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Coastal eutrophication, land use changes and *Ceratium furca* (Dinophyceae) blooms in Pago Pago Harbor, American Samoa 2007–2009*

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Abstract The bloom forming dinoflagellate, *Ceratium furca*, has been linked with coastal eutrophication worldwide in tropical and subtropical locations. During the summer of 2007, an unusual 6-month long bloom of *C. furca* was observed in Pago Pago Harbor, Tutuila Island, American Samoa. Incidents of dinoflagellate blooms in this area have not been previously reported. The bloom was first reported in May and dissipated in November 2007. In February–March 2009, a similar *C. furca* bloom was observed. During both blooms, no fish mortality events were reported. Maximum cell counts were observed on September 20, 2007 at 9 200 œll/mL. At this time, total nitrogen was measured at 1.2 mg/L while total phosphate was below detection limits.

Changes in land use practices may have been the primary driver of these blooms. Intense fertilization of athletic fields coupled with ineffective management strategies is hypothesized to have a direct link to the increase in nutrients found in the Pago Pago Harbor and may have been the trigger for the initialization of these blooms. During 2008, the fields were not used due to an infestation of the fire ant, *Solenopsis geminata.* Once controlled, the fields were opened again in 2009 and fertilizers were applied in January, a month before the bloom was observed.

Keyword: eutrophication; American Samoa; *Ceratium furca*

1 INTRODUCTION

Algal blooms, including toxin events can be natural phenomena. Many harmful algal bloom species (HABs) are increasing in world wide distribution, with negative effects on economy and human health (Smayda, 1997). The dinoflagellate, *Ceratium furca* is known to cause anoxic red tides, which have direct effects on fish by damaging gills or promoting low dissolved-oxygen concentrations (Horner et al., 1997). Persistent blooms have been reported in the North Sea, North Atlantic Ocean, Indian Ocean and southeastern Asia area (Graham, 1941; Nordli, 1953; Elbrachter, 1973; Qasim et al., 1973; Machida et al., 1999; Baek et al., 2006). *C. furca* is a slow growing, relatively large dinoflagellate linked to coastal eutrophication worldwide.

Many sources of nutrients can stimulate HABs, including sewage and animal wastes, atmospheric deposition, and groundwater flow, as well as agricultural and other fertilizer runoff (Anderson et al., 2002). Fertilizer application on land remains a major contributor to nonpoint nutrient pollution and is increasing at an alarming rate in many geographic regions (Vitousek et al., 1997). Many studies have shown a strong correlation between total N input into estuaries and coastal water with total phytoplankton production (Anderson et al., 2002). Repeated incidence of increased, high-biomass blooms provides evidence of a broadly

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based, stimulatory effect on phytoplankton from anthropogenic nutrients.

This manuscript describes a repeated high-biomass bloom of *Ceratium furca* and land use change which promoted this bloom occurring in Pago Pago Harbor, American Samoa. Long lasting algal blooms from this location were not observed at this location until 2007.

2 MATERIAL AND METHOD

A red water event was first reported to the local newspaper in May 2007. To identify this bloom, whole water samples were collected by water quality research staff of the American Samoa Community College using kayaks (Fig.1). Samples were observed live and subsequently preserved in 2% gluteraldehyde. Cell counts were conducted using a 1-mL Sedgewick Rafter Counting Chamber. For species identification, fixed samples were desalted using a 10% step gradient from seawater to freshwater on polycarbonate filter paper and dehydrated by using a step gradient of acetone (10%–100%), coated with 1.5 nm of gold using a Denton Desk II sputter-edge coater (Moorestown, USA) and examined under the SEM JOEL 5600LV (Tokyo, Japan). Nutrient concentrations were measured with the Hach total nitrogen and phosphorous colorimetric test kits.

3 RESULT AND DISCUSSION

3.1 2007

Pago Pago Harbor turned a red-brown for the first time in May 2007. An observation of this bloom was first reported by The Samoa News, the local newspaper. Collected samples were identified as *Ceratium furca* using both light and electron microscopy (Fig.2). The bloom was a monospecific bloom with cell counts greater than 1 000 cell/mL. The highest cell density observed was 9 200 cell/mL, which occurred in September 2007. At this time total nitrogen was measured at 1.2 mg/L. The bloom continued until October 2007, which coincided with the discontinuation of fertilizer application.

During the height of the bloom, two separate transects were undertaken using kayaks and the samples analyzed for the presence of *C. furca* (Fig.3). The first transect, in July 2007, had the highest cell abundance of 4 700 cell/mL at stations A and B. The abundance of *C. furca* decreased as one progressed to the mouth of the harbor. At this time,

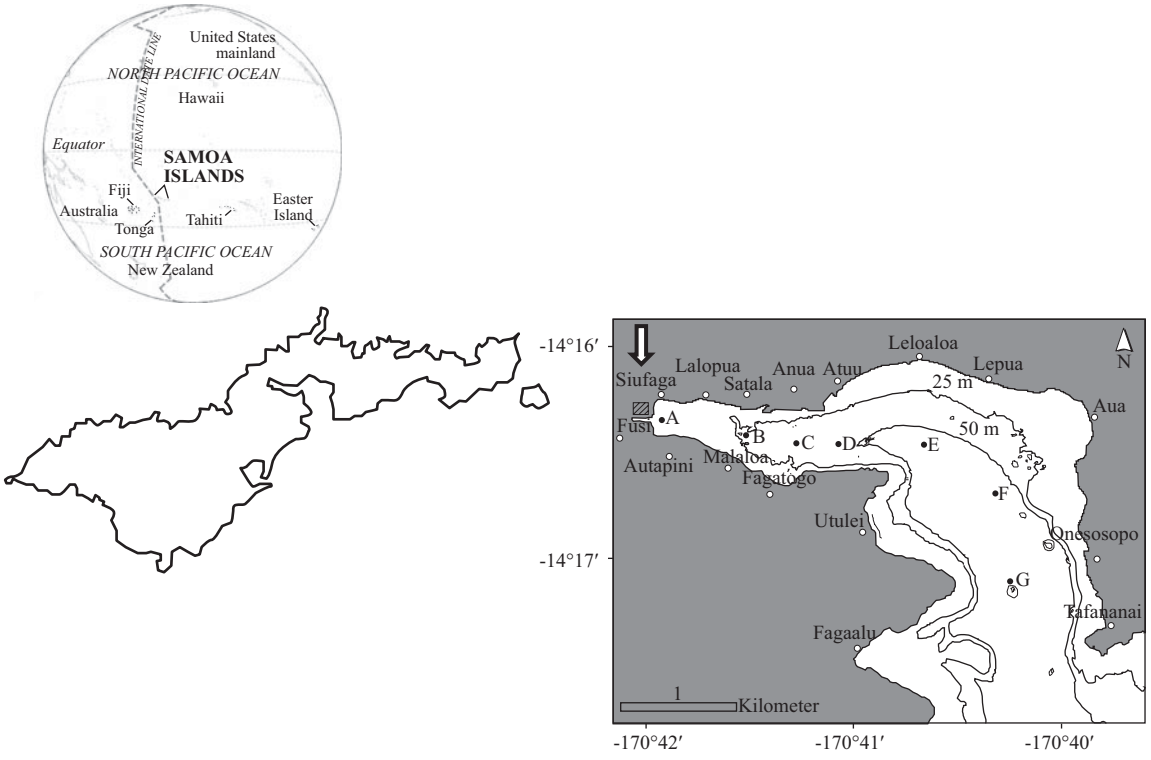

Fig.1 Location of American Samoa in the Pacific Ocean (top) and Pago Pago Harbor along with the transect stations (bottom) (Arrow indicates the location of the FIFA soccer field)

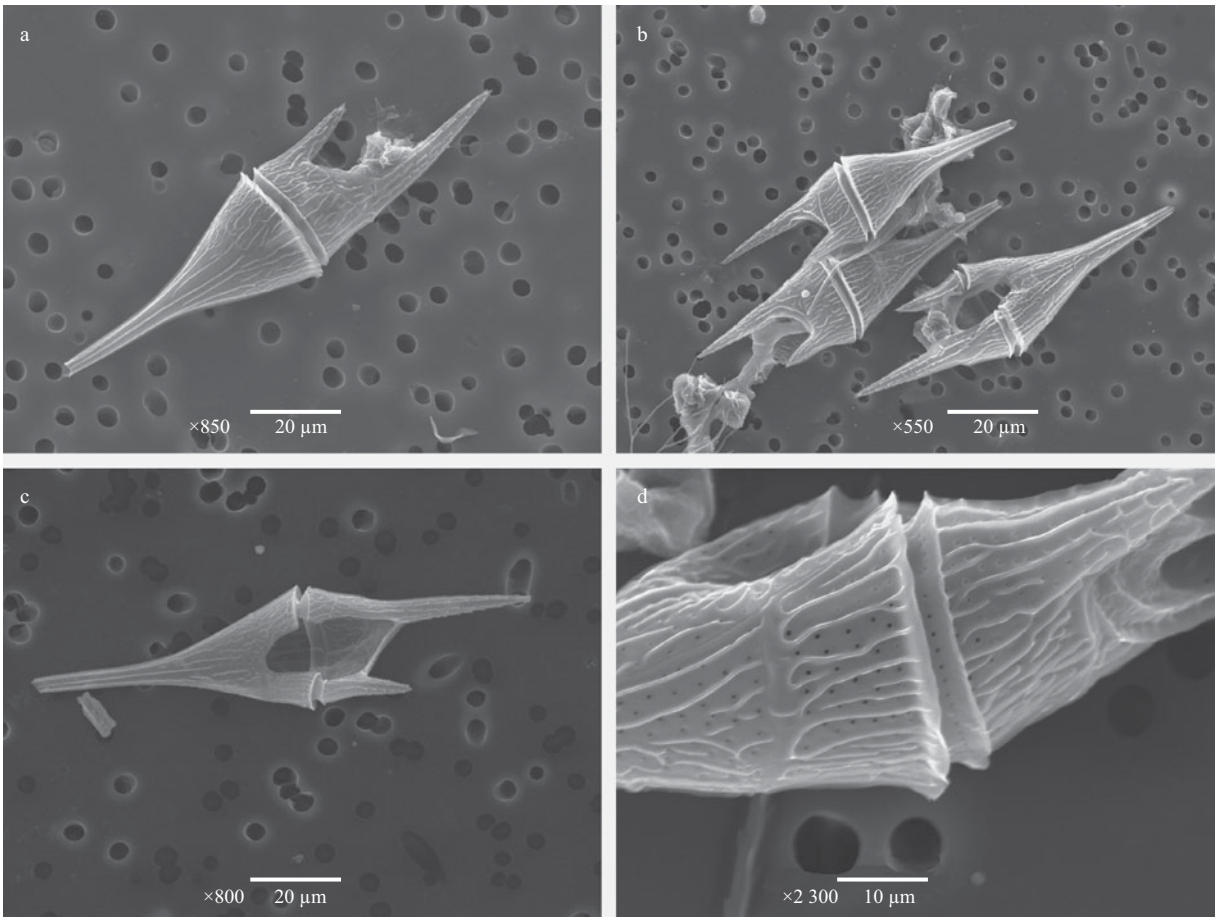

Fig.2 Scanning electron micrograph of *Ceratium furca*

a. dorsal view of a single cell; b. three cells of *C. furca*; c. ventral view of *C. furca* showing the enlarged sulcus; d. view of the thecal surface

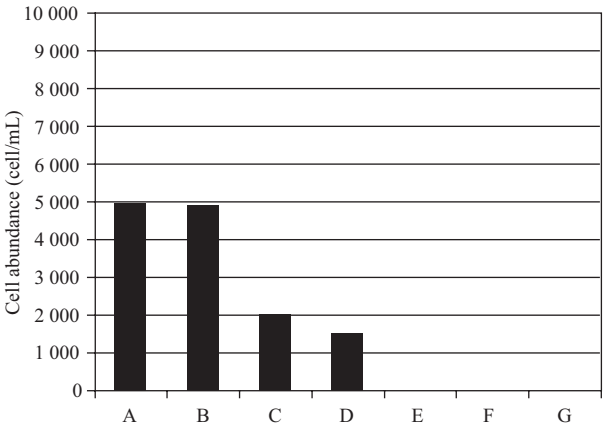

Fig.3 July 2007 transect where the highest cell abundance of 4 700 cell/mL at stations A and B

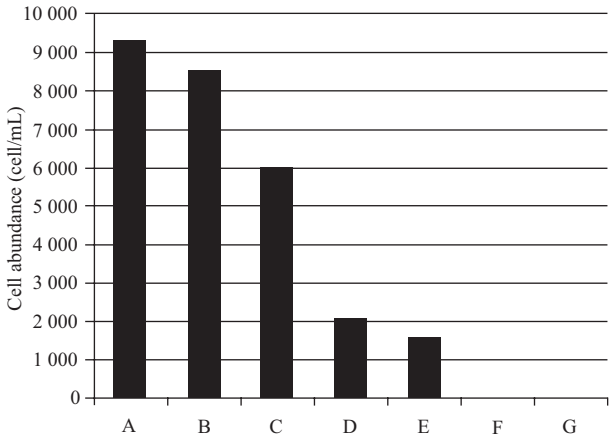

Fig.4 September 2007 transect where the highest cell abundance of 9 200 cell/mL at station A

total nitrogen was measured at 1.5 mg/L while total phosphate was below detectable levels. The second transect, in September 2007, at approximately the same sites as the July transect, again found the highest cell number at station A, with counts decreasing with distance from the head of the harbor. During the September transect, the highest cell number was 9 200 cell/mL at station A despite having slightly lower total nitrogen concentrations (1.2 mg/L) (Fig.4). The bloom also extended one

additional station farther into the harbor than the July transect.

Since this high biomass bloom occurred for several months at densities greater than 1 000 cell/mL, a constant or near constant source of nutrients was examined. Possible sources included the harbor's tuna fleet, Pago Pago's pig farming and the newly constructed International Federation of Association Football (FIFA) soccer field located near the mouth of the harbor. The practices of both the tuna fleet and pig farms on Pago Pago have changed little over the years, and as such would have impacted the harbor prior to 2007 (personal observations). This made the soccer field the logical source of the nutrient additions. During the installation to increase drainage, gravels columns leading to draining tiles emptied directly into Vaipito stream which feeds Pago Pago harbor. Construction of this field was finished in March 2007 and followed in April 2007 by an aggressive every third day fertilizer application. A cap of locally available coral sand was used for the construction of the 1-hectare fields lying adjacent to the head of the harbor. Nutrient tests indicated its pH was above 8.0 and it was extremely low in both phosphorus and potassium. In an attempt to establish the struggling turf in time for a mid-September 2007 opening, liquid phosphate, chicken manure, dried sewage sludge, and ammonium sulfate were liberally applied. (L. Stubbing, personal comm. Jan. 21, 2008). Between April and October 2007 over 1 000 kg of fertilizer was applied to the field. The 1 000 kg value was derived from the number of 50-kg bags of fertilizer used by the applicator. Furthermore, no natural buffer or effective run-off management practices were implemented to mitigate the effects of this regiment on the harbor.

3.2 2008

The soccer field was rendered unplayable due to an infestation of fire ants (*Solenopsis geminata*). First recorded in American Samoa in 2002 (Wetterer and Vargo, 2003), these invasive ants have since become widely established in areas of well-drained, sandy soil. The large colonies of fire ants kept the field closed for the 2008 season until the species was controlled. The Environmental Protection Agency banned the use of then-available insecticides to control the fire ant infestation. Consequently, no bloom was reported while fertilization was discontinued and hydramethylnon applied to control the ants.

3.3 2009

In preparation for the field's use, fertilizer was applied in January 2009. The bloom of *C. furca* reappeared in February 2009. At this time the maximum cell abundance observed was 4 300 cell/mL at station A. Nutrient concentrations were not measured during this bloom. The fertilizer application was halted in March and the bloom soon dissipated rapidly. Further fertilizer applications were halted until better management practices and changes in the drainage of the field were completed.

On September 29, 2009, a magnitude 8.0 earthquake triggered a tsunami which devastated Pago Pago. Several American Samoan villages were completely destroyed including the soccer field and related structures. Presently, the soccer field is currently being rebuilt using best management practices to reduce the influence of nutrient addition.

4 CONCLUSION

This high biomass algal bloom in nutrient-poor tropical waters is remarkable, and is probably due in part to low tidal exchange coupled with the almost constant supply of fertilizer. The primary factor involved was likely the increased drainage of the soccer field supplying the harbor with the necessary nutrients to sustain these blooms. The combination of low tidal exchange and routine influx of nutrients produced an environment analogous to a chemostat culture of *Ceratium furca*. Culture experiments by Baek et al. (2008) showed that growth rates of *C. furca* increased readily in high N:P nutrient conditions. Thus, *C. furca* has an advantage over other algal species in phosphorus-limited environments. This event serves as a good example of the necessity for scientists to be accessible and approachable by community planners. Open dialogue between all involved allowed for the identification of the source of this issue and the implementation of necessary changes to affect positive results.

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