A review: effect of harmful algal blooms on pulmonary function

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Abstract

Harmful algal blooms (HABs) are events caused by excessive growth of algae which result in fish die-off. Algae of HABs contain toxins which negatively affect human health and the economy of coastal areas. Concern over the increase in HAB occurrence and distribution has resulted in studies on the health impacts of red tide aerosols. Persons with preexisting respiratory conditions could be at higher risk of severe reaction to HAB toxins. This paper reviewed eight studies investigating the relationship between red tide aerosols and pulmonary function. The correlational studies found a positive correlation between exposure to red tide and increase in respiratory symptoms and visits to the ER. The experimental studies found that exposure to red tide aerosols resulted in damaged pulmonary function. While there is no known treatment for HAB-induced symptoms, some of the studies observed gradual relief when time is spent away from aerosols. Given that HABs are naturally-occurring, and exacerbated by anthropogenic activities which are difficult to reverse, future research should focus on learning more about the occurrence frequency of HABs and developing detailed prediction models.

Keywords

Red tide, harmful algal blooms, aerosols, brevetoxins, pulmonary function, asthma

Introduction

Red tide, also known as harmful algal bloom (HAB), is the rapid accumulation of mobile and aquatic single-celled microorganisms known as dinoflagellates. Upwelling of high nutrient concentrations from cold and deep water causes dinoflagellates to multiply. During HABs, a significant amount of oxygen is removed through respiration, which leads to fish die-offs (National Ocean Service). Red tide algae, such as *Karenia brevis*, contain toxins that are linked to environmental, economic, and human health problems.

Every United States coastal state has reported the occurrence of HABs, and 40 percent of the US residents live on coasts (National Ocean Service). One of the major problems associated with red tide is food poisoning. Toxin concentration from HABs increases up the food chain through bioaccumulation. There are 500,000 food poisoning incidents per year from HABs (Auerbach, 2017). The problems associated with HABs carry economic consequences, and in 2018 Florida lost $184 million in tourism as well as 2900 jobs due to red tide (Ferreira et al., 2022). The two drivers of HABs are higher nutrient concentration and higher water temperature, both of which are increasing due to anthropogenic activities. As a result, the occurrence of HAB events may be increasing (National Ocean Service).

When HAB cells rupture, toxins are released into the water (EPA). Asthma is a respiratory condition that affects over 25 million individuals in the US (CDC). This article reviews 8 studies which investigate the correlation between red tide events and asthmatic symptoms and the effects of HAB aerosolized toxins on pulmonary function, especially in asthmatic individuals.

Results

Eight studies were conducted to investigate the effect of harmful algal blooms (HABs) on pulmonary function. Table 1 summarizes the methods and results of each study.

A correlational study measured the effect of exposure to red tide brevetoxins on asthmatics as part of a long-term investigation (Fleming et al., 2007). Ninety-seven asthmatic participants ages twelve to sixty-nine were instructed to spend 1 hour on Siesta Beach in Sarasota, Florida during inactive and active *K. brevis* blooms. Before and after the beach walk, participants were evaluated by questionnaire and spirometry. There was a positive correlation between exposure to *K. brevis* and increase in asthmatic symptoms and changes in pulmonary function.

To examine the relationship between red tide blooms and visits to the emergency room, a correlational study compared the rate of respiratory diagnoses at Sarasota Memorial Hospital for a 3 month period in 2001, when there was a red tide bloom, to the rate of respiratory diagnoses for a 3 month period in 2002, when there was no red tide (Kirkpatrick et al., 2006). In 2001, a total of 1295 patient records were found compared to 1235 patients in 2002. In both years, the average age was around 47, around 60% were female, and approximately 90% of patients lived inland. The result was a positive correlation between the presence of a red tide bloom and visits to the ER for respiratory issues.

The effect of *P. brevis*, the former name of *K. brevis*, on the canine tracheal smooth muscle was studied in an experiment (Asai et al., 1982). Twenty samples of tracheal smooth muscle tissue from mixed-breed dogs were extracted and exposed to 0.15-30 μg/mL of brevetoxin. Dose response curves of the canine trachea muscle strips to the brevetoxins and control agents were analyzed. Exposure to *P. brevis* caused canine tracheal smooth muscle contraction.

An experiment investigated the effect of red tide brevetoxins on human airway smooth muscle (Richards & Bourgeois, 2009). Lung tissue was collected from vascular organ donors ages 29 to 35 of equal male to female ratio. The depolarization response of the human airway smooth muscles to 0.01-1.2 μg/mL of brevetoxin was measured, and exposure to brevetoxins caused significant muscle depolarizations in the asthmatic airway smooth muscle.

Forty-eight surfers, mostly male and 34 years old on average participated in a study on the relationship between respiratory symptoms and red tide blooms in Monterey Bay, California (O'Halloran et al., 2017). Over an eight month period, participants completed online surveys which identified any symptoms they experienced after surfing, and a positive correlation was found between periods of red tide and upper respiratory symptoms in the surfers.

To assess the effect of red tide aerosols on cytokine production, samples from 11 asthmatic subjects with allergies and 7 healthy control subjects were used in a 2010 experiment (Dorsey et al., 2010). Pro inflammatory cytokine levels were measured after 1 hour of exposure to brevetoxin using bead array analysis. The study found that when exposed to red tide brevetoxins, base IL-8 cytokine levels were elevated. The IL-8 levels in asthmatic samples did not decrease as much as the non-asthmatic samples after exposed.

A 2010 experiment was conducted to study the effect of *K. brevis* on pulmonary response to influenza A in rats (Benson et al., 2010). The animals in the study were 6 to 8 week old male F344 rats from Charles Rivers Laboratory, weighing 200 grams. The rats were exposed to red tide brevetoxin for 2 hours per day for 12 consecutive days. On day six the rats were given influenza A. The researchers weighed the rats and made clinical observations. Some of the rats were euthanized, and their lungs were harvested and analyzed. Brevetoxin inhalation increased the severity and duration of influenza A.

The effect of red tide aerosols on airway responses of sheep was investigated in an experiment in 2011 (Zaias et al., 2011). Twenty-three adult sheep allergic to the *Ascaris suum* antigen, and 17 non-allergic to *Ascaris suum* were exposed to increasing concentrations from 30 to 300 picograms per

milliliter of brevetoxin for four consecutive days. Pulmonary airflow resistance was measured via esophageal balloon and BAL fluid samples. Exposure to brevetoxins caused airway inflammation in the sheep.

Table 1: Table of Studies Linking Red Tide Aerosols with Harmful Pulmonary Conditions

Authors/year	**Type of study/Research question**	**Subjects**	**Methods or how variables were measured**	**Results**
Fleming et al., 2007	Correlational study What is the relationship between *K. brevis* and asthma?	97 asthmatic persons: ages 12 to 69, 56 female and 41 male, 94 white and 3 Hispanic, 42 had used medications previously, 71 had previous exposure to Florida red tide, 9 were smokers.	Questionnaire, nasal swabbing, and spirometry	Positive correlation between *K. brevis* and asthmatic symptoms
Kirkpatrick et al., 2006	Correlational study What is the relationship between red tide blooms and visits to the ER?	2001 patients: 1295 total, average 47 years old, 60% female, 79% white, 89% lived inland 2002 patients: 1235 total, average 46 years old, 61% female, 79% white, 90% live inland	Comparison of ER visit rates in periods with (2001) and without (2002) red tides.	Positive correlation between red tide blooms and visits to the ER
Asai et al., 1982	Experiment What is the effect of *P. brevis* (former name for *K. brevis*) on the canine tracheal smooth muscle?	Mixed breed dogs of 15 to 22 kg	Dose response curve of trachea muscle strips to brevetoxins and other agents.	*P. brevis* caused canine tracheal smooth muscle contraction.
Richards & Bourgeois, 2009	Experiment What is the effect of red tide brevetoxins on human airway smooth muscle?	Vascular organ donors from Tampa, Florida, equal male to female ratio, ages 21 to 35.	Depolarization response of human airway smooth muscle to toxin	Exposure to 0.01-1.2 μg/mL of brevetoxins caused significant depolarizations in asthmatic ASM.
O'Halloran et al., 2017	Correlational study What is the relationship between red tide blooms and upper	48 surfers, 72% male, 19 to 60 years old, 45% college graduates 69% non-smokers, 25% with allergies, 17% had asthma, 10% had high cholesterol,	Surveys, which asked about symptoms after surfing during blooms	Red tide blooms and upper respiratory symptoms positively correlated.

	respiratory symptoms?	69% took no prescribed medication.		
Dorsey et al., 2010	Experiment What is the effect of red tide Brevetoxin on cytokine production in asthmatics?	Samples from 11 asthmatic subjects with allergies and 7 healthy control subjects.	Bead array analysis of cytokine levels	Exposure to red tide brevetoxin caused elevated baseline IL-8 cytokine levels.
Benson et al., & 2010	Experiment What is the effect of *K. brevis* on pulmonary response to influenza A in rats?	Male F344 rats from Charles Rivers Laboratory (Wilmington, MA), 6 to 8 weeks old, weighed 200 grams.	Clinical observations, weighing, necropsy, lung harvest, and tissue processing	Brevetoxin inhalation increased the severity and duration of influenza A.
Zaias et al., 2011	Experiment What is the effect of red tide aerosols on airway responses of sheep?	23 adult sheep allergic to *Ascaris suum* antigen, 17 nonallergic	Pulmonary airflow resistance measured via esophageal balloon and BAL fluid samples	Exposure to brevetoxins caused airway inflammation.

Discussion

Red tide aerosols cause significant pulmonary effects in asthmatic and allergic airways. Three correlational studies found positive correlations between the presence of red tide blooms and an increase in asthmatic and adverse upper respiratory symptoms (Fleming et al., 2007), (O'Halloran et al., 2017), and visits to the ER (Kirkpatrick et al., 2006). In addition, several experimental studies examined the internal mechanisms of dissected airway muscles in response to red tide aerosols (Asai et al., 1982), (Richards & Bourgeois, 2009), (Dorsey et al., 2010). Exposure to red tide aerosols resulted in changes in pulmonary function. Furthermore, the two experimental studies which tested living animal subjects found that exposure to red tide aerosols resulted in prolonged illness and airway inflammation (Benson et al., 2010), (Zaias et al., 2011).

The correlational study which compared red tide bloom with visits to the ER did not use individual exposure information in its analysis, such as location and time of exposure (Kirkpatrick et al., 2006). Daily toxin amount in the air was not known, since wind speed and direction was not accounted for. The other two correlational studies used retrospective surveys for data collection, which is generally less reliable (Fleming et al., 2007), (O'Halloran et al., 2017). One of these studies had a very small sample size, and both the studies neglected previous exposure to red tide aerosols in participants (O'Halloran et al., 2017). There may have been unmeasured variables involved, such as wildfires or aerial pesticide spraying, due to the uncontrolled beach environment. By contrast, the experimental studies were conducted in controlled environments, and were able to directly measure the effect of red tide aerosols on pulmonary function. Some of the experimental studies used animal tissues and subjects, which could have different reactions than humans (Asai et al., 1982), (Benson et al., 2010), (Zaias et al., 2011).

Since red tide bloom is a naturally occurring phenomenon, the goal is not to prevent or mitigate red tide. These studies indicate that any adverse effects caused by red tide aerosol exposure can be managed by leaving the area of exposure. Management of coastal areas where red tide is prominent should issue warnings to beachgoers when red tide aerosol measurements reach harmful concentrations. Since many of these studies indicate that red tide aerosols have a more significant effect on asthmatic and allergic airways, red tide warnings should recommend that persons with preexisting pulmonary conditions avoid going to the beach for long periods.

Red tide aerosols can cause adverse pulmonary symptoms after prolonged exposure. In order for coastal governments to issue warnings to beachgoers, more detailed information and models on annual red tide blooms are needed. Currently, it is suspected that warming ocean temperatures are causing HABs to become more prevalent. Future research should examine how climate change and anthropogenic activities are impacting the scope and frequency of HABs.

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