Control of marine harmful algal blooms: assessing the state of current technology

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HAB Management Approaches
(Boesch et al. 1997)

<u>Prevention</u>

"…environmental management options for reducing the incidence and extent of [HABs] before they begin…"

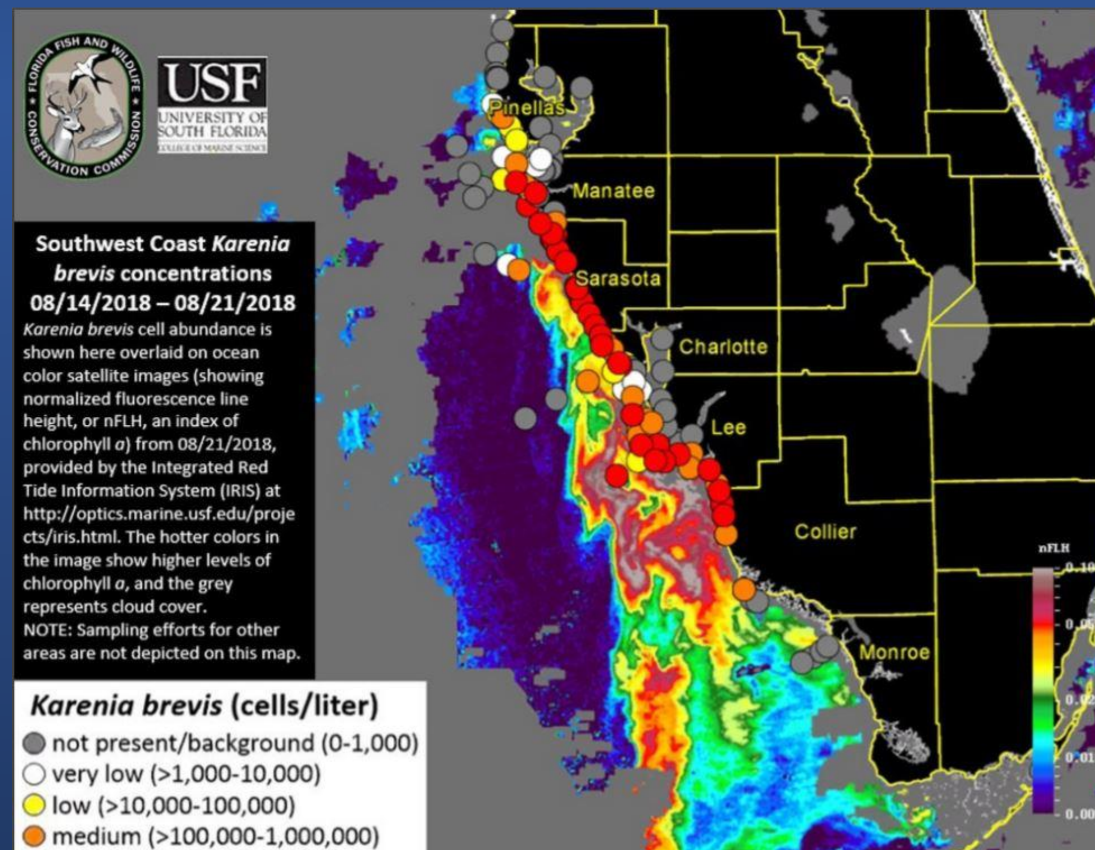
<u>Mitigation</u>

"…steps that can be taken to reduce the losses of resources and economic values, and to minimize human health risks…"

<u>Control</u>

"…actions that can quell or contain blooms…"

During the 2017 – 2019 red tide, the HAB scientific and management community let the people of Florida down. Faced with a major, sustained crisis (a disaster), we had nothing to offer in terms of bloom control strategies.



Why?

- A long history of inaction, an overabundance of environmental caution, <u>and</u> few, scalable technologies.
- This is true in the US and in most (but not all) countries affected by HABs.

Bloom control or suppression

- chemical control
- biological control
- physical control

Chemical control - Copper sulfate dispersal

Rounsefell and Evans (1958) U.S. Fish and Wildlife Service, Special Report No. 270

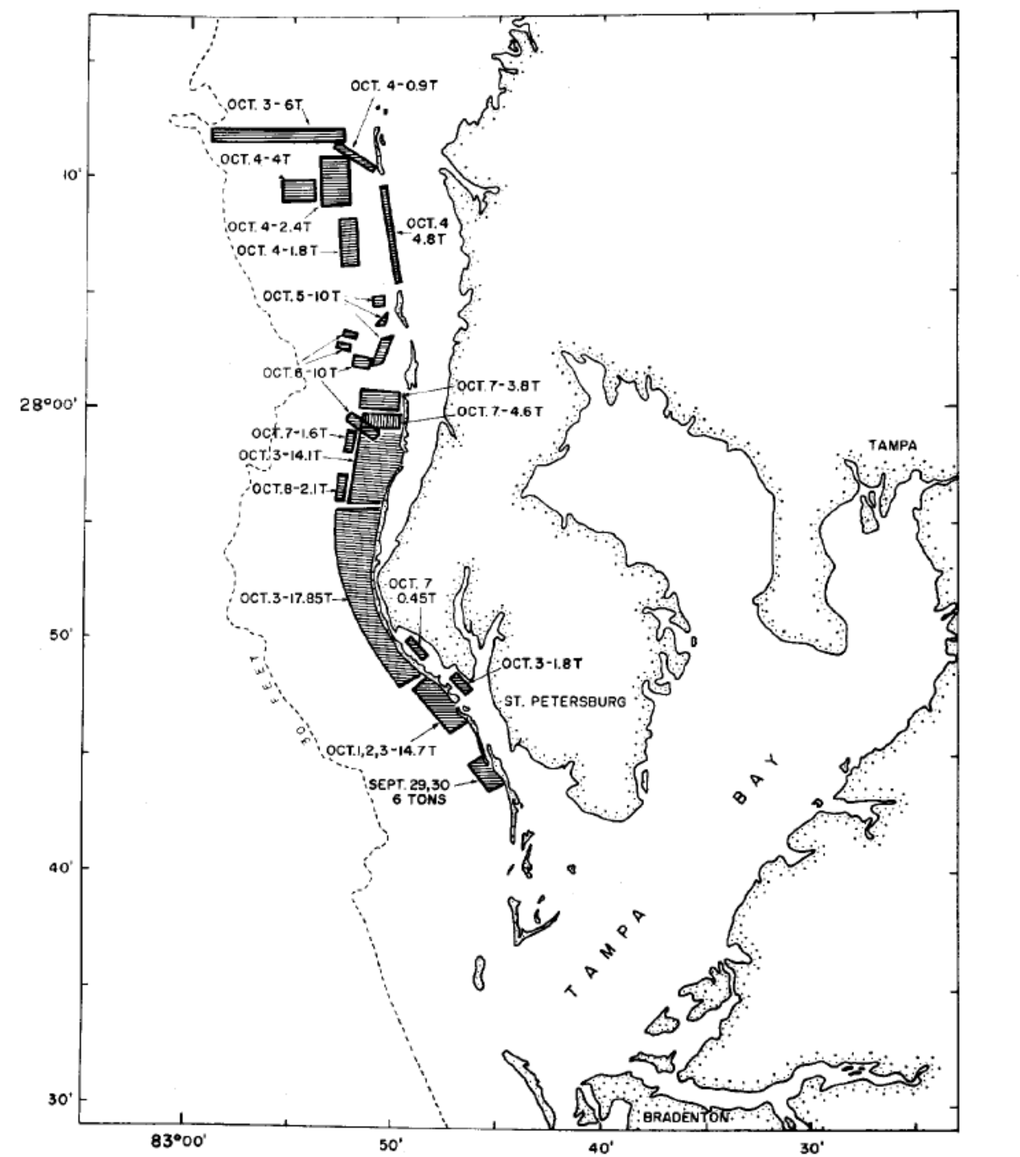


Figure 2.--Areas dusted with copper sulfate showing the dates and the tonnage used (see table 1).

First (and last) large-scale treatment of a marine red tide or HAB in the U.S.

September-October 1957

Bloom: 10 million cells/L

Area: 16 mi² (~40 km²)
Alongshore: 32 mi (~50 km)
Offshore: 3 mi
Depth: 10 – 20 ft

Dosage: 0.18 ppm (ca. 20 lbs/acre)
Total used: 105 tons

Dispersal methods:
- boats dragging burlap bags
- crop dusting planes

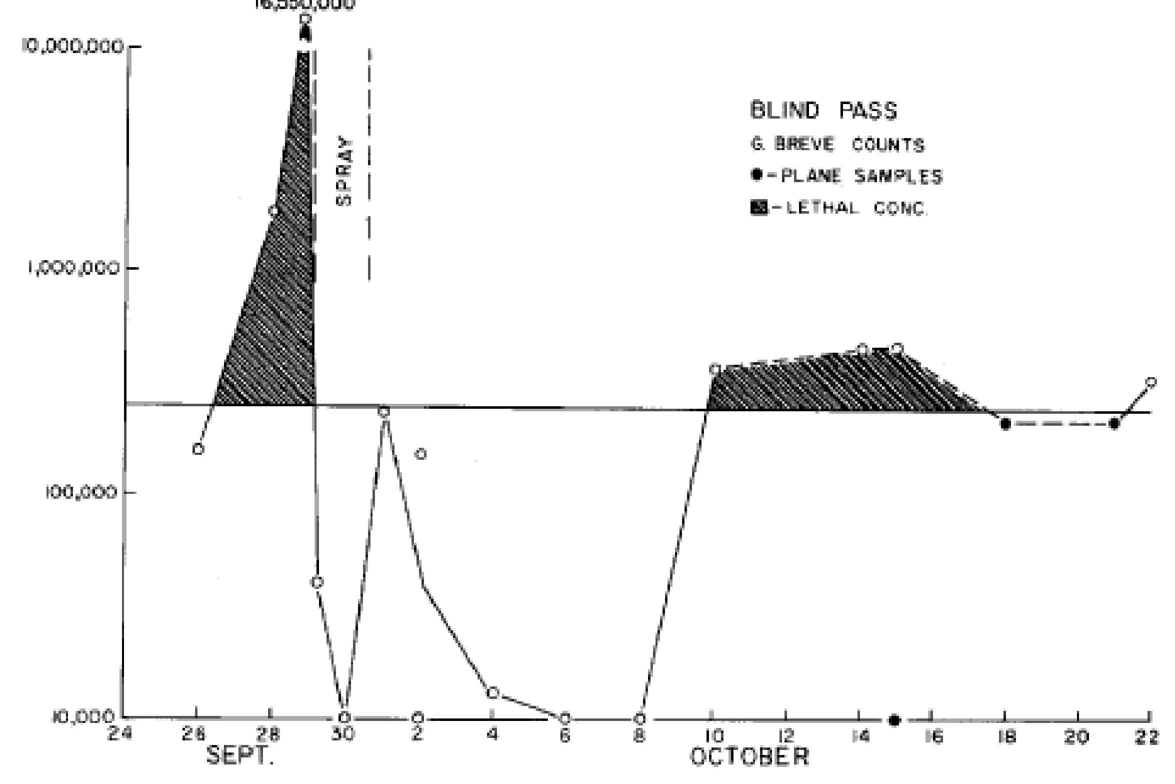


Figure 14.--Numbers of red tide organisms per liter off Blind Pass.

Results:

1) Rapid effect – cell concentration decreased to 0, relief from aerosol problems

2) Small red tide returned in 2 out of 5 localities after 10-14 days

3) Method deemed effective but only provided temporary relief, considered costly ($10.000/mi^2 in 2019 dollars), with unknown but broad collateral damage – not recommended for future outbreaks

Chemical screening

Martin and Proctor (1964) U.S. Fish and Wildlife Service Data Report 2

Preliminary tests

4,306 compounds were tested (between 0.01 to 1.0 ppm)

Karenia brevis cultures at 1-2 million cells/L (no soil extract, no EDTA)

Compounds causing 100% mortality after 24 hrs at 0.01 ppm tested further

Number of compounds lethal at dilutions as low as	0.01 p.p.m.	55
Do.	.04	191
Do.	.10	284
Do.	.40	740
Do.	1.00	1,047
Number of compounds not toxic at	1.00	3,259

Martin and Proctor (1964) Fish Bull, 66(1): 163-164

Final tests

Only 5 of 55 compounds showed low lethality to test species after 24 hrs at 0.01 ppm

Of the 5, only diethylthiocarbamic acid was consistent in killing *K. brevis*, with only 10% mortality in 2 of the 8 test organisms

This compound was ultimately rejected due to cost.

Rich Pierce to give an update of possible chemical control of red tides

Chemical control:

We have not yet found a “magic bullet” chemical that can kill or suppress a target HAB species without causing mortalities of other, co-occurring organisms.

Solutions?

- Accept some level of collateral mortality if justified by the benefits.

But – will agencies and the public allow us to put such chemicals into the ocean?

Biological control

Introduction of non-native predatory or pathogenic species or enhancement of native species.

Is it possible?

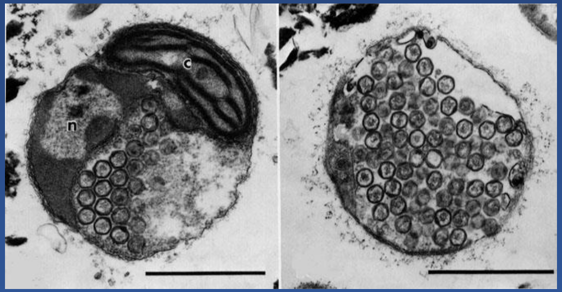
Theoretically – yes. We have host-specific predators, parasites and pathogens for many HAB species, including *Karenia*.

Examples of Biological Control

Viruses

Target species	Agent	Reference
Heterosigma akashiwo	virus HAV01	Nagasaki et al., 1999
	virus HaNIV	Lawrence et al., 2001
Heterocapsa circularisquama	virus HcV	Tarutani et al., 2001
Aureococcus anophagefferens	VLP	Gastrich et al., 2002
Alexandrium catenella	VLP	Onji et al., 2000
Gymnodinium mikimotoi	VLP	Onji et al., 2000
Tetraselmis sp.	VLP	Onji et al., 2000
Lyngbya majuscula	virus	Hewson et al., 2001

VLP = virus-like particles

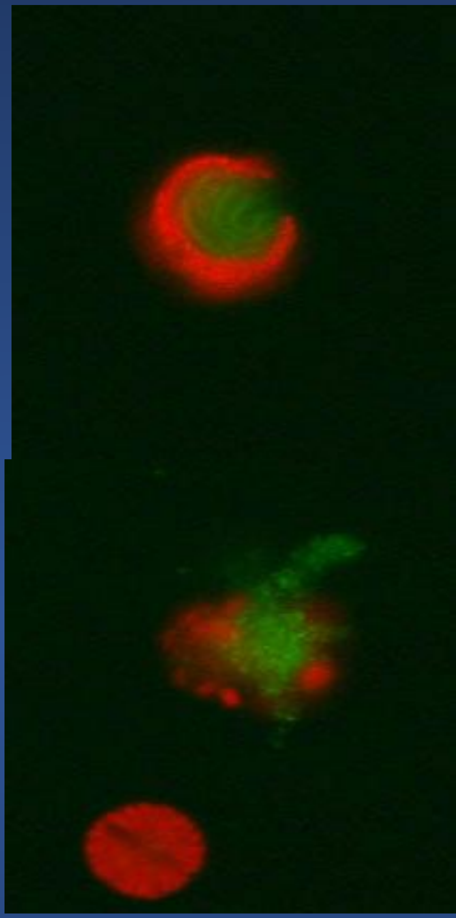


Bacteria

Target species	Agent	Reference
Heterocapsa circularisquama	Cytophaga sp AA8-2	Nagasaki et al., 2000.
Heterosigma akashiwo	H. akashiwo-killing bacteria (HAKB) H. akashiwo-killing bacteria (HAKB)	Kim et al., 1998 Yoshinaga et al., 1998
Cochlodinium polykrikoides	Micrococcus sp. LG-1	Park et al., 1998
Chattonella ovata	Altermonas sp. strain S, strain R, Cytophaga sp J18/M01	Imai 1997
Chattonella verruculosa	Altermonas sp. strain S, strain R, Cytophaga sp J18/M01	Imai 1997
Karenia mikimotoi	28 strains	Yoshinaga et al., 1997
Karenia brevis	bacterium 41-DBG2	Doucette et al., 1999

Parasites

Target species	Agent	Reference
Peridinium balticum	*Coccidinium duboscqui*	Chatton and Biecheler, 1934
Dinophysis sp.	*Parvilucifera infectans*	Noren et al., 1999
Alexandrium spp.	*Parvilucifera infectans*	Noren et al., 1999
Alexandrium catenella	*Amoebophrya ceratii*	Taylor, 1968
	Amoebophrya ceratii	Nishitani et al., 1984
Alexandrium tamarensis	*Amoebophrya ceratii*	Jacobson, 1987
Dinophysis norvegica	*Amoebophrya ceratii*	Fitz and Nass, 1992
	Amoebophrya ceratii	Janson et al., 2000
Akashiwo sanguinea	*Amoebophrya ceratii*	Coats and Bockstahler, 1994
Gyrodinium uncatenum	*Amoebophrya ceratii*	Coats et al., 1996
Prorocentrum minimum	*Amoebophrya sp.*	Maranda, 2001



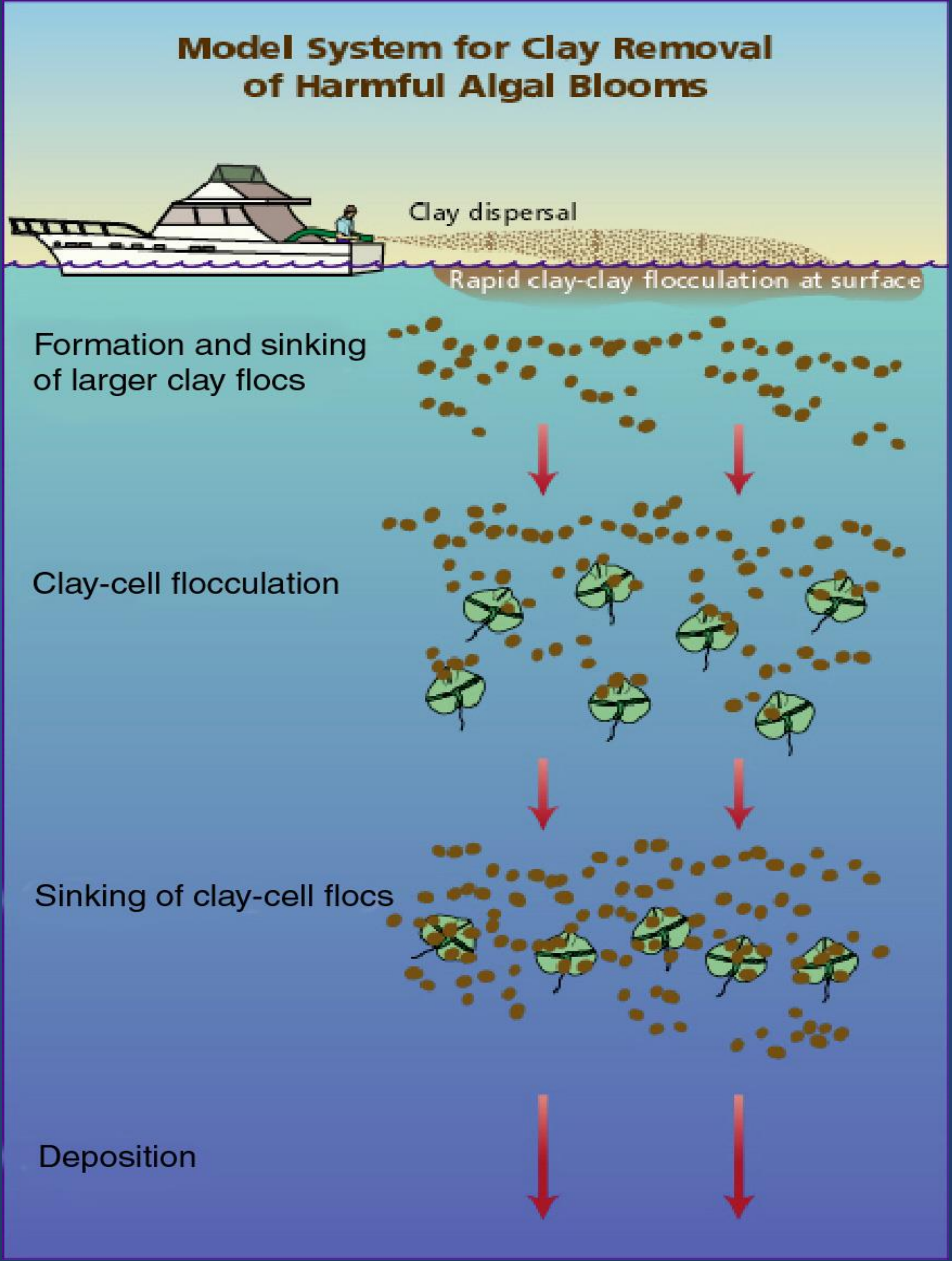
Biological control

- Research has demonstrated high host specificity and rapid proliferation of some pathogens against some HAB species in laboratory studies.
- But, there have been no tests of biocontrol using introduced pathogens in the field.

- Concerns:
  1. Will the introduced species impact organisms other than the original target species?
  2. How can one economically grow enough cells to affect a bloom?
  3. Will society allow a pathogen or other biocontrol agent to be introduced?
     - *Bacillus thuringiensis* for insect control

Physical cell removal

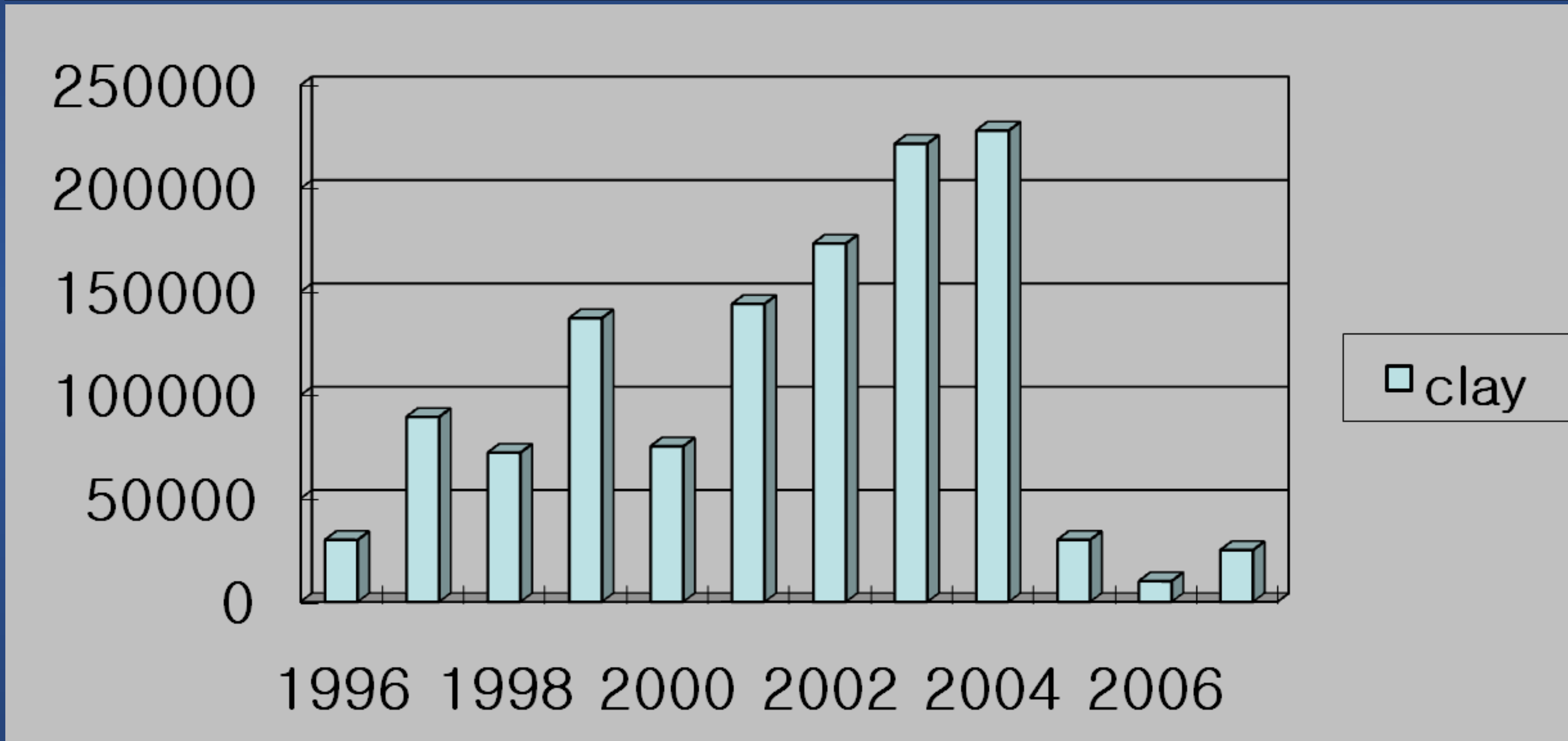
– clay and flocculants



- Why Clay?
  - Successful use against HABs in Korea and China
  - Abundant, relatively inexpensive
  - Present in most aquatic systems
  - Low environmental impacts

South Korea - clay dispersal now routine as a HAB mitigation strategy at fish farms

The amount of clay dispersed (tons) to fight *Cochlodinium* blooms in Korean waters since 1996.

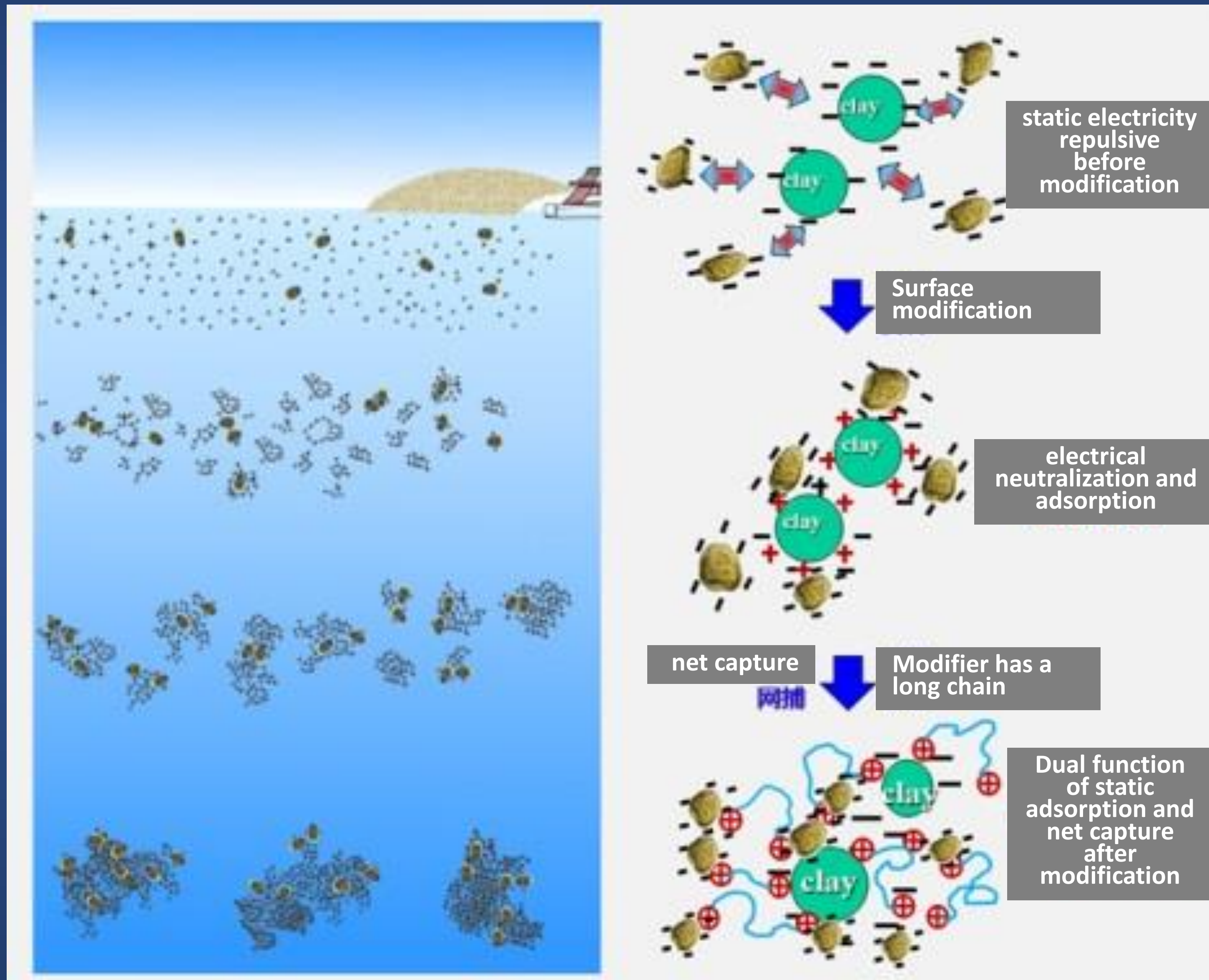


"Numerous HAB mitigation methods have been examined in Korea, including yellow clay, marine bacteria, microscreen filtration and ozone, ultraviolet radiation, parasitic dinoflagellates, and microzooplankton predators of bloom species. Nevertheless, no other control methods have been used extensively in the sea except yellow clay. " Park et al. 2013.

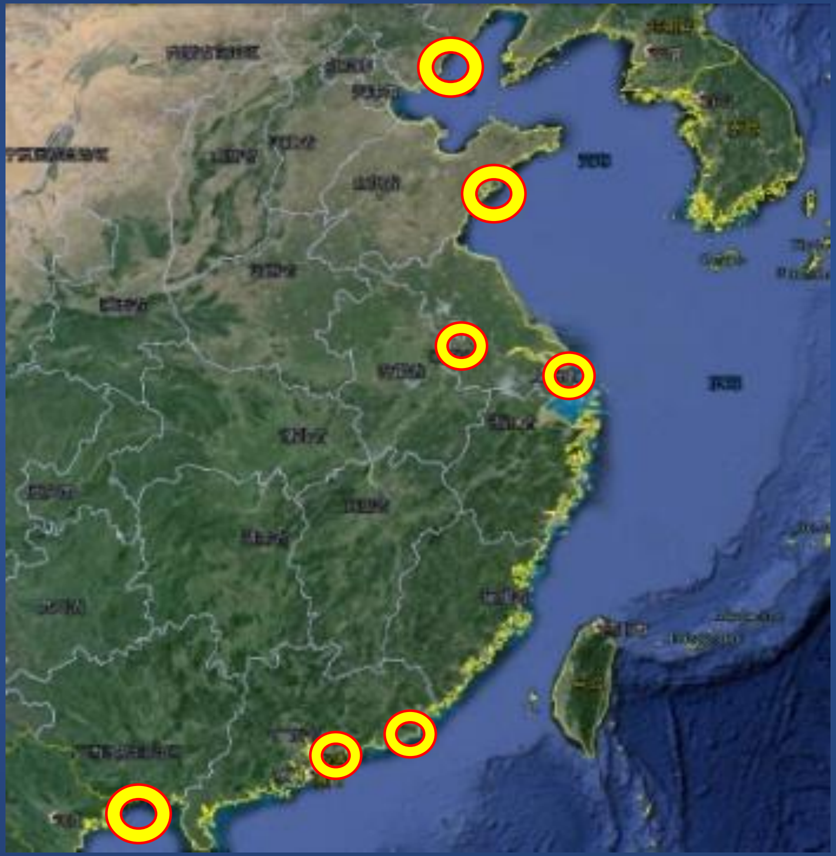
Area typically treated
~ 80 km^2 (30 mi^2)

Application of modified clays - the Chinese approach

Modified clay has a high removal efficiency



HAB treatment using clay in China



- Modified clay has been used for large-scale HAB control on more than 20 occasions along the coast of China. Treatment areas are all large and some have exceeded 100 km^2 (~40 square miles)
- The amount used in the field is generally 4-10 tons /km^2.
- The cost of the clay is ~ $500/ton, so $2,000 - $5,000 per km^2

Yu, Z., Song, X., Cao, X. and Liu, Y., 2017. Mitigation of harmful algal blooms using modified clays: Theory, mechanisms, and applications. *Harmful algae*, *69*, pp.48-64.

Environmental impacts

- Benthos
  - The thickness of clay deposited after a treatment is exceedingly small. Assuming an even deposition:

Clay loading used	Thickness of deposited layer
4 tons/km^2	0.012 mm
10 tons/km^2	0.04 mm

  - Marine organisms are well adapted to clay in sediments. Tests of a range of benthic indicator organisms shows adverse effects only at unrealistically high clay loadings, or when the clays are kept suspended for days to weeks.

  - <u>Korea</u>: *"Ecosystem impacts due to clay dispersion, particularly the benthos, have been assessed since 1998. No significant differences in biomass or species composition of the benthos such as annelida, mollusca, decapoda, or anthropoda have been observed between the areas of clay dispersal and control areas*. (NFRDA 2008, cited in Park et al., 2013).

  - <u>China</u>: *"Both laboratory and field results have demonstrated that modified clays can improve water quality after treatment and pose no negative effects on aquatic ecosystems.*

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Toxicity of clay flocculation of the toxic dinoflagellate, *Karenia brevis*, to estuarine invertebrates and fish

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Abstract

The environmental effects of clay flocculation used to remove red tide dinoflagellate blooms from the water column are relatively unknown on benthic organisms. The primary objective of this study was to determine the laboratory-derived toxicities of clay flocculation of the toxic dinoflagellate, *Karenia brevis*, for four common estuarine test species. Phosphatic clay mixed with a coagulant (polyaluminum hydroxy chloride (PAC)) was not acutely or chronically toxic in most cases to infaunal amphipods (*Leptocheirus plumulosus* and *Ampelisca abdita*), grass shrimp embryos (*Palaemonetes pugio*) and larval sheepshead minnows (*Cyprinodon variegatus*). *K. brevis* alone (density range = 3880–5060 cells ml^{-1}; brevetoxin (Btx) range = 19.8–140.7 $\mu g\, l^{-1}$) was very toxic to *C. variegatus* and, to a lesser extent, *L. plumulosus*. The addition of clay–coagulant did not usually reduce this toxicity. The combination of clay, coagulant and *K. brevis* cells when settled over a natural sediment were usually as toxic to the benthic test species as *K. brevis* alone. This result suggests that clay flocculation of *K. brevis* blooms will neither increase, nor decrease toxicity to benthic organisms relative to that attributable to an untreated bloom. Validation of this conclusion, however, is required since it is based on laboratory-derived, single species toxicity data using media collected from a simulated red tide event. The determination of environmental effects on indigenous benthic biota in near-coastal areas during a natural red tide event, prior to and after treatment with clay flocculation, would provide the perspective needed for a more realistic hazard assessment of this possible control procedure.

"This result suggests that clay flocculation of *K. brevis* blooms will neither increase, nor decrease toxicity to benthic organisms relative to that attributable to an untreated bloom."

Brevetoxin adsorption onto clay

Toxin removal experiments

Objective: To determine the efficiency of brevetoxin removal using phosphatic clay and PAC as flocculating agents (0.25g/L clay)

K. brevis	cell concentration (cells/L)	loading (g/L)	PAC (ppm)	toxin removal rel. to control
intact	5×10^6	0.25	-	99%
intact	5×10^6	0.25	5	99%
intact	10×10^6	0.25	5	99%
lysed	5×10^6	0.25	-	80%
lysed	10×10^6	0.25	-	68%
intact	5×10^6	3.3	-	94%
intact	5×10^6	3.3	5	98%

Conclusions:

- 94 - 99% of the cells were removed from the culture within 4 hours
- 70 – 80% of dissolved toxin removed in 4 hours

Pierce, R.H., Henry, M.S., Higham, C.J., Blum, P., Sengco, M.R. and Anderson, D.M., 2004. Removal of harmful algal cells (*Karenia brevis*) and toxins from seawater culture by clay flocculation. *Harmful Algae*, *3*(2), pp.141-148.

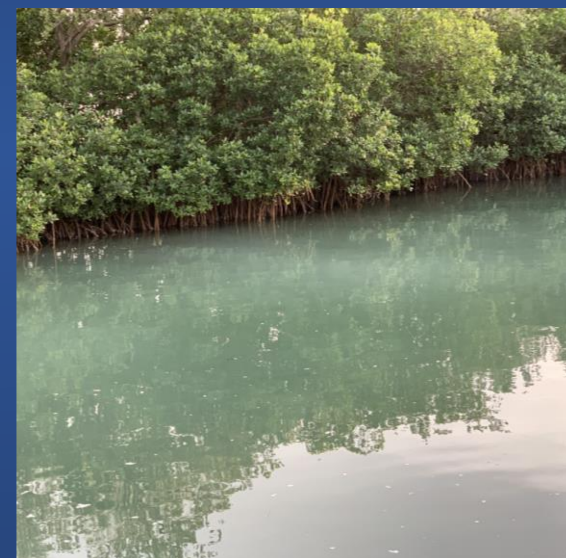
Pilot study: Field dispersal of modified clay Sarasota Outboard Club, December 2018

Parameters

- Sensors：salinity、pH、DO、turbidity
- Biology：Chla、cell counts of *Karenia brevis,* other phytoplankton; bacteria
- Toxin (both in water and sediment)：PbTx-2、PbTx-3、PbTx-C.A.
- Chemistry：turbidity, COD、PN、PC、PP, NH_4-N、PO_4-P, NO_3
- Heavy metals：Mn、Fe、Co、Ni、Cu、Zn、Cd、Pb, Al
- Benthos






Final thoughts – what do we know?

- Many red tides are disasters and should be treated as such
- The public (and politicians) want some level of red tide control.
- There are promising bloom control strategies that are either in use in other countries, or that are in stages of laboratory development that justify field trials. Of these , clay dispersal is the most widely used globally. Pilot-scale studies of this approach are planned in southwest Florida over the next several years.
- There will be no single red tide control method for all locations. Multiple approaches need to be explored.
- Large-scale control of established blooms over hundreds of kilometers of coastline may never be feasible, but targeted applications at the onset of blooms, or in localized areas like bays, passes, or canals may be.
- Some who oppose bloom control often fail to acknowledge the damage cost of the HABs to that same environment -- what are the impacts of the HAB itself? That should be the control condition against which impacts of the treatment are assessed.
- The increased prevalence and awareness of freshwater HABS in the US may help advance the field of marine HAB control, as control practices are more common in freshwater lakes and reservoirs that are smaller, less dynamic, and more easily treated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Acknowledgments

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Cost estimates

- Cost of modified clay ~ US$ 500/ton
- Application rate 4- 10 t/km^2 .
- Clay cost to treat one km^2 ~ US$2,000 - $10,000
- Vessel costs ~ US$ 1,000 – 5,000 / ship /day.
- Labor ~ ?????

- Aerial spraying???????

Sierra Club criticizes use of clay to stem red tide outbreak

Posted September 25, 2018 by Seán Kinane & filed under News and Public Affairs.

Summary of pilot study results

- Chl -*a* was low and *Karenia brevis* was virtually absent in the study area.
- No significant changes were observed in dissolved or particulate nutrients, trace metals, benthic clams, or dissolved toxins after the treatment.
- Chl-*a* decreased about 53% following treatment. This is a relatively low removal efficiency, but reflects the absence of high concentrations of large *Karenia* cells, which flocculate and are removed much more easily than smaller species.
- Turbidity decreased after the clay treatment, but some residual cloudiness (around 30% of initial levels during spraying, and 5X control levels) remained after 3 hours. One possible explanation is that the area had high dissolved organic material concentrations (DOM), which can inhibit flocculation

commentary

Turning back the harmful red tide

Harmful algal blooms are a serious and increasing problem in marine waters, yet scientists and funding agencies have been slow to investigate possible control strategies.

Donald M. Anderson

Each holiday season I await the visit of one relative with trepidation. Years ago he asked whether I had "stopped that red tide problem yet?" — a simple question from one convinced that science solves problems directed to a so-called expert on the destructive and often visible 'blooms' of phytoplankton that kill fish, make shellfish poisonous and cause numerous other problems in coastal waters. I explained that we did not understand the causative organisms, their ecology or oceanography well enough to propose control strategies, but that one day we would.

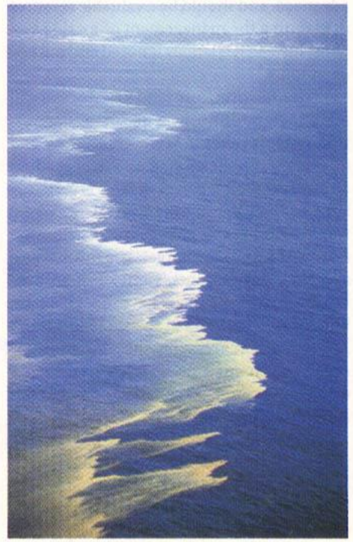
Although temporarily satisfied with my argument, each year thereafter my brother-in-law repeated the question, and each year my answer was the same. Whatever progress had been made, there were new questions to be addressed. Eventually, he concluded that I did not want to solve the problem, as that would end my research programme. He is wrong, of course, but the explanation is far more complex than he would think, and is in part the subject of this article.

Throughout history, blooms of microscopic algae have had a major impact on fish, birds, mammals and other organisms in the

recent proliferation of harmful blooms[1]. There is debate about the nature and causes of this expansion. Some call it a global epidemic linked to pollution and human changes to coastal ecosystems[2]. Others argue that the expansion is in part an artefact reflecting increases in the number of scientists, advances in toxin detection, and the proliferation of aquaculture and other activities requiring product monitoring[1,3].

One thing is certain — there is a growing global problem at a time when human reliance on coastal zones for food, recreation and commerce is rapidly expanding. Nevertheless, there is practically no exploration of direct control of marine blooms — attempting to kill or remove the cells or reduce their toxicity. At an international conference on harmful algae held in Vigo, Spain, in June, only one contribution of more than 400 abstracts from 58 countries addressed direct control of marine blooms. Imagine the difference if the conference had been on agricultural pests or on algal blooms in fresh water, where control efforts are common.

Research efforts on mitigation strategies such as shellfish-monitoring and aquaculture site management are critically important, but they treat the symptoms without



P. J. S. FRANKS, SIO

Some red tides, such as this non-toxic bloom of *Noctiluca* off California, cover huge areas, making it difficult to foresee environmentally benign bloom-control strategies (see also http://www.redtide.whoi.edu/hab/).

"Harmful algal blooms are a serious and growing problem in marine waters, yet scientists and funding agencies have been slow to investigate possible control strategies"

1997 Anderson, D. M. Turning back the harmful red tide. Nature 388:513-514.