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The global distribution of surf diatom accumulations

Distribución global de acumulaciones de diatomeas en la zona de rompiente de las olas

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ABSTRACT

Surf diatoms regularly cause brown water discoloration at suitable beaches in the southern hemisphere as well as a few beaches of North and Central America. Species involved are taxonomically and morphologically unrelated. Different localities usually have one or two species dominant in the brown water, but up to five species have been found to be co-dominant. There is no global pattern of species distribution other than that the phenomenon is more common in the southern hemisphere. *Anaulus australis* Drebes et Schulz is restricted to the southern hemisphere; *Asterionella socialis* Lewin et Norris is endemic to the northern hemisphere while *Aulacodiscus africanus* Cottam appears to be a tropical species. The remainder of the surf accumulating diatoms (*Attheya armatus* (West) Crawford, *Aulacodiscus kittonii* Arnott, and *Asterionellopsis glacialis* (Castracane) Round) occur in both hemispheres. Records from the tropics show that the original biogeographic limits previously set at between 29° S and 42° S are too narrow. Most surf diatoms are confined to surf-zones, never being recorded elsewhere (*A. armatus*, *A. australis*, *A. kittonii* and *A. socialis*) but at least one is a cosmopolitan species (*A. glacialis*). Accumulations form at fixed localities of the coastline and are semi-permanent features of the sandy beaches where they are found. The coastal features at the beaches where they have been recorded are similar.

Key words: *Anaulus, Asterionella, Attheya, Aulacodiscus, Asterionellopsis.*

RESUMEN

Las diatomeas de la zona de rompiente de las olas originan en forma regular coloraciones café en el agua de playas del hemisferio sur, como también en playas de Centro y Norte América. Las especies involucradas estan taxonómica y morfológicamente no relacionadas. Localidades diferentes tienen usualmente una o dos especies dominantes en el agua café, pero se han encontrado hasta cinco especies como codominantes. No hay un patrón global de distribución, sólo que el fenómeno es más común en el hemisferio sur. *Anaulus australis* Drebes et Schulz está restringido al hemisferio sur; *Asterionella socialis* Lewin et Norris es endémica del hemisferio norte, mientras que *Aulacodiscus africanus* Cottam parece ser una especie tropical. El resto de las diatomeas acumulantes de la zona de rompiente (*Attheya armatus* (West) Crawford, *Aulacodiscus kittonii* Arnott, y *Asterionellopsis glacialis* (Castracane) Round) ocurren en ambos hemisferios. Registros de aguas tropicales muestran que los límites biogeográficos originales previamente señalados entre 29° S y 42° S son muy estrechos. La mayoría de las diatomeas de la zona de rompiente están limitadas a esa zona (*A. armatus, A. australis, A. kittonii* y *A. socialis*), pero al menos una es una especie cosmopolita *(A. glacialis)*. Las acumulaciones se forman en localidades fijas de la costa y son características semipermanentes de las playas de arena donde ocurren. Las características de la costa donde estas diatomeas se han registrado son similares.

Palabras clave: *Anaulus, Asterionella, Attheya, Aulacodiscus, Asterionellopsis.*

INTRODUCTION

Sandy beach coastlines are turbulent zones where the harsh environment has mostly resulted in a barren phycocommunity: yet at a few beaches we find an abundance of diatoms belonging to a few taxa that thrive in these extreme conditions.

The oldest record of diatoms turning the water brown in surf-zones was in 1896 (Van Heurck 1896) who reported that "a large number of the *Aulacodiscus* are found in keep tropical seas, where they are sometimes formed in immense numbers; it was in this way that my friend, Mr. Hens in his botanical expedition to the Congo, found the sea-coast at Banana covered with a greenish bed of *Aulacodiscus africanus* Cott. and was able at once to fill a large vessel with this species, absolutely pure". The next reports were from the west coast of the United States of America (Becking et al. 1927; Thayer 1935)

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and Nicaragua (Thayer 1935) where the species was not determined. Thereafter there is a long gap in reports. The studies of surf ecosystems in New Zealand began the recent phycological interest in these ecosystems (Rapson 1954, Cassie & Cassie 1960). It is not certain whether people did not notice the brown patches in the water or whether their colour intensity was low, but very few records exist before 1950. In the second half of the century, the number of reports increased and today nearly 100 papers and reports have been published on sandy beach surf-zones with high diatom biomass.

The term "surf diatom" is used in this paper to refer to those diatoms that accumulate to high cell concentrations in surf zones. These diatoms form the brown patches in the surf on a semi-permanent basis (Campbell 1986, Odebrecht et al. 1995).

The first assessment of the global distribution of these diatom "blooms" in surf-zones was published in the proceedings of the First International Symposium on Sandy Beaches (Lewin & Schaefer 1983). An update appeared in a review by Talbot et al. (1990). The current knowledge of the distribution and characteristics of surf diatom accumulations is presented here.

Surf diatom species

In the first reports of the distribution of surf diatom accumulations, the following species were listed as being accumulation forming: *Anaulus australis* Drebes et Schulz (then incorrectly referred to as *A. birostratus* (Grunow) Grunow or *A. mediterraneus* Grunow); *Asterionellopsis glacialis* (Castracane) Round; *Asterionella socialis* Lewin et Norris; *Aulacodiscus kittonii* Arnott; *Aulacodiscus* petersii Ehrenberg; *Aulacodiscus africanus* Cottam and *Attheya armatus* (West) Crawford (Lewin & Schaefer 1983, Talbot et al. 1990). Several new localities have been reported since then. The earliest reference for each species at each recorded locality is given in Table 1.

Taxonomically, there is no connection between the diatom species that form surf accumulations. Both pennate and centric diatoms are represented. Cell morphology and habit also vary considerably. Surf diatoms vary from single cells to colonies and from large discoid (*Aulacodiscus kittonii*) to needle shapes (*Asterionella socialis*).

Types of patches

Originally the discoloration of the water by diatoms was referred to as a "bloom", i.e. caused by populations in an exponential growth phase that disappear when the bloom decays (Lewin 1974, McLachlan & Lewin 1981, Lewin & Schaefer 1983). After ecophysiological studies were undertaken (Campbell 1986), it was established that *Anaulus australis* and possibly several other surf diatoms do not bloom, but are a semi-permanent feature of surf-zones where they divide at a constant rate (Talbot & Bate 1986). This led to a change to using the term "accumulation" rather than "bloom" for *A. australis* (Campbell 1987, Talbot et al. 1990 and references cited therein). On the basis of the reports of other species, accumulating surf diatoms are: *Anaulus australis*, *Asterionella socialis*, *Attheya armatus* and *Aulacodiscus kittonii* as they are a semi-permanent feature at the localities where they are found (Cassie & Cassie 1960, Lewin 1974, Kindley 1983, Campbell & Bate 1990).

Asterionellopsis glacialis is a semi-permanent feature in southern Brazil for over 600 km of the coastline (VMT Garcia personal communication, May 1995, Odebrecht et al. 1995). McLachlan & Hesp (1984) also infer that *A. glacialis* may be a semi-permanent feature on the Australian coast at Goolwa (Table 1). However accumulations at Sundays River beach, South Africa were found to switch species from *Anaulus australis* to *Asterionellopsis glacialis* on occasion (Du Preez et al. 1990). After a few years of data collection it become evident that this switch always occurred in spring (Fig. 1). The species change to *A. glacialis* at Port Elizabeth lasted from 1 week to 1 month and coincided with the onset of the coastal spring bloom. Surf discolorations caused by this species could be considered to be either a bloom (surf bloom: as in South Africa or oceanic bloom: as in India, Choudhury & Panigrahy 1989) or an accumulation (as in South America and Australia).

TABLE I

The earliest reference for each locality at which surf diatom discolorations have been reported. The first record for each species is also given. The letters in parentheses following the reference refer to the localities shown in Figure 2

Referencias más antiguas para cada localidad en que se han mencionado descoloramientos de diatomeas en la zona de rompiente de las olas. También se entrega el primer registro para cada especie. Las letras en paréntesis que siguen a las referencias se refieren a las localidades que se muestran en la Figura 2

Locality	Reference	Species
Zaire	Van Heurck 1896 (A)	*Aulacodiscus africanus* Cottam
United States of America: Washington & Oregon	Thayer 1935 (B)	*Aulacodiscus kittonii* Arnott *Asterionella socialis* Lewin et Norris
Nicaragua	Thayer 1935 (C)	Unknown
New Zealand: Ninety Mile Beach	Rapson 1954 (D)	*Attheya armatus* (West) Crawford *Asterionellopsis glacialis* (Castracane) Round
New Zealand: North Island west coast	Cassie & Cassie 1960 (D)	*A. armatus* *A. glacialis*
United States of America: Washington & Oregon	Lewin & Norris 1970 (B)	*A. armatus*
South Africa: Cape Town, Port Elizabeth	McLachlan & Lewin 1981 (E)	*Anaulus australis* Drebes et Schulz
New Zealand: North Island west coast	Lewin & Schaefer 1983 (D)	*A. kittonii*
New Zealand: North Island east coast	Lewin & Schaefer 1983 (F)	*A. armatus* *A. kittonii*
Tasmania: Strahan beach	Lewin & Schaefer 1983 (G)	*A. armatus* *A. australis*
Brazil: Southeast coast	Lewin & Schaefer 1983 (H)	*A. glacialis*
Costa Rica & Panama	Lewin & Schaefer 1983 (I)	*A. africanus*
Australia: Warren beach	McLachlan & Hesp 1984 (J)	*A. australis*
Australia: Goolwa beach, Coorong	McLachlan & Hesp 1984 (K)	*A. glacialis* *A. australis*
South Africa: 12 beaches between Cape Town and Cintsa Bay	Campbell & Bate 1991b (E)	*A. australis*
South Africa: Port Elizabeth	Du Preez et al. 1990 (E)	*A. glacialis*
Gopalpur: India	Choudhury & Panigrahy 1989 (L)	*A. glacialis*
Argentina: Peuhen Co beach *A. glacialis*	Gayoso & Muglia 1991 (M)	*A. armatus*
Australia: Waratah Bay	Campbell sampled 1992 (N)	*A. australis*
New Zealand Waiuku beach	Campbell sampled 1992 (O)	*A. armatus, A. kittonii, A. australis,* Asterionella cf. *formosa, A. glacialis*
Venezuela	Gianuca pers. comm. (P)	Unknown

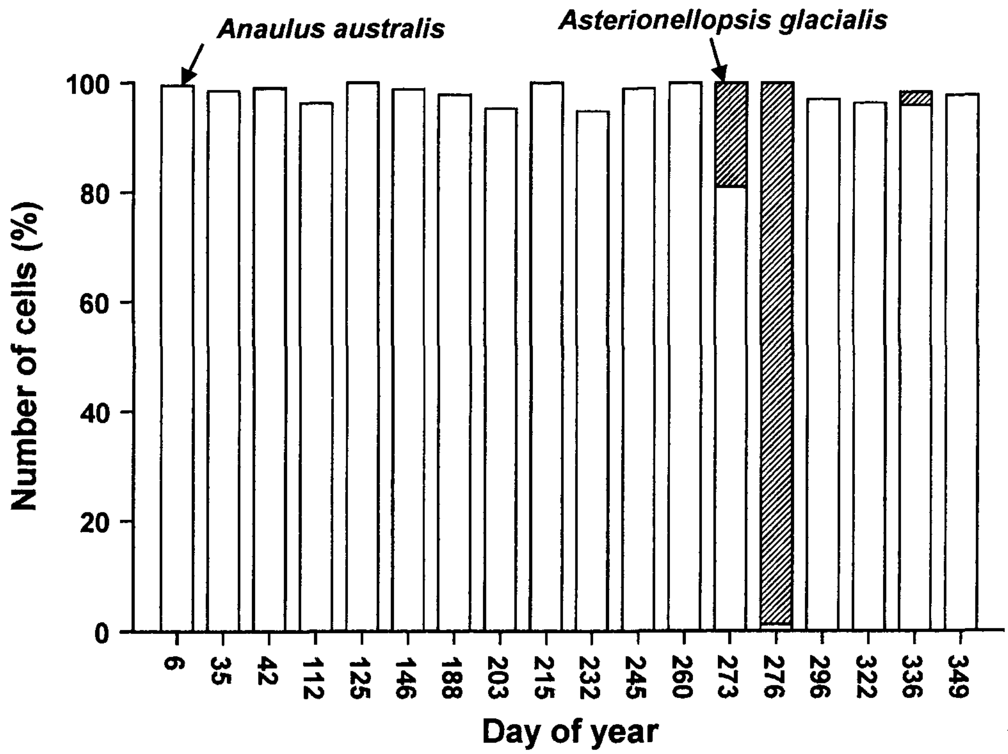

Fig. 1: The proportion of cells of *Anaulus australis* Drebes et Schulz and *Asterionellopsis glacialis* (Castracane) Round in surf diatom accumulations over a year at the Sundays River beach near Port Elizabeth, South Africa.

Proporción de células de *Anaulus australis* Drebes et Schulz y *Asterionellopsis glacialis* (Castracane) Round en acumulaciones de diatomeas de la zona de rompiente de las olas de la playa Sundays River cerca de Port Elizabeth, South Africa.

The other species that has been reported to bloom in surf-zones is *Aulacodiscus petersii* (Romer 1981, cited in Lewin & Schaefer 1983) but this species has never been reported to have turned the water brown. It cannot be grouped with the rest of the accumulating species, although it is confined to surf-zones. For this reason *A. petersii* is removed from the list of surf-zone accumulating species in this report (Table 1).

No information is available on how persistent *Aulacodiscus africanus* is.

Global distribution

Fig. 2 illustrates the areas where surf diatom accumulations have been recorded up to the present. The original suggestion of Talbot et al. (1990) that the active zone is a narrow strip in the southern hemisphere ranging from 29° S to 42° S is supported in that some of the new records fall within this strip. However, the tropical records cannot be ignored. Unfortunately, the species causing the discoloration in one of these reports is unknown.

The distribution of *Anaulus australis* is confined to surf-zones with very few cells found behind the breaker line (Talbot & Bate 1988). Accumulations of *A. australis* have been recorded between 32° S and 42° S in South Africa, Australia and New Zealand. No records exist for South America or the northern hemisphere.

Until recently, *Attheya armatus* was thought to form accumulations only in Australia, New Zealand and the west coast of the United States of America, but Gayoso & Muglia (1991) reported accumulations of *A. armatus* from the east coast of South America. No *A. armatus* cells have been reported from South Africa or the Australian continent, but are found as close as the Tasmanian west coast. This species has also been reported from the sandy beaches and inshore plankton of England, Scotland and

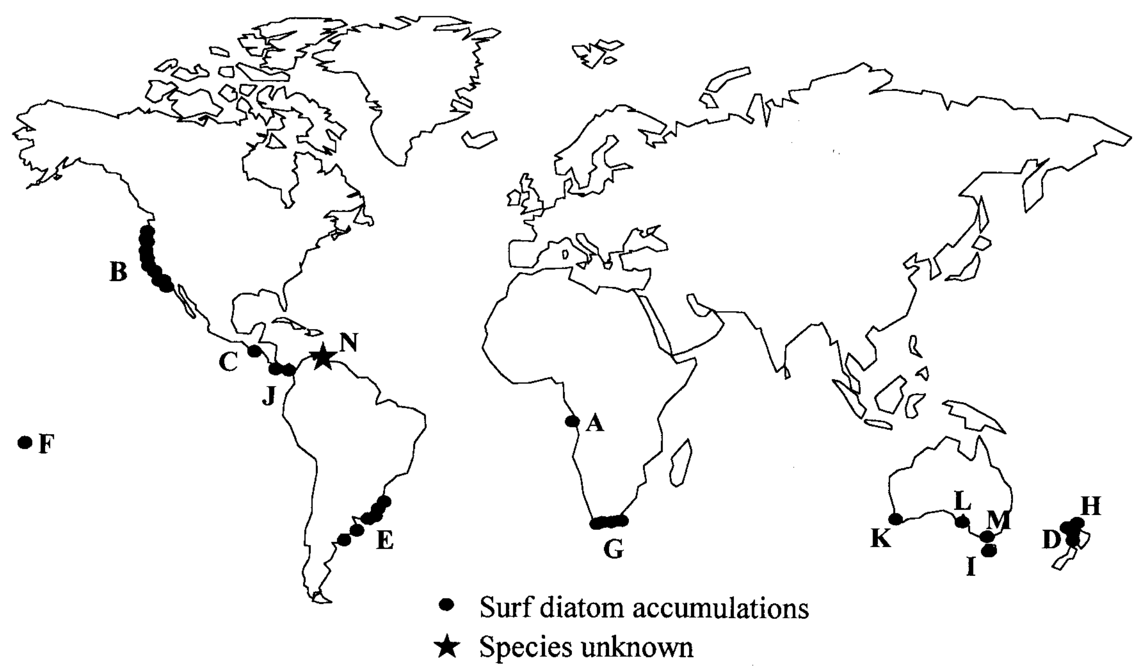

Fig. 2: The locations of reports of surf diatom accumulations. The letters refer to references listed in Table 1.

Localizaciones de los registros de acumulaciones de diatomeas de la zona de rompiente de las olas. Las letras se refieren a las referencias que se entregan en la Tabla 1.

Wales (Crawford et al. 1994). At these beaches conditions are probably unsuitable for accumulation development.

Accumulations with *Aulacodiscus kittonii* as the dominant species are limited to New Zealand. Thayer (1935) reported *A. kittonii* to be dominant on the west coast of North America, but all reports since 1970 show no further activity there.

Asterionella socialis appears to be endemic to the west coast of North America (Lewin & Norris 1970).

Asterionellopsis glacialis is a cosmopolitan species that is found in oceanic waters as well as in surf-zones. Oceanic occurrences of *A. glacialis* blooms (e.g. Choudhury & Panigrahy 1989) are excluded from this discussion. *A. glacialis* was found to be commonly dominant in diatom accumulations of South America (Gianuca 1983, Gayoso & Muglia 1991, Odebrecht et al. 1995) and Australia (McLachlan & Hesp 1984), and sub-dominant to occasionally dominant in South Africa (Du Preez et al. 1990), Tasmania (McLachlan & Hesp 1984) and New Zealand (Rapson 1954).

Aulacodiscus africanus is endemic to the tropics (Van Heurck 1896, Lewin & Schaefer 1983).

All surf diatom accumulations were found to contain one or two species that become dominant and comprised more than 95% of the cells in the patch. However, one exception was found recently. On a sampling trip to New Zealand in 1992, a diatom accumulation was sampled at Waiuku beach, New Zealand. This accumulation was dominated by *Aulacodiscus kittonii* but contained an almost equal abundance of *Attheya armatus*, and many cells of *Anaulus australis* and *Asterionellopsis glacialis*. It can no longer be accepted that at most two species co-dominate surf diatom accumulations (Talbot et al. 1990). The same sample contained an abundance of the freshwater diatom, *Asterionella formosa* Hassall in the brown surf foam (third most abundant). The dynamics of such observations are unknown.

It is impossible to formulate a distribution hypothesis without long-term studies at sites where accumulations have been recorded. It is however probable that the global distribution of surf diatoms is not based on latitude, but that accumulations may form wherever the coastal conditions are suitable. Suitable conditions have been listed as: long sandy beach of moderate to high energy; rip current activity and an associated dune system (Campbell & Bate 1990) providing nutrients by groundwater flow (Campbell & Bate 1991a, 1991b). It is likely that any beach that complies with these prerequisites may have surf diatom accumulations. It is possible that the northern hemisphere, with its large land masses and sheltered coastlines, has very few suitable beaches, with the exception of the U.S.A. west coast. Testing the hypothesis developed (Campbell & Bate 1990, 1991a, 1991b) resulted in a new record for Australia and another new one for New Zealand (Table 1). An investigation of all potential sites based on these three features should be done rather than concentrating on a latitude-based hypothesis.

It is also possible that increased urbanisation is resulting in increased nutrient input into coastal systems and that beaches that were nutrient poor, are now able to support a larger biomass of primary producers. Increased urban and agricultural pollution of coastal aquifers together with the mismanagement of aquifer resources will result in an increased nutrient loading into surf-zones.

An example of nutrient input increasing surf diatom biomass is in False Bay, South Africa. At times the water turns black with diatoms (Campbell & Bate 1991b). Up to 10 million *Anaulus australis* cells have been recorded per millilitre in this water. This black water causes an outcry from the public complaining about the "polluted" water. However, before 1980, the public did not notice the diatom discolouring the water. On the basis of the recent increase of coastal eutrophication on a world-wide scale it is possible that surf diatom accumulations may increase both in intensity and distribution.

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