Distribution and ecology of *Didymosphenia geminata* (Lyngbye) M. Schmidt (Bacillariophyta) in Trentino watercourses (Northern Italy)

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Abstract - In 2000 the European Parliament and The European Union Council recommended that member countries assess water quality using diatoms, as part of the phyto-benthos. In Italy this recommendation has given new impetus to the study of diatom communities and the application of biotic indices. During the summer of 2004, a total of 11 rivers of the Trentino province (Northern Italy) were sampled, revealing the presence in low abundances of the diatom *Didymosphenia geminata* (Lyngbye) M. Schmidt. The sites where this diatom occurred were characterised by a low pollution impact; they were also lake fed or had a regulated flow regime, although with different geologies. Morphological features of *D. geminata* frustules were analysed using LM and SEM and specimens could be referred to the morphotype "geminata". In many countries this species is expanding its distribution and in New Zealand it is considered an invasive alga. This work provides an initial report on the presence of *D. geminata* in the Trento province, and contributes to increasing the knowledge on its distribution in Italy and its ecology in the Alps.

*Didymosphenia geminata* / diatoms / biological indicators / invasive species / Italy

INTRODUCTION

Directive 2000/60/EC (WFD) (European Parliament, 2000) establishes a framework for Community action in the field of water policy and introduces an holistic vision of aquatic ecosystems, considering both biotic and abiotic elements involved in the definition of the quality of the ecosystem. Among biotic parameters, diatoms (as part of the phyto-benthos) are one of the most studied groups. In Italy the Water Framework Directive has given new impetus to the study of diatom communities and the applicability of biotic indices, such as the Eutrophication and Pollution Index with Diatoms (EPI-D) (Bell’Uomo, 2004).

During the summer of 2004, 11 rivers of the Trentino province in the Trentino-Alto Adige region (Northern Italy) were sampled and the presence of *Didymosphenia geminata* (Lyngbye) M. Schmidt in A. Schmidt et al. (Bacillariophyta) was recorded.

Due to its relatively large size and characteristic shape, *Didymosphenia geminata* is one of the earliest described diatom species. It was first described in 1819 as *Echinella geminata* Lyngbye and in 1899 the genus *Didymosphenia* M. Schmidt in A. Schmidt et al. was established. Frustules are heteropolar both in valvar and girdle views, and are usually capitulate at the poles (Krammer & Lange-Bertalot, 1997a). The central area is characterized by the presence of one or more stigmata. Several studies have been conducted on its morphological variability: Dawson (1973) gave a detailed description of the frustule structure and Antoine & Benson-Evans (1984) found greater variability in size, number, and distribution of stigmata in the central area for populations from England, Scotland, and Wales compared to those indicated in the literature they used for comparison. Stoecker et al. (1986) carried out a quantitative morphological investigation, revealing the presence of several geographically differentiated morphotypes. Metzelín & Lange-Bertalot (1995) reviewed the genus *Didymosphenia* as a whole and distinguished five species and three morphotypes of *D. geminata*. Kociolek et al. (2000) described the ultrastructure of *D. doerna* (Dorogostaisky) Skwirzow & Meyer from Lake Baikal, suggesting a taxonomic differentiation from *D. geminata*. In 2006 a new species, *D. tatrensis* Mrozińska, Czerwik-Marcinkowska & Gradziński, was described from streams of the Western Carpathians of Poland and Slovakia (Mrozińska et al., 2006).

*Didymosphenia geminata* is an epilithic and epiphytic diatom, attached to the substratum via a mucilage stalk secreted from small, unoccupied pores at the base pole of the valves (Round et al., 1990).

*Didymosphenia geminata* is autochthonous in northern Europe and North America. In Europe it has been recorded in the Czech Republic (Jíryová & Marvan, 2002), Finland (Kawecka & Eloranta, 1987), Iceland (Jonsson et al., 2000), Ireland (Ellwood & Whitton, 2007), Norway (Skulberg & Sillén-Larsen, 1984), Poland (Kawecka & Sanecki, 2003; Noga, 2003), Serbia (Subakov-Simic & Cvijan, 2004), Spain (Blanco & Ector, 2008), Sweden (Johansson, 1982), Switzerland (Robinson & Kawecka, 2005), and the United Kingdom (Ellwood & Whitton, 2007). Its presence has been mentioned also in Turkey (Kolayık & Şahan, 1998; Şahan, 2001), China (Li et al., 2003) and even in the southern hemisphere (Chile: Asprey et al., 1964; Rivera & Gebauer, 1989; New Zealand: Kitroy, 2004). Although described as typical of the upper mountain reaches of oligotrophic rivers, recent studies have revealed its presence in a wider range of ecological conditions such as mesotrophic or occasionally eutrophic waters of middle river reaches (Krammer & Lange-Bertalot, 1997a; Kawecka & Sanecki, 2003). Figure 1 shows its fossil and recent distributions in Europe as far as is known based on the existing literature. In Italy its presence has been reported in northern regions such as Alto Adige (Cappellotti et al., 2007; Beltrami et al., 2008), Friuli Venezia Giulia (Zorza et al., 2006), Lazio (Giajerová & Abate, 1994), Lombardy (Bonardi, 1888), Piedmont (Battegazzore et al., 2007), and Val d’Aosta (Brun, 1880).

![European distribution of Didymosphenia geminata. Black dots: recent records; white dots: fossil or subfossil records.](image-url)
Massive proliferations of *Didymosphenia geminata* can create benthic mats mainly made up by the long stalks, composed of sulphated xylogalactan, uronic acid and proteins (Gretz, 2007). These events, which are characteristic of this species, are often seasonal and can disappear rapidly (Kawecka & Sanecki, 2003; Ellwood & Whittan, 2007). These “nuisance blooms” (Spaulding & Elwell, 2007) appear to arise under oligotrophic conditions (Jonsson et al., 2000; Sherbot & Bothwell, 1993; Kirkwood et al., 2007); a high phosphatase activity, localized in the stalk, may give a competitive advantage to the species (Ellwood & Whittan, 2007).

In New Zealand, where it was observed for the first time in the Waiau River in 2004 (Kilroy, 2004), *Didymosphenia geminata* is considered as an invasive alga. Since then it colonized 14 river and lake systems in the South Island (Vieglais, 2007), forming “invasive blooms” in many sites (Spaulding & Elwell, 2007). Several actions have been undertaken by Biosecurity to understand the ecology of the species and prevent the spreading in the North Island (Kilroy et al., 2005; Vieglais, 2007). Such blooms seem to have a high impact on the ecosystem: the streambed can be totally covered by *D. geminata* mats, whose massive growth alters macroinvertebrate communities with a dominance of Diptera and a reduction of Ephemeroptera, Plecoptera and Trichoptera taxa (Kilroy et al., 2006; Larmed et al., 2006). However, no apparent impact has been noticed on fish communities, neither in Europe, North America or New Zealand (Bothwell et al., 2007; Jonsson et al., 2007; Lindstrom & Skulberg, 2007; Sherbot et al., 2007). Only Larson & Carreiro (2007) found a significant decline in trout adult population in sites where nuisance blooms were observed. According to Mundie & Crabtree (1997) *D. geminata* can cause gill troubles in fry and can limit spawning of trout adults. Furthermore, massive growths can have an economic impact, plugging water filters and limiting the utilization of stream water (Kilroy & Sanecki, 2003; Spaulding & Elwell, 2007).

In Italy, massive benthic mat formations were noticed in September 2006 along the Brusagio stream, a small oligotrophic siliceous watercourse in the northeastern area of the Trento province (Beltrami et al., 2007), and in the Erro stream in the Alessandria province (Lombardy) in June 2007 (G. Bona, pers. comm.).

The objectives of this work are to provide a first report on the presence of *Didymosphenia geminata* in the Trento province, to give new data on its distribution in Italy, and to improve our knowledge on its ecological preferences in the Southern Alps.

**MATERIAL AND METHODS**

River surveys were conducted from June to October 2004 in 11 rivers in Trentino (Northern Italy), for a total of 30 sampling sites (Fig. 2). Physical and chemical characteristics of sites are shown in Table 1, geodata are reported in Gauss-Bogda (W Fuse) on Rome 40 datum (Italian datum).

Chemical analyses were conducted monthly (APAT-IRSA/CNR, 2003). Standard procedures for diatom sampling were followed (Kelly et al., 1998; European Committee for Standardization, 2003). Diatoms were cleaned using 30% hydrogen peroxide and hydrochloric acid. Cleaned diatom frustules were mounted in permanent slides using Naphrax as mounting medium. Slides were observed using light microscopy (LM) at 1000 magnifications, and

**RESULTS**

Table 1 shows yearly average values of physical and chemical parameters for all sampling sites: the trophic state of sites ranges from oligotrophic to eutrophic (TP: 0.01-0.8 mg L⁻¹; N-NO₃: 0.5-2.74 mg L⁻¹), with low to medium mineral content and neutral to alkaline pH.
Table 1. Mean annual values of physical and chemical characteristics of sampling sites and their geo-referenced location (Gauss-Boaga, W Fuse on Rome 40 datum).

<table>
<thead>
<tr>
<th>Site code</th>
<th>Watercourse</th>
<th>Station</th>
<th>Sampling date</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Altitude m</th>
<th>Distance from source km</th>
<th>Conductivity $\mu S cm^{-1}$</th>
<th>pH</th>
<th>$%O_2$</th>
<th>$BO_3^{-}$ mg l$^{-1}$</th>
<th>COD mg l$^{-1}$</th>
<th>Cl$^-$ mg l$^{-1}$</th>
<th>$SO_4^{2-}$ mg l$^{-1}$</th>
<th>$N-NH_2^+$ mg l$^{-1}$</th>
<th>$N-NO_2^-$ mg l$^{-1}$</th>
<th>$N-NO_3^-$ mg l$^{-1}$</th>
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Table 1. Mean annual values of physical and chemical characteristics of sampling sites and their geo-referenced location (Gauss-Boaga, W Fuse on Rome 40 datum) (continued).
Analysis of the diatom community and application of IPS and EPI-D suggested that sites had a good water quality. They were classified either as unpolluted or slightly polluted, i.e. I or II quality class (Table 2).

Table 2. Water quality assessed applying IPS and EPI-D indices and Didymosphenia geminata occurrence in monitored sites of Trentino Province.

<table>
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<th>Site code</th>
<th>D. geminata presence</th>
<th>IPS values</th>
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<th>EPI-D values</th>
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<td>15.8</td>
<td>I</td>
</tr>
<tr>
<td>VA1</td>
<td>YES</td>
<td>18.1</td>
<td>I</td>
<td>16.6</td>
<td>I</td>
</tr>
</tbody>
</table>

Didymosphenia geminata (Figs 3 and 4) was found in 21 of the 30 sites monitored (Tab. 2), always with low relative abundance (less than 1%, Appendix 1); during sampling no periphytic mats were observed. It was less frequent in the upper reaches of the sampled streams, being absent in sites with altitude > 900 m and present in less than 50% of sites with distance from source < 40 km (Figs 5, 6).

In the Trentino province D. geminata had a preference (Table 3) for moderate conductivity, alkaline and oxygen-saturated waters, and was tolerant to medium pollution levels (TP: 0.01-0.06 mg l-1; BOD5: 1-3.2 mg l-1), with a preference for mesotrophic waters (TP: 0.03 mg l-1).

The LM-based analysis of valve morphological features (Table 4) was compared to data available in the literature. Morphometric ranges were: length 60-106 µm, width 28-40 µm, 8-11 striae/10 µm, 9-12.5 puncta/10 µm; 1 to 4 stigmata.

In some individuals a marginal ridge ending in two spines at the head pole was seen (Fig. 7). SEM images showed that striae were uniseriate and bore large poroids. Areolae were located deeply in the siliceous wall, surrounded by inclined walls, and their openings were circular on the internal valve face (Fig. 11).
Diatom analysis of 11 rivers of Trentino revealed the presence of Didymosphenia geminata in this Province of Northern Italy. By analysing LM and SEM images and comparing the size range in our samples with those found in the literature, we were able to identify the presence of this diatom species in the Trentino watercourses.

Table 3. Ecological preferences of Didymosphenia geminata in monitored sites: weighted averages and range of physical and chemical parameters where it occurred.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Weighted average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (µS cm⁻¹)</td>
<td>65</td>
<td>372</td>
<td>254</td>
</tr>
<tr>
<td>pH</td>
<td>7.7</td>
<td>8.6</td>
<td>8.3</td>
</tr>
<tr>
<td>%O₂</td>
<td>95.0</td>
<td>111.0</td>
<td>103.5</td>
</tr>
<tr>
<td>BOD₅ (mg l⁻¹)</td>
<td>1.0</td>
<td>3.2</td>
<td>2.0</td>
</tr>
<tr>
<td>COD (mg l⁻¹)</td>
<td>5.0</td>
<td>6.3</td>
<td>5.4</td>
</tr>
<tr>
<td>CT (mg l⁻¹)</td>
<td>1.4</td>
<td>7.1</td>
<td>3.9</td>
</tr>
<tr>
<td>SO₄²⁻ (mg l⁻¹)</td>
<td>6.0</td>
<td>78.0</td>
<td>34.8</td>
</tr>
<tr>
<td>TP (mg l⁻¹)</td>
<td>0.01</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>NH₄⁺ (mg l⁻¹)</td>
<td>0.02</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>NO₃⁻ (mg l⁻¹)</td>
<td>0.003</td>
<td>0.025</td>
<td>0.010</td>
</tr>
<tr>
<td>NO₂⁻ (mg l⁻¹)</td>
<td>0.62</td>
<td>1.75</td>
<td>0.89</td>
</tr>
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</table>

Table 4. Morphological features of Didymosphenia geminata: data from literature and from specimen of Trentino (100 individuals from the Adige river, site San Michele-AD1, and 55 from the Noce stream, site Mezzolombardo-NO4).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Didymosphenia geminata morphotype geminata</th>
<th>length (µm)</th>
<th>width (µm)</th>
<th>n. striae</th>
<th>n. stigmata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dawson, 1973</td>
<td>90-120</td>
<td>35-40</td>
<td>9-10</td>
<td>3-5</td>
<td></td>
</tr>
<tr>
<td>Antoine &amp; Benson-Evans, 1984-Great Britain</td>
<td>58-151</td>
<td>25-47.5</td>
<td>9-14</td>
<td>0-9</td>
<td></td>
</tr>
<tr>
<td>Moffat, 1994-America</td>
<td>125-140</td>
<td>35-45</td>
<td>8-8.5</td>
<td>3-5</td>
<td></td>
</tr>
<tr>
<td>Metzeltin &amp; Lange-Bertalot, 1995-Faroe-Island</td>
<td>73-97</td>
<td>28-36</td>
<td>8-8.5</td>
<td>2-5</td>
<td></td>
</tr>
<tr>
<td>Metzeltin &amp; Lange-Bertalot, 1995-Ireland</td>
<td>82-105</td>
<td>31-37</td>
<td>8</td>
<td>2-5</td>
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<tr>
<td>Metzeltin &amp; Lange-Bertalot, 1995-Sibiriens</td>
<td>60-110</td>
<td>25-39</td>
<td>8-5.10</td>
<td>1-6</td>
<td></td>
</tr>
<tr>
<td>Metzeltin &amp; Lange-Bertalot, 1995-Scotland</td>
<td>85-132</td>
<td>35-42</td>
<td>8</td>
<td>2-6</td>
<td></td>
</tr>
<tr>
<td>Metzeltin &amp; Lange-Bertalot, 1995-Onegasee</td>
<td>60-127</td>
<td>34-45</td>
<td>8-9</td>
<td>2-5</td>
<td></td>
</tr>
<tr>
<td>Kawecka &amp; Sanecki, 2003-Poland</td>
<td>82.5-110.4</td>
<td>31.9-43.2</td>
<td>8-11</td>
<td>2-3</td>
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<tr>
<td>Noga, 2003-Poland</td>
<td>80-117</td>
<td>33-41</td>
<td>9-12</td>
<td>1-5</td>
<td></td>
</tr>
<tr>
<td>Subakovic-Simić &amp; Cvijan, 2004-Serbia</td>
<td>88-116</td>
<td>34-44</td>
<td>9-11</td>
<td>1-4</td>
<td></td>
</tr>
<tr>
<td>Trentino-Noce Rupe</td>
<td>60-101</td>
<td>30-40</td>
<td>8-11</td>
<td>1-4</td>
<td></td>
</tr>
<tr>
<td>Trentino-Adige S. Michele</td>
<td>75-106</td>
<td>20-40</td>
<td>8-10</td>
<td>1-3</td>
<td></td>
</tr>
</tbody>
</table>

while externally the margin presented some spines or dendritic projections. Stigmata had open foramina towards the external valve face (Fig. 8), while on the internal face they appeared to be occluded by masses of silica (Fig. 10). The base pole (Figs 11, 12) was characterized by lines of fine unoccluded pores on both valve sides, through which the mucilage stalk was secreted (Fig. 13).

The raphe was central, with terminal raphe endings hook-shaped in external views, turning towards the side without stigmata in the central area. In internal views helictoglossa were visible (Figs 9, 12). The external central raphe endings were expanded as pores (Fig. 8), while internally the raphe fissure continued across the central nodule (Fig. 10).

In the 30 sites investigated, 91 diatom taxa were identified (Appendix 1). The most common species (mean relative abundance > 5%) were Achnanthidium pyrenacum (Hustedt) Kobayasi, A. minutissimum (Kützing) Czarnecki, Cocconeis placenta var. lineata (Ehrenberg) Van Heurck, C. placenta var. pseudolineata Geitler, and Nitzschia fonticola Grunow.

**DISCUSSION**

Diatom analysis of 11 rivers of Trentino revealed the presence of Didymosphenia geminata in this Province of Northern Italy. By analysing LM and SEM images and comparing the size range in our samples with those found in the...
literature, we were able to refer the sampled populations to the morphotype "geminata" (Metzeltin & Lange-Bertalot, 1995). Stigmata were always found on one side of the central nodule only, which agrees with the general finding in the literature. Only Antoine & Benson-Evans (1984) described the presence of stigmata on both sides of the central area.

The areolae morphology is distinctive of the species: Mrozinska et al. (2006) compared their ultrastructure with that of Didymosphenia tatarensis, whose areolae are deeply seated in the wall (as in D. geminata), but are surrounded by vertical walls and lack spines.

Didymosphenia geminata was found in all the water courses investigated with the exception of Astico and Fersina streams. A survey conducted during 1999 in 6 sampling sites of the Fersina basin did not reveal the presence of D. geminata (Ciutti et al., 2003). The possibility that it was overlooked was limited by the observation of both fresh material and several permanent slides.

During sampling no periphytic mats were observed and the presence of Didymosphenia geminata was discovered only during the slide analyses, which confirmed that this diatom was present in low abundance; the abundance of large-sized species is often known to be underestimated during counting (Jonsson et al., 2000; Spaulding & Elwell, 2007), especially when communities are dominated by small-sized taxa.

Some authors suggested a possible relationship between the presence of Didymosphenia geminata and regulated or lake fed streams, probably due to regular flows (Skulberg, 1982; Kilroy et al., 2005, 2006; Kawecka & Sanecki, 2003; Kirkwood et al., 2007). This hypothesis should be tested in our region: D. geminata was found both in regulated stream reaches with low water discharge and
downstream the water release point in reaches characterized by hydropoeaking. The Fersina and Astico streams, where *D. geminata* is absent, have no reservoirs along their watercourses, on the other hand this diatom is also present in upstream basins, for instance in the site NO$_2$, which is located above the Santa Giustina reservoir. It could be asked if artificial lakes may constitute a starting-point for the diffusion of *D. geminata*, or if dams can represent a barrier to its diffusion to the upper reaches of watercourses. The hypothesis that waterfowl, for instance cormorants (Foged, 1953), could be local vectors for the diffusion of this species should be tested. In Trentino the population of *Phalacrocorax carbo sinensis* (Blumenbach, 1798) cormorants increased from a few individuals in 1993-1994 to 317 in 2002-2003 (Pedrini et al., 2005). Their favourite feeding areas are lakes or wetlands, and they roam from roosting areas to the feeding ones following the main Trentino watercourses with a pattern similar to the distribution of *D. geminata*.

From our data it is difficult to relate the presence or absence of *Didymosphenia geminata* only to physical and chemical characteristics of the water because it appears to be present in a wide range of environmental conditions. In Poland *D. geminata* has also been found in rivers classified as mesotrophic, suggesting the possible presence of different ecotypes or else that this diatom can live in wider ecological conditions (Kawecka & Saneczki, 2003). In Serbia *D. geminata* was first recorded in a glacial lake and was then found in 1997 in the Tisa river, which has moderately polluted water (Subakovic-Simić & Cvijan, 2004). A literature review (Kilroy et al., 2005) underlined the difficulties in correlating nutrient concentrations to *D. geminata* ecological preferences and distribution.

In this study *Didymosphenia geminata* was not very frequent in the upper reaches of watercourses, although the only massive proliferation observed in the province (Beltrami et al., 2007) was in a site situated at 1100 m a.s.l. and 5 km away from the source. From our data it cannot be established if *Didymosphenia geminata* is an invasive diatom in Trentino watercourses and there is very little historical data available for comparison. In any case, Largaiolli (1905) and Giaj-Levra & Abate (1994) did not mention the occurrence of *D. geminata* in the Trentino Province. In Italy this diatom probably has a wider distribution, and further investigations are necessary to better define its autecology and colonization patterns. A periodical control would be important in order to predict if this diatom should be considered as an invasive or nuisance species, which may cause a decrease in the quality status of the water bodies in Italy and neighbouring countries.

In our samples, *Didymosphenia geminata* was found with low relative abundance values, and in the Trentino province only a few blooms have been observed since 2006. The colonial growth behaviour of this species appeared similar to the one observed in the other European countries, and at the moment it should not create public alarm. However, sites where *D. geminata* occurred should be surveyed periodically in order to monitor the possible occurrence of nuisance blooms and their effects on other aquatic organisms, as well as monitoring the diffusion of this species to other rivers and water bodies in the Alps.

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REFERENCES


LECOINTE C., OSTE M., RYGIEL J., 1993 - "OMNIDIA": software for land-use data acquisition.
LI Y., XIE P., GONG Z., AND SHI Z., 2003 - Cymbellaceae and Gomphonemataceae (Bacillariophyceae) from the Hengduan Mountains region (southwestern China).


SUBAKOV-SIMIĆ G. & CVJIAN M., 2004 - Didymosphenia geminata (Lyngby) M. Schmidt (Bacillariophyceae) from the Tisza river (Serbia) - its distribution and specific morphological and ecological characteristics. Algalogical studies 114: 53-66.


**APPENDIX 1**

List of diatom taxa identified in the 30 sampling sites monitored. Values of mean and maximum relative abundance (percentage) are reported for each taxa.

<table>
<thead>
<tr>
<th>Denomination</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnanthes minutissima Kützing var. inconspicua Oestrup</td>
<td>0.23</td>
<td>6.78</td>
</tr>
<tr>
<td>Achnanthes atomoides Monnier, Lange-Bertalot et Ector</td>
<td>3.63</td>
<td>55.4</td>
</tr>
<tr>
<td>Achnanthes minutissimus (Kützing) Czarnecki</td>
<td>22.1</td>
<td>69.7</td>
</tr>
<tr>
<td>Achnanthes pyrenicum (Hustedt) Kobayasi</td>
<td>32.1</td>
<td>91.1</td>
</tr>
<tr>
<td>Achnanthes strambyanticum (Lange-Bertalot) Lange-Bertalot</td>
<td>0.02</td>
<td>0.73</td>
</tr>
<tr>
<td>Adlafia minuscula (Grunow) Lange-Bertalot</td>
<td>0.08</td>
<td>1.04</td>
</tr>
<tr>
<td>Adlafia minuscula var. muralis (Grunow) Lange-Bertalot</td>
<td>0.02</td>
<td>0.49</td>
</tr>
<tr>
<td>Amphora copulata (Kützing) Schoeman et Archibald</td>
<td>0.05</td>
<td>0.93</td>
</tr>
<tr>
<td>Amphora inariensis Krammer</td>
<td>0.3</td>
<td>2.16</td>
</tr>
<tr>
<td>Amphora pediculus (Kützing) Grunow</td>
<td>0.85</td>
<td>4.92</td>
</tr>
<tr>
<td>Caloneis silicula (Ehrenberg) Cleve</td>
<td>0.02</td>
<td>0.48</td>
</tr>
<tr>
<td>Cocconeis pediculus Ehrenberg</td>
<td>1.2</td>
<td>6.8</td>
</tr>
<tr>
<td>Cocconeis placenta var. euglypta (Ehrenberg) Grunow</td>
<td>0.39</td>
<td>4.92</td>
</tr>
<tr>
<td>Cocconeis placenta var. linearata (Ehrenberg) Van Heurck</td>
<td>4.98</td>
<td>20.3</td>
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<td>Cocconeis placenta var. pseudolineata Geitler</td>
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<td>Cyclotella atomus Hustedt</td>
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<td>0.25</td>
</tr>
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<td>Cyclotella cyclopuncta Håkansson et Carter</td>
<td>0.05</td>
<td>0.97</td>
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<td>Cyclotella ocellata Pantocsek</td>
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<td>Cymbella affinis Kützing</td>
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<td>Cymbella helvetica Kützing</td>
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<td>Eolimna minimus (Grunow) Lange-Bertalot</td>
<td>0.2</td>
<td>1.18</td>
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<tr>
<td>Eolimna subminimata (Manguin) Mesar, Lange-Bertalot et Metzeltin</td>
<td>0.08</td>
<td>1.75</td>
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</tbody>
</table>

**Didymosphenia geminata in Trentino watercourses**

<table>
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<th>Denomination</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
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<td>0.26</td>
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<td>Meridion circulare (Greville) C.A. Agardh var. circulare</td>
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<td>0.5</td>
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<td>Navicula rostellata Kützing</td>
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<tr>
<td>Navicula splendicula Van Landingham</td>
<td>0.01</td>
<td>0.25</td>
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<td>Navicula triqueta (O.F. Müller) Bory</td>
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<td>Navicula viridula (Kützing) Ehrenberg</td>
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<td>Nitzschia amphibia Grunow</td>
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<td>Nitzschia archibaldii Lange-Bertalot</td>
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<td>Mean</td>
<td>Max</td>
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<tr>
<td>Nitzschia dissipata (Kützing) Grunow</td>
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<tr>
<td>Nitzschia fonticola Grunow</td>
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<td>Nitzschia hantzschiana Rabenhorst</td>
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<td>Nitzschia inconspicua Grunow</td>
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<tr>
<td>Nitzschia linearis (C.A. Agardh) W.M. Smith</td>
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<td>Nitzschia perminuta (Grunow) M. Peragallo</td>
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<td>Nitzschia pura Hustedt</td>
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<td>Nitzschia pusilla (Kützing) Grunow</td>
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<td>Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot</td>
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<td>Planothidium lanceolatum (Brebiisson ex Kützing) Lange-Bertalot</td>
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<tr>
<td>Psammothidium bioretii (Germain) Bukhtiyarova et Round</td>
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<td>Surirella angusta Kützing</td>
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<td>Surirella brebissonii Krammer et Lange-Bertalot</td>
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<td>Ularia ulna (Nitzsch) Compère</td>
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