A new alien diatom, *Didymosphenia geminata* (Lyngbye) Schmidt: its biology, distribution, effects and potential risks for New Zealand fresh waters

NIWA Client Report: CHC2004-128
November 2004

NIWA Project: ENS05501

A new alien diatom, *Didymosphenia geminata* (Lyngbye) Schmidt: its biology, distribution, effects and potential risks for New Zealand fresh waters

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Prepared for

Environment Southland

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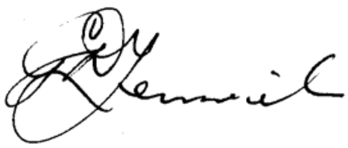

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Executive Summary

1. *Didymosphenia geminata* (Lyngbye) Schmidt is a diatom (a type of alga) that historically has had a Northern Hemisphere distribution, particularly occurring in oligotrophic, clear-water montane or northern boreal streams. Since the mid-1980s its range has gradually expanded in Europe and North America, often forming large nuisance growths.

2. This report was commissioned by Enivironment Southland following the discovery in mid-October 2004 of a bloom of *D. geminata* in the lower Waiau River, Southland. The aim of the report is to review the biology and distribution of *D. geminata* and provide an assessment of the risks to New Zealand fresh waters, with comment on its possible future dispersal.

3. *Didymosphenia geminata* is one of the larger freshwater diatoms and grows attached to both stone and plant substrates by long mucilaginous stalks. Other diatoms indigenous in New Zealand have a similar growth habit but are not considered a nuisance because they are smaller and less persistent.

4. This Waiau River growth may represent a new incursion into New Zealand waters. The most plausible explanation for its sudden appearance is a human-assisted transfer. Birds and animals, as well as humans, could possibly be factors in any future dispersal within New Zealand.

5. In the Northern Hemisphere, both within and outside its natural geographic range, *D. geminata* is exhibiting a much greater tolerance for different water chemistry conditions than expected. Other favourable environmental conditions for proliferations of *D. geminata* include high light and stable flows. Many of the proliferations reported from overseas are in regulated or lake-fed rivers, although there are exceptions to this. The occurrence of blooms over both space and time is reported to be unpredictable, but is possibly associated with geology and periods of low flows.

6. There appear to have been few formal studies on the ecological effects of *D. geminata* blooms. Work undertaken in British Columbia, Canada, indicated effects on invertebrates and fish habitat. In New Zealand, ecological effects are currently unknown, but are likely to be similar to those in British Columbia and also similar to those resulting from blooms of other benthic algae. The more extensive and persistent growths of *D. geminata* may result in more pronounced effects. This remains to be tested.

7. Human health risks are probably limited to eye irritation in swimmers. No reports from overseas of adverse effects on water quality have been located, and no reports of any animal health issues.

8. Economic effects overseas include deterioration of freshwater fishing, and reports of blockage/fouling in water intakes. Similar effects are possible in New Zealand.

9. Many New Zealand waterways and lakes may be susceptible to blooms of *D. geminata*; the seriousness of any resulting problems will depend on how widespread the diatom becomes.

10. There appear to have been no attempts overseas to control or eliminate *D. geminata*, and no studies to date on how the species spreads. In view of the high number of potential habitats for the species in New Zealand, containment seems desirable. Its distribution within the country still has to be confirmed, but early data indicate that it may be confined to the lower Waiau / Mararoa River catchment.

1. Introduction

On 15 October 2004, during a routine survey of periphyton in the lower Waiau River, Southland, staff from NIWA and Southland Fish & Game noted an unusual growth on the river substrate at a site accessed through Jericho Farm (site coordinates E209 0753 N548 7403). The growth comprised a thick whitish-brown mat that almost completely covered the substrate at the river margin out to a water depth of at least 0.5 m. The mat extended well beyond the 40 m long reach of the river that was sampled. The growth was remarkable because of its thickness (up to 3 cm), its very tough "woolly" consistency, its firm attachment to the substrate, and its habit of covering all substrates, including forming thick "rats tails" around submerged plants (Figure 1).

Because of its unusual appearance, a sample was collected and identified at NIWA, Christchurch, on 19 October (by CK) as the diatom *Didymosphenia geminata* (Lyngbye) M. Schmidt. This was of immediate concern for two reasons:

1. It was suspected that this was the first time this species had been reported outside the Northern Hemisphere.

2. There had been reports about 10 years ago of this diatom forming large and problematic blooms in rivers in British Columbia, Canada.

Initially, Meridian Energy (who funded the periphyton survey) and Southland Fish & Game were advised of the finding, and a preliminary search for information about the diatom was conducted, mainly using internet sources. Environment Southland (ES) was notified of the finding on 20 October, via Meridian Energy, and there was a discussion with NIWA (CK) on the following day. Dr Don Robertson (NIWA, General Manager, Biodiversity & Biosecurity) notified MAF Biosecurity on 22 October. At that stage there was evidence that the diatom had previously been recorded in New Zealand, therefore no steps could be taken by MAF until these records were verified or otherwise.

In view of the large, invasive growth of this diatom in the lower Waiau River, the present report was subsequently requested by ES to provide information on the following aspects of *Didymosphenia geminata*:

- Its biology and distribution.

- An assessment of the risk associated with its presence in New Zealand fresh waters, including some comment on the potential for further spread.

Figure 1
Didymosphenia geminata **growth in the lower Waiau River.**

Top: typical growth on a stone.

Bottom: The diatom attaches to both stones and plants, and anything in between.

Inset: growth completely covering a submerged plant.

Photos: Environment Southland; inset: Southland Fish &Game.

Information used in this report has been gathered from a number of sources, including:

- The international diatom literature: standard texts used for identifying diatom species, which generally provide comments on ecological preferences and distribution.

- An international literature search.

- Responses and follow-up correspondence to a query posted on the DIATOM-L list-server, an international group with over 750 subscribers, all with a specific interest in diatoms.

- Conversations with and/or email queries to individuals known to or likely to have had experience with *Didymosphenia geminata*.

In the text that follows, quotes and information from responses to the DIATOM-L query (and subsequent correspondence) are identified as follows: (name of the respondent, institution/country, "diatom-L response", date). Quotes and information from people contacted directly are identified as: (name, institution/country, "pers. comm..", date).

Since work on this report was started, Environment Southland and Southland Fish & Game staff have checked other sites in the lower Waiau River and in its tributary, the Mararoa River. Growths of *D. geminata* were found extending to the upper part of the Mararoa catchment, just downstream of Mavora Lakes, and in the lower Waiau both upstream and downstream of the Jericho Farm site where the diatom was first discovered. To date *D. geminata* has not been reported from other catchments, though a thorough survey of the region has yet to be undertaken.

2. *Didymosphenia geminata*: description and general biology

2.1. Description

Didymosphenia geminata is a freshwater alga belonging to the Bacillariophyta (diatoms). Diatoms are characterized by possessing silica cell walls, which are often intricately patterned. The silica part of the cell wall fits together in two halves (known as **valves**), like a Petri dish, generally with one valve slightly smaller than the other. The whole structure is known as the **frustule**. The frustule viewed from the top gives the **valve view**, and from the side the **girdle view**. Frustule shape, size and the exact form of the patterning are used in the identification of diatom genera and species.

The distinguishing features of *D. geminata* include a large, triundulate frustule, shaped something like a jelly baby or a curved bottle; very large size compared to other freshwater diatoms (often >100 µm long, >35 µm wide – it is one of the larger freshwater diatoms); prominent **striae** (regular lines of holes starting at the centre line of the valve faces), which are radially arranged and variable in length at the centre (Figure 2). In girdle view the frustules are wedge-shaped. Three "morphotypes" of *D. geminata* have been designated (Metzeltin & Lange-Bertalot 1995). The populations in the lower Waiau River are *D. geminata* morphotype *capitata*, the form that is commonly found in northern Europe (D. Metzeltin, pers. comm., December 2004).

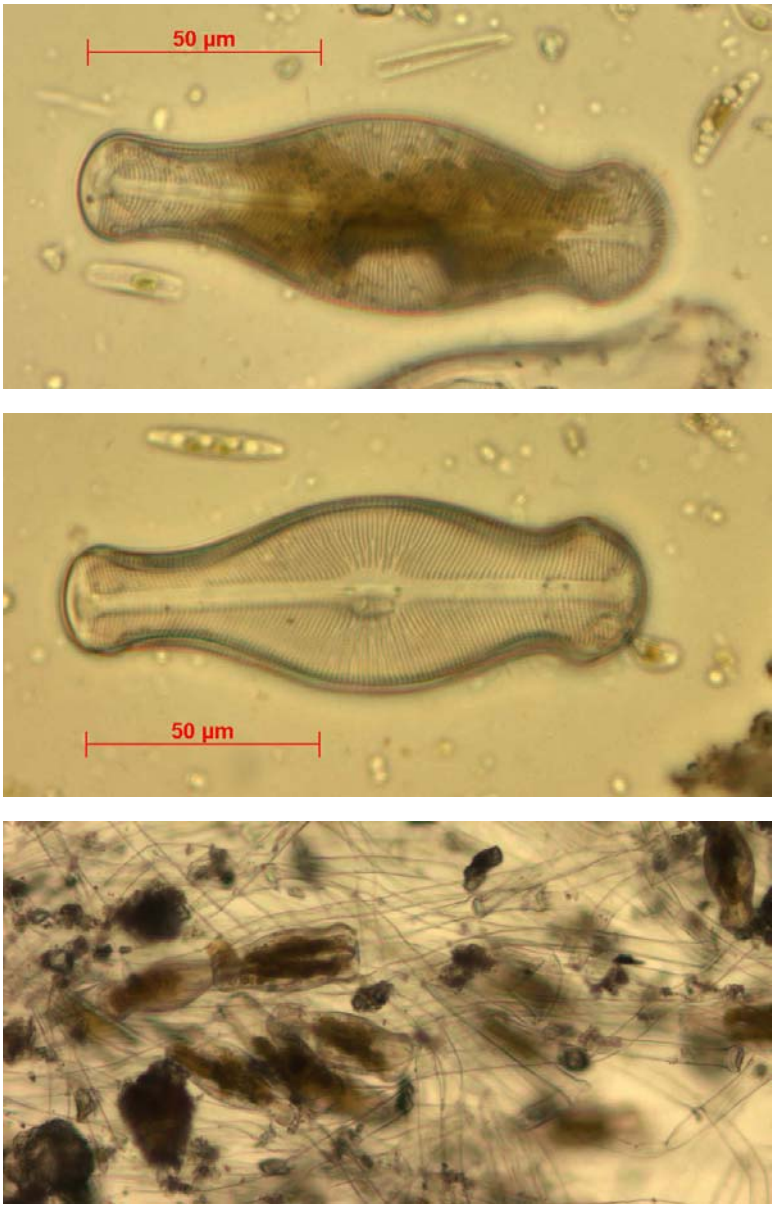

Figure 2

***Didymosphenia geminata*, from the lower Waiau River, Southland.**

Top: valve view of live cell showing chloroplast;

Middle: empty frustule, showing arrangement of striae;

Bottom: cells attached to long stalks.

A further feature of the genus *Didymosphenia* is that the live cells attach to the substrate (either stones or vegetation) by long, branched mucilage (polysaccharide) stalks (Figure 2). The stalk is exuded through tiny holes that cover the smaller end of the frustule (Round et al. 1990). Other diatom genera already known in New Zealand grow on stalks, e.g. the closely related genus *Cymbella*, many species of *Gomphonema*, and *Gomphoneis*. However, *Didymosphenia* is remarkable for the great length and thickness of the stalks in comparison to the cell body, and for the very strong attachment of the stalks to the substrate. In addition, *D. geminata* is capable of attaching to a variety of substrate types. It is both epilithic (attaching to stones) and epiphytic (attaching to plants) (Round et al. 1990).

Because of its large size and distinctive outline, *Didymosphenia geminata* is very easy to identify. Indeed, this species was one of the earliest diatoms to be recognized. Although it was first described in 1819 (as *Echinella geminata* Lyngbye, later transferred to *Gomphonema geminatum* (Lyngbye) Agardh), the diatom had been known for over 30 years before that (Patrick & Reimer 1975). The present genus *Didymosphenia* was erected in 1899.

2.2. Reproduction

Like other diatoms, *Didymosphenia* populations grow by vegetative cell division, in which the two valves of the cell each form a new valve that fits inside the original one. The slight size difference between the valves means that repeated cell divisions result in a gradual average reduction in cell size in a population (for details see Round et al. 1990). Thus, a population of diatoms will contain individuals in a range of sizes. In stalked diatoms like *Didymosphenia*, each branch point in the stalk represents a vegetative cell division. Most diatoms also undergo sexual reproduction at some stage, involving the division of cell contents in two cells to form haploid gametes (one set of genes). The main outcome of sexual reproduction, apart from exchange of genetic material, is to restore the size of the cells to their maximum.

There is sparse information on the generation times of freshwater diatoms. In culture trials Baars (1983) found that growth rates varied considerably among species, and also with temperature and light intensity. In many cases, generation times were quite rapid (< 30 h at temperatures between 12 and 20°C). The shortest generation time was recorded for a large freshwater species *Pinnularia gibba*, which divided every 13 h under the highest light – temperature (20°C) combination. No specific information could be located on generation times for *Didymosphenia*, but a cell division every 30 h or less could lead to rapid accumulation of biomass, as the species' cell and colony sizes are so large.

3. Distribution

3.1. Original distribution

Didymosphenia geminata was first described from the Faroe Islands, which lie to the north of Scotland (Patrick & Reimer 1975). An early taxonomic description (Cleve 1894 – 1896) lists records from Spitsbergen (Norway), Scotland, Ireland, Sweden, Finland, France, Spain, Switzerland, and Vancouver Island. The species is therefore assumed to be indigenous in these countries and in other Northern Hemisphere boreal or montane regions. Krammer & Lange-Bertalot (1997) (currently the most thorough diatom identification guide available) quote a distribution in boreal and alpine regions of Europe, Asia (including the Himalayas), North America (rarely). *D. geminata* has also been recorded from alpine locations in China (Li et al. 2003) and is common in at least one river in northern Turkey (Hara & Sahin 2000).

Within its original range *D. geminata* may occasionally form large growths (e.g., in tributaries of the R. Tees, England (Whitton & Crisp 1984) and in R. Caragh, Ireland (Heuff & Horkan 1984), Glama R., Norway (Skulberg & Lillehammer 1984)).

Didymosphenia geminata has been cited as a classic example supporting the idea of widespread regional endemism in diatoms: a very distinctive species with a restricted distribution in the Northern Hemisphere (Kociolek et al. 2004).

3.2. Recent proliferations and new records

Since the mid-1980s *D. geminata* appears to have been gradually expanding its geographical range in Europe and North America. There are also reports of large growths in places where it was known previously, but always in low concentrations. Instances of both scenarios are given below.

- Proliferations of *D. geminata* in rivers where they had not been experienced previously "… happened in British Columbia about 10 years ago (although *Didymosphenia* was known to occur there previously)" (E.F. Stoermer, University of Michigan, diatom-L response, October 2004). [More information about the British Colombia blooms is on the Government of BC website: wlapwww.gov.bc.ca/wat/wq/didy_bcstrms.html. The text is included as Appendix 1.]

- "In Hungary, the species was first found in the late 1980s and is now occurring in more and more rivers. It is regarded as an invasive species" (Eva

Acs, Eotvos L. University, Microbiological Dept, Budapest, diatom-L response, October 2004).

- In Poland, in the mid-1990s, *D. geminata* appeared in the Carpathian tributaries of the R. Vistula (mesotrophic rivers), especially in the R. San downstream of two reservoirs (Kawecka & Sanecki 2003).

- The species has occurred as nuisance growths in some rivers in Iceland since 1994 - generally in unregulated rivers (Jonsson et al. 2000).

- In 1999, "… a big lake above Galway (Ireland) showed a large 'bloom' of *D. geminata* in the littoral zone, where we never saw this diatom before" (Rene van Wezel, East Malling Research, UK, email to DIATOM-L, November 1999).

- "I have been informally watching this diatom over many years (since about 1995) and it appears to be expanding its range in the state of Colorado, a watershed at a time. It has the characteristics of an invasive species" (Sarah Spaulding, Institute of Arctic and Alpine Research, University of Colorado, diatom-L response, October 2004).

- "In the western USA, *Didymosphenia geminata* has been found abundant in systems in which it was previously unknown" (Pat Kociolek, California Academy of Sciences, diatom-L response, October 2004).

- "We are confronting … massive development of *Didymosphenia geminata* (Lyngb.) in some Romanian rivers, ranging from mountainous to lowland regions" (Cristian Gudasz, Department of Taxonomy and Ecology, Cluj-Napoca 400006, Romania, email to DIATOM-L, January 2004).

4. Ecology

4.1. Water chemistry and temperature

Taxonomic accounts of *Didymosphenia geminata* generally refer to the species as a northern and alpine form (Cleve 1894-96, Hustedt 1930, Patrick & Reimer 1975, Krammer & Lange-Bertalot 1997). Krammer & Lange-Bertalot (1997) stated that the species is found "only in cold oligotrophic waters of the Alps, though ranging from low to high electrolyte content".

Some recent unpublished accounts have also emphasized that *D. geminata* prefers low-nutrient waters. For example, in British Colombia, Canada, the rivers where it occurs are: "nutrient-poor and highly phosphorus limited" (E. Stoermer, University of Michigan, response to diatom-L, October 2004). Information on a British Columbia website states: "It thrives in clear, warm, shallow and nutrient-poor water" (See Appendix 1). It has been difficult to find formally published ecological information that corroborates a definite requirement for nutrient-poor conditions. For example, Lowe (1974) listed *Didymosphenia geminata* in his comprehensive assessment of ecological preferences of many diatom species but provided no ecological information (presumably because there was no reliable information available at that time). Kelly & Whitton (1995) assigned *D. geminata* a sensitivity value in the centre of a 5-point scale of sensitivity to phosphorus concentration.

From 1991 to 1999, three volumes in a series entitled "Use of algae for monitoring rivers" were published (Whitton et al. 1991, Whitton & Rott 1996, Prygiel et al. 1999). A search for specific information about *D. geminata* in these three volumes yielded two mentions:

- In Norway, *D. geminata* is listed as one of 12 indicator species. It falls in the range of unpolluted to moderately polluted rivers (up to the centre of a range from unpolluted to strongly polluted. Median pH is 7.39 (Lindstrom 1991).

- In the Tisa River, Ukraine, a diatom association based on *D. geminata* is tentatively connected with "… heavy polluted and dirty waters" (Bukhtiyarova 1999).

Kawecka & Sanecki (2003) in discussing proliferations of the species in mesotrophic rivers of southern Poland concluded that "… *D. geminata* occurs over a wider ecological range than previously assumed".

In Transylvania, Romania, *D. geminata* has been found within the last year (2003–4) "in lowland rivers and also high up in the mountains. It seems to have a large ecological amplitude" (Cristian Gudasz, Babes-Bolyai University, Cluj, Romania, pers. comm., November 2004).

Therefore while the original distribution of the species suggests that cool, oligotrophic waters are the preferred habitat, the species is clearly not confined to such environments. The species is normally found in water with pH ≥7, but "certainly does well where there is some calcium" (EY. Haworth, pers. comm., December 2004).

4.2. Flow velocity and habitat stability

Investigations following the appearance of *D. geminata* blooms in British Columbia summarized the favourable flow conditions as follows (E. F. Stoermer, University of Michigan, response to diatom-L, October 2004):

- Growth is favoured by periods of low flow.
- Found in depths ranging from 10 cm to 1.5-2.0 metres.
- Tends to be excluded from very slow moving water and from areas of fast flowing waters (>1 m/s).

The first appearance of the blooms on Vancouver Island in 1988 were preceded by a period of depressed monthly mean and maximum river flows over the whole area (Sherbot & Bothwell 1993).

Stable flow and a stable substrate are probably required for the initial attachment to the substrate. Most of the proliferations of *D. geminata* reported from overseas (Section 4) occur either in lake-fed rivers or in regulated rivers (below dams), i.e. generally stable flows. In ecological notes on the species in the UK, Cox (1996) stated that it "occurs particularly on damp rock faces in upland and northern areas, forming macroscopic growths", suggesting a requirement or preference for very stable substrates in regions where it is indigenous.

Once a colony is established, fast currents are likely to enhance growth by promoting transfer of nutrients to the cells at the mat surface. Biggs et al. (1998) showed that the biomass of colonies of a smaller stalked, mucilage-forming attached diatom (mainly *Gomphoneis minuta* var. *cassieae* – an indigenous diatom in New Zealand) increased as current velocity increased up to 0.6 m/s in moderately enriched waters. Colonies of *Gomphoneis minuta* var. *cassieae* are similar to those of *D. geminata* but their attachment to the substrate appears much looser (C. Kilroy, personal observation; no studies have been located that compare the relative strengths of the stalk attachments in different diatom species).

The implication is that, because of its large size and strong attachment, *D. geminata* would be expected to develop very high and persistent biomass in quite fast water velocities. The resulting blooms would be much more resistant to scouring than the stalked diatoms already present in New Zealand rivers. Note also that the *D. geminata* growth was unusual because of the time of its appearance. On the Waiau and similar rivers, large algal growths are generally expected during low flows later in the summer (though blooms often occur in spring in other rivers, e.g. thick spring growths of diatoms and green algae in the Selwyn River, Canterbury (C. Kilroy, personal observations)).

In the lower Waiau River, Maurice Rodway (Southland Fish & Game) reports that the bloom seems to be in a band along the river, thinning out towards the faster flowing water and also less thick or absent in very slow-flowing or still water at the margins. The blooms have remained in place in spite of at least 5 freshes of almost 3 times the median flow since the growth was first discovered, as well as 36 h at ~6 times the median flow just prior to the discovery. (The river's median flow is approximately 17 cumecs.) No published information could be located on specific water velocity requirements/ranges in relation to the biomass or growth of *D. geminata*.

Apparently, blooms of *D. geminata* can be quite unpredictable. For example, in Poland, huge proliferations grew in the San River for ~5 years, then disappeared (A. Witkowski, Univ. Szczecin, Poland, diatom-L response, October 2004) [It has not been possible to verify this.] Observations of the blooms in British Colombia over several years suggested that flow conditions over the previous winter determined whether or not a bloom would occur the following spring. A period of low flows seemed to be required (D. Kelly, NIWA, formerly of BC, pers. comm., November 2004). On the other hand, a bloom in Boulder Creek, Colorado, has persisted for at least 30 months, with no change in appearance through the winter. The stalks accumulate fine sediment and the matrix contains many other diatoms. Mats are denser in spring and summer (Sarah Spaulding, Univ. Colorado, diatom-L response, October 2004).

Didymosphenia geminata also seems to tolerate quite turbulent wave action along lake shores. For example: "… the build up of a big population [of *D. geminata* in an Irish lake] seems to be problematic because of the turbulence of the water. The diatom was attached to the rocks with very long stalks… [which] … have to be pretty strong, because the water is quite turbulent." (Rene van Wezel, East Malling Research Station, UK, DIATOM-L query, November 1999). This is the only reference located of the diatom growing to bloom proportions in a lake. However, in the UK, "…in early summer it (*D. geminata*) can frequently be found on stones on the shores of [Lake] Windermere, along with *Gomphonema* and *Cymbella*, all stalk producers to hold on in the turbulence" (Dr. E.Y. Haworth, Freshwater Biological Association, UK, diatom-L response (to R. van Wezel), November 1999). The shoreline populations in Lake Windermere apparently are never large, and *D. geminata* was not found in any of the smaller upland tarns of the Lake District, UK, during surveys in 1983-6 (E.Y. Haworth, pers. comm., December 2004). Nevertheless, the species' natural habitat extends to lakes. As in rivers, it seems probable that the diatom is capable of maintaining low populations that can potentially expand to bloom proportions under suitable conditions. No information about these conditions could be located.

Other species of *Didymosphenia* are found in Lake Baikal but apparently do not form large growths (Stoermer et al. 1986).

In summary, the responses of *D. geminata* to water velocity and flow stability are likely to be similar to those found for related stalked diatoms already in New Zealand. However, because *D. geminata* is so much larger, appears to attach much more strongly than the other species, and attaches to both rock and plant material, its potential to form very large blooms may be much greater. Whether or not a bloom appears each year may depend on preceding flow conditions, but experience overseas indicates that the persistence and recurrence of blooms can vary widely. Blooms can also form along the margins of lakes.

4.3. Light

Another important habitat requirement for *Didymosphenia* is plenty of light (Kawecka & Sanecki 2003). The British Columbia investigations summarized the light requirements as follows:

- Found in depths ranging from 10 cm to 1.5-2.0 meters.
- Heaviest biomass occurs in most well lit areas, e.g., solar arc greater than 90 degrees.
- Heaviest biomass occurs in east/west-oriented reaches, i.e., greater exposure to sunlight.

These observations on *D. geminata* light requirements are consistent with the those for growths of the other stalked diatom species already known in New Zealand, such as *Cymbella* spp. and *Gomphoneis minuta* var. *cassieae*, both of which frequently form thick slimy growths in shallow, open streams and rivers during summer low flow. Indeed, degree of shading is often the most important determinant of periphyton community composition in New Zealand streams (Biggs & Kilroy 2004).

The investigators in British Columbia suggested that *Didymosphenia* may proliferate because of increased exposure to ultraviolet (UV) radiation. This effect could arise because UV reduces the grazer populations that would normally limit accumulation of the diatom, or because *Didymosphenia* out-competes other species of algae under increased UV. If this theory is correct, then warmer winters and reduced flows may favour the growth of *Didymosphenia*. In other words, climate change may be playing a part in the range expansion currently being observed for *D. geminata*. Trials to test the theory were inconclusive (D. Kelly, NIWA, formerly in BC, pers. comm., November 2004), although previous work had shown UV-induced enhancement of other types of stalked diatoms (Bothwell et al., 1993).

4.4. Observations on regional distributions

In Iceland an attempt was made to link *D. geminata* distributions to regional characteristics or water conductivity. No correlations were found, and the distribution patterns were attributed to gradual dispersal from an initial source in south or west Iceland (Jonsson et al. 2000). The same lack of predictability has been noted in the UK. Thus: "…the factors which control the distribution of *D. geminata* remain unknown." (Kelly & Whitton 1995). More recently, Dr. Martyn Kelly (UK, diatom-L response, October 2004) added: "We get Dg in great masses in a few areas …, and there can be masses in one stream and virtually none in a stream a few km away. I suspect that there is a link to geology, or possibly via geology to drainage patterns. I've always regarded its distribution in the UK as a largely natural phenomenon. It does tend to reappear at most sites where it is found every year, but there are a few reports of one-off blooms. There are some regions where there are many streams with Dg plus a few places where there seems to be one isolated population."

As noted in Section 4.2, proliferations of *D. geminata* overseas are variable over time as well as spatially.

A detailed analysis was carried out to determine whether any climatic, geological, hydrological or water chemistry patterns over space could be linked to blooms of *D. geminata* that first appeared in 1988 in several rivers in central Vancouver Island, Canada (Sherbot & Bothwell 1993). Catchments with blooms were also compared with two unaffected control catchments. The main findings of the study in relation to distributions over space were:

- The blooms were apparently unrelated to human influence in the affected catchments.

- All the affected catchments were contained within a zone with less than 180 frost-free days.

- Catchments with *D. geminata* blooms all originated in zones with humo-ferric podzol soil types. These are all zones with low buffering potential (in other words, highly sensitive to acidic deposition). One of the unaffected catchments was also in this category but the other unaffected catchment had higher buffer potential. [Areas with low buffer potential have parent geology of hard intrusive or volcanic rock, rather than softer sedimentary rock such as limestone.]

- Neither pH level nor nutrient enrichment (N+P) appeared to be important factors in explaining the presence or absence of blooms.

- Silicon levels were higher in rivers with *D. geminata*, but there was insufficient data to conclude that this was significant factor connected with the blooms. [Silicon is required for frustule formation in diatoms.]

In summary, it appears that the distribution of *D. geminata* over space *may* be linked to geological factors and temperature. There is no strong evidence for any definite links to water chemistry factors.

5. How long has *Didymosphenia geminata* been in New Zealand?

A 1984 checklist of the freshwater diatoms of New Zealand (Cassie, 1984) included *Didymosphenia geminata*, based on a single record of the species reported in an MSc thesis (Mather 1928). This record has been determined to be both uncertain and unverifiable for the following reasons:

- The habitat in which the diatom was recorded – a shaded, near-stagnant ditch, liable to drying out – is not typical for *Didymosphenia geminata* (see Section 4).

- The record of *D. geminata* could have been a mis-identification of large forms of a similarly shaped diatom *Gomphonema constrictum*, which is also listed in the thesis and is well-known in New Zealand. These two species have been confused in the past.

- There are no illustrations or voucher specimens.

Interestingly, the only record located of *D. geminata* in Australia is an early identification, which is also now considered unreliable. (See Appendix 2 for more details of both these New Zealand and Australian records.)

A more recent arrival in New Zealand is suggested because, in spite of widespread collecting of diatoms within New Zealand, there has not been a single report of the species since Mather's thesis was completed. *Didymosphenia geminata* is so large and distinctive (Section 2.1) that a *complete* lack of records would be very surprising if the diatom were already established in New Zealand.

Periphyton in the lower Waiau River, where *D. geminata* now appears to be established, has been monitored at three or four sites by NIWA since 1997. This was initially as a resource consent requirement by Meridian Energy, and in the last two years as part of a continuing programme to try to use flows in the river to control the large periphyton growths that tend to accumulate in summer in regulated rivers. Environment Southland also monitor periphyton at two sites on the river, further downstream than the NIWA sites. No *D. geminata* has been recorded at any of these sites previously, though a small amount was found at one of the Environment Southland sites in the survey following the initial find at Jericho farm. Not all of the NIWA sites have been checked yet.

Most regional councils now monitor periphyton species composition in streams and rivers in their regions, as part of their State-of-the-Environment reporting programmes. Samples collected in these surveys are processed by various agencies. It is possible that *D. geminata* has been seen in other samples and either mis-identified, or identified correctly, but not recognized as significant. A check of recent algae species records is required to check these possibilities, followed up by verifications of identifications as necessary.

Thus, on the evidence available at this stage, it seems most likely that the recent appearance of *Didymosphenia geminata* in the Waiau - Mararoa catchment represents either a new or a latent incursion of the species in New Zealand. It is impossible to say exactly how long it has been in the catchment, but the lack of previous sightings in ongoing monitoring programmes suggests that it could be quite a short time. The fact that the species is also well established well upstream in the Mararoa River could indicate that the infestation started there and has gradually moved downstream into the lower Waiau. Again, it is impossible to say how long this might have taken.

6. How did *Didymosphenia geminata* reach New Zealand?

Like other groups of micro-organisms, freshwater diatoms have many representatives with cosmopolitan distributions. An early freshwater diatom study in New Zealand emphasized that most species were "British forms" (Lauder Lindsay 1867, in Foged 1979). However, how these cosmopolitan freshwater species disperse is still unknown.

Much of the literature on diatom dispersal concerns marine diatoms, and discussions relating to freshwater diatom dispersal are often based on conjecture. In a general discussion on the biogeography of diatoms, Kociolek & Spaulding (2000) argue that cosmopolitanism in freshwater diatoms is the exception rather than the rule. Their view is partly based on the great difficulty in proving that natural means of dispersal, such as wind and birds, can transport *living* diatom cells (see following paragraphs). It has also proved difficult to establish cosmopolitanism by molecular means. In the view of Kociolek & Spaulding (2000): "The extent of taxa with widespread distributions may be related to human impact". Also: "Humans have not only transported species, but also created environments … in which common species may thrive". This argument seems very relevant to the arrival of *Didymosphenia geminata* in New Zealand, and also to the species' pervasive spread into other regions in the Northern Hemisphere, beyond its original range (see Section 3).

As mentioned, two vectors often cited for natural dispersal of freshwater diatoms are wind and birds. In both cases there is limited evidence for the transport of live cells. Harper (1999) discussed the transport of diatoms by wind as markers of atmospheric transport, but the few examples provided of dispersal of live diatoms were marine species. Diatoms generally are less tolerant of desiccation than other types of algae, and this has been demonstrated in several experimental studies (e.g. Mosisch 2001; Bergey 2000). Neverthless, species like *D. geminata*, in which the live cells are mixed with mucilaginous material (the stalks), could remain viable for some time in a mucilage mass, as long as the interior remained damp. Wind dispersal of such masses would likely be short-range only.

It is conceivable that clumps of *D. geminata* could pass live through the guts of birds or animals. Atkinson (1980) experimentally fed freshwater planktonic algae to ducks and found viable cells of the diatom *Asterionella formosa* in two cultures. However, because of the very long times involved in long-distance bird migration, this again seems most likely as a means of local transport rather than global dispersal. Another possible mode of local transport of diatom clumps could be on feet or feathers/fur of birds and animals. See Kociolek & Spaulding (2000) for more examples.

Some diatoms form spores or resting stages that allow the species to withstand periods of unfavourable conditions, such as desiccation (Round et al. 1990). These stages provide a potential means of long-range dispersal of a species. However spores are much more frequent in marine species than in freshwater species and, among the latter, most species that form spores or resting cells are planktonic (McQuoid & Hobson 1996). No literature has been located to date suggesting that *Didymosphenia* or any related genera form such spores.

If *D. geminata* were capable of dispersing very long distances via natural means, it would most likely have arrived in New Zealand long ago. So, overall, it is difficult to conceive of any means of spread of *D. geminata* so far beyond its natural range, other than by human intervention, for example, on footwear, fishing equipment, boats, etc. It may never be possible to establish the origin of the populations now in the Waiau/Mararoa Rivers. However, some idea may be obtained from a comparison of the molecular structure of the Waiau population with that of populations from elsewhere. Live material has been sent to Dr Eva Acs, Eotvos University, Budapest, Hungary, for this purpose. One possibility – speculation at present – is that the increasing occurrence of large growths of *D. geminata* (see Section 3.2) may be attributed to a genetic variant that has broader tolerances than the original species.

In conclusion, dispersal of *D. geminata* from its original geographical range into other parts of continental Europe and USA could conceivably have been assisted by avian vectors. However, this is a most improbable explanation for the sudden appearance of the species in New Zealand. The most plausible explanation is that the species has entered the region on a human vector. Birds and animals (as well as humans) could possibly be factors in any future dispersal within New Zealand (see section 8.7 for further comment).

7. Impacts of *Didymosphenia geminata* proliferations: overseas experience

Information received on the effects of *Didymosphenia* blooms has been largely anecdotal. Despite the many reports from overseas of massive growths of *D. geminata*, there seems to have been surprisingly little research that has specifically addressed the impacts of these growths. The most comprehensive study to date is that done in British Colombia, Canada (BC), in response to the blooms that first appeared in 1988. The complete reports (internal reports, and not in electronic form) have not yet been received, but a summary of the findings (including other effects) appears on the Government of British Columbia website (see Appendix 1). The impacts following the BC blooms noted below are from a summary by E.F. Stoermer, University of Michigan (BC in brackets after the comment). Although huge blooms have been reported from central European countries, there has been limited comment about their effects. In fact in Romania, the people involved with water quality monitoring "… don't know much about it and …we may say don't care too much." (Cristian Gudasz, Cluj-Napoca Univ., Romania, pers. comm., November 2004).

The State of Montana, USA, has recently (October 2004) called for proposals to study the macrozoobenthos below the Libby Dam on the Kootenai River, including an investigation of *D. geminata* on the macrozoobenthos and development of recommendations for controlling the growths (see www.discoveringmontana.com/doa/

GSD/OSBS/Detail.asp?So1IdNum=1150). Attempts to secure funding to investigate *D. geminata* proliferations in the western USA are underway (S. Spaulding, pers. comm., November 2004). A call for sightings of excessive *D. geminata* growth has just appeared (late November 2004) on the US Environmental Protection Agency website (http://www.epa.gov/region08/water/monitoring/didymosphenia.html).

7.1. Ecological effects

- Benthic [bottom-living] invertebrate populations may shift from a diverse community of caddisflies, stoneflies, mayflies, chironmids, blackflies, etc. to a community completely dominated by chironomids. While occasional caddisflies remain, there are no stoneflies, mayflies or blackflies (BC). [In other words, there may be a shift in invertebrate community composition from species normally favoured by fish as food, to more tolerant invertebrates that are less favoured by fish.]

- Fisheries staff have observed that in areas of substantial biomass, salmonid parr are absent from their traditional rearing areas. This may be due to gill irritation or clogging due to diatom sloughing or to the changes in food availability (BC).

- In areas of high biomass, the algal mat may result in significant diurnal dissolved oxygen (D.O.) fluctuations. During the early fall as the algal mats break apart and begin to decompose, there is a potential for substantial D.O. depressions to occur particularly during a very low flow summer followed by late fall rains (BC).

- In Iceland, where *D. geminata* has occurred since 1994, "The algae covered the stony bottom as a grayish woolen cover and seemed to cover and finally eliminate macrophytes and moss." (Jonsson et al. 2000). Note that these authors also found that in spite of the nuisance appearance and high biovolume of a *D. geminata* bloom, the specific rate of photosynthesis was not much higher than that in a river not containing this diatom, presumably because much of the mat comprises stalks. Compare this with findings by Biggs & Hickey (1994) on periphyton mats dominated by mucilaginous diatoms in New Zealand (see Section 8.2).

- In Colorado "… I have observed streams with every available substrate covered with thick (3-5 cm) mats. … As the cells die, the stalks persist over weeks, even months … on the exposed surfaces of stream boulders through the winter (snow and ice) season. Fine sediment becomes trapped in the mucilaginous stalks, then other diatoms colonise and seem to stabilize the "leftover" stalks. The whole mess seems to be resistant to grazers, and the usual invertebrates are not reported from those sites" (Sarah Spaulding, Univ. Colorado, diatom-L response, November 2004).

- In some streams, *D. geminata* growth covers over 90% of available substrates, forming dense mucilaginous mats up to several centimeters in length. The dense mats can cover 2-3 kilometers of stream length. The dense mats exclude the growth of other diatoms, an important source of food for aquatic invertebrates. As a result, a decline in aquatic invertebrates causes a decline in food available for fish. In some parts of the western US, fisheries have declined by 90% in 2003 and 2004. State land managers are greatly concerned about the negative impact of *D. geminata* on fisheries and the spread of the diatom along stream reaches and across stream drainages. Recent excessive populations have been confirmed in Colorado, Utah, and South Dakota. (EPA website)

7.2. Aesthetic effects

- Aesthetic complaints regarding recreational use have been steady. These include: mistaking dried *D. geminata* mats for toilet paper, causing concerns about possible upstream sewage discharges; wet mats fouling fishing gear and lines; the slimy covering on rocks spoiling swimming holes. (BC)

7.3. Human health effects

Didymosphenia geminata does not seem to degrade water quality (except possibly taste/odour – see next section) and the only human health issue reported so far is from swimmers.

- Swimmers have complained of scratchy, red, watery eyes after swimming in "affected" areas. This is likely due to the continual sloughing of frustules, which simply get into one's eyes while swimming (BC).

7.4. Economic effects

Economic effects could occur when large blooms block water intakes and cause fouling that must be cleaned up. There are also potential economic effects to freshwater fisheries as a result of any ecosystem changes.

- Water intakes at several locations, such as the Gold River pulp mill, Oyster River spawning channel, have become clogged, leading to taste and odour complaints (BC).

- From the western USA, there is a report of *D. geminata* causing problems in hydro-power canals: “In 1997 I was working on problem algae growth in hydro-power canals … came across an area with significant *Didymosphenia* growth. It would grow in long brownish to white ribbons and periodically detach and accumulate on the intake screens at the powerhouse. The water was not particularly high in nutrients and was extremely cold” (diatom-L response, to R. van Wezel, November 1999).

- “In the western USA, …growth along the dam faces was so thick that workers with rakes piled the materials knee deep along the banks of the reservoir outflows” (Pat Kociolek, California Academy of Sciences, diatom-L response, October 2004).

- In Poland in1994, *D. geminata* “occurred in such masses below the Solina and Myczkowce reservoirs that gelatinous material plugged water filters, impeding the use of river water in supply systems. Its effect on water quality caused concern and discussion about how to prevent its mass occurrence” (Kawecka & Sanecki 2003).

- In Iceland, where *D. geminata* has occurred since 1994, “… for fisherman and landowners in particular, this algal growth was feared to economic consequences” (Jonsson et al. 2000). [No information that follows up on this statement has been located.]

8. Risks associated with the presence of *Didymosphenia geminata* in New Zealand fresh waters

All effects summarized in Section 7 could cause problems in New Zealand. In view of the importance of clean waterways and lakes to New Zealand’s tourism industry, any very large and persistent blooms of benthic algae are undesirable (though it should be understood that in summer low-flow conditions, prolific algal growth in some rivers is natural; spring blooms also occur in some rivers).

8.1. Susceptible waterways

The ecological requirements of *D. geminata* described in Section 4 suggest that many New Zealand waterways and lakes may be susceptible to invasion by this diatom.

Didymosphenia geminata could colonise any rivers in which other species of stalked diatoms currently form large colonies during low flows, particularly hill-country streams and rivers (Biggs & Kilroy 2004). Also expected to be susceptible are any other clear-water, unshaded rivers, which often experience stable flows (regulated and lake-fed rivers may be most vulnerable to large blooms), with water velocities <1 m/s, and pH 6.5 upwards. The ability of *D. geminata* to colonise in some places *may* be limited by geology, soil type, temperature and possibly water chemistry (see Section 4.4). However, there is insufficient information available to make any firm statement about this. Rivers with unstable (mobile) substrates and periodic large floods, or cloudy glacier-fed waters, are probably less susceptible, but this is not known for certain at this stage.

8.2. Ecological effects

Based on the observations from BC and other places, ecological effects are likely to be similar and could be significant.

Ecological effects in New Zealand may include changes to invertebrate communities, impairment of fish food and habitat, and smothering of mosses and aquatic plants. The impacts are expected to be similar to those of naturally occurring growths of periphyton in New Zealand. This has already been demonstrated in the lower Waiau River, where high periphyton biomass is often associated with high densities of snails, midges and worms, rather than mayflies and sensitive caddisflies (Kilroy 2004). Suren et al. (2003a,b) showed the same effect in the enriched Waipara River, Canterbury. Because *D. geminata* seems to form a much more complete mat, covering all surfaces and adhering very firmly, the impact on the invertebrate may be expected to be more pronounced. Overseas information also suggests that the mats are much more persistent than algal blooms currently seen in New Zealand.

In the Ohau River, Otago, Biggs & Hickey (1994) found that the chlorophyll *a* content of mats of stalked diatoms (including *Gomphoneis minuta* var. *cassieae* and *Cymbella kappii*) did not differ as mat thickness increased, which is in agreement with the finding of Jonsson et al. (2000) in Iceland (see Section 7.1). However, Biggs & Hickey (1994) also found that ash-free dry mass of the mats increased with thickness, as did total respiration (i.e. total oxygen uptake) in the mat. This suggests that thick periphyton mats are certainly capable of depressing oxygen levels in adjacent waters.

There could also be effects on biodiversity (of algae, plants and fish). Impacts on native fish should be considered.

Investigations are needed to get a better idea of the ecological effects in NZ.

8.3. Water quality effects

Overseas information suggests that no significant adverse effects on water quality are likely.

In New Zealand, water quality changes are not expected to differ from those caused by blooms of other types of benthic algae.

8.4. Aesthetic effects

Aesthetic effects are likely to be significant. Large blooms covering all available substrate with thick slime create potentially unpleasant conditions for swimming, kayaking, etc., as well as being unsightly. The dried mats are also aesthetically unappealing (though similar in appearance to dried mats of algae already commonly seen around NZ rivers).

The first *D. geminata* growth found at Jericho Farm, lower Waiau River, already exceeds the current guidelines for algal proliferations in New Zealand for aesthetics /recreation purposes. A thick mat covered 75% of the area surveyed. The guideline is 60% cover of mats more than 0.3 cm thick (Biggs 2000). In the lower Waiau, the guideline for trout habitat/angling (less than 200 mg/m^3 chlorophyll *a*) was estimated to be equivalent to a cover of 80% (Kilroy 2002). Chlorophyll *a* measured from quantitative samples collected from 20 stones at the Jericho site on 12 November 2004 was 298 mg/m^3, almost 50% higher than the guideline (for method of measurement see Biggs & Kilroy 2000).

8.5. Human health effects

Only minor human health effects are expected (if any).

Eye irritation in swimmers is possible, as reported from British Colombia. This could be especially an issue for swimmers in any lakes that may be affected. Water quality changes that affect humans are not expected. No reports of ill-effects to animals have been located.

8.6. Economic effects

Overseas experience suggests that significant effects to the freshwater fishing industry may be possible, especially in clear-water rivers. Any structures or activities within affected waterways may be vulnerable, e.g. aquaculture operations, hydroelectricity intakes, irrigation intakes and channels. Since *D. geminata* appears to require plenty of light to form blooms, rivers, lakes and canals fed by water containing glacial flour may not be susceptible, but this has yet to be tested.

8.7. Potential for dispersal

The seriousness of any problems will depend on how widespread *D. geminata* becomes. As mentioned in section 2, the extent of the species in Southland is still unknown. It also remains to be confirmed that there have been no earlier records of the species from other parts of New Zealand (Section 5). As indicated in section 6, the most likely vector for its introduction into New Zealand is via human activities. I have been unable to trace any overseas investigations into how the species spreads from catchment to catchment. Again, humans again seem the most likely candidates, although it is also possible that birds could act as vectors (section 6). The probability of transfer by bird vectors is unknown.

9. Can *Didymosphenia geminata* be controlled, contained or eliminated?

No published examples of attempts to control or eliminate blooms of *D. geminata* have been located. A specific question about this in the internet query to the DIATOM-L list-server yielded no information, but comments that the question has never really been addressed. There also seem to have been no attempts to contain the species once it appears in a catchment.

At the time of completing this report (late November 2004), it appears that *D. geminata* may be confined to the lower Waiau / Mararoa River catchment. There were no sightings of the diatom growth during a survey of rivers in neighbouring and more distant catchments in Southland and Otago (25–26 November 2004). If its distribution is currently restricted, then it certainly seems worthwhile to attempt to contain it within this catchment by minimising any spread by humans.

10. Conclusions

Based on available evidence and knowledge of diatom biology, it is considered that *Didymosphenia geminata* has the potential to cause significant impacts in New Zealand streams and rivers if it spreads unchecked. As indicated above, it would be desirable to contain the species if at all possible. While such containment is in progress, it is recommended that the ecological effects of this diatom be investigated urgently in order to better understand the potential effects on rivers should it eventually spread. In addition, research and/or more investigations into any work carried out overseas are needed to establish likely effects on lake ecosystems. As discussed above, its effects in New Zealand can be guessed, but are actually unknown.

11. Acknowledgements

Thanks are due to the many overseas researchers who took the time to respond to my queries about *D. geminata* in New Zealand, and provided much valuable information; correspondence is ongoing in some cases. Barry Biggs and Don Robertson also provided valuable advice and feedback. Graham Fenwick made many suggestions to improve and clarify the text. Thanks to Maurice Rodway, Bill Jarvie and Stuart (Southland Fish & Game), and Environment Southland for regular updates on new sightings, and for observations of the growth since the initial find. Thanks also to Neil Blair and John Clayton for undertaking a quantitative survey at very short notice, and to Karen Robinson for doing the chlorophyll *a* analyses. Dave Herrick (Meridian Energy) is thanked for confirming interest in and support for investigations into this unexpected outcome of the routine monitoring programme on the lower Waiau River. Finally, thanks to Environment Southland (Scott Crawford and staff) for providing the opportunity to review the potential effects of this species in New Zealand.

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APPENDIX 1

Didymosphenia geminata in British Columbia Streams

(text of a summary posted on the Government of British Colombia website:
wlapwww.gov.bc.ca/wat/wq/didy_bcstrms.html)

What is *Didymosphenia geminata*?

In recent years, the Ministry of Water, Land and Air Protection has received several reports of dense mats of algae, called *Didymosphenia geminata*, growing in several streams throughout the province. Although the white algal mats can cover large areas of stream bed, they are not generally considered an indication of degraded water quality. *Didymosphenia geminata* is a species of algae belonging to a group known as the diatoms. Diatoms are unique among algae because they consist of a silica shell, called a frustule, which fits together in two halves like a pill box. Diatoms are generally free-floating plankton; however, there are species that grow attached to the stream bed. The frustules of *Didymosphenia* are attached to rocks by a gelatinous stalk that form mats when growing in high densities.

Where does *Didymosphenia* grow?

Didymosphenia geminata is normally present at low levels throughout the province. It thrives in clear, warm, shallow and nutrient-poor water, and is influenced year to year by weather and rainfall patterns.

Didymosphenia has been reported to grow to nuisance levels in a number of river systems around the province — especially throughout central Vancouver Island, where it was first reported in 1989. It has also been found in significant quantities in the Bulkley, South Thompson, Kettle, Columbia and Kootenay Rivers.

It is thought that *Didymosphenia* may proliferate because of increased exposure to ultraviolet (UV) radiation. UV radiation may reduce the aquatic insect population that normally limits the accumulation of *Didymosphenia*, or perhaps *Didymosphenia* out-competes other species of algae under relatively high UV conditions. Increased UV exposure due to loss of streamside vegetation, warmer winters, reduced ice cover and reduced flows may all favour the growth of *Didymosphenia* — if the UV theory is correct.

As sunlight decreases at the end of summer, *Didymosphenia* stops growing and dies off. The growth of *Didymosphenia* in a given stream is unpredictable and may not occur from one year to the next.

What are the mats?

Didymosphenia has a somewhat unusual growth habit in that each diatom frustule (the silica shell) is found on the end of relatively long stalk. The stalks are multi-branched, giving an overall appearance similar to that of a microscopic palm tree.

When conditions are favourable, *Didymosphenia* can form mats that will cover large areas of stream bottom. The mat consists mainly of the stalks, which contain no chlorophyll, giving the mat a colour that ranges from pale yellow-brown to white. As stream levels drop, the drying mats remain on the rocks and can be mistaken for toilet paper, causing concerns about possible upstream sewage discharges.

Are there any health concerns?

Based on the available information, *Didymosphenia* does not appear to affect the safety of drinking water, although taste and odour problems may be a concern. Swimmers have occasionally complained about itchy eyes after swimming in areas downstream of large *Didymosphenia* mats. This is likely due to high quantities of the diatom frustules finding their way into swimmers' eyes and causing a reaction similar to that triggered by pollen.

Are there any fisheries concerns?

Fisheries concerns include possible reduced rearing habitat for salmonids — due to changes in invertebrate communities and populations, physical impacts such as gill irritations and clogging, and displacement of some fish species at high concentrations of *Didymosphenia* growth. The mats may also restrict the flow of water, and therefore oxygen, to the eggs and fry in gravel. Finally, the decomposition of the algal mats may deplete dissolved oxygen in the water.

Are there other concerns?

Water intakes (both domestic and those used for fish hatcheries) are sometimes clogged with growing mats of *Didymosphenia* or with algal material from sloughing mats. Many reports have been received from recreational users complaining about the appearance of their favourite swimming holes, slippery rocks and algae fouling fishing lines and gear.

Should I report *Didymosphenia*?

If you find an area that is significantly affected by *Didymosphenia geminata*, contact the nearest regional office of the Ministry of Water, Land and Air Protection.

APPENDIX 2

Early records of *Didymosphenia geminata* in New Zealand and Australia

A checklist of the freshwater diatoms of New Zealand (Cassie 1984) includes *Didymosphenia geminata*, based on a single record of the species (Mather 1928). I have obtained a copy of the source, an MSc Thesis: "Freshwater Algae of the Hutt Valley". The work comprised collecting algae from 18 sites in the Hutt Valley, monthly from November 1926 to September 1927, along with habitat information. There is no description of the methods or magnifications used for examining and identifying species.

Gomphonema geminatum (designated as the new genus *Didymosphenia* in 1899, see 2.1) is recorded at one site only: Melling Ditch. This was described as: "… a country roadside ditch close under the western hills. It is shaded during the greater part of the day by the overhanging bush and also by … grass, watercress, *Lemna minor* and other weeds… Two tiny hill springs rising about 1000 yards away give it a depth of about 2 inches but were not sufficient to prevent it drying up in December and February. The flow is from slow to still. The substratum is clayey sand … silt".

The description of the algae at the site mentions some green algae species, and states "The diatoms were not very numerous nor in great quantity." *G. geminatum* is listed as "common" in August only (category 3 in a 5-point scale of relative abundance).

G. geminatum is also listed in another site (Stokes Valley stream), but no abundance estimates are given and the name has been crossed out. The species next on the list is *Gomphonema constrictum*, which ranges from "abundant" to "few" from February to July.

There is no reference to *G. geminatum* or its growth form in the descriptive text in the rest of the thesis.

The thesis includes a two-page bibliography, which suggests that the author had adequate references (for that time) from which to make identifications. However, there are no illustrations of any of the algae listed. The only mention of illustrations (apart from photographs of some of the sampling sites) is a single reference to drawings of species where the identification was doubtful. There is no indication that the thesis ever included those drawings. There is also no indication that voucher specimens of the collections were kept.

Without illustrations it is impossible to verify or reject the identification. However there are some clues.

First, the habitat in which *G. geminatum* is recorded is not typical for *Didymosphenia geminata*, which is consistently referred to in the literature as cool, alpine, boreal waters of low electrolyte content, and in flowing water (or wave-washed lake shores). Even though recent distribution records of *D. geminata* indicate a wider ecological tolerance than implied from its natural distribution (section 4.1) a shaded, near-stagnant ditch liable to dry out seems an unlikely habitat.

Second, *Gomphonema constrictum* is a similarly shaped, smaller diatom that could possibly have been misidentified as *G. geminatum*. To confuse matters, both species were recorded from Melling Ditch. Krammer & Lange-Bertalot (1990) state a wide size range for *G. constrictum*[1], of 13 to 75 µm long, which overlaps the range stated for *D. geminata* (60 – 140 µm long). Thus a possible scenario is that Mather assigned larger forms of *G. constrictum* to *G. geminatum* and small forms to *G. constrictum*. This is, of course, conjecture, but in the absence of a high-power microscope, quite possible.

Third, Patrick & Reimer (1975) describe some confusion over *G. constrictum* and its synonyms in the 1830s. "Ehrenberg … in 1838 … also made *G. geminatum* Lyngbye and other diatom synonyms [of *G. truncatum* (= *G. constrictum* – see footnote)], which are very different taxa." If Ehrenberg could confuse the two taxa, then Mather may have done the same.

From the above it is clear that Mather's identification of *G. geminatum* (= *Didymosphenia geminata*) is probably unreliable and is certainly unverifiable. It is possible that *D. geminata* has reached New Zealand much more recently, but this cannot be proved.

Note that a search of the Allen Herbarium database (Landcare, Lincoln) brings up records of *Didymosphenia geminata* on two slides in Vivienne Cassie-Cooper's collection, but with no locality information. A check with VCC confirmed that these slides were made from material from the UK, not New Zealand.

In relation to a possible mis-identification, it is interesting to note the response to an enquiry about *D. geminata* in Australia. The Census of Freshwater Algae in Australia

[1] Note: *G. constrictum* Ehrenberg is now named *G. truncatum* Ehrenberg. The two species are synonymous, and since the name *truncatum* predated *constrictum*, the former is now applied to this species.

(Botanic Gardens Trust, Sydney) lists *Didymosphenia geminata* as occurring in Victoria. The answer to my request for more information follows:

> "There are two records from Victoria, both from a collector called Watts in the 1880s. Watts was a bad one for putting European names on Australian species (making them 'fit', as it were) and we suspect that this is what happened in this case, as it's not been recorded since that I know of. Sadly there are no herbarium vouchers of his collections at the Victorian Herbarium, only written records, so we can't go back and check. I've also done a search on the algal records from the Queensland herbarium as well as our own (NSW) records and *Didymosphenia* doesn't show up at all (or *Gomphonema geminatum*)." (Lucy Nairn, Botanic Gardens, Sydney, pers. comm., 11 November 2004)