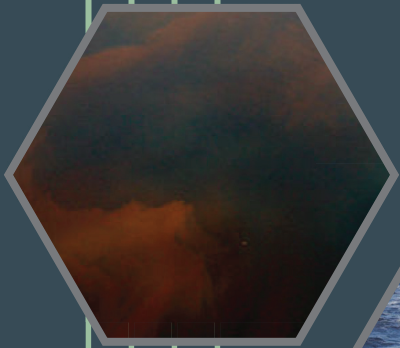

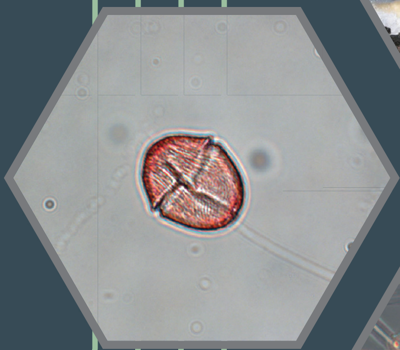
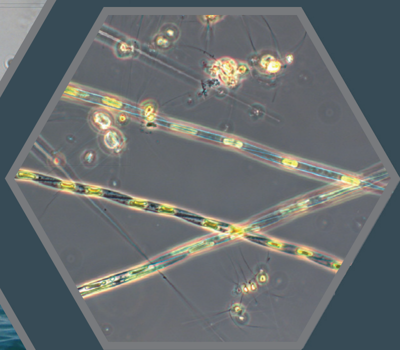
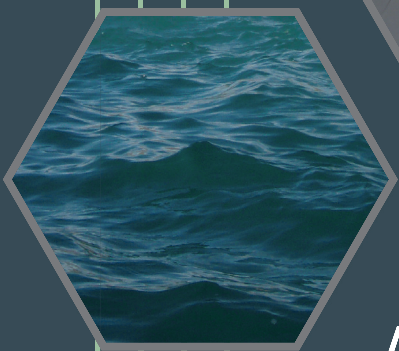

A Primer on California Marine HARMFUL ALGAL BLOOMS

Common questions and answers for stakeholders, decision makers, coastal managers, and the education community

A Primer on California HARMFUL ALGAL BLOOMS

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Cover Photographs

Clockwise from top:

Aerial photo of *Lingulodinium* bloom in southern California

Red Tide near Fort Bragg, CA, October 2011. B. Johnson

Pseudo-nitzschia spp.

Green/blue water in Monterey Bay

Gymnodinium spp.

WHAT IS A HARMFUL ALGAL BLOOM (HAB)?

Microscopic algae (phytoplankton) support healthy ecosystems by forming the base of the food web and producing oxygen. However, some species can cause harmful conditions for humans, animals, and the environment when they bloom. An algal bloom occurs when optimal conditions allow algae cells to grow and reproduce rapidly. A bloom can be harmful in many ways. Some species produce dangerous toxins that can move up the food chain from fish to larger animals and humans, while others can clog fish gills, deplete nutrients, or decrease light penetration.

HAB outbreaks in coastal waters can result in economic losses to recreation, commercial fisheries, tourism, can be dangerous to human health, and are a challenge for coastal management. Environmental managers, researchers, public health officials and the public alike want to predict, prevent, control, and lessen the impacts of HABs.

HABs appear to be increasing in frequency and intensity. While some of the apparent increase in HABs may be due to better detection through monitoring programs, there is growing evidence that human behaviors are causing the blooms to occur more often, be larger, and last longer.

WHAT CAUSES HABS?

Natural physical, chemical, and biological factors contribute worldwide to the occurrence of HABs. Human activities play an active role as well.

PHYSICAL AND CHEMICAL FACTORS

The salinity, nutrient content, temperature, and light levels of water influence phytoplankton growth and HAB formation. Each phytoplankton species has unique growth requirements and blooms under different conditions. For example, some species require lower salinity levels and thrive in estuaries, while others need the higher salinity of coastal waters.

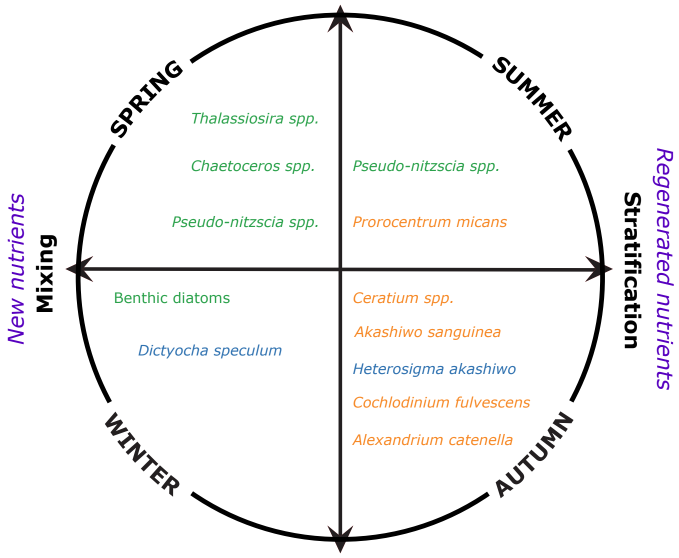
Top left: abalone and gumboot chitons killed by a bloom of *Gonyaulax*. Top right: A bloom of *Lingulodinium* in La Jolla, CA. Bottom: Whale swimming in *Lingulodinium* bloom.

Nearly all HAB species require nitrogen and phosphorus to grow. While these nutrients are a natural part of the environment, their availability is an important factor in bloom development, distribution, and duration.

Physical characteristics play an important role as well. In California, springtime winds lead to upwelling and an infusion of cold, nutrient-rich water along the coast, causing some species to bloom. Different species bloom in the fall when winds are calm and coastal bays contain warm, stratified water. Winds and currents can also transport phytoplankton from one location to another, introducing oceanic species into bays and estuaries or causing blooms to migrate along the coast.

BIOLOGICAL FACTORS

The timing, extent and duration of a HAB event depends greatly on the biology of the HAB species as well as other organisms present in the ecosystem. Natural succession provides a seasonal "rhythm" to many marine ecosystems as populations of different phytoplankton, including HAB species, grow and decline.



A simplified scheme of the succession of main phytoplankton species and groups, varying with nutrient availability and mixing of the water column. Green are diatoms, orange are dinoflagellates, and blue are "other."

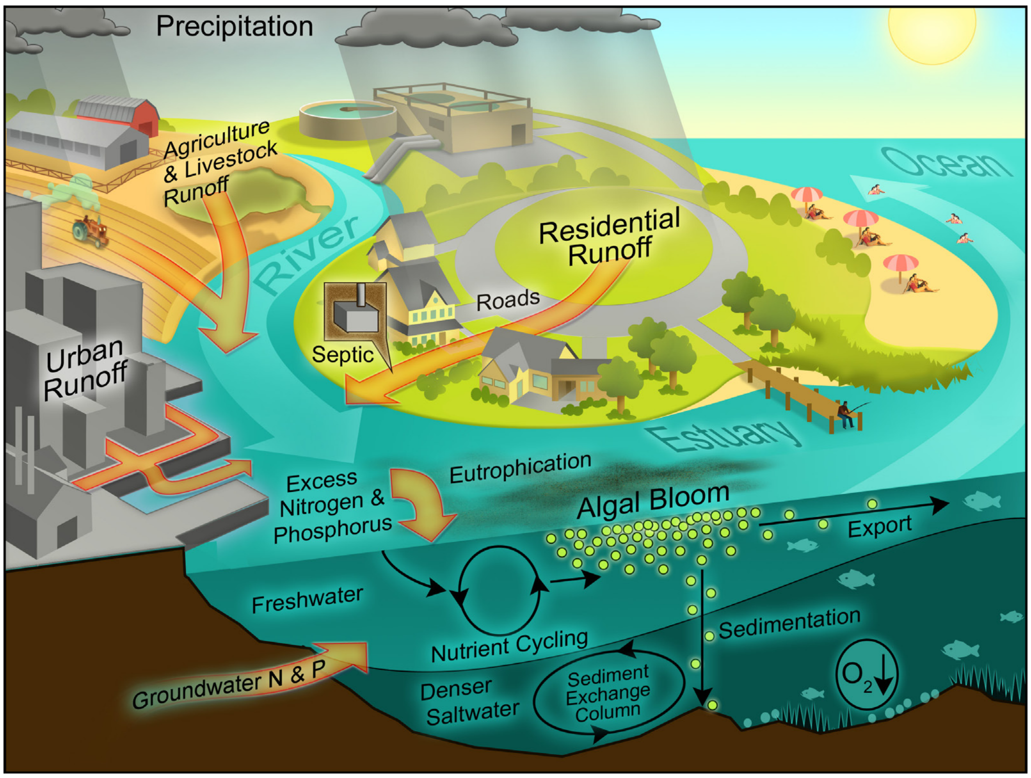
HUMAN FACTORS

Harmful algal blooms are naturally occurring events, but they appear to be increasing in intensity and frequency. Humans may be influencing blooms in a number of ways; examples include increasing nutrient availability via runoff, sewage, fertilizer, etc., climate change, or merely by assisting in the transport of new species from one place to another.

HOW DO HABS AFFECT CALIFORNIA ECOSYSTEMS?

HABs affect marine ecosystems in many ways. HABs that produce toxins can greatly disrupt an ecosystem as the effects of the toxins are passed up the food chain. While shellfish feeding on toxigenic phytoplankton are not themselves harmed, fish and marine mammals that consume the shellfish ingest the toxins, which can lead to severe illness and death.

Toxigenic HABs are also dangerous to human health. Ingesting toxins through consumption of filter-feeding shellfish can lead to illness, paralysis, or even death. Because of the limitations of volunteer samplers and the prevalence of HABs during certain seasons, California has a statewide quarantine on sport-harvested shellfish each year from May through



Graphic shows how human factors, as well as biological, chemical and physical properties of marine and terrestrial environments, all contribute to algal bloom and HAB formation.

Image: A. Joyner, UNC-CH Institute of Marine Sciences

October. During this period, consumers are warned to avoid eating recreationally harvested bivalve shellfish, including clams, oysters, mussels and scallops. Commercially sold shellfish from approved sources are subjected to monitoring and testing, and are safe to eat.

Not all HABs are toxic. Some kinds of HABs that do not produce toxins can be so thick as to deprive other organisms of oxygen or sunlight, or can kill organisms through physical means like clogging gills. Additionally, HABs have a tremendous negative impact on the economy. Researchers and economists estimate that the impact of HABs on the US economy is over $95 million each year. Economic loss is difficult to quantify for many reasons. HAB-related impacts are primarily in the categories of commercial fisheries and human health, but can include tourism, recreation, property value, and more.

WHAT ARE THE PREVALENT HAB SPECIES IN CALIFORNIA?

Harmful algal blooms occur along both coasts of the United States. Some species are widespread, while others have a more restricted range. There are many groups of harmful algae that have a strong presence in California.

Akashiwo
(dinoflagellate)

Unarmoured cells with conical epitheca and bilobed hyoptheca. Cells may form resting spores. *Akashiwo* can form extensive blooms that color the water red, often with *Ceratium furca*. *Akashiwo* has been associated with fish kills and seabird deaths.

Right: The yellow staining on the feathers of this Pacific Loon was caused by a non-toxic *Akashiwo* bloom. Foam produced by the bloom stripped feathers of their waterproof coating. An *Akashiwo* bloom also caused the red/brown water in the sea lion photo.

Alexandrium
(dinoflagellate)

Small armoured cells, usually spherical. Some species form chains, and all species form resting cysts. Several species, including *A. catenella,* produce saxitoxins, among other toxins, which lead to paralytic shellfish poisoning. Dense blooms of *Alexandrium* can be red or brown.

Cochlodinium
(dinoflagellate)

Cochlodinium is a relative newcomer in California. Dense blooms can turn the water brown or red. *Cochlodinium* species are toxin producers. Cells are unarmoured and often form chains, and have a distinctive spiral cingulum.

Dinophysis
(dinoflagellate)

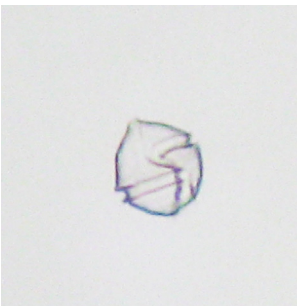
Urmoured, oval, laterally-flattened cells. Some species produce okadaic acid and dinophysistoxins, which cause diarrhetic shellfish poisoning.

Syndrome	Toxin(s)	Causative Organism	Symptoms
Paralytic Shellfish Poisoning (PSP)	Saxitoxin and its derivatives	*Alexandrium* spp. *Pyrodinium* spp. *Gymnodinium* spp.	Numbness and tingling of the lips, mouth, face, and neck, nausea, and vomiting. Severe cases result in paralysis of the muscles of the chest and abdomen possible leading to death
Amnesic Shellfish Poisoning (ASP)	Domoic acid	*Pseudo-nitzschia* spp. *Nitzschia navis-varingica*	Nausea, vomiting, diarrhea, headache, dizziness, confusion, disorientation, short-term memory deficits, and motor weakness. Severe cases result in seizures, cardiac arrhythmia, respiratory distress, coma, and possibly death
Diarrhetic Shellfish Poisoning (DSP)	Okadaic acid and its derivatives	*Dinophysis* spp. *Prorocentrum* spp.	Nausea, vomiting, severe diarrhea, and abdominal cramps
Diarrhetic Shellfish Poisoning (DSP)[1]	Yessotoxin	*Gonyaulax spinifera* *Protoceratium reticulatum* *Lingulodinium polyedrum*	Nausea, vomiting, abdominal cramps, reduced appetite, cardiotoxic effects, respiratory distress

[1] Yessotoxins are grouped with DSP syndrome (Draisci et al., 2000) but may be more like PSP since yessotoxin exposure does not lead to diarrhea (Paz et al., 2008).

Human syndromes caused by ingestion or exposure to marine HAB toxins that occur in California. Table adapted from Anderson et al., 2014.

Dinophysis is common worldwide, and several species can be found in California.

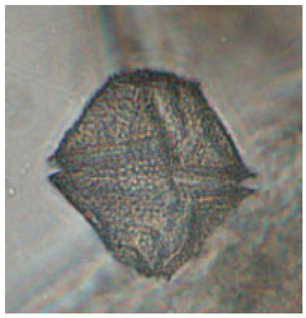


Gonyaulax
(dinoflagellate)

Gonyaulax are armoured, ovoid cells that can form resting cycts. They can produce yessotoxins, and have been associated with large-scale shellfish mortality events.

Heterosigma akashiwo
(raphidophyte)

H. akashiwo are small bi-flagellated cells. Blooms can develop from resting cysts. *H. akashiwo* blooms can be deadly to fish, and are responsible for massive fish mortality events in both wild and farmed fish populations. An unidentified toxin can be produced during blooms, though the mechanism for mortality events is poorly understood.

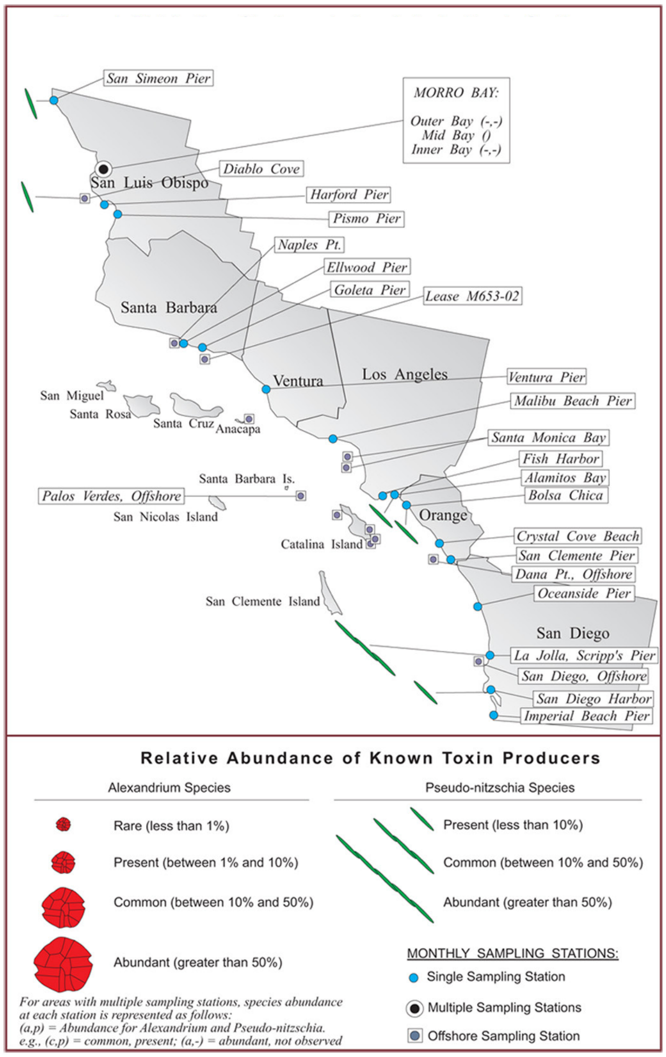


Lingulodinium
(dinoflagellate)

Armoured polyhedral cells with no spines or horns that can form distinctive cysts. Cells are bioluminescent, and can produce yessotoxins.

Pseudo-nitzschia
(diatom)

Many species produce domoic acid, a neurotoxin that is responsible for Amnesiac Shellfish Poisoning. In California, well known toxin producers *P. australis* and *P. multiseries* often form dense blooms. Bait fish, such as anchovies and sardines, may feed on these blooms and subsequently transfer the domoic acid to their predators, which include seabirds and marine mammals. The toxin has a deleterious effect on these animals, often resulting in their deaths.



Map shows distribution of toxin-producing phytoplankton in southern California in February 2014. Figure taken from the monthly biotoxin report produced by the CDPH.

The species of *Pseudo-nitzchia* capable of producing domoic acid do not do so all the time. The conditions that trigger toxin production are of great interest to researchers.

WHERE DO HABS OCCUR IN CALIFORNIA?

HABs occur along the entire length of the California coastline. The CDPH maintains a monitoring program and produces a map of toxigenic species that is updated regularly, so it's easy to see when and where HABs are present.

HOW ARE HABS DETECTED AND MANAGED FOR HUMAN HEALTH?

The prevalence and intensity of HABs is a growing concern in coastal regions. California experiences a variety of HAB events each year. Risks to human health are mitigated by current monitoring and management practices, including ongoing research and public education efforts to inform people of health risks associated with HABs.

CDPH: The California Department of Public Health Marine Biotoxin Program coordinates a volunteer-based monitoring effort for toxic phytoplankton along the entire California coastline. The program relies on trained volunteers to collect and submit phytoplankton samples, which inform decisions about shellfish quarantines and other management practices.

CalHABMAP: The California Harmful Algal Bloom Monitoring and Alert Program is a proactive HAB alert network that provides information on current algal blooms and facilitate information exchange among HAB researchers, managers

Top left: water sample collection from a wharf using a plankton net. Top right: collecting mussels for toxin testing. Bottom: A *Pseudo-nitzschia* bloom viewed under a microscope.

and the general public throughout the state of California. CalHABMAP hosts a website where weekly algae and toxin data from eight California piers can be accessed.

The eight sampling locations are:

Santa Cruz Wharf
Monterey Wharf
Cal Poly Pier
Goleta Pier
Stearns Wharf
Santa Monica Pier
Newport Pier
Scripps Pier

CeNCOOS: CeNCOOS helps support routine algae and toxin sampling at coastal locations throughout the region. Algae samples are currently being collected weekly at wharves in Santa Cruz and Monterey with the aid of CeNCOOS funds. Samples are also being collected at a Tiburon station in San Francisco Bay. Additionally, UC Santa Cruz frequently analyzes HAB toxins for government agencies, conservation groups, scientists, and others with the help of CeNCOOS support.

IDENTIFCATION OF HAB SPECIES

HAB species are typically identified and counted manually. Scientists collect water samples and examine the samples using microscopes. Some HAB species can be identified and counted using a light microscope, which magnifies organisms 100 to 1000 times. Light microscopes are routinely used throughout California for HAB species identification. Certain HAB species, like many species of Pseudo-nitzschia, can only be identified using an electron microscope, with much greater magnification, or by using stains or cell probes. Cell probes are fluorescentiy-labeled chemicals that are applied to a phytoplankton sample and bind to the RNA of specific cells. The labeled cells will then fluoresce while others don't, and they can be counted with a microscope.

WHAT SOLUTIONS ARE THERE TO HABS?

To mitigate the negative effects of HABs, research, monitoring, management, education, and prevention practices must be integrated.

RESEARCH: Continued support of research in phytoplankton ecology, ecosystem dynamics and water quality is necessary to understand HABs and lesson their impact.

MONITORING AND MANAGEMENT: Sustained supporting of monitoring and management programs is important for keeping the public safe. Monitoring programs provide information on current blooms and toxicity events and mitigate risks to public health.

EDUCATION: Educating both water quality managers and the public about HABs, including how to know when one is present, is an important component of public safety.

PREVENTION: The extent and duration of blooms of some HAB species can be reduced by changes in human activities that impact the oceans. Examples include decreasing nutrient pollution, minimizing species spread through ballast water transport, limiting contruction (harbors, artificial beaches) that facilitate water confinement and modifiy circulation patterns, and designing ecologically sustainble aquaculture practices.

HOW CAN YOU HELP?

As citizens, we can take action to help reduce the occurrence of HABs.
Here are some suggestions:

- Fertilizer runoff fuels many HABs. Minimize fertilizer use and learn responsible fertlizer practices

- Wetlands help apsorb nutrients before they enter the ocean. Support the protection and restoration of natural wetlands and the development of artificial wetlands

- Notify your local environmental agency of any unusual sightings such as fish kills or discolored water.

- Support best wastewater treatment and management practices in your community.

- Support HAB legislation. Visit www.hablegislation.com for more information.

- Report your sightings!

  To report a red tide or other unusual marine sighting:
  www.jellywatch.org

  To report a marine mammal stranding:
  California Academy of Sciences - dead strandings in the San Francisco Bay area only
  Pacific Marine Mammal Center - Orange County
  Long Marine laboratory - dead strandings in Santa Cruz County only
  Marine Mammal Care Center at Fort MacArthur - Los Angeles County
  Monterey Bay Aquarium - sea otters only
  Northcoast Marine Mammal Center - Humboldt and Del Norte Counties
  Sea World San Deigo - San Diego County
  Marine Mammal Center - for more information

  To report a seabird stranding:
  Monterey County SPCA Humane Wildlife Services - live strandings in Monterey County
  Native Animal Rescue - live strandings in Santa Cruz County

RESOURCES

California Harmful Algal Bloom Monitoring and Alert Network
www.HABMAP.info

Central and Northern California Ocean Observing System
http://www.cencoos.org/learn/blooms

Southern California Coastal Ocean Observing System
http://www.sccoos.org/data/habs/

Monterey Bay Harmful Algal Bloom Portal
http://oceandatacenter.ucsc.edu/MBHAB/

Phytoplankton Identification Gallery
http://oceandatacenter.ucsc.edu/PhytoGallery/

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