Red Tide Algal Bloom, Pago Pago Harbor

In May 2007, people in American Samoa noticed something unusual happening in their main harbor. The water at the head of Pago Pago Harbor, a commercially important deep water harbor that nearly bisects the island of Tutuila, took on a color resembling red primer. By mid-June, a solid patch of this hue extended several hundred meters from the head of the harbor, where Vaipito Stream empties into it (Figure 1). People living and working around the harbor began to speculate as to the cause. Opinions ranged from a sewage leak in Pago Pago Village (through which the steam runs), raw piggery waste being washed into the stream, high-phosphate detergents used to clean boat hulls, a major diesel fuel leak, to an underwater volcano.

Figure 1. Pago Pago Harbor, 21 June 2007. (Photo: S. Fanolua).

In early July marine biologist Douglas Fenner speculated that the off-color water was probably caused by a harmless red dinoflagellate, since it was not accompanied by fish kills. He attributed the algal bloom to high nutrient levels, possibly from high-phosphate laundry detergents.

Having only a stereoscope but no microscope, Dr. Fenner asked our assistance. Our Plant Pathologist, Fred Brooks, quickly confirmed Dr. Fenner's educated guess. Dr. Brooks tentatively identified the alga as the dinoflagellate *Ceratium furca* (Figure 2). Ceratium-dinoflagellates are protists, a poorly defined group of organisms that are neither bacteria, fungi, plant, nor animal. But like animals, they can capture food directly from the water or, like plants, produce their own food through photosynthesis. Unlike some other dinoflagellates that are usually responsible for red tides, *C. furca* does not produce a neurotoxin that could kill fishes and other marine animals.

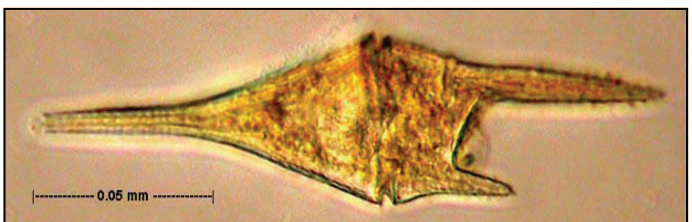

Figure 2. *Ceratium furca.* (Photo: F. Brooks)

The harbor mouth is open to prevailing easterly trade winds, so little mixing occurs at the harbor head. Because of the obvious abundance of *C. furca* over several months, Dr. Fenner's assumption that high nutrient levels were sustaining the bloom was probably correct. To test this, we collected surface water samples (Figure 3) in order to compare cell counts to nitrogen and phosphorus levels. We sampled from the head of the harbor to its mouth

Figure 3. Sample collection (Photo: A. Vargo).

(Figure 4). With the aid of a Sedgwick-Rafter, a 1 ml sample holder resembling a microscope slide but with a grid of 1,000 etched squares (Figure 5), we obtained accurate and reproducible cell counts. We tested the water for total N and total P after filtering and persulfate digestion. While no phosphate was detected, a plot of cell counts and total N at each collection site confirmed Dr. Fenner's guess (Figure 6).

Because the algal bloom originated at the harbor head, where Vaipito Stream enters into it, we suspected that the source of the excess nitrogen originated at that point as well. We hypothesized that a nitrogen flush ended shortly before our sampling occurred, and that flow from the stream pushed the N-plume a distance of over 1 km away from the harbor head. The dinoflagellate, being active swimmers and suspended—not dissolved—may have offered some resistance to this flow. The presence of *C. furca* at site G may represent either the remnant from an earlier N-flush or the vanguard of the latest N-flush.

A sample of algae sent to Steve Morton, Program Lead at NOAA's Phytoplankton Monitoring Network in Charleston, South Carolina, confirmed the organism was *C. furca.* Dr. Morton also acknowledged that a consistent nutrient source was required for such an extensive bloom to persist for such a long period. Finally, Dr. Morton sent a scanning electron micrograph of our dinoflagellate (Figure 7).

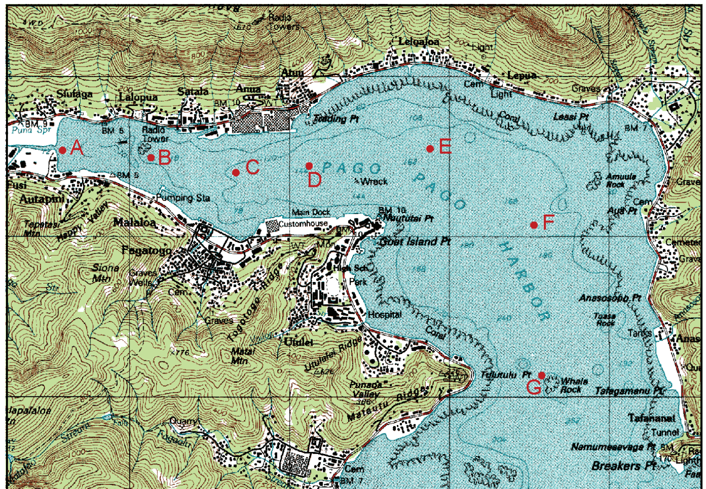

Figure 4. Seven collection sites in Pago Pago Harbor, 06 July 2007. Length of track from the head, at A, to G is about 4 km.

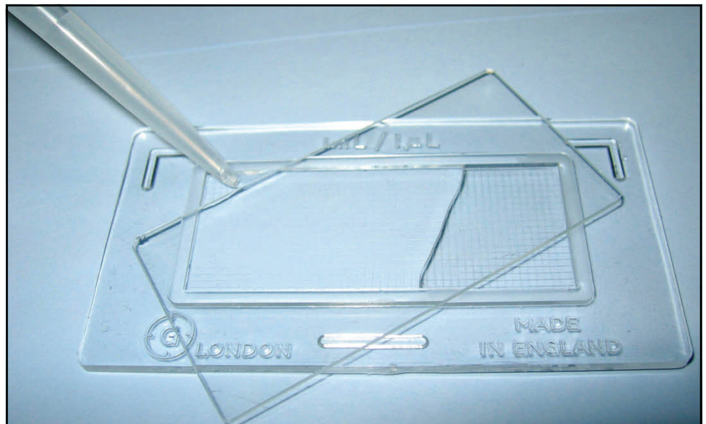

Figure 5. Sedgwick-Rafter for counting alga cells.

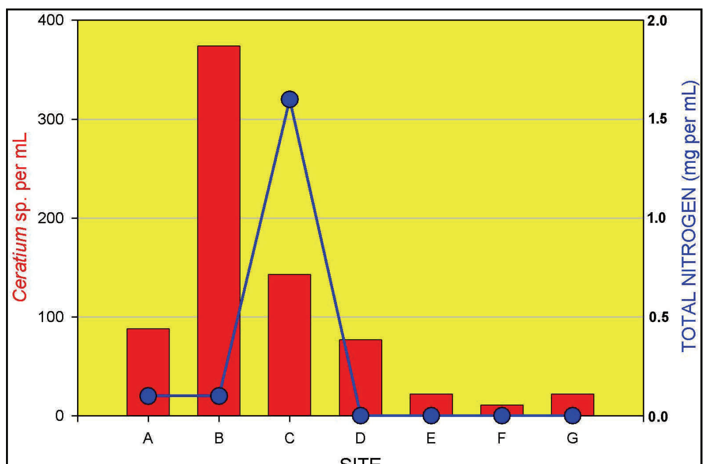

Figure 6. Correlation of *C. furca* cell counts to total nitrogen at the seven collection sites in Pago Pago Harbor.

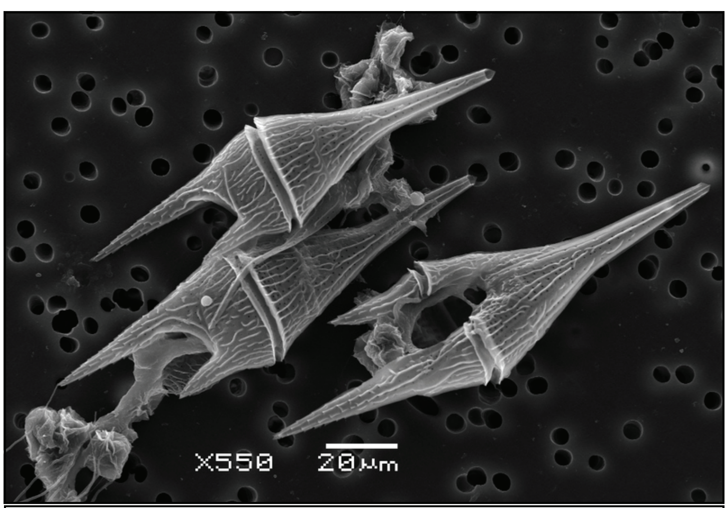

Figure 7. *Ceratium furca*. (Photo: L. Symon).

Figure 8. Pago Pago Harbor, 25 December 2007. The FIFA soccer field lies to the right of the widened mouth of Vaipito Stream. The stream runs through Pago Pago Village, seen in the background. (Photo: D. Vargo).

To identify the source of the nitrogen contamination, we walked the course of Vaipito Stream. We failed to find a piggery and any evidence of a septic tank leak. However, adjacent to both the stream and the harbor was a new International Federation of Association Football (FIFA) soccer field. We learned from the field manager that the turf was being treated with weekly applications of ammonium sulfate in order to prepare for the official opening in mid-September. An underlying cap of calcareous sand and drainage tiles allowed excess fertilizer to quickly find its way into the harbor. Suggestions by our Cooperative Extension Service on best management practices allowed for a much reduced application rate of fertilizer without sacrificing turf quality. The result was a substantial savings in fertilizer costs and the eventual disappearance of the algal bloom (Figure 8).

Although we found no excess phosphorus in our search for a cause of the 2007 red tide algal bloom in Pago Pago Harbor, phosphorus must have been present nevertheless. Like nitrogen, phosphorus is a limiting nutrient vital for plant growth. One pound of phosphorus, for instance, can grow 700 pounds of algae. It has been implicated in the eutrophication of natural waters and algal blooms elsewhere. For this reason, laundry detergents sold in the United States may no longer contain phosphates since being banned in 1993. However, the ban did not extend to the US Territory of American Samoa.

One consequence of the Pago Pago Harbor algal bloom was the issuing of Executive Order No. 010-2007 by American Samoa Governor Togiola Tulafono. Primarily addressing efforts to ameliorate global climate change, the order also included a provision that, “In order to combat the destruction of coral reefs by increased algae blooms, the importation of all high-phosphate (greater than 11%) detergents will be banned beginning October 1, 2007.”

In order to identify which, if any, laundry detergents sold in American Samoa were considered “high-phosphate” according to the Executive Order, a high school honors student determined phosphates levels in a dozen locally popular laundry products. Talaleu Fanene, a senior at Tafuna High School, began her study under our supervision in January 2008. In addition to testing a handful of widely sold powders and liquids, she tested three bar soaps used in hand laundering. Into each 3 cm x 5 cm x 34 cm bar is impressed “COLGATE-PALMOLIVE CP” on one 5-cm side and “PACIFIC” on the other. Manufactured in Fiji, they are differentiated only by color: yellow, green, and orange.

Phosphate may be present in one or more of four forms in a laundry detergent: sodium tri-polyphosphate (NaP_3O_{10}), sodium pyrophosphate ($Na_4P_2O_7$), sodium hexametaphosphate $(NaPO_3)_6$, and sodium orthophosphate (Na_2HPO_4). This latter form—orthophosphate—is the only form available to plants. It is the form for which colorimetric methods have been developed for measuring its concentration in solution. Ms. Fanene, therefore, measured phosphate concentrations twice: once by determining the amount of orthophosphate and again after converting the other forms of phosphate that might be present into orthophosphate. This latter technique requires heating the sample in sulfuric acid and is reported as "total phosphorus." She found that none of the samples tested was considered "high-phosphate" as defined in the Governor's Executive Order (Figure 9).

Phosphates are commonly added to laundry products in order to remove any calcium cations that may be dissolved in the water. Otherwise, calcium would bind to the soap or detergent and lessen its cleaning power. The concentration of calcium cations (and to a lesser degree, magnesium cations) dissolved in water is a measure of the water's hardness. Based on an average hardness (calc.) of 22.9 $\pm$ 12.7 mg equivalents $CaCO_3$/L, derived from over 1,000 measurements of Tutuila Island's streams between 2003 and 2005, and assuming the hardness of ground water matches that of surface water, the concentration of calcium and magnesium cations in our water is insignificant to affect the cleansing power of soaps and detergents. Therefore, phosphates in soaps and detergents are unnecessary American Samoa and only serve to pollute our streams and ocean.

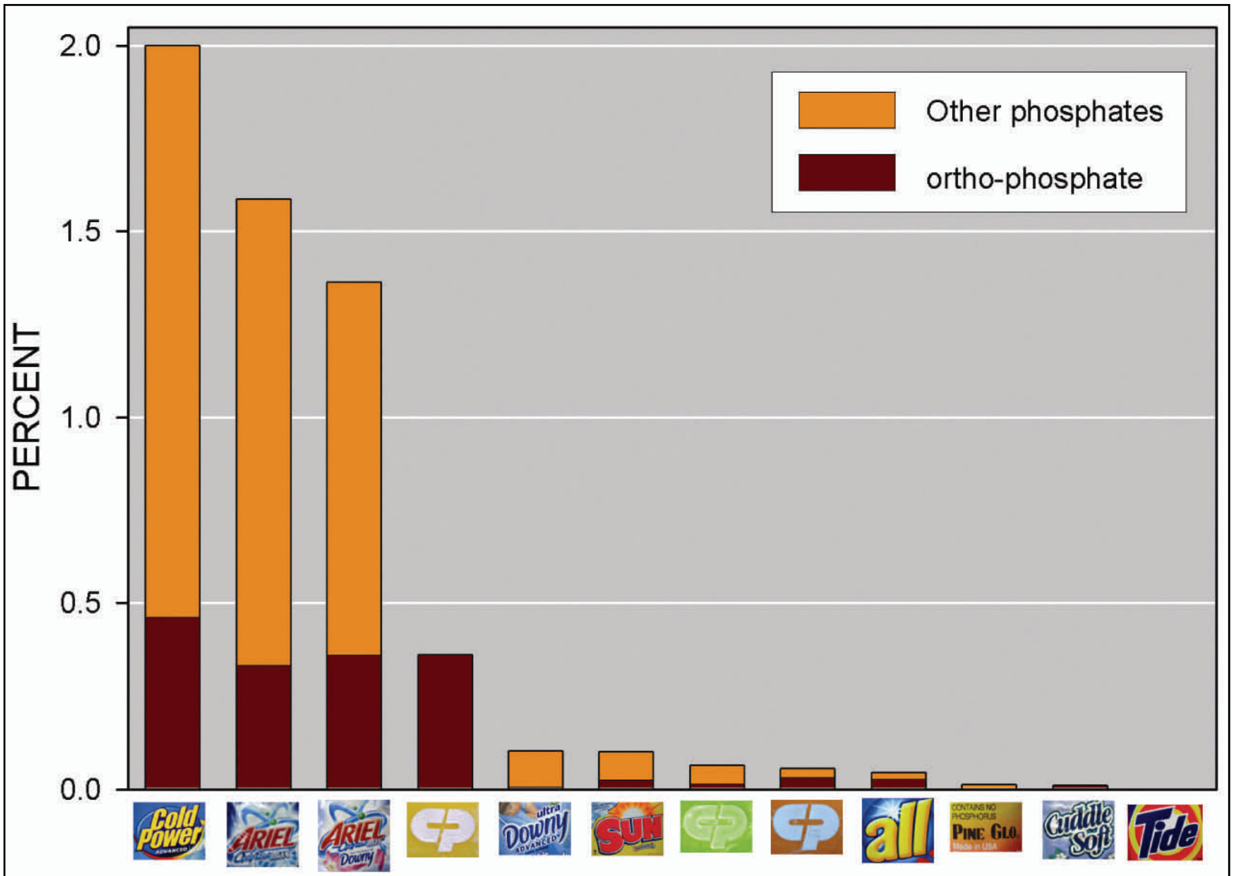

Figure 9. The percent phosphate, by weight, in popular laundry products sold in American Samoa in 2008. Cold Power, Ariel, Ariel with Downy, Sun, and All are powders. Downy, Pine Glo, Cuddle Soft, and Tide are liquids. The three CP products are bar soaps.

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