemistry and biology of lakes and rivers with time. From a detailed multielement chemical analysis of four drill cores from 6 to 18 cm length representing a time span from about 1000 AD up to now it can be deduced that the chemical composition of the lake sediments is nearly constant (A. FUGANTI & G. MORTEANI, 1999). Only the most recent sediments are enriched in silica due to abundant remains of siliceous algae.

Two samples (No. 13715 and 13714) of the most superficial part of the sediments were taken in the Red Bay at the southern end of the lake and analysed for phytochemicals.

Analyses of the pesticide contents in the lake sediments were made in the laboratory of the Hydroisotop Co. at Schweitenkirchen (Germany) through a preliminary concentration with ^{18}C columns with subsequent analysis by gas chromatography with NPD (**n**itrogen **p**hosphorus **d**etector) and ECD (**e**lectron **c**apture **d**etector). The latter was used specifically to detect halogenated compounds.

The polycyclical aromatic hydrocarbons phenantrene, fluoranthene and pyrene resulted to be present in sample 13714 only in concentrations of 0.02, 0.03 and 0.02 mg/kg. The other ones (naphtalin, acenaphthylen, acenaphthen, fluoren, anthracen, benzo(a) anthracen, chrysen, benzo(b)fluoranthen, benzo(k)fluoranthen, benzo(a)pyren, indeno(1,2,3)pyren, dibenz(a.h)anthracen, benzo(g,h,i)perylen resulted to be absent or below the detection limit (0.02 mg/kg) of the used method.

Of the N-containing phytochemicals in sample 13715 chlortoluron, cyanazin, desethylatrazin, desethylterbuthylazin, hexazinon, metolachlor, prometryn and propazin were detected with 0.06, 0.01, 0.02, 0.05, 0.19, 0.03, 0.08 and 0.01 mg/kg, in total 1.29 mg/kg, respectively. In sample 13714 only chloridazon and desethylatrazine with 0.03 and 0.02 mg/kg could be determined. All other phytochemicals such as atrazin, bromacil, chloridazon, chloroxuron, chlorpropham, crimidin, desisopropylatrazin, diuron, isoproturon, linuron, metazachlor, methabenzthiazuron, metobromuron, metoxuron, metribuzin, propham, sebutylazin were below the detection limit of 0.01 mg/kg in both samples.

All determined phytochemicals are herbicides. Chlortoluron, an analogon to urea, intervenes in photosynthesis of plants, has a low water solubility and is considered low toxic for animals and humans. The triazines, like hexazinon, simazin, cyanazin and terbutylazin are also products that disturb photosynthesis of plants and have a low toxicity for animals and humans (E. SIGLOCH & W. MÜCKE, 1996).

4. Discussion and conclusion

Presence of pesticides in the uppermost sediments of the Tovel lake shows that in the very recent history of the lake phytochemicals were introduced into the water of the lake and stored in the sediments. This happened most likely from 1960 onward. No precise age can be determined for the introduction of the phytochemicals into the lake sediments because the sediment samples could not be dated from their stratification or by other methods with sufficient accuracy. Powerful sorption capacity of aquifer sediments for pesticides is pointed out e. g. by J. E. RAE et al. (1998).

Herbicide contents in the lake sediments are rather low, so it may be a matter of discussion if the data demonstrate that the concentration in the water was sufficient to suppress the growth of the algae *Glenodinium Sanguineum* March. In such a discussion the open points are obviously the response of the algae *Glenodinium Sanguineum* March.

a) to individual herbicides,
b) to the given mixture of phytochemicals and
c) the unknown partition coefficient lake water/sediment for the different phytochemicals.

Recent attempts to study the mixture toxicity have revealed that the simple concentration/addition model is true for chemicals with the same mode of action. If the mode of action is different then the response/addition model can be applied but the result is questioned (P. A. Pape-Lindström & M. J. Lydy, 1997). All detected products intervene in photosynthesis of plants, but it is not clear if the mechanism is identical, so that a synergistic toxicity cannot be excluded without an experimental toxicological study. Nevertheless, from the demonstrated presence of herbicides, it is now very likely that these are the real reason for the disappearance of the alga *Glenodinium Sanguineum* March.

The only source of the phytochemicals are the apple farms of the Val di Non, where the determined phytochemicals have been used, starting from the 1960's, extensively, to control e. g. the growth of grass between the rows of apple trees. Presence of phytochemicals in lake sediments proves that agrochemical bearing aerosols, produced by farmers in the orchards of the Val di Non, are transported by wind over a distance of at least 5 km into the valley where Tovel lake is located. A production of phytochemical-bearing aerosols in the surroundings of the Tovel lake can be excluded because the entire valley of the lake is covered by conifer forest (Fig. 3). A key role in the introduction of herbicides into the lake water is played by the high mountain ridge limiting the valley to the W and deviating the herbicide carrying winds from the Val di Non into the forested Tovel valley. The thick woods acted as a filter for the wind-carried aerosols.

The input of phytochemicals in the environment of the study area has markedly decreased in the last years due to a very strict control of the use of these chemicals in the orchards of the Val di Non. Nevertheless, it cannot be deduced from that, that the situation in the lake will improve soon. It must be assumed in fact that, with the decreased concentration of herbicides in the lake water, a flux of herbicides from the sediments into the lake water following the concentration gradient will occur. This means that a quick return of huge amounts of *Glenodinium Sanguineum* March. and the consequent reddening of Lake Tovel will take its time which strongly depends on the affinity of the different phytochemicals to the lake sediments.

Summary

Until 1964 the water of the Tovel lake (Brenta Dolomites, Trento province, Italy) was red due to the explosive growth of the red alga *Glenodinium Sanguineum* March. in warm summer days. The reddening disappeared completely in 1965, most likely due to the presence of herbicides, like chlortoluron, cyanazine, desethylatrazine, des-

ethylterbuthylazine, hexazinone, metolachlor, prometryn and propazine in the sediments of the Tovel lake. The herbicides are carried over a distance of about 5 km into the valley of the Tovel lake by the summer winds coming from the big orchards of the Val di Non where phytochemicals are extensively used.

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Zusammenfassung

Bis zum Jahr 1964 färbte sich der Tovel See (Brenta Dolomiten, Provinz Trento, Italien) an warmen Sommertagen durch das massenhafte Auftreten der Rotalge *Glenodinium Sanguineum* March. dunkelrot. Der Nachweis der Herbizide Chlortoluron, Cyanazin, Desethylatrazin, Desethylterbuthylazin, Hexazinon, Metolachlor, Prometryn und Propazin in den Seesedimenten lässt vermuten, dass das Verschwinden der Rotalgen und der damit verbundenen Rötung des Wassers auf den Eintrag von Herbiziden zurückzuführen ist. Als Quelle der Herbizide kommen die ausgedehnten Obstgärten im Val di Non in Frage, da diese nur 5 km entfernt in der sommerlichen Hauptwindrichtung liegen und die Herbizide in den vergangenen Jahren dort intensiv eingesetzt wurden.

Keywords: algae, Dolomites, herbicides, lake, sediments, wind, Italy
Stichwörter: Algen, Dolomiten, Herbizide, See, Sedimente, Wind, Italien