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Atypical *Tabularia* in Coastal Lake Erie, USA

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ABSTRACT

Tabularia populations collected at a coastal site in Lake Erie, near Cleveland, Ohio, USA exhibit highly abnormal morphology. Frustules may be bent, asymmetric, have irregular striae patterns, irregular margins, or any combination of these characters. The majority of specimens in the collection are abnormal to some degree. Although specimens are so atypical that identification is difficult, relatively simple morphometric analysis shows that morphologies similar to most described members of the genus are present in the collection. *Tabularia* is probably not indigenous to the Laurentian Great Lakes but occurs in areas that have been highly modified, particularly by saline discharges. The collection site is subject to such discharges, and also to other industrial contaminants. The abnormalities present may be related to these factors, or simply to stresses imposed on species growing out of their preferred habitat. In any case, the occurrence of numerous forms of *Tabularia* in a localized area where it is not native is remarkable.

Key words: diatoms, *Tabularia* populations, morphological abnormality, Lake Erie

INTRODUCTION

There are number of causes of morphological abnormalities in diatom frustules. Non-lethal mechanical damage may produce clones of cells that have obvious structural defects. This is relatively rare in natural populations. The most obvious causes are attacks by grazers that damage frustules, but do not kill cells, and simple mechanical crowding, as is found in dense periphyton mats. Attacks by fungal or protozoan parasites may also cause abnormal structural changes in diatom frustules. Physical crowding may also produce frustular abnormalities in cultured populations, particularly benthic species (Drum 1964). Both simple frustular abnormalities and special adaptations such as craticular stages, internal valves, and different valve morphologies in a single species (Stoermer 1967) are often associated with habitats that periodically undergo desiccation. Based on our observations, it also appears that frustular abnormalities are common in diatom communities that undergo toxic stress. In general, it is probably safe to say that diatoms growing in unstable habitats are particularly susceptible to abnormal frustule formation.

The nearshore waters of many areas of the Laurentian Great Lakes are examples of ecological instability. Large population and industrial centers on the shores of these originally highly oligotrophic lakes lead to large spatial and temporal gradients in nutrient, conservative ion, and toxic material concentrations. Partially because of the large variation in ecological conditions, a large number of diatom species have been reported from the Laurentian Great Lakes (Stoermer et al. 1999) and undoubtedly many remain to be discovered. These lakes are very young geologically, having reached their present configuration only ca, 4000 years ago. They lack the highly specialized indigenous floras characteristic of ancient great lakes (Stoermer and Edlund 1999), although speciation appears to have occurred in the offshore plankton (Theriot and Stoermer 1984). Some indigenous species appear to have been exterminated (Stoermer et al. 1987) and numerous non-native species have been introduced and become established (Mills et al. 1993). Most non-indigenous diatoms that have become successful in the Great Lakes come from estuarine habitats (Hohn 1969, Hasle and Evenson 1975, 1976, Hasle 1978). Considering their inland location and normally low salinities this may appear unusual, however, many industries in the region are based on extraction of salt (NaCl) from large deposits that underlie substantial parts of the area. Salt is also widely used as a melting agent to facilitate travel during the region's notoriously harsh winters. The lakes are also directly connected to transoceanic shipping through the St. Lawrence Seaway and the Welland Canal. Thus, large salinity gradients, particularly in harbors has allowed invasion of many exotic invertebrates, such as zebra mussels (*Dreissena* spp.), fish, such as gobies (*Gobius* spp.), (Mills et al. 1993) and algae, such as *Bangia* (Lin and Blum 1977).

In the following we discuss an unusual population of an apparently invasive taxon, *Tabularia* that is usually found in estuarine habitats. The genus was relatively recently separated from *Synedra* (Williams and Round 1986) and circumscription of species in the genus remains controversial. The population discussed comes from a site on the shores of Lake Erie that has had a long history of disturbances of several types. Lake Erie is generally considered the most modified of the Laurentian Great Lakes, and became a focus of concerns about water pollution in the later decades of the twentieth century. Although water quality has improved in the main body of Lake Erie, primarily due to reductions in phosphorus loading and increased transparency resulting from zebra mussel feeding (Stoermer et al. 1996), many shoreline sites remain problematic.

MATERIALS AND METHODS

The site from which the material used in our investigation was collected is such a problematic shoreline area. The material was collect by Dr. G. Sgro as part of the Great Lakes Environmental indicators project. The material collected is described as "algae growing on shoreline rocks". The locality (41° 29' 0.9N; 81° 42' 58.7"W) of collection is locally known as Whiskey Island (Fig. 1). The island was actually a peninsula found at the mouth of the Cuyahoga River in Cleveland, Ohio. A shipping channel eventually cut it off from the mainland. Its name is derived from a distillery that was built there in 1836, hence its name. The island has been subjected to multiple uses. It has been an industrial site, ship graveyard and waste disposal area. It is currently the site of a salt mine, and has recently been developed as a large marina. Similar to other such areas in the Great Lakes region, further development as a recreational area is contemplated.

In this regard, the area has a legacy of severe environmental problems. During the late 1950'sand 1960's Lake Erie was often cited as an example of extreme water pollution because of large cyanobacterial blooms, massive overgrowths of *Cladophora*, and high levels of toxic materials. The Cuyahoga River gained particular notoriety in the period because it was so contaminated that it occasionally caught fire. The more obvious ecological problems have now been contained, if not eliminated, but the legacy of previous environmental insults remains.

The material was prepared by oxidation in nitric acid. Acid was removed by decantation with distilled water to remove acid and oxidation by-products. The cleaned and washed material was dried on number one cover glasses and mounted in Naphrax. Prepared slides were observed and measurements were made with a Leica DMRX microscope. Images were captured with a Sony DKC 5000 video camera suing Adobe Photoshop software. Illustrations were prepared using the same software. Measurements were made of

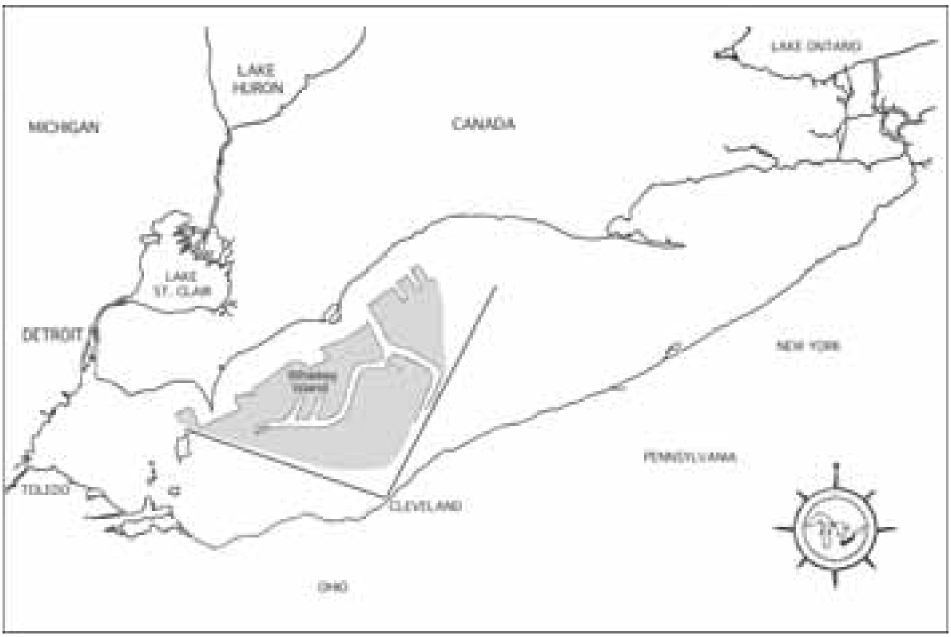

Fig. 1. Outline map of Lake Erie, showing approximate location of sampling site. Insert shows detail of Whiskey Island.

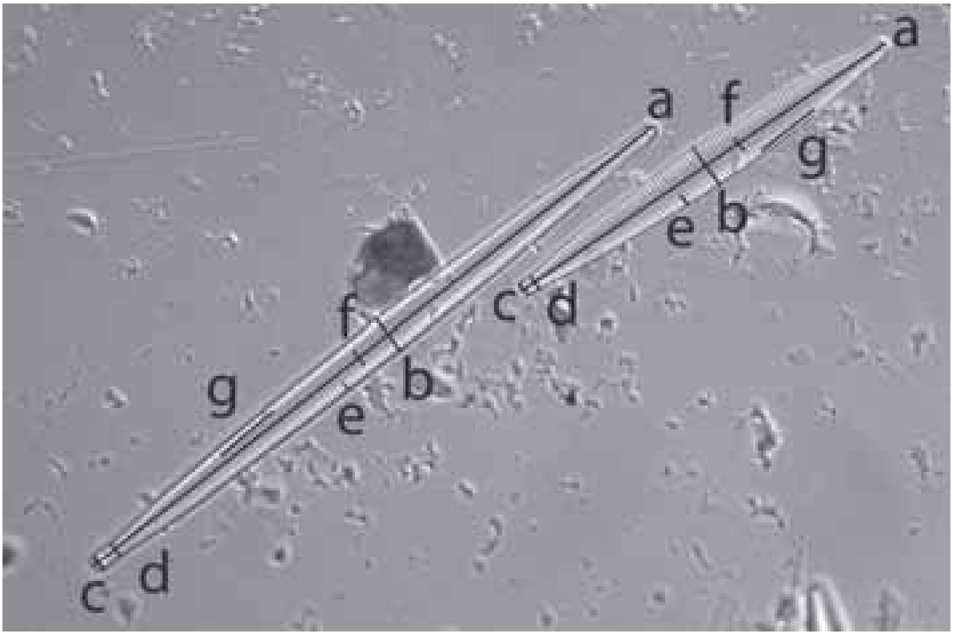

Fig. 2. Specimens with dimensions measured indicated: a - total length of frustule; b - maximum width of frustule; c - Maximum width of frustule end; d - Width of end constriction; e - maximum length of striae; f - Maximum width of central area; g - number of striae in 10 µm (bar is 10 µm).

100 unobstructed specimens and recorded using NIH Image software (Stoermer 1996). Measurement made (Fig. 2) include:

A - Total length of frustule
B - Maximum width of frustule
C - Maximum width of frustule end
D - Width of end constriction
E - Maximum length of striae
F - Maximum width of central area
G - Number of striae in 10 µm

Untransformed data were analyzed using Data Desk software. A cluster analysis (Fig. 3) was performed using the complete linkage option.

RESULTS

Initial observations showed an extreme variety of atypical shapes (Fig. 4), although it was apparent that some coherent trends in morphology were present. Results of the cluster analysis (Fig. 3) indicated the presence of five groups of specimens with similar morphology. Inspection of the cluster results indicate that more coherent morphological

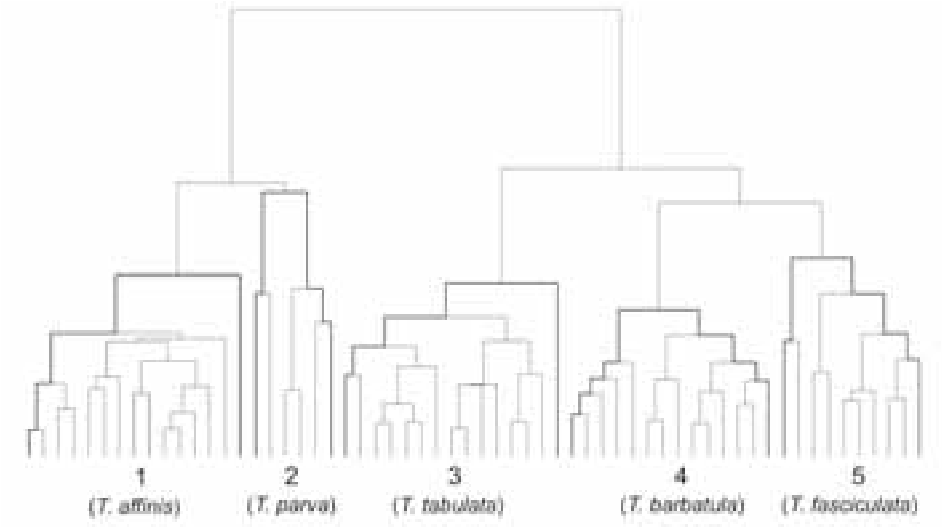

Fig. 3. Results of cluster analysis. Groupings and nominal name assignments for each cluster indicated below.

series may be present as indicated by high-level outliers in some of the groups. Besides possible lack of resolution due to under-sampling, taxonomic results are not entirely satisfying. We think it clear that these specimens belong to the genus *Tabularia (*Kütz.) Williams and Round, as currently conceived. The taxon was originally circumscribed as a subgenus of *Synedra* (Kützing 1844), and raised to generic status by Williams and Round (1986). As is the case with many diatom genera, *Tabularia* has historically been treated with very compressed taxonomy, which includes relatively few species and a large number of "varieties" or other subordinate taxa (Cleve-Euler 1953). Although taxonomic treatments have become more discriminatory in the past few decades, taxonomy of the genus and its assumed relatives remains controversial (e. g. Williams and Round 1986, Krammer and Lange-Bertalot 1991).

Despite these difficulties, it is apparent that one of the series present, if not identical to, is at least closely related to *T. tabulata* (C. A. Agardh) Snoeijs. Similarly, another series most likely belongs to *T. fasciculata* (C. A. Agardh) Williams and Round. Nomenclaturally correct designation of the other populations present is more difficult. The more strikingly rostrate forms may belong to *T. barbatula (*Kütz.) Williams and Round (*Synedra gracilis sensu* Kützing 1844), although further study would be necessary to validate this conclusion. Other populations present have likely been referred to *Synedra affinis* Kützing (*sensu* Hustedt 1930) and *Tabularia parva* (Kütz.) Williams and Round. The latter species is reported as one of the more abundant periphyton species in the Salton Sea (Lange and Tiffany 2002), a highly polluted and unusual habitat. Other unusual habitats where *Tabularia* is found include sea ice (von Quillfeldt et al. 2003).

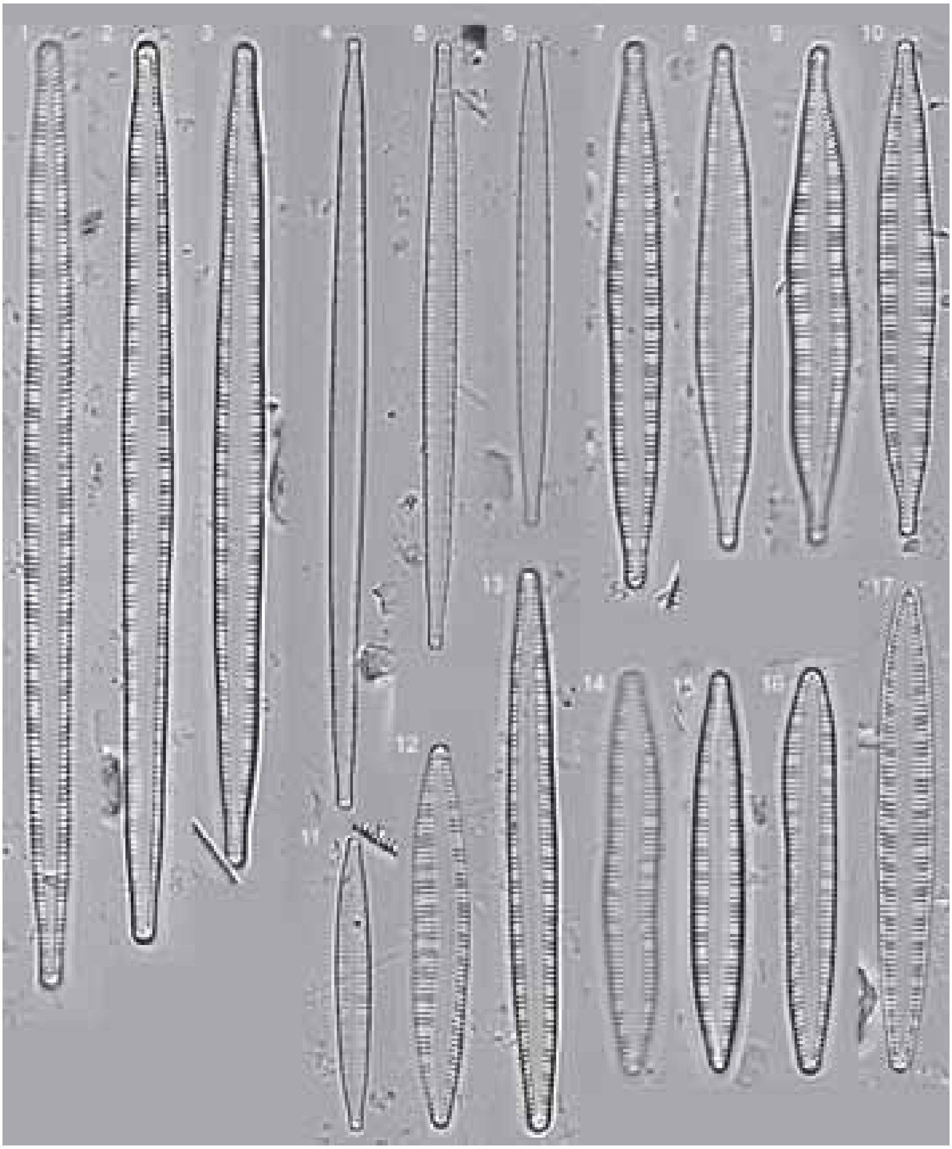

Fig. 4. Representative species from the collection, arranged according to results of cluster analysis. Figs 1-3 group 3 (*T. tabulata*); Figs 4-7 group 1 (*T. affinis*); Figs 7-10 group 4 (*T. barbatula*); Figs 11-13 group 2 (*T. parva* - note that Fig. 11 is an extreme outlier and probably belongs to another taxon); Figs 14-17 group 5 (*T. fasciculata*).

DISCUSSION

Aside from problems caused by the abnormal forms exhibited by the specimens studied, firm identification of taxa present are complicated by present uncertainties in the taxonomy of *Tabularia* and its subsidiary taxa. Despite these difficulties, we think it clear that several taxa are present in this collection and that they are closely related to, if not identical with commonly reported marine and estuarine taxa. Further research will be necessary to firmly establish this conclusion. Given the apparent invasive capability of some diatom species, their ability to evolve rapidly, and the present state of diatom taxonomy resolving true relations will necessitate further taxonomic revision of this entire group.

How and when these entities became resident in the nearshore waters of Lake Erie is a question of current interest. It is commonly perceived that the Laurentian Great Lakes are presently undergoing a high rate of invasions by non-indigenous species (Mills et al. 1993, Loughead and Stevenson 2004), but this may not be an entirely correct perception, at least in the case of diatom populations. We know that estuarine diatom species, such as *Actinocyclus normanii* fo. *subsalsa* (Juhl.-Dannf.) Hust. were present in Lake Erie in the mid 1800's (Stoermer et al. 1987, 1996) and eventually became biomass dominants in the western basin of the lake (Hohn 1969). The date of first notable occurrences in is soon after opening of the Erie Canal, which reached lake Erie in 1825, opening the first direct connection between the sea and the Great Lakes. As is often the case, diatoms could have been a useful early indicator of an emerging problem. Unfortunately, the history of this invasion was discovered only much later through paleolimnological studies.

Of course, it is entirely possible that isolated populations of primarily marine diatom species were found in the numerous salt springs and seeps of the Great Lakes region prior to gross human modification of this ecosystem. At present, knowledge of the diatom flora of this region and its history are not sufficient to support any firm conclusions about the first occurrences of *Tabularia*, or any other primarily estuarine genus in this region. This problem might be solved through paleolimnological studies, but we are not aware of any effort directed at the problem of diatom invasions. There are indications that uncontrolled spread of non-indigenous diatom species is a worldwide problem. *Asterionella* apparently invaded New Zealand soon after European settlement (Harper 1994), and *Gomphoneis* relatively recently became a nuisance in French streams, a habitat where it had not previously been noted (LeCohu and Coste 1995). Similar nuisance occurrences of *Didymosphenia* are apparently now occurring in New Zealand (Cathy Kilroy National Institute of Water and Atmospheric Research, New Zealand, personal communication).

The cause of frustular abnormalities observed is equally uncertain. Abnormalities in diatom valve structure have been noted and reported virtually since the group was first studied (Taylor 1929) and classifications of deformity have been proposed, both as to type (e.g. Cox 1891) and as to presumed causality (Barber and Carter 1981). Of the possible causes suggested by Barber and Carter, their first category, "chemical abnormalities in the habitat" seems most likely in the populations we studied. There is no evidence of parasitism or sexual reproduction, and the cells and types of abnormalities observed do not suggest clonal populations. Given the history and current impacts on the site studied, exotic chemical inputs are not unexpected. Given the plethora of possible "abnormal" chemicals affecting these populations, choosing a most probable cause without experimental evidence is difficult. In general, deformities have been associated with pollution or eutrophication (Antoine and Benson Evans 1986, Belcher et al. 1966, Klee and Schmidt 1987). More specific chemical causes include silica limitation (Booth and Harrison 1979) and increased salinity in freshwater habitats (Tuchman et al. 1984).

Andresen and Tuchman (1991) noted widespread frustular abnormalities in planktonic diatom populations from several areas in the Laurentian Great lakes collected in 1983, but were unable to assign any particular cause to their observations. Feldt et al. (1973) reported apparently abnormal *Synedra* populations were from Lake Superior, but these populations have persisted, and apparently are the result of genetic modification (unpublished observations).

The occurrence of morphological abnormalities in birds (Ludwig et al. 1993, 1996) fish (Smith et al. 1994), and invertebrates (Dickman et al 1992, Diggins and Stewart 1993), particularly in the coastal region of Lake Erie and its tributaries, is well known. These effects are usually attributed to toxic organic compounds. Reports of similar effects on benthic diatoms are more rare, but not unknown (Dickman 1998, Gómez and Licursi 2003). We are not aware of such published reports from the Laurentian Great Lakes. The late Brian Shero (personal communication, Dr. Brian Shero, Medaille College, Buffalo NY) found numerous deformities in diatoms collected from contaminated sites in the Niagara River, but these observations were apparently never effectively published.

The presence of benthic diatoms that are atypical, in terms of both distribution and morphology, in the Great Lakes may offer valuable insights into toxic effects and the ability of exotic populations to invade the lakes. Although the present state of knowledge does not permit firm conclusions concerning the populations described here, investigation of benthic diatom populations in the Great Lakes is a neglected topic that deserves more research attention.

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