Title

Oceans and Human Health: Harmful Algal Blooms and Acute Health Symptoms Among Surfers and Lifeguards

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Oceans and Human Health: Harmful Algal Blooms and Acute Health Symptoms among Surfers and Lifeguards

By

Christina Lee O'Halloran

A dissertation submitted in partial satisfaction of the

requirements for the degree of

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in

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of the

University of California, Berkeley

Committee in charge:

Professor John M. Colford, Jr., Chair
Professor William Satariano
Professor Eileen Gambrill

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Abstract

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Oceans and human health is an emerging interdisciplinary field. The oceans modulate our climate and provide food resources, recreational opportunities, and esthetic enjoyment. Marine ecosystems are under threat due to population growth, anthropogenic pollutants, tourist activities, aquaculture production, and global shipping transportation. Additionally, harmful algal blooms (HABs), although naturally occurring, have increased dramatically worldwide. Microbial and chemical contamination of seawater and seafood has had a negative effect on human health. Preservation and restoration of the oceans is critical to the health of marine organisms, marine mammals, and humans.

This dissertation comprises three research chapters. The research question of interest is "what acute health risks, if any, are associated with exposure to seawater?" Chapter one presents a meta-analysis that reviewed acute human health effects associated with harmful algal blooms. *Karenia brevis*, a microalgae, produces a suite of natural toxins known as brevetoxins. These brevetoxins were found to be associated with acute health symptoms of nasal congestion, eye irritation, and cough. Specifically, this meta-analysis revealed there was a 3.58 increase in relative risk of eye irritation [95% confidence intervals (CI), 2.00 – 6.42], 2.45 increase in relative risk of nasal congestion (95% CI 1.51 - 3.98), and 2.24 increase in relative risk of cough (95% CI 1.49 - 3.38) associated with exposure of aerosolized brevetoxins.
Chapter two and three examined the acute health effects among lifeguards and surfers. They were ideal participants for these studies due to their high levels of seawater exposure. In both studies upper respiratory symptoms were the most commonly reported acute health symptoms at 21% and 29% respectively. Findings from the surfer health study, in chapter two, demonstrated that surfers

who previously experienced acute health symptoms while surfing during a HAB were 1.63 times more likely to have upper respiratory symptoms than surfers who have not experienced any acute health symptoms during a HAB event (95% CI = 1.09, 2.44). Surfers with housemates with upper respiratory symptoms were 1.72 times more likely to have upper respiratory symptoms as compared to surfers with healthy housemates (95% CI = 1.22, 2.43). Surfers with a physician diagnosis of allergies were 1.41 times more likely to have upper respiratory symptoms in comparison to surfers without allergies (95% CI = 1.01, 1.97). Chapter three describes the national cross-sectional study of ocean lifeguard. Lifeguards with a history of surfers ear were 2.95 times more likely to have upper respiratory symptoms than lifeguards who did not have a history of surfers ear (95% CI = 1.33, 6.54). Lifeguards who reported they have had acute health symptoms after exposure to a HAB were 1.5 times more likely to upper respiratory symptoms than lifeguards with no such history (95% CI = .72, 3.47). Gastrointestinal symptoms were 2.49 times more likely among lifeguards with a history of acute health symptoms after HAB exposure than lifeguards who reported no history of acute health symptoms after exposure to HABs (95% CI = 0.76, 8.16). Lifeguards with a history of physician diagnosed anxiety were 1.69 times more likely to have acute stress symptoms after a rescue than lifeguards without a history of anxiety (95% CI = 1.31, 2.17). Lifeguards with a history of physician diagnosed asthma were 1.66 times more likely to experience acute stress symptoms after a rescue as compared to lifeguards without a history of asthma (95% CI = 1.30, 2.11). Additionally, lifeguards with acute health symptoms after exposure to a HAB were 1.42 times more likely to experience acute stress symptoms after a rescue than lifeguards without a history of acute health symptoms after a HAB (95% CI =1.08, 1.86).

In conclusion, evidence from these studies suggests that there is a positive association between HAB exposure and acute health symptoms in humans. Future studies are necessary to assess the human health risks of the different algal toxins produced during a HAB. Additionally, co-occurring bacteria and viruses, with exponential growth, during these HAB events need to be further investigated.

For Mary Wilcox Silver
and
my sunshine, Mateo, Pablo, and Ted

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DISSERTATION INTRODUCTION

The oceans cover 71% of the planet and connect our global population of 6 billion people. Worldwide, 60% of the population lives in coastal areas, with an approximate 4 billion people living within 4 km of a coastline (US Ocean Commission 2004). In the United States, 53% of the population lives on approximately 17% of coastline (Pew Oceans Commission 2003). Globally, the coastal environment is under threat due to increases in population growth, anthropogenic pollutants, tourist activities, climate change & extreme weather events, aquaculture production, shipping, and harmful algal blooms. Individually and cumulatively these factors contribute to higher risks for public health and disease (Bowen et al. 2006). Globally, marine ecosystems have been dramatically altered as demonstrated by overfishing, coral bleaching, and ocean acidification (Epstein et al.1993).

In 1999, the World Health Organization estimated that contaminated seawater caused approximately 250,000,000 cases of mild gastroenteritis and upper respiratory disease a year (Shuval 1999). Although living in a coastal environment poses health risks it also provides numerous benefits to people including fresh seafood, recreational opportunities, ports for trade, and marine natural products with pharmaceutical benefits. Marine sponges produce chemicals for self-defense that have potent anticancer and antiviral properties. There are numerous pharmaceutical benefits yet to be garnished from the ocean. Eighty percent of the fish consumed in the United States is imported. Seafood safety is linked to the quality of the environment from which it is harvested.

Harmful algal blooms

Approximately 4000 species of microscopic unicellular algae known as phytoplankton form the base of the marine food web worldwide. Phytoplankton, photoautotroph's, are the oceans primary producers and fixers of carbon. Only several geneses of phytoplankton produce naturally occurring toxins that cause harm in the marine ecosystem and ultimately to humans. Harmful algal blooms cause detrimental effects due to toxin production or accumulation of biomass in the marine ecosystem. The primary transmission of algal toxins to humans has been through ingestion of shellfish or fish. Other modes of transmission include inhalation of aerosolized particles, epidermal and ocular contact. Wave and wind action can cause cell lyses and release aerosolized algal toxins. These aerosolized toxins are potential health concerns for susceptible populations including asthmatics and children (Fleming et al. 2007).

HABs have been recorded since biblical times but are globally on the rise due to anthropogenic effects of point source and non-point source pollution that have increased nutrients and minerals in the ocean. Global changes in environmental conditions of increased seawater temperatures and increased nutrients favor phytoplankton, which produce toxins in marine environments. Several types of human intoxication clinical syndromes caused by marine toxins have been identified. They include paralytic shellfish poisoning, neurotoxin shellfish poisoning, amnesic shellfish poisoning, diarrheic shellfish poisoning, ciguatera, and puffer fish (Walsh et al. 2008).

Internet surveys

The Internet has been found to be an effective and low cost way to survey people for food borne as well as fresh and marine waterborne illnesses (Kuusi et al. 2004 and Turbow et al. 2008). Marine illness reports from seawater exposure could assist in the development of a marine disease surveillance system (Turbow et al. 2008). In addition, social desirability or acquiescence is less of a problem with sensitive data with Internet surveys than with other survey modes (Dillman 2006).

Oceans and Human Health

Oceans and Human Health is an emerging interdisciplinary field with researchers from diverse backgrounds such as epidemiology, oceanography, toxicology, harmful algal blooms, environmental microbiology, engineering, marine natural products chemistry, pharmaceuticals, and comparative animal physiology. In 2004, the Oceans and Human Health Act provided funding through the National Science Foundation and the National Institute of Environmental Health Services, for four Centers for Oceans and Human Health. The centers are located at University of Washington, University of Hawaii, Woods Hole Oceanographic Institution, and University of Miami. In addition, the National Oceanic and Atmospheric Administration established and funded three centers at Hollings Marine Laboratory, Charleston, South Carolina, Northwest Fisheries Science Center, Seattle, Washington and Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan. The goal of the Oceans and Human Health (OHH) centers is to provide interdisciplinary research collaborations to improve the understanding and management of the oceans and the Great Lakes thereby increasing the benefits to human health and decreasing public health risks (http://oceansandhumanhealth.noaa.gov/).

This dissertation comprises three distinct research chapters that focus on ocean and human health concerns. The primary goal of this dissertation is to investigate what acute health effects, if any, are associated with ocean exposure. Chapter 1 is a meta-analysis that investigates the association of harmful algal blooms (HABs) and acute health symptoms of cough, nasal congestion, and eye irritation. Chapter 2 describes a prospective cohort of Monterey Bay, California surfers and examines acute health symptoms and ocean exposure. Lastly, chapter 3 discusses the acute health risks among ocean lifeguards that are employed on United States coastal beaches.

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I am especially grateful to my wonderful husband, Ted Holman, and sons, Pablo and Mateo for all the joy they bring to my life. Mary Odegaard's love and care of my boys has been a great help in assisting me to pursue my passion of oceans and human health. I am also grateful to family and friends who have been emotionally supportive throughout this very long process. I am forever indebted to Mary Silver for her inspiration, encouragement, mentorship, friendship, and support on this journey to oceans and human health. Thanks to all my Peace Corps pals for twenty years of laugher, love, and support. Finally, I am extraordinarily grateful to my parents and Irish immigrant grandparents who worked hard to provide a much better life for their children.

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CHAPTER ONE

Acute health symptoms and marine harmful algal blooms

Abstract

A meta-analysis was conducted to determine whether an association exists between exposure to marine harmful algal blooms (HABs) and acute health symptoms of eye irritation, cough, and nasal congestion. MEDLINE, EMBASE, Cochrane Collaboration, BIOSIS, Web of Science, and AFSA electronic databases were searched. The bibliographies of pertinent articles were also reviewed for additional articles. An initial 464 citations from published studies were identified and screened. Only five of these studies met the eligibility criteria and were included in the meta-analysis. The studies reported acute health symptoms and exposure to aerosolized brevetoxin, a potent neurotoxin, produced by harmful algal blooms of the phytoplankton *Karenia brevis*. This meta-analysis suggests that there is a 3.58 increase in relative risk of eye irritation [95% confidence intervals (CI), 2.00 – 6.42], 2.45 increase in relative risk of nasal congestion (95% CI 1.51 - 3.98), and 2.24 increase in relative risk of cough (95% CI 1.49 - 3.38) associated with exposure from inhalation of aerosolized brevetoxins due to harmful algal blooms of *Karenia brevis*.

Introduction

The purpose of this meta-analysis was to determine if ocular irritation, cough, and nasal congestion are associated with exposure to marine phytoplankton toxins. This association is of public health importance, because people who live within a mile of the ocean may be at increased risk for eye irritation, cough, and nasal congestion when exposed to aerosolized brevetoxin. Exposures to algal blooms of *Karenia brevis* that produce brevetoxin have been shown to be an environmental trigger for asthmatics (Fleming et al. 2005). Additionally, brevetoxin may be an allergen for some susceptible populations such as infants, young children, the elderly, immune-compromised, and people with other respiratory ailments.

A comprehensive search of research articles using key words HABs, red tides, eye irritation, cough, nasal congestion, respiratory symptoms found only one type of marine phytoplankton, *Karenia brevis*, to be linked to eye irritation, cough, and nasal congestion. Anecdotal evidence suggests that there may be other microalgae that produce toxins and cause acute health symptoms that have not yet been investigated. This is the first meta-analysis on marine HABs and acute health symptoms.

Background

Approximately 4000 species of microscopic unicellular phytoplankton form the base of the marine food web worldwide. Phytoplankton, photoautotroph's, are the oceans primary producers and fixers of carbon. Only several geneses of phytoplankton produce naturally occurring toxins that cause harm in the marine ecosystem and ultimately to humans. HABs have been recorded since biblical times but are globally on the rise due to anthropogenic effects of point source and non-point source pollution that have increased nutrients and minerals in the ocean (Anderson 1989 and Hallengraeff 1993). Current environmental conditions of increased seawater temperatures and increased nutrients favor toxic phytoplankton in marine environments.

The terms harmful algal blooms and red tides are used interchangeably but are quite different. Harmful algal blooms cause detrimental effects due to toxin production or accumulation of biomass in the marine ecosystem. Red tides occur when phytoplankton with reddish pigments cause water discoloration due to prolific growth but do not produce toxins or cause harm.

The primary transmission of algal toxins to humans has been through ingestion of shellfish or fish. Other modes of transmission include inhalation of aerosolized particles, epidermal and ocular contact. Several types of human intoxication syndromes caused by marine toxins have been identified. They include paralytic shellfish poisoning, neurotoxin shellfish poisoning, amnesic shellfish poisoning, diarrheic shellfish poisoning, ciguatera, and puffer fish (Walsh et al. 2008). Reports of toxic shellfish poisonings are rare in the United States. Approximately 30 cases of toxic shellfish poisonings are reported annually in the US. The number of shellfish poisonings may be greater but many milder cases are not diagnosed or reported. In addition, in most states, healthcare providers are not required to report these shellfish illnesses. The CDC has estimated from available data that one-mortality occurs every four years from toxic seafood poisonings (CDC 2005).

Karenia brevis

The photosynthetic toxic phytoplankton, *Karenia brevis*, is found in low concentrations throughout the Gulf of Mexico in the coastal waters of Mexico, Texas, Louisiana, Mississippi, Alabama and western Florida. The highest concentration of cells and longest duration of blooms are along the southwest coast of Florida. Data collected from 1954 to 2002 showed a 20-fold increase during this time period in the abundance of *Karenia brevis* within five kilometers of the shoreline. In addition, blooms extended farther offshore with longer duration of blooms most likely caused by increased coastal population and greater nutrient availability in the marine ecosystem (Brand et al. 2007).

Karenia brevis produces a suite of ten neurotoxins called brevetoxins. Additionally, *Karenia brevis* produces a natural inhibitor of brevetoxin called brevenal. Brevenal is known to block bronchoconstriction. Brevenal concentrations in algal blooms have been found to vary (Cheng et al. 2005). Ingestion of fish or seafood with brevetoxins can cause neurotoxin shellfish poisoning (NSP) which can cause gastroenteritis, paralysis, muscle cramps, seizures, and other neurological symptoms (Walsh et al. 2008). In the United States government agencies have effective monitoring programs to protect people from shellfish poisonings.

Wave and wind action causes cell lyses of *Karenia brevis* in which brevetoxin is aerosolized and incorporated into seawater spray. When inhaled brevetoxin has been associated with such respiratory problems as eye, nose, and throat irritation, and chest tightness, coughing, wheezing, and shortness of breath (Milian et al. 2007, Kirkpatrick et al. 2004, Fleming et al. 2007, Backer et al. 2005). In the normal population, upper respiratory irritation and bronchoconstriction are usually reversible immediately upon leaving the beach or going to an air-conditioned building. However, susceptible populations such as asthmatics, the elderly or people with chronic lung disease can have prolonged symptoms from inhalation of aerosolized brevetoxin (Fleming 2008).

High cell concentrations of *Karenia brevis* that range from 15–90 mg/m^3 form HABs that can last for months along the Florida coast waters (Fleming et al. 2011). The particle sizes of brevetoxin aerosols have a geometric mean of 8–9 μ. In general, brevetoxin aerosol particle sizes are too large to enter the lower airway that requires particle sizes to be less than 5 μ (Cheng et al. 2004). Air samples taken during a *Karenia brevis* HAB demonstrated that brevetoxin aerosols were transported as far as a mile inland from the ocean (Kirkpatrick et al. 2010). Studies of allergic sheep found that brevetoxin aerosols are potent airway constrictors (Abraham et al. 2005). Dr. Fleming's research on asthmatics found an increased risk of respiratory symptoms during a *Karenia brevis* HAB event. Fortunately, asthma medication has been shown to effectively reduce and prevent the respiratory effects of during a HAB.

Brevetoxin contaminated food webs can have detrimental health impacts on fish, marine mammals, and humans. Brevetoxins are responsible for large fish kills of one million or more fish (Bourdelais et al. 2002). This has had a negative impact on both commercial and recreational fishing. Mortality of threatened species of sea turtles, dolphins, and manatees have been linked to *Karenia brevis* blooms (Flewelling et al. 2005). These deaths are of concern due to the small population sizes and low reproductive rates of these species (Flewelling et al. 2005). Additionally, high concentrations of brevetoxin in sea grass, shellfish, and fish pose health risks to marine mammals and humans even after *Karenia brevis* blooms have subsided (Flewelling et al. 2005).

Materials and methods

Search strategy.

Several electronic databases were searched: MEDLINE, BIOSIS, Cochrane Collaboration, EMBASE, Web of Science, and Aquatic Sciences & Fisheries Abstracts (AFSA). The computerized searches included the key words "harmful algal blooms and aerosolized toxins, harmful algal blooms and eye irritation, harmful algal blooms and nasal congestion, harmful algal blooms and cough, harmful algal blooms and acute health effects, harmful algal blooms and respiratory, harmful algal blooms & human effects, algal toxins & human health effects, algal toxins & human illness, brevetoxins & human illness, toxins & red tides, aerosolized toxins & red tides". A review of 464 titles and abstracts was conducted. Relevant studies were fully reviewed. The bibliographies of the relevant studies were also examined for additional references. Studies from peer reviewed journals, conference proceedings, research letters, and reports were reviewed. Studies in foreign languages were also reviewed provided that the abstract was in English or Spanish.

Selection criteria.

Studies were included in the review if they included marine HAB exposure and gave an effect measure or data to calculate an effect measure for eye irritation, cough, and nasal congestion. Quality of reporting of meta-analyses (QUORUM) guidelines were incorporated in this meta-analysis.

Water exposure.

Studies that measured exposure to marine harmful algal blooms were included in the study. Fresh water harmful algal blooms were excluded in this meta-analysis.

Health outcomes.

Eye irritation, nasal congestion, and cough were the health outcomes of concern.

Data abstraction.

Data was abstracted from the five studies with relative risks and 95% confidence intervals or data that allowed for their calculation. Information retrieved from each study included study design, participants (*i.e.* asthmatics), outcome measures, exposure, study location, patient characteristics, and sample size. QUOROM (Moher et al. 1999) guidelines were followed.

Data analysis.

Data related to the exposure and outcomes were obtained and tabulated, if necessary, and pooled using meta-analysis. Relative risks, confidence intervals, and heterogeneity were analyzed for eye irritation, nasal congestion, and cough. In the two Backer *et al*. studies in which two exposure groups were identified the highest exposure group was used. Relative risks were calculated using fixed-effects and the Shore method. When heterogeneity was present random-effects methods were calculated. Heterogeneity was assessed using the chi-squared test for heterogeneity (X^2) and/or Q statistic.

The different populations studied, healthy, asthmatic, or susceptible could explain heterogeneity. All analyses were conducted using STATA 11 (version 11; Stata Corp., College Station, TX) and Craig Steinmaus' (UCB) meta-analysis spreadsheets.

Inclusion/Exclusion criteria

Studies that measured marine HABs exposure and listed eye irritation, cough, and nasal congestion and effect measures were included. Studies of fresh water HABs exposure were excluded. Five research study articles were included in this meta-analysis.

Results

Figure 1 shows the flow diagram of the study selection process. Initially, 464 titles or abstracts were reviewed. Twenty-two of the citations appeared relevant and were further reviewed. Twelve studies were fully reviewed. Five studies (Table 1) met the criteria to be included in this meta-analysis. Seven studies (Table 2) were excluded due to lack of effect measures or data to calculate effect measures such as means, standard deviations, and standard errors or data was previously published.

Data analysis.

Separate analyses were conducted for each acute health symptom of eye irritation, cough, and nasal congestion. The characteristics of the five studies in this meta-analysis ranged in sample size from 20 to 129 participants (Table 3). The mean age of the participants was 35 years of age, ranging from 12 to 80 years old. Thirty four percent of the study participants were female and 95% were Caucasian. Sixteen percent of the participants identified themselves as smokers.

Four of the studies included in this meta-analysis were prospective cohorts. These studies used a case cross over design in which each subject served as their own control comparing pre and post HAB exposure. The CDC outbreak study interviewed dredge workers with low HAB exposure, aboard a ship and high HAB exposure, on the beach.

In this meta-analysis HAB exposure was verified by bloom conditions and cell concentrations in the seawater samples. The unexposed group varied in the studies from no HAB exposure to low HAB exposure. The CDC study compared low exposure to high exposure. A limitation of this meta-analysis is that all the studies determined the outcome of acute health symptoms through self-report of the study participants.

Quantitative relationships between eye irritation, cough, nasal congestion and HABs.

Relative risks and confidence intervals (CI's) were calculated for eye irritation, cough, and nasal congestion. Table 4 summarizes these acute health symptoms after exposure to aerosolized brevetoxins. The forest plot (Figure 1) represents the pooled estimate showing a positive association between brevetoxin exposure and the outcomes of eye irritation, cough, and nasal congestion. The grey shaded boxes on the graphs represent study-specific estimates with area proportional to the weight each study contributes in the meta-analysis. The horizontal lines represent the 95% CIs. The blue diamond represents the combined relative risk random effects estimate and 95% confidence intervals.

Discussion

Only a few epidemiologic studies of acute health risks of marine recreational water have focused on the effects of potent toxins from phytoplankton blooms that are associated with acute health risks. This meta-analysis summarizes the data collected from five different observational studies conducted in Florida. The data were synthesized for pooled results.

There are several strengths and limitations of this meta-analysis. First, a comprehensive search of several databases was performed to identify relevant peered reviewed studies for this meta-analysis. The pooling of data from these five studies suggests that eye irritation, nasal congestion, and cough after exposure to aerosolized brevetoxins are not due to chance. The relative risks and confidence intervals for the symptoms are summarized on Table 4. The pooled relative risk for eye irritation was 3.58 (95% CI 2.00-6.42), cough was 2.24 (95% CI 1.49 - 3.38) and nasal congestion was 2.45 (95% CI 1.51 - 3.98). The pooled results of the studies found a positive association between eye irritation, cough, and nasal congestion after exposure to aerosolized brevetoxins.

There are a few limitations that include sources of potential bias that are of concern in these studies. First, the healthy worker bias is of note in the Backer et al. 2005 study of lifeguards and the CDC's dredge worker study. Both studies findings suggest that exposure to aerosolized HAB toxins is associated with eye irritation, nasal congestion, and cough. The healthy worker bias would underestimate the true effect. The two Fleming et al. studies (2005 & 2007) looked at a sensitive population, people with physician-diagnosed asthma.

Asthmatic medication use may have played a role in decreasing the effect of eye irritation, nasal congestion, and cough symptoms. Once again the bias would underestimate the true effect.

Reporting bias is possible due to self-reported symptoms by the participants in these studies. Participants were aware of when there was a HAB. Additionally, individual exposure to aerosolized toxins of HABs varied widely as a result of wind direction, phytoplankton cell concentrations, particle size, other toxins and constituents associated with the aerosolized particles as well as other environmental factors (Fleming et al. 2005 and Backer et al. 2005). Publication bias is always a concern in meta-analyses. Studies that found no effect may not have been published.

Conclusion

In conclusion, the peer reviewed published studies used in this meta-analysis provide evidence of an association between eye irritation, cough, nasal congestion and exposure to aerosolized brevetoxin, produced by high cell concentrations of the phytoplankton *Karenia brevis*. This association is of public health concern to those who live within a mile of the coast and may be at increased risk of eye irritation, cough, and nasal congestion due to aerosolized brevetoxin exposure. Additionally, current anthropogenic activities and climate change conditions favor the increase in incidence, duration, and geographic spread of HABs worldwide (Milian et al., 2007, VanDolah, 2000). Timely investigation or surveillance of *Karenia brevis* HABs could provide a warning to people especially those who are susceptible, with histories of asthma or allergies. Further research studies are necessary to investigate additional acute health effects, other possible susceptible populations such as children, elderly, and immune compromised people as well as possible chronic effects of HAB toxins on humans.

Figure 1. Flow diagram of study selection.

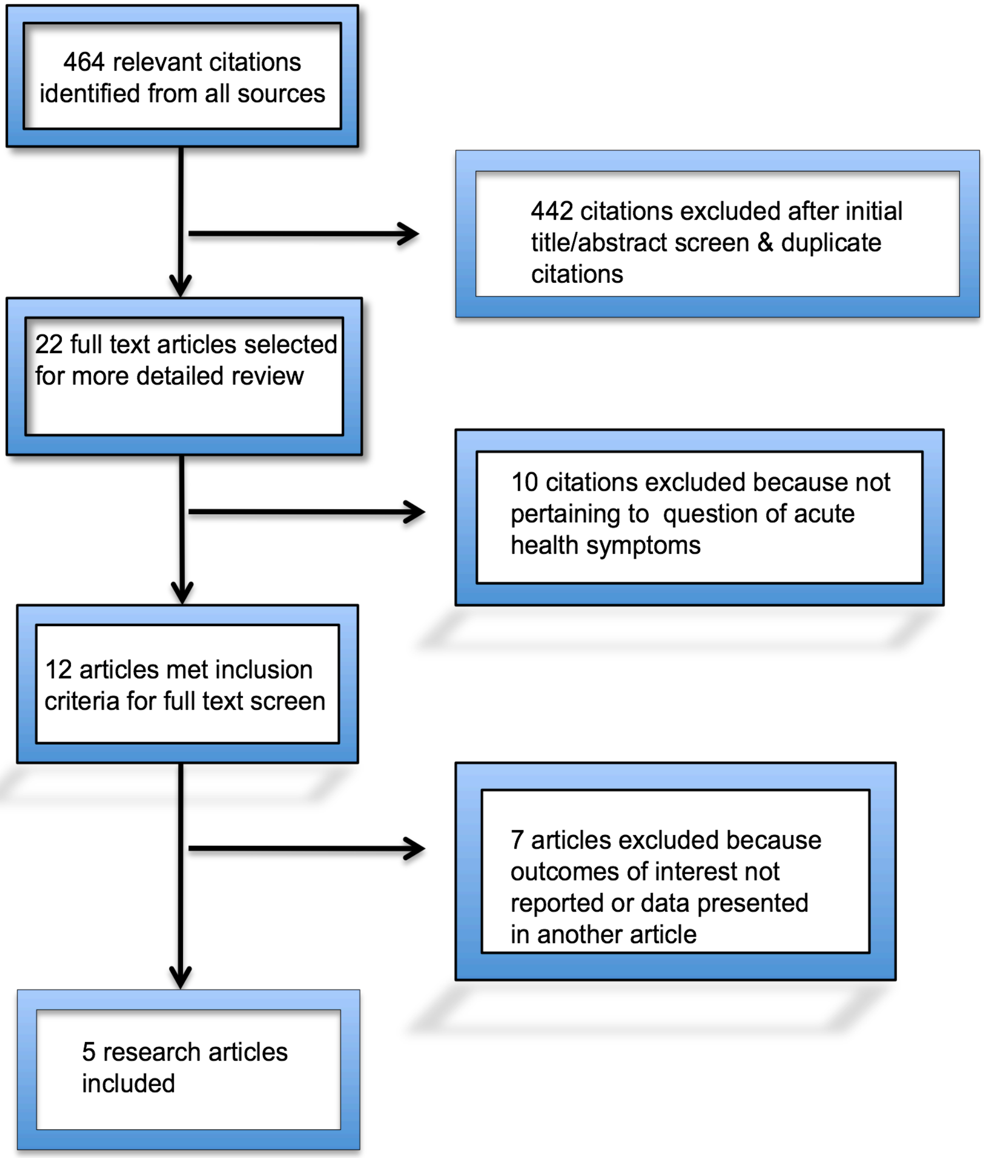
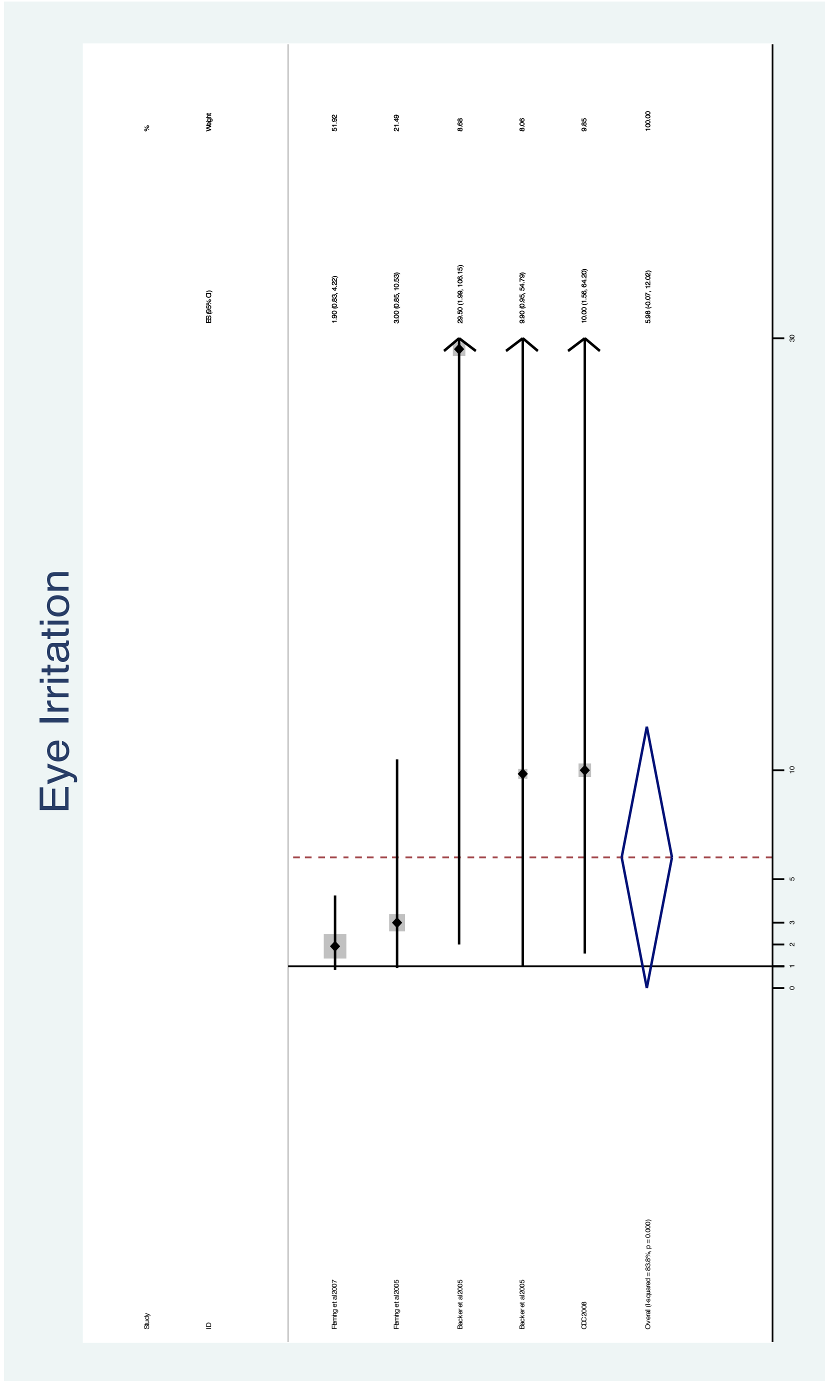
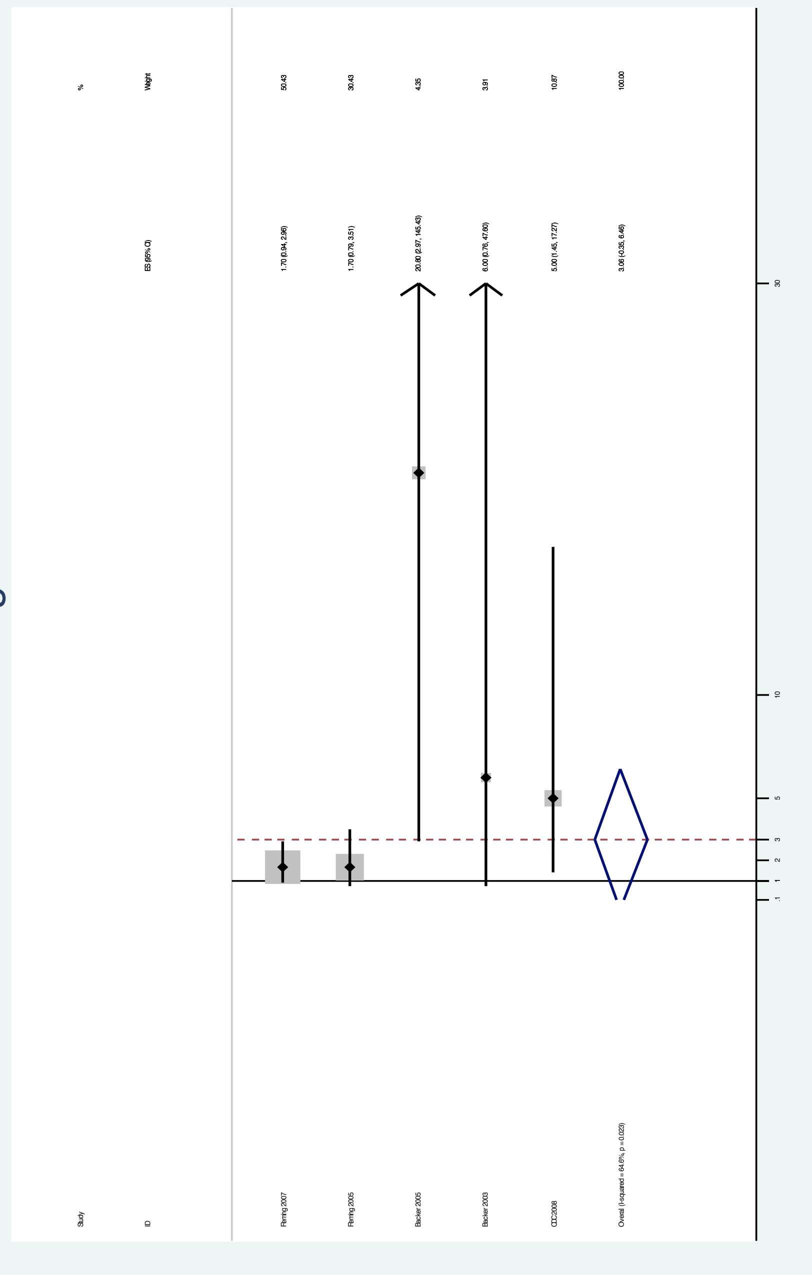


Figure 2. Forest Plots of Eye Irritation, Cough, and Nasal Congestion.



Cough



Study
ID
ES (95% CI)
%
Weight
Fleming 2007
1.70 (0.94, 2.96)
50.43
Fleming 2005
1.70 (0.79, 3.51)
30.43
Backer 2005
20.80 (2.97, 145.43)
4.35
Backer 2003
6.00 (0.76, 47.60)
3.91
CDC2008
5.00 (1.45, 17.27)
10.87
Overall (I-squared = 64.6%, p = 0.023)
3.06 (-0.35, 6.46)
100.00
.1
1
2
3
5
10
30

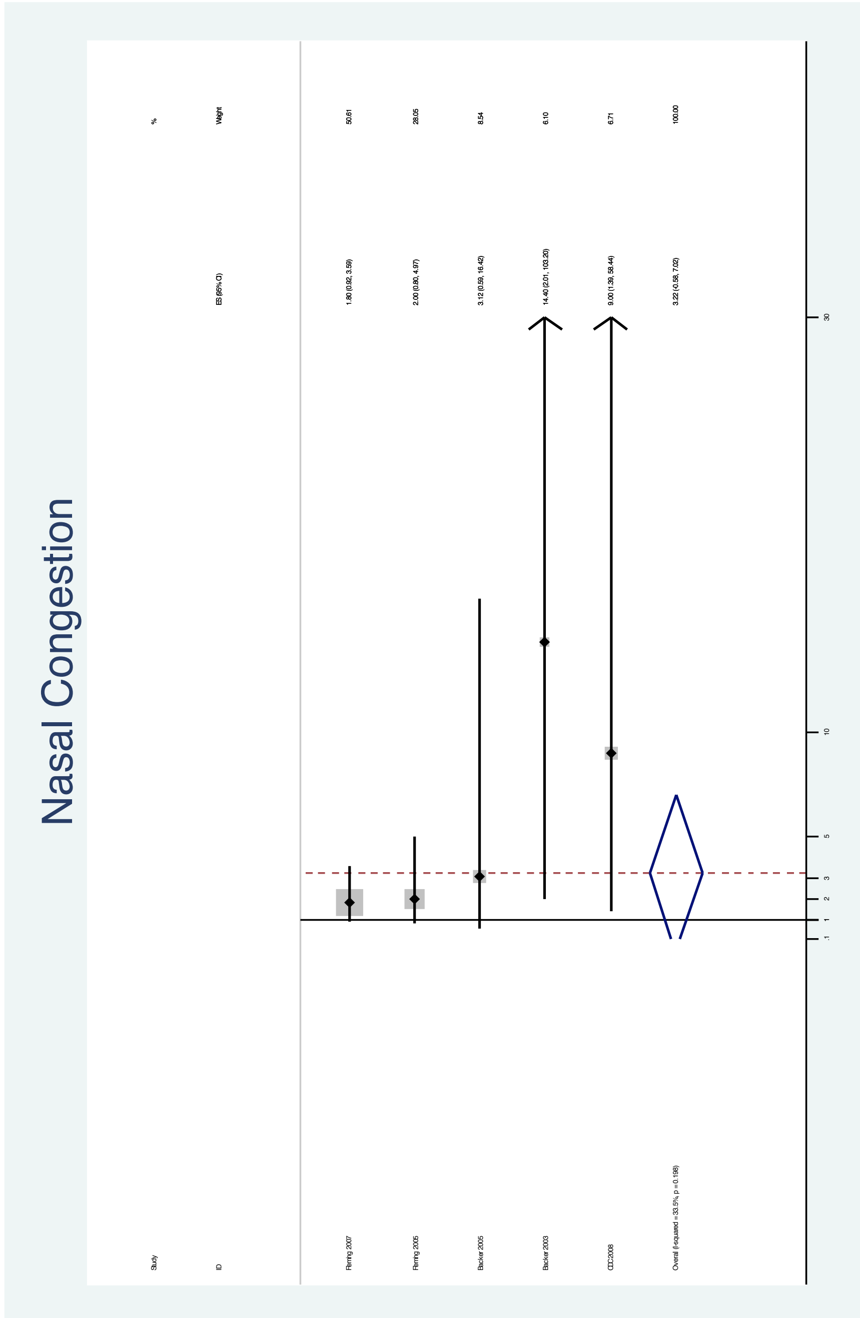

Nasal Congestion
Study
ID
ES (95% CI)
%
Weight
Fleming 2007
1.80 (0.92, 3.59)
50.61
Fleming 2005
2.00 (0.80, 4.97)
28.05
Backer 2005
3.12 (0.59, 16.42)
8.54
Backer 2003
14.40 (2.01, 103.20)
6.10
CDC2008
9.00 (1.39, 58.44)
6.71
Overall (I-squared = 33.5%, p = 0.198)
3.22 (-0.58, 7.02)
100.00
.1
1
2
3
5
10
30

Table 1. Studies included in the meta-analysis

Authors	Type	Cases	Exposure	Outcome	Participants	Location
Backer *et al*. 2003	p. co.	129	brevetoxin	eye, nasal, cough	beach goers	Florida
Backer *et al.* 2005	p. co.	28	brevetoxin	eye, nasal, cough	lifeguards	Florida
Fleming *et al*. 2005	p. co.	59	brevetoxin	eye, nasal, cough	asthmatics	Florida
Fleming *et al.* 2007	p. co.	97	brevetoxin	eye, nasal, cough	asthmatics	Florida
CDC 2008	outbk	20	brevetoxin	eye, nasal, cough	dredge worker	Florida

p. co. = prospective cohort
outbk = outbreak

Table 2. Studies Excluded in meta-analysis

Authors	Type	Cases	Exposure	Outcome	Participants
Gallitelli *et al*. 2005	cs	28	HAB os	resp symp, fever	marine rec/workers
Fleming *et al*. 2009	p co	87	brevetoxin	resp symp	asthmatics
Kirkpatrick *et al*. 2000	p co	17	brevetoxin	resp symp	research cruise staff
Kirkpatrick *et al*. 2006	eco	2530	brevetoxin	resp. dx	ER patients
Moe *et al*. 2001	p co	492	HAB pf	neurops, skin	marine rec/workers
Morris *et al*. 2006	cc	152	HAB pf	neurops, resp	water men
Durando *et al*. 2007	outbk	228	HAB os	resp symp, fever	marine rec

HAB pf = HAB pfiesteria HAB os = HAB ostereopsis
neuropsych = neuropsychological
marine rec = marine recreation
cc = case control outbk = outbreak cs = case series

Table 3. Characteristics of participants in the 5 studies.

Characteristic		
Mean age (range)	35	(12-80)
Gender (female)	34%	
Race		
Caucasian	95%	
Latino	2%	
African American	2%	
Asian	1%	
Smoker	16%	

Table 4. Summary Relative Risks & Confidence Intervals for eye irritation, cough, nasal congestion and HAB brevetoxin exposure.

	Fixed effects			**Shore**		**Random effects**			**Heterogeneity**		
Symptoms	RR	CIl	CIu	CIl	CIu	RR	CIl	CIu	X^2	p	df
Eye Irritation	3.58	2.00	6.42	1.50	8.54	5.32	1.99	14.21	8.88	.06	4
Cough	2.24	1.49	3.38	1.22	4.13	3.05	1.47	6.31	8.93	.06	4
Nasal Congestion	2.45	1.51	3.98	1.35	4.44	2.9	1.48	5.67	6.03	.19	4

CHAPTER TWO

Surfer Acute Health Symptoms Associated with Marine Water Exposure in Monterey Bay, California

Abstract

The objective of the Surfer Health Study was to determine what acute health risks, if any, were associated with surfers exposure to seawater in Monterey Bay, Santa Cruz County, CA. Specific symptoms and illnesses measured focused on upper respiratory, gastrointestinal (GI), eye, ear, and skin symptoms. Monterey Bay coastal waters are impacted by point source and non-point sources of pollution as well as harmful algal blooms (HABs). Surfers were ideal participants for this study due to their high levels of water exposure.

The study had three specific aims. First, to determine whether acute illness or symptoms (*e.g.* stomach pain, ear infection, eye infection, skin rashes, cough, nasal congestion, nausea…) in surfers was associated with bacteria levels measuring point source pollution in Monterey Bay coastal waters. Second, to determine whether surfer respiratory complaints or other health symptoms were associated with harmful algal blooms. Third, to determine whether surfer health symptoms were associated with seasonal variations (*e.g*. rainfall, water temperature, salinity, chla, nutrients).

This was an open prospective cohort study of 48 surfers who were followed from February to October 2008. Screening for enrollment in the study included surfing at least 30 minutes a week in Santa Cruz County coastal waters and 18 years old or older. Study enrollment and participation was online using Survey Monkey (www.surveymonkey.com).

In this study upper respiratory symptoms were the most commonly reported symptoms by surfers (29%). Ten percent of surfers reported gastrointestinal symptoms during the study. Findings from this study demonstrate that surfers who previously experienced acute health symptoms while surfing during a HAB are 1.63 times more likely to have upper respiratory symptoms than surfers who had not experienced any acute health symptoms during a HAB event (95% CI = 1.09, 2.44). Surfers with housemates with upper respiratory symptoms were 1.72 times more likely to have upper respiratory symptoms as compared to surfers with healthy housemates (95% CI = 1.22, 2.43). Surfers with a physician diagnosis of allergies were 1.41 times more likely to have upper respiratory symptoms in comparison to surfers without allergies (95% CI = 1.01, 1.97).

This study establishes baseline information on human acute health symptoms and illnesses due to marine water exposure in Monterey Bay. Acute health symptoms/illness surveys from marine exposure using the Internet could assist in the development of a marine disease surveillance system to assess our coastal water quality. Research of this type may assist legislators in making scientifically based decisions for safer marine waters.

Introduction

Globally, the coastal environment is under threat due to increases in population growth, climate change & extreme weather events, recreational/tourist activities, aquaculture production, shipping, ocean current movement of pathogenic microorganisms & chemical contaminants, and harmful algal blooms. Cumulatively, these anthropogenic factors contribute to higher risks for disease and worldwide public health concerns. Four billion people, worldwide, live within 4 km of the ocean (U.S. Ocean Commission 2004). In 1999, the World Health Organization estimated that contaminated seawater caused approximately 250,000,000 cases of mild gastroenteritis and upper respiratory disease a year (Shuval 1999).

The coastline comprises 17% of the U.S. with 53% of the population inhabiting the coastal area (Pew Commission 2003). The Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000 was a response to concerns of pathogenic microbial diseases among people who engaged in recreational water activities. The EPA authorizes BEACH Act grants to states, territories and tribes to develop and implement water quality monitoring for fecal indicator bacteria to protect the public and notification programs for coastal and Great Lakes recreational waters. Water quality monitoring has numerous challenges (*i.e.* sampling timing, frequency, depth, number of replicates all influence outcomes). Additionally, monitoring policies are individually determined by beach management jurisdictions.

Although living in a coastal environment poses health risks it also provides numerous benefits to people. Fresh seafood, recreational opportunities, ports for trade, and marine natural products with pharmaceutical benefits. Marine sponges produce chemicals for self-defense that have potent anticancer and antiviral properties. There are numerous pharmaceutical benefits yet to be garnished from the ocean.

The California coastline is a tourist and recreational resource of great economic value. Public health concerns of coastal water quality, water pollution, and harmful algal blooms require monitoring for safe recreational conditions. The site location of this preliminary surfer health study was the coastal waters of Monterey Bay, Santa Cruz County on the Central California coast. The bay opens to the Pacific Ocean with the salinity ranging from 32-33.5 psu. The Monterey Bay is an area of high biological productivity due to an upwelling period that brings nutrient rich cold water to the surface. The annual red tide and HAB season runs May through October.

Below the sea surface of the scenic Monterey Bay exists a marine ecosystem that at times is toxic due to harmful algal blooms. Microscopic unicellular organisms, phytoplankton, form the base of the marine food web. When there is a proliferation of phytoplankton causing an HAB event the marine ecosystem transfers toxins to numerous marine organisms and ultimately to humans. There exist several algal toxins in Monterey Bay that cause morbidity and mortality to organisms, marine mammals and humans. Along the California coast including Monterey Bay HABs of *Pseudonitzschia* have produced domoic acid. This potent toxin is transferred through the food web to sardines, anchovies and planktivorous fish. Seabirds and marine mammals mortalities have been caused by the transfer of domoic acid through the food chain (Lefebvre et al. 1999 and Scholin et al. 2000).

Additionally, sea birds have died from an unknown protein surfactant produced by *Akashiwo sangenium*. There is a ban on recreational harvesting of mussels from May to October due to saxitoxins, which are produced by the phytoplankton *Alexandrium.* In late August 1997, necropsies of common murres (*Uria aalge*) in Monterey Bay, California, revealed that the 400 sea bird deaths were the result of brevetoxicosis (Jessup et al. 1998). *H. akashiwo*, a known brevetoxin producer, was present in water samples taken from the Santa Cruz pier (O'Halloran et al. 2005).

In Monterey Bay coastal waters surfers are one of the dominant ocean recreational groups due to cold water temperatures (yearly range 48-58°F). Surfers have high exposure to marine water through ingestion, inhalation of marine aerosolized particles, and skin contact. They are ideal participants for a coastal environmental quality study examining baseline information on human health symptoms and illnesses due to marine water exposure.

Anecdotally, newspaper articles in the local Santa Cruz, CA, newspaper, Sentinel, publishes frequent articles concerning acute health complaints of surfers after water exposure especially during red tides/HAB events. During a red tide in Monterey Bay that lasted a month in November 2007 surfers complained of respiratory issues after surfing in the reddish brown waters. This red tide caused over 600 sea birds to be rescued by the Department of Fish and Game in Santa Cruz. The sea bird mortalities and morbidities were linked to the red tide due to the production of an unidentified protein surfactant (Santa Cruz Sentinel 11/28/07). Additionally, surfers complain of gastrointestinal symptoms when surfing after heavy rains when storm drains flow into the ocean. Previous studies on surfer health have focused predominately on accidents, injuries from surfboards, sprains, lacerations, strains, fractures, rock or coral contact, jelly fish stings, sun burns, skin cancer, skin irritations and ear problems (Zoltan et al. 2005).

Water Quality Measures

The US EPA Beaches Environmental Assessment and Coastal Health Program require coastal water quality monitoring for the publics safety. Enterococcus bacteria, E. coli, and total coli form are the traditional fecal indicators for monitoring water quality. In 1986 the EPA recommended the use of enterococci as indicators in marine waters. The acceptable public health risk for gastrointestinal illness due to marine recreational exposure is 19 cases of GI illness out of 1000 swimmers. The US EPA guideline is a steady state geometric mean indicator density of 35 CFU/100ml or a single sample density of 158 CFU/100ml. The WHO guideline is 40 CFU/100ml.. Single samples are problematic since pathogen concentrations vary greatly among space and time (Boehm et al. 2002). Rapid detection methods, within 2 hours, to measure indicator organism concentrations were found to be predictive of GI illness in people swimming at 2 recreational beaches of the Great Lakes (Wade et al.

2006). In California in response to coastal pollution, AB 411 requires coastal counties to weekly monitor water quality from April through October at beaches where over 50,000 people visit a year or within 150 meters of a river mouth (California State DHS 1997).

Busch et al. (2001) found that swimmers/surfers followed the signs to stay out of the water for 72 hours after a heavy rain but disregarded the beach closure advisories posted by the health department. Previous studies have found that public health beach closure advisories have been inaccurate due to delays in detection methods (Rabinovici et al. 2004). A systematic review and meta-analysis of water quality guidelines for recreational waters in the prevention of gastrointestinal (GI) illness found current EPA standards of enterococcus to be the best water quality indicator for marine fecal contamination (Wade et al. 2003). Additionally, a literature review of 22 epidemiology studies examining the health effects of swimmers from recreational water exposures found that enterococci bacteria counts correlated the best with health outcomes in marine water (Pruss 1998). A cohort study in England found acute health risks increased with increased recreational ocean exposure. Surfers or divers were found to be 81% more likely to have health problems than non-swimmers, while the risks for swimmers and waders were 31% and 25% greater than non-swimmers (Balarajan 1991). In a cross sectional study of 518 Oregon surfers it was estimated that surfers ingested 170ml of seawater a day during a surfing session (Stone et al. 2008). A cross-sectional study on the health effects associated with recreational water (mean total coli form) among surfers in Santa Cruz and Orange County found that urban runoff increased the risk of illness for every acute health symptom by 10% for every 2.5 hours of weekly water exposure (Dwight et al. 2004). The authors' findings suggest that discharging untreated urban runoff poses health risks.

Harmful Algal Blooms

Phytoplankton forms the base of the marine food web. Several geneses of phytoplankton produce naturally occurring toxins that are transferred throughout the marine food web. Several types of phytoplankton (*Pseudo-nitzschia*, *Alexandrium*, *Heterosigma, Akashiwo, Chattonella, Fibrocapsa, Cocliodinium*) have been identified in Monterey Bay that can produce dense blooms and generate ROS - super oxide anions, hydrogen peroxides, hydroxyl radicals, singlet oxygen (Silver per. comm.). Environmental stress disturbs the balance of antioxidants and prooxidants, in some cases triggering the production of ROS (Twiner et al. 2000). Wave and wind action can cause cell lyses and release aerosolized algal toxins. These aerosolized toxins are potential health concerns for surfers or people enjoying other ocean recreational activities in Santa Cruz County. The recent November 2007 red tide in Monterey Bay introduced a new concern with the production of a protein surfactant related to the algal bloom or degradation of the bloom or a byproduct of species killed during the bloom (Squires, Sentinel 11/28/07).

Backer et al. found that lifeguards in Florida complained of more upper respiratory symptoms after being exposed to aerosolized brevetoxin than during non-exposed brevetoxin times (Backer et al. 2005).

Elevated bacterial counts occur during HAB events. This is due to the change in seawater composition. Dissolved organic material during a HAB can cause explosive growth of bacteria such as Vibrio cholerae (Lipp et al. 2002). A case report of a scuba diver in Monterey Bay, California documents severe acute otitis media and bilateral mestoiditis due to high levels of coliform bacteria as a result of a red tide (Honner et al. 2010).

Internet surveys

Data collection of study participants can be conducted face-to-face, by mail, by telephone, by touchtone data entry on the telephone, or on-line. Different survey modes pose different challenges to survey quality. Questions are constructed in different ways in the different survey modes, which may result in different responses (Dillman 2007).

On-line surveys have the advantage of being low cost, convenient, and social desirability or acquiescence is less of a problem with sensitive data than with other survey modes (Dillman 2006). As with any survey mode, measurement error is a potential concern with on-line surveys. The design of on-line surveys can affect the choice of responses. First, the visual design of a survey can affect responses. The respondents of survey questions with multiple columns have been found to focus and select the choices on the top row rather than the subsequent rows. In contrast, questions with choices in one vertical column are read from top to bottom (Dillman 2007). Second, when the survey design includes subgroups it is more common for respondents to check a response from each group. This has been found to yield different responses than if a vertical list is used (Dillman 2007). Third, research findings suggest that yes/no questions receive more yes responses than questions that just request "check all that apply" (Dillman 2006).

In addition, the Internet has been found to be an effective and low cost way to survey people for food borne as well as fresh and marine waterborne illnesses (Kuusi et al. 2004, Turbow et al. 2008). Turbow et al. examined the Surfriders Ocean Health survey from an 11-year period. The findings from these surveys suggest that marine swimmers and surfers will volunteer information on health symptoms and illnesses over the Internet. Illness reports from marine exposure could assist in the development of a marine disease surveillance system (Turbow et al. 2008).

Objectives

The objective of this study was to examine what acute health effects, if any, were associated with marine water exposure in surfers in Monterey Bay Central California coastal waters. The study had three specific aims. First, to determine whether acute illness or symptoms (*e.g.* stomach pain, ear infection, eye infection, skin rashes, cough, nasal congestion, nausea…) in surfers was associated with bacteria levels measuring point source pollution in Monterey Bay coastal waters. Second, to determine whether surfer respiratory complaints or other health symptoms were associated with harmful algal blooms. Third, to determine whether surfer health symptoms were associated with seasonal variations such as rainfall, water temperature, salinity, chlorophyll a, nutrients.

Materials and methods

A prospective cohort study of 48 surfers with 697 weekly observations investigated the acute health risks, if any, associated with surfer seawater exposure. The Surfer Health Study was approved by the institutional review board of the University of California, Berkeley. The study location was the coastal waters of Monterey Bay, Santa Cruz County, California. Santa Cruz was recently voted the world's best surf destination (London Times 5/14/10, http://www.timesonline.co.uk/tol/travel/holiday_type/water_sports/article7126609.ece).

Study population.

Surfers were recruited for the study in a variety of ways. Ads were placed in three local newspapers (Good Times, Sentinel, & Metro) and online through Google ads and a Craig's list ad. Mass emails advertising the study were sent through local ocean non-profit agencies (*i.e.* Surfriders, Save Our Shores, Monterey Bay Research Institute) and academic institutions (University of California Santa Cruz and Cabrillo College). Flyers were also distributed at local surf spots and surf shops.

Surfers were eligible to participate in the study if they were 18 years and older, surfed at least 30 minutes a week in Santa Cruz County coastal waters, had Internet access, and were able to read and complete an online survey in English. An open cohort of surfers participated in the study from February 2008 to October 2008. As an incentive to participate in the study every time a participant submitted a weekly online survey they received $1 toward a gift card sent to them at the end of the study. In addition, they were entered into a drawing at the end of the study to win one of five gift certificates worth $500, $250, $100, $100 or $50.

Forty-eight surfers met the study eligibility criteria. They provided informed consent, completed the baseline health survey, and weekly health surveys using the on-line data survey system, Survey Monkey. The baseline surfer health survey began with the informed consent document. Once a surfer agreed to participate in the study they could proceed with the questionnaire which consisted of the following types of questions: 1) demographic information, including race, income, education level; 2) water exposure time; 3) existing physician diagnosed health problems potentially related to the study outcomes (*e.g.* chronic diarrhea); 4) types of food consumed; 5) prescription and non-prescription medications; 6) acute health conditions (*e.g*. GI, respiratory, skin, eye or ear) experienced since the visit to the beach; and 7) general immune compromising conditions (*e.g.* cancer). The checklist guide lines for strengthening the reporting of observational studies in epidemiology (STROBE) for cohort studies was followed for this study (appendix 5).

Every week surfers were sent an email reminder to complete a weekly surf log regardless if they had surfed or not. The weekly surf logs requested information in regards to surf locations, water exposure time, acute health illnesses of surfers and those that reside with them, medications taken during the week, symptoms of allergies or asthma, and consumption of raw foods and rare meats.

Environmental Data.

Oceanographic time series data (*e.g*. water temperature, salinity, chlorophyll a, phytoplankton cell concentrations of *Pseudo-nitzschia australis* and *Alexandrium* and domoic acid toxin) were collected weekly from the end of the Santa Cruz wharf (36.57^{O}N, 122.01^{0}W) in Monterey Bay from February 2008 to October 2008 (Fig. 1). Marine water samples were collected and processed by a member of Professor Mary Silver's ocean sciences lab at the University of California Santa Cruz. Net tow samples were collected using a ¼ meter net with 20 um mesh that was dragged from three meters to the surface. Surface seawater was also collected with a bucket. Collected water samples were transported to the lab for immediate processing. An inverted microscope (Olympus IMTIO) was used for identification of the phytoplankton community in the net two. A 40 ml aliquot of the net tow sample was preserved in neutral Lugol's iodine for archival purposes. A digital thermometer was employed on site at the wharf to measure water temperature of the collected water. Salinity was processed by conductivity (Portasal). A flurometer (Turner TD700) was used to measure chlorophyll a. Five hundred milliliters of surface seawater were filtered through Whatman GF/F filters with a low vacuum pump. These filters were stored at -20^{0}C for a couple of months prior to analysis. Particulate domoic acid in phytoplankton seawater samples was measured when toxic *Pseudo-nitzschia* cell density exceeded 1000 cells l^{-1}, except during the summer of 2008 when toxic *Pseudo-nitzschia* cell density exceeded 100 cells l^{-1}. HPLC was used to measure particulate domoic acid in the samples. 10% MeOH was used for extraction of domoic acid from the Whatman GF/F filters. Particulate domoic acid was analyzed by the 9 fluorenyl-methoxycarboxyl (FMOC) method (Pocklington et al. 1990) and equipment was employed as described by Vigilant & Silver (2007). The limit of detection of domoic acid in the samples was 0.06 ng ml^{-1}.

Weekly water quality data (*e.g*. *Enterococcus* counts) was obtained from the Santa Cruz County Department of Environmental Health Services (http://sccounty01.co.santacruz.us/eh/environmental_water_quality/current_water_quality_data/index.htm) and Surfriders (http://www.surfridersantacruz.org/water_test_tcs.php). Both agencies conduct weekly water quality sampling at numerous beaches (up to 18 beaches weekly) in Santa Cruz County throughout the year. The seawater quality results are reported weekly online at their websites.

Statistic analyses

Descriptive statistics and other statistical analyses were performed using Excel 2007, Survey Monkey, and STATA 11 statistical program. Demographic data has been compiled and presented in tables and charts. The frequency, percent, and person-weeks of acute health outcomes in surfer participants were calculated. Bivariate associations of potential predicators with respiratory illness were evaluated (*i.e.* gender, allergies, asthma, household exposures, smoking status, age, years surfing…). The proportion of weeks with respiratory illness for male and female surfers was evaluated. The median and mean of this proportion was compared in females and males. Graphs of upper respiratory illness and various environmental conditions were generated using STATA 11. The full regression model simultaneously assessed 12 potential predictors (household respiratory illness, allergies, asthma, gender, smoking status, water temperature, water salinity, water chlorophyll a, surfer seawater exposure in hours per week, *Enterococcus* count, *Pseudo-nitzschia australis* cells per liter, *Alexandrium* cells per liter) on the risk of respiratory illness. Odds ratios and risk ratios were estimated and compared by generalized estimating equation (GEE), generalized linear model (GLM), and logistic model adjusting for covariates associated with upper respiratory symptoms.

Results

The Surfer Health pilot project was an open prospective cohort study conducted over an eight-month period (2/22/08-10/22/08) with no surfer in the cohort completing more than 31 weeks of surveys. Forty-eight surfers completed a baseline demographic and health survey and at least one weekly health log online using Survey Monkey, an online survey tool. There were a total of 697 weekly observations for the surfer participants.

The baseline characteristics and demographic data of the surfer cohort are presented in Table 1 and Chart 1. The mean seawater exposure of this cohort of surfers was 4 hours per week. The majority of the surfer participants were males (72%), the mean age was 34 years (range 19 – 60), most of the participants were non-smokers (69%) and 17% had a physician diagnosed history of asthma and 25% had a physician diagnosed history of allergies (non food). The median years surfing was 13 years with a range from 1 to 45 years. Diseases with a physician confirmed diagnosis are presented in Table 2. The surfers in this cohort, in general, were healthy and physically fit. They did, however, have a higher percentage of people with allergies (25% vs. 9-16%) and asthma (17% vs. 7%) than the general United States population. High cholesterol (10% vs. 17%), hypertension (6% vs. 19%) and diabetes (0 vs. 8%) percentages were well below that of the general US population.

Self reported acute health symptoms are presented in Table 3. Twenty-nine percent of the surfers had upper respiratory symptoms during the study. Upper respiratory disease was defined as having one or more of the following symptoms: eye irritation, nasal congestion, runny nose, cough, or sore throat. Only 10% of the surfers reported gastrointestinal problems during the study. Thirty nine percent of surfers reported at least one acute health effect during the study.

The results from the environmental sampling are presented in Graphs 1-4. Water sampling and analysis of phytoplankton recorded the highest concentration of *Alexandrium* (4×10^1 cells/L) and the highest concentration of *Pseudo-nitzschia australis* (4.55×10^4 cells/L) on 8/5/08 (Graphs 3 & 4). In addition, on 8/5/08, 50% of surfers completing the weekly log reported upper respiratory symptoms, the highest percentage during the study. The highest level of domoic acid, toxin produced by *Pseudo-nitzschia australis,* was recorded a week later on 8/12/08 at .8 ppm.

Table 4 presents surfer self-reports of previous acute health symptoms related to red tide exposure during surfing. Fifty one percent of the surfers (23/45) reported previous acute health symptoms related to surfing during a red

tide. Sinus problems were the most predominately reported symptom with 34% of the surfers complaining of nasal congestion or a runny nose.
Pseudonitzchia australis cell counts (cells/Liter), *Alexandrium* cell count (cells/Liter), *Enterococcus* count, and surfer water exposure in hours per week were considered as potential risk factors. In addition, eight other covariates were considered as potentially confounding factors household respiratory illness exposure, allergies, asthma, gender, years surfing, smoking, water temperature, water salinity, and chlorophyll a. Of the 12 independent variables considered, allergies, household respiratory illness exposure (nasal), gender, and history of acute health problems during red tides were statistically significant.
Table 5 shows the Generalized Estimated Equation (GEE), Generalized Linear Model (GLM), and logistic model comparisons of odds ratio and risk ratio estimates. GEE, GLM, and logistic regression results were similar finding associations for surfer upper respiratory symptoms and allergies, household respiratory illness symptoms, female gender, and history of acute health symptoms during red tide. GEE was the best model for this study because it accounts for the possibility that multiple weekly observations on the same surfer are correlated or non-independent. GEE also allows the baseline risk of respiratory disease to be different for each surfer.

Surfers who previously experienced acute health symptoms while surfing during a HAB were 1.63 times more likely to have upper respiratory symptoms than surfers who had not experienced any acute health symptoms during a HAB event (95% CI = 1.09, 2.44). Surfers with housemates with upper respiratory symptoms were 1.72 times more likely to have upper respiratory symptoms as compared to surfers with healthy housemates (95% CI = 1.22, 2.43). Surfers with a physician diagnosis of allergies were 1.41 times more likely to have upper respiratory symptoms in comparison to surfers without allergies (95% CI = 1.01, 1.97). Female surfers were 1.25 times more likely to have upper respiratory symptoms than male surfers (95% CI = .91, 1.71). The effect of gender on upper respiratory symptoms in surfers in this cohort may be due to chance. We cannot reject the null hypothesis in this case.
The logistic equation is
ln [P/(1-P)] = b0 + b1 household upper respiratory exposure + b2 red tide exposure with acute health symptoms + b3 gender + b4 allergies
household respiratory exposure = 1 if the surfer has a housemate with upper respiratory symptoms/illness during the past week and 0 otherwise
red tide exposure with acute health symptoms = 1 if experienced acute health illness or 0 if not
allergies = 1 if the surfer has a physician diagnosis of allergies or 0 otherwise
gender = 1 for females, 0 for males

Discussion

In this study we examined the association of acute health symptoms and exposure to the coastal marine water of Monterey Bay, Santa Cruz County, California, USA. Anecdotal evidence from surfers suggested that acute health outcomes (*i.e.* gastrointestinal symptoms after a storm or respiratory symptoms after a red tide) were associated with surfing in the coastal waters of Monterey

Bay. In this study, household upper respiratory symptoms, previous history of acute symptoms surfing during a red tide, gender, and allergies were associated with increased upper respiratory symptoms or illness in surfers. The full model without interaction included 14 risk factors: phytoplankton *Pseudo-nitzchia australis*, phytoplankton *Alexandrium*, domoic acid, sea water temperature, salinity, chlorophyll, enterococcus counts, seawater exposure, household upper respiratory symptoms, age, asthma, allergies, red tide acute health problem, and gender. This appears to be the first surfer prospective cohort study.

The most parsimonious model examining the effect of surfer upper respiratory symptoms included four covariates: household upper respiratory symptoms, HAB acute health symptoms, gender, and allergies.

Surfers who had household family members or housemates with upper respiratory symptoms during the previous week had a 2.6 increase in the odds of respiratory illness as compared to surfers whose housemates had no upper respiratory illness or symptoms (95% CI = 1.65, 4.16). The relative risk as expected was lower than the odds ratio. Common illnesses verses rare illnesses will have lower relative risks than the odds ratios. The relative risk was 1.72 (95% CI = 1.22, 2.43). This finding is biologically plausible since most respiratory infections are contagious. Direct contact with an ill person, especially children, through large or small droplets from coughs or sneezes, as well as contact with tissues, linens, or other surfaces holding the virus at home will cause respiratory illness in other family members or housemates. (http://www.health.harvard.edu/fhg/updates/update0803b.shtml).

Surfers who identified a history of previous acute health symptoms or illness after surfing during a red tide event were 1.63 times more likely to have upper respiratory symptoms than surfers who had not experienced any acute health symptoms during a HAB (95% CI = 1.09, 2.44). Women surfers had 1.25 times the relative risk of upper respiratory symptoms as compared to male surfers (95% CI = .91, 1.71). Although not statistically significant, gender was retained in the multivariate model because numerous larger studies have found women have a higher incidence of upper respiratory symptoms or illness than men. A meta-analysis by Schachter et al. (2009) indicates that after adjusting for age and smoking upper respiratory symptoms were more common in women and lower respiratory symptoms were more common in men. The findings of this meta-analysis suggest that women may represent a more vulnerable population for upper respiratory disease. Surfers with a previous physician diagnosed history of allergies (non-food) were more likely to report upper respiratory symptoms than surfers without allergies. Surfers with a physician diagnosis of allergies had a relative risk of 1.41. They were 1.41 times more likely to have upper respiratory symptoms in comparison to surfers without allergies (95% CI = 1.01, 1.97). Environmental allergens (*i.e.* pollen) were not controlled for in this study. Additionally, other unmeasured confounding factors include wild fires and aerial pesticide spraying for the apple moth that occurred during the study. Either or both may have had a positive effect on upper respiratory symptoms.

HABs

Several genera of phytoplankton produce naturally occurring toxins such as neurotoxins, heptotoxins, dermatotoxins, and carcinogens. Harmful algal blooms occur when there is dramatic increased growth of these unicellular algae. These potent toxins produced in HABs can bio-accumulate and transfer to high tropic levels in the marine food web.

Several types of phytoplankton found in Monterey Bay are responsible for harmful algal blooms (*Alexandrium*, *Pseudo-nitzshia*, *Akashiwo sangineum, Heterosigma akashiwo, Dinophysis, Fibrocapsa, Chattonella, Coccolidinium, Prorocentrum,* & *Microcystics).* One or more of these phytoplankton genera may be associated with upper respiratory symptoms or other acute health effects in surfers in the Monterey Bay. This is an emerging field of study with limited research in this area. Along the Florida Gulf of Mexico coast large cell numbers of the phytoplankton, *Gymnodindium brevis*, cause red tides in which aerosolized toxins are released that have been associated with respiratory symptoms (Backer 2005). In North Carolina *Pfiesteria* has been linked with neurological problems and skin ulcers.

Three months prior to the start of this study there was a month long HAB of *Akashiwo sangineum* in Santa Cruz coastal waters in which numerous surfers anecdotally reported acute upper respiratory symptoms. Unfortunately, this study did not collect data during that harmful algal bloom which produced an unknown protein surfactant (pers. comm. Dave Jessup).

During this study there were bloom conditions, high density of cells for two genera of phytoplankton, *Alexandrium* and *Pseudo-nitzshia australis*. *Alexandrium* produces a very potent toxin, saxitoxin, at much lower cell concentrations than *Pseudo-nitzshia australis* produces domoic acid. The graphs in this study (Graphs 1-4) show that the second highest water temperature and highest density of cell concentration of phytoplankton coincides with the highest reported levels of upper respiratory illness. However, water temperature and phytoplankton cell concentrations are not statistically significant when we adjusted for other independent variables such as household upper respiratory symptoms/illness, gender, previously identified history of acute illness due to HAB exposure, and physician diagnosis of allergies.

Fifty one percent of surfers reported on the baseline questionnaire that they had an acute health symptom related to surfing during a red tide (Table 4). The most commonly reported symptom was sinus symptoms among 34% of the surfers. Future research is necessary to focus on acute health effects associated with specific types of phytoplankton at various cell concentrations. In addition, bacteria and viruses that co-occur and have exponential growth during red tides need to be investigated. The HAB connection with Vibrio cholerae has been well established but other pathogenic bacteria need to be studied (Lipp et al 2002). From a public health perspective, it is important to recognize HAB toxins in the environment and understand their exposure route as well as the transfer of toxins through the food web. This is especially important during this time of changing environmental conditions, which favor the occurrences of HABs.

Strengths and limitations of the study

Chance findings are always of concern in small observational studies with limited power such as this one. However, the odds ratios, risk ratios, and confidence intervals in this study demonstrate statistically significant findings. Data from experimental studies are always superior to observational studies because randomization equalizes all confounding variables between comparison groups. Confounding of measured variables is adjusted for in the multivariate model statistical analysis. Other unknown confounding factors may not be accounted for since they are not identified in the model.

There are several limitations to this study. The small sample size of 48 surfers with 697 weeks of observations is a limitation. Additionally, self-reported baseline health histories, weekly acute health symptoms, and self-reported weekly water exposure time, is a potential weakness; objected observed data would have been preferable. The healthy worker effect is a concern in this study. Surfers in this cohort were healthier than the general United States population. The healthy worker bias would underestimate the true effect. Asthmatic or allergy medication use may have played a role in decreasing the effect of respiratory symptoms. Once again the bias would underestimate the true effect.

Reporting bias may be a limitation of this study design since illness was based on self-report rather than with medical verification from a doctors visit. Information bias due to self-reporting of questionnaire information of respiratory symptoms and/or lack of verification of medical diagnosis of respiratory illnesses by surfers could lead to misclassification of exposure thereby reducing the magnitude of the estimated odds ratio. In addition, recall bias could be a concern, if surfers were unable to accurately remember their acute health illness/symptoms for the past week. In this case misclassification of exposure could occur. Recall bias is a problem if there was misrepresentation of information to questions on the questionnaire (*i.e.* history of asthma and medication use). The direction and magnitude of the bias would be variable. Non-participation bias may also have been a problem. Surfers who decided to participate in the study maybe different from those who chose not to participate. Surfers who participated in this study where perhaps somewhat more concerned about water quality issues than those who chose not to participate. Within-person confounding is possible due to environmental and transient exposures that were not identified and measured (*i.e.* seasonal allergen).

Internet surveys

This study corroborates the findings of other studies (Kuusi et al. 2004, Turbow et al. 2008) that people will provide information online about health symptoms and illness in regards to marine exposure. Completing questionnaires online is a low cost and effective way to survey people for marine waterborne illnesses. These findings may aid support for a national marine human health surveillance system.

Generalisability

The relatively small sample size of the surfer cohort makes generalizing the results of this study to the larger surfer target population difficult. The findings of this study are of limited local interest due to local factors such as water quality and community illnesses. These findings cannot be generalized to other populations in different geographic coastal environments.

Conclusions

Anecdotal reports from Santa Cruz, California surfers indicated that red tides potentially caused acute health symptoms in surfers. This study demonstrated that exposure to HABs, female gender, allergies, and household upper respiratory symptoms were associated with upper respiratory symptoms in this cohort of surfers.

Public health concerns of coastal water quality and toxins produced by HABs require monitoring for safe recreational conditions. Health symptoms or illness surveys from marine exposure using the internet can assist in the development of a marine disease surveillance system to assess our coastal water quality and assure the publics safety, especially since no other surveillance programs are in effect in California. Future studies are required in Monterey Bay to identify acute health symptoms associated with specific HAB toxins. In addition, it will be important to assess co-occurring pathogenic bacteria and viruses that also proliferate during these HAB events to determine what role, if any, they have in human illness.

Figure1: Monterey Bay, Santa Cruz County, California site map

Figure 2: "Surf City USA" Santa Cruz, CA lands No. 1 spot on the London Times (5/14/10) list of the world's best surf destinations. "Santa Cruz, south of San Francisco, has a seemingly endless selection of surf spots for surfers of all abilities. If you rip, there's Steamer Lane, a world-class right-hand point break, while intermediate-to-good surfers will love Pleasure Point and the Hook, two nearby right-handers. If you're a beginner, there are easy waves at Cowell's, while along the coast Waddell Creek can provide almost empty, though sometimes sharky, surf."
http://www.timesonline.co.uk/tol/travel/holiday_type/water_sports/article7126609.ece

Table 1. Demographic data of the surfer cohort (n=48).

Characteristic	n	(%)
Race		
Caucasian	42	89
Sex		
Male	34	72
Mean Age (years [range])	34 [19-60]	
Smoking status		
No	33	69
Education		
B.A./B.S.	21	45
Health Insurance		
Private insurance	39	83
Weekly water exposure/hour (mean)	4	
Years Surfing (years [range])	13 [1-45]	
Level of concern about the water		
Very concerned	22	47
Marital status		
Single	21	49
Allergy or asthma medication		
No	40	83
Daily medications		
None	33	69
Hours of exercise/week (mean [range])	12	(2-30)
Daily alcohol consumption		
1-2	27	57
Vitamins		
Sometimes	17	35
Annual income		
40K-100K	22	46
Fruit & veggie consumption per day		
two	12	25

Table 2. Diseases experienced by surfers (Physician-diagnosed). n=48

Symptom	n	(%)	CDC US Prev. (%)
Allergies	12	25	9-16
Asthma	8	17	7
Cancer (skin)	2	4	
Cancer (other)	1	2	
Diabetes	0	0	8
High cholesterol	5	10	17
Hypertension	3	6	19
Irritable bowel	1	2	
Skin problems	3	6	
Crohn's disease	0	0	

Table 3. Surfer Acute Health Effects.
n=697 person-weeks

Disease	n	%	% *
Upper Respiratory (total)			29
Sore throat or cough	76	11	
Nasal congestion or Runny nose	158	23	
Eye irritation	19	3	
Gastrointestinal (total)			10
Diarrhea	48	7	
Stomach pain	20	3	
Vomiting	12	2	
Nausea	16	2	
External (total)			9
Ear	26	4	
Skin	15	2	
Fever	16	2	
Chills	15	2	
One or more of the above health effects	39%		

*not mutually exclusive categories

Upper respiratory illness

respill	Frequency	Cumulative Percent	Cumulative Frequency	Percent
0-no	495	71.02	495	71.02
1-yes	202	28.98	697	100.00

GI illness

gill	Frequency	Cumulative Percent	Cumulative Frequency	Percent
0-no	625	89.67	625	89.67
1-yes	72	10.33	697	100.00

External illness (irritation)

extill	Frequency	Cumulative Percent	Cumulative Frequency	Percent
0-no	635	91.10	635	91.10
1-yes	62	8.90	697	100.00

Any illness

anyill	Frequency	Cumulative Percent	Cumulative Frequency	Percent
0-no	422	60.55	422	60.55
1-yes	275	39.45	697	100.00

Table 4. Surfer reports of previous acute health symptoms related to surfing exposure during a red tide (n=45), not mutually exclusive categories.

Symptom	%
Nausea	4
Stomach ache	4
Ear infection	6
Sinus problems	34
Cold/Flu	8
Headaches	4
Sore throat	6
Cough	6
Skin rash	2
Swollen glands	2
Fever	2
Asthma	2
Eye irritation	2
Respiratory irritation	4
Total with symptoms	51

(2 reported taking antibiotics)

Table 5. GEE, GLM, & Logistic Model Comparisons of Odds Ratio & Relative Risk Estimates.

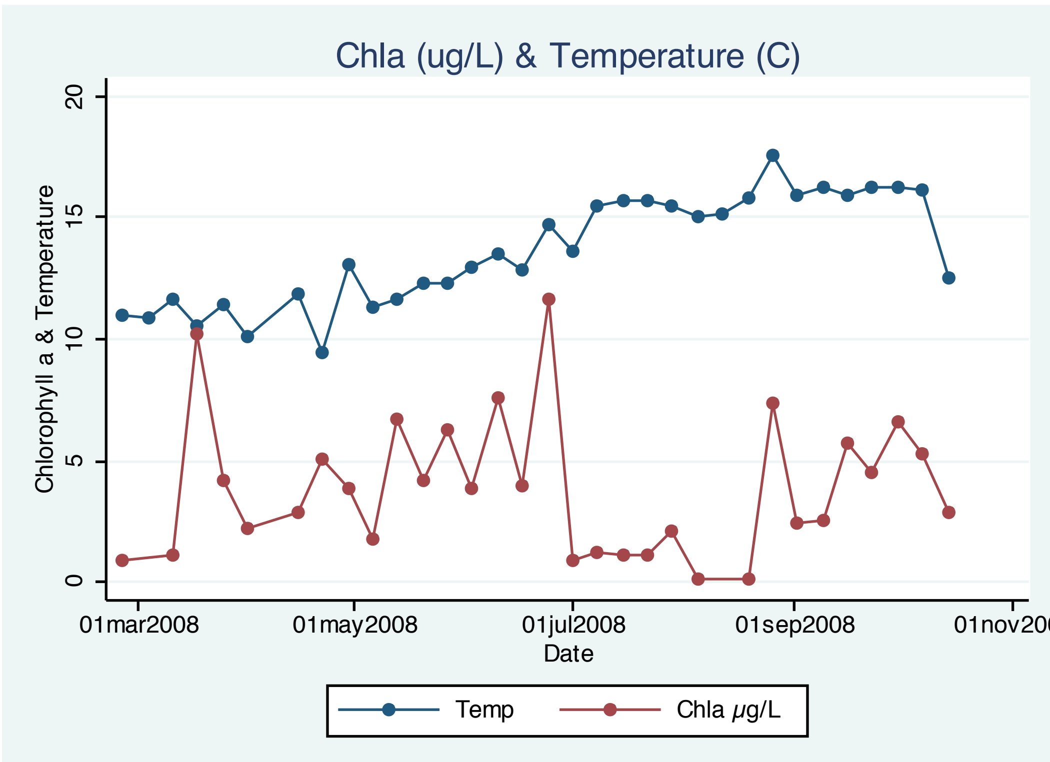
Household respiratory symptoms	GEE, robust SE	GLM, robust SE	Logistic Regression
OR	2.6	3.2	3.20
SE	.62	.84	.85
95% CI	1.65, 4.16	1.91, 5.38	1.91, 5.38
90% CI	1.77, 3.86	2.07, 4.95	2.07, 4.95
RR	1.72	1.85	
SE	.30	.39	
95% CI	1.22, 2.43	1.21, 2.82	
90% CI	1.29, 2.29	1.29, 2.64	

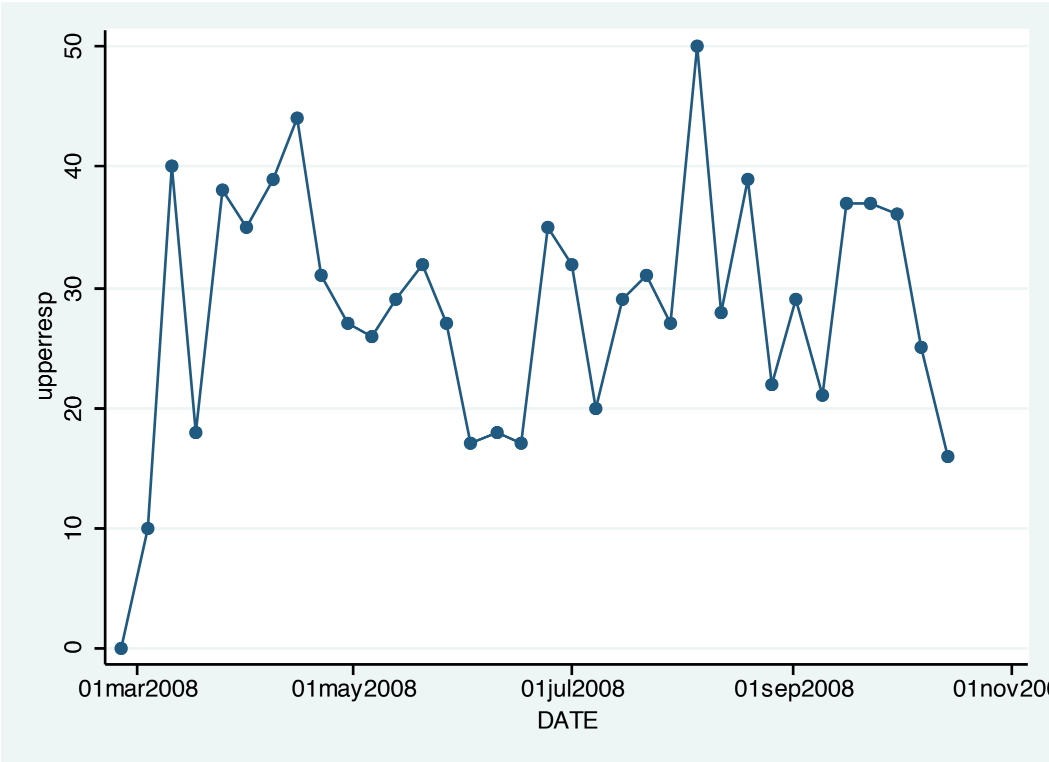
HAB exposure with acute health symptoms	GEE, robust SE	GLM, robust SE	Logistic Regression
OR	2.06	2.47	2.47
SE	.56	.73	.73
95% CI	1.20, 3.52	1.38, 4.41	1.38, 4.41
90% CI	1.31, 3.23	1.51, 4.01	1.51, 4.01
RR	1.63	1.79	
SE	.33	.39	
95% CI	1.09, 2.44	1.17, 2.75	
90% CI	1.17, 2.29	1.25, 2.57	

Allergies	GEE, robust SE	GLM, robust SE	Logistic Regression
OR	1.99	2.05	2.05
SE	.69	.77	.77
95% CI	1.01, 3.94	.98, 4.30	.98, 4.30
90% CI	1.12, 3.53	1.10, 3.82	1.10, 3.82
RR	1.41	1.53	
SE	.24	.29	
95% CI	1.01, 1.97	1.06, 2.22	
90% CI	1.07, 1.86	1.13, 2.09	

Female	GEE, robust SE	GLM, robust SE	Logistic Regression
OR	1.71	1.84	1.84
SE	.58	.68	.68
95% CI	.88, 3.33	.89, 3.78	.89, 3.78
90% CI	.98, 2.99	1.00, 3.36	1.00, 3.36
RR	1.25	1.39	
SE	.20	.25	
95% CI	.91, 1.71	.97, 1.98	
90% CI	.96, 1.63	1.03, 1.87	

Graph 1. Chlorophyll a and Temperature.





upperresp
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50
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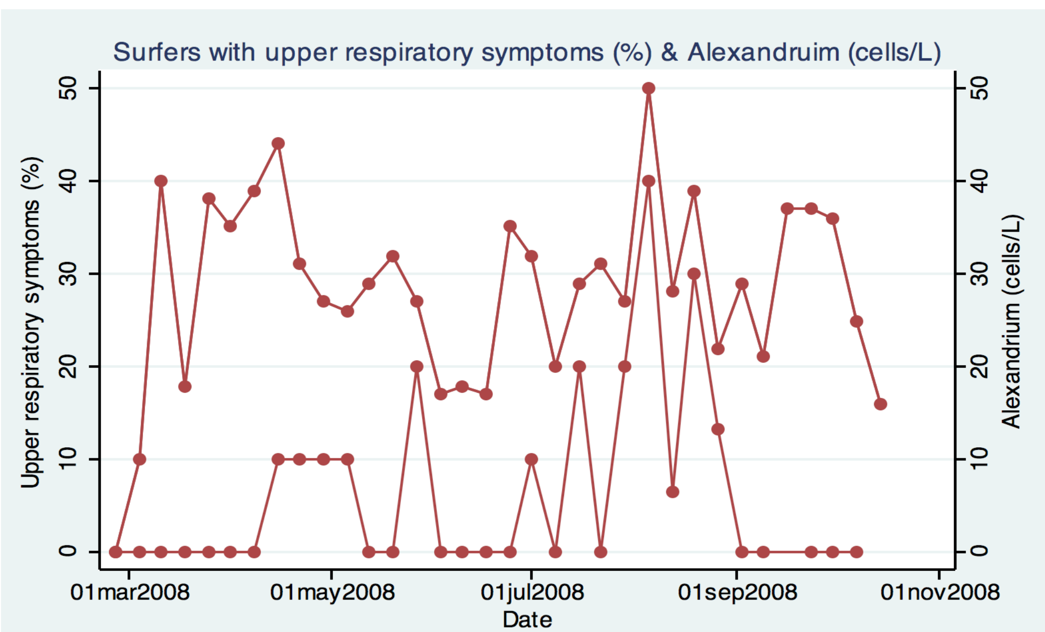

Surfers with upper respiratory symptoms (%) & Alexandruim (cells/L)
Upper respiratory symptoms (%)
Alexandrium (cells/L)
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40
50
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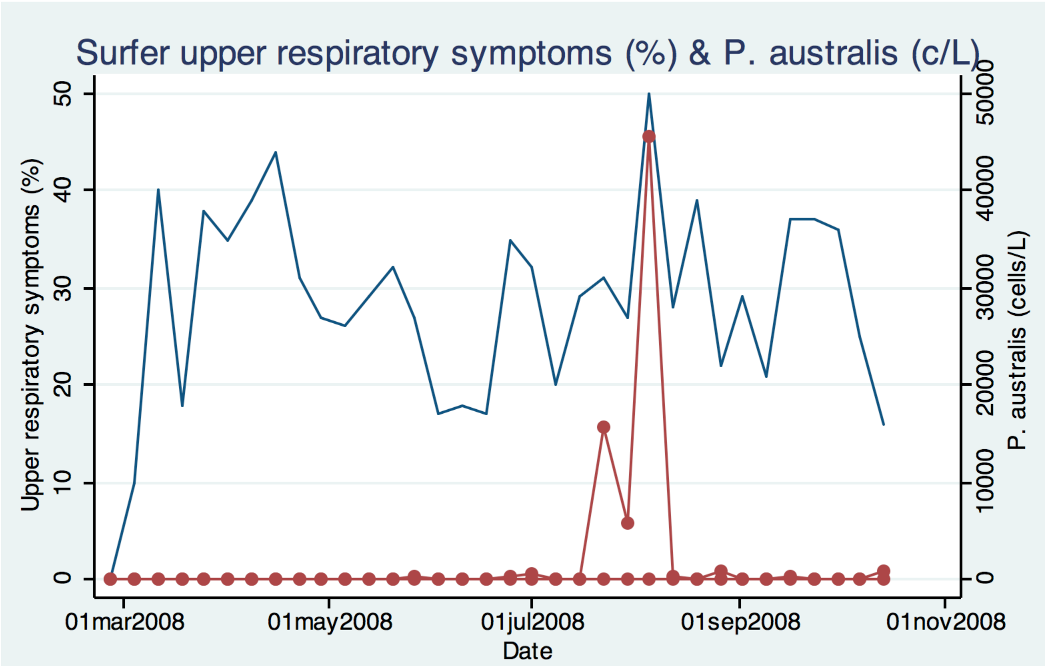
Surfer upper respiratory symptoms (%) & P. australis (c/L)
Upper respiratory symptoms (%)
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P. australis (cells/L)
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CHAPTER THREE

Seawater exposure and acute health effects among ocean lifeguards in the United States

Abstract

The purpose of the ocean lifeguard health study was to determine what health risks, if any, were associated with lifeguards exposure to seawater along the United States coastline. Specific symptoms and illnesses measured focused on upper respiratory, gastrointestinal symptoms (GI), ear problems, skin irritation and acute stress symptoms. United States coastal waters are impacted by point source and non-point sources of pollution as well as harmful algal blooms (HABs). Ocean lifeguards were ideal participants for this study due to their high levels of seawater exposure.

Specific aims of the study were:

To determine whether ocean lifeguard acute illness or symptoms such as fever, ear infection, eye infection, skin rashes, cough, nasal congestion, runny nose, and nausea were associated with seawater exposure or other coastal environmental factors.

To determine whether lifeguard respiratory complaints or other health symptoms are associated with harmful algal blooms.

To determine whether lifeguard ocean rescues were associated with acute stress symptoms.

One hundred and sixty eight United States ocean lifeguards completed a one-time survey using the statistical software Survey Monkey online (www.surveymonkey.com). They responded to questions on demographics, environmental exposures, health symptoms, and acute stress symptoms after a rescue. This cross-sectional study provided a snapshot of the health status of United States ocean lifeguards during August – November 2010.

In this prevalence study 21% of the lifeguards reported upper respiratory symptoms, 48% reported acute stress symptoms after being involved in an ocean rescue and 10% had gastrointestinal symptoms during the past week.

Multivariable logistic regression analyses were employed. The findings of the specific objectives of the study were:

Gastrointestinal symptoms among lifeguards were associated with a history of acute health symptoms after a HAB exposure (RR = 2.49; 95% CI = .76, 8.16). Upper respiratory symptoms were associated with a history of surfers ear (RR = 2.95; 95% CI = 1.33, 6.54) and history of acute health symptoms after exposure to a HAB (RR = 1.57; 95% CI = .72, 3.47). Acute stress symptoms due to ocean rescues were associated with a history of physician-diagnosed anxiety (RR = 1.69; 95% CI = 1.31, 2.17), previous acute health symptoms after exposure to a HAB (RR =1.42; 95% CI =1.08, 1.86), and a history of physician diagnosed asthma (RR =1.66; 95% CI =1.30, 2.11).

Introduction

Worldwide the coastal environment is under threat due to increases in population growth, anthropogenic pollutants, tourist activities, aquaculture production, shipping, and harmful algal blooms. Individually and cumulatively these factors contribute to higher risks for public health and disease (Bowen et al. 2006). In the US, 53% of the population lives on the 17% of coastline (Pew Oceans Commission 2003). Visits to coastal beaches are a tourist industry of great economic value. Lifeguards play a critical role in keeping the United States population safe as they enjoy marine recreational activities and the seashore. They perform ocean rescues and provide lifesaving medical interventions.

The purpose of the United States Lifeguard Health Study was to determine what acute health risks in lifeguards, if any, were associated with exposure to seawater along the coastal United States or other environmental exposures. Specific symptoms and illnesses measured focused on gastrointestinal symptoms (GI), upper respiratory symptoms (UR), ear problems, skin irritation, fevers and chills.

The specific objectives of the study were:

1. To determine whether acute health symptoms (i.e. diarrhea, vomiting, nausea, stomach ache, sinus infection, nasal congestion, runny nose, sore throat, headache, ear problems, high fevers, chills, skin irritation, cough, and eye infection) in lifeguards are associated with ocean water exposure.
2. To determine whether lifeguard upper respiratory symptoms or other health symptoms are related to harmful algal blooms.
3. To determine whether ocean rescues are associated with acute stress.

Coastal waters are impacted by point source and nonpoint sources of pollution as well as harmful algal blooms (HABs) that can pose risks to human health.

Ocean lifeguards were ideal study participants due to their long hours of daily seawater exposure. Potential modes of transmission of seawater exposure for lifeguards were through water ingestion, skin contact, or inhalation of marine aerosolized particles.

Literature review

Drowning is the leading cause of unintentional injury death for children ages one to four years old. The death rate from drowning for this age group is 3 per 100,000. Children under 1 and 15-19 had drowning death rates of 1.6 per 100,000 in 2009. (CDC, http://www.cdc.gov/safechild/Fact_Sheets/Drowning-Fact-Sheet-a.pdf)

United States Lifeguard Association national lifesaving statistics are collected annually from America's beach lifeguards on a collaborative and volunteer basis. In 2010 US beach attendance was estimated to be 15,008,071. There were 3,639 ocean rescues. Rip currents were the cause of 66% of ocean rescues and problems in the surf accounted for remaining 34% of rescues. There are a limited number of studies on lifeguards. A pubmed search with the key word lifeguards yields 62 studies. A key word search using beach lifeguards yields just 14 studies on sun protection, red tides, lung function, drowning, rescues, anaphylactic reactions on the beach, fitness standards, visual acuity, and swimming performance in the surf.

There are only several studies on lifeguards that examine health effects and none that look at acute stress symptoms or acute stress due to occupational rescues. Backer et al. 2005 conducted a pilot study on 28 lifeguards in Florida.

They examined lifeguard respiratory effects of inhaled aerosolized brevetoxins during a red tide and then during a non red tide period. They found that lifeguards exposed to aerosolized brevetoxins reported more symptoms of upper respiratory irritation (eye irritation, nasal congestion, runny nose, and cough) and headache than during times of no red tide. Thaller et al. 2008 found exposure to pollutants (ambient PM2.5 and ozone) at lower levels than national standards had a negative impact on respiratory functioning on lifeguards. PM2.5 was associated with reduced lung volumes and increasing O3 levels were associated with airway obstruction. Two studies looked at the feasibility of using lifeguards to gather water safety data. Kirkpatrick et al. 2008 provided beach lifeguards in two counties in Florida with PDAs for real time reporting of the level of respiratory irritation among people at the beach, amount of dead fish, water color, wind direction, surf condition and flag warnings. The authors report the pilot was well received by the public since it provided important information to minimize exposure to toxic marine aerosols. Williamson 2006, examined what water safety data could accurately be collected by lifeguards. Data accurately recorded were: tide times, wave type, sea conditions, rip tides, and weather and wind conditions. Rescue data accurately collected were age group, sex, lifeguard who performed the rescue, water depth and nearest rescue equipment. Only one paper examined acute illnesses among lifeguards. Sullivan et al. 1989 conducted a case control study among Los Angeles County Lifeguards from 1980-86. They examined the records of 112 lifeguards who had filed work related compensation claims and matched them to healthy lifeguards working in the same year with the same job classification. Eighty-four of the 112 lifeguard cases were due to ear problems/infections, 6 had dermatitis, 2 had rashes, 6 had skin infection, and 5 had conjunctivitis. The results suggested that the acute illnesses among lifeguards were associated with microbial contamination in Southern Santa Monica Bay work locations.

Water Quality Measures – point source pollution

Point source and non-point sources of pollution as well as harmful algal blooms are potential causes of human illness. A literature review of 22 epidemiology studies examining the health effects of swimmers from recreational water exposures found that enterococci bacteria counts correlated the best with health outcomes in marine water (Pruss 1998). They also found increased rates of GI symptoms in swimmers as compared to non-swimmers. A dose response relationship was identified with increased water exposure causing increased rates of GI symptoms (Pruss 1998). A cohort study in England found acute health risks increased with increased recreational ocean exposure. Surfers or divers were found to be 81% more likely to have health problems than non-swimmers, while the risks for swimmers and waders were 31% and 25% greater than non-swimmers (Balarajan 1991).

Harmful Algal Blooms

Phytoplankton forms the base of the marine food web. They are the oceans primary producers and fixers of carbon. They are photosynthetic, microscopic and bloom under various environmental conditions. Several geneses of phytoplankton produce naturally occurring toxins that are transferred throughout the marine food web. There are several clinical syndromes (Neurotoxin shellfish poisoning, Amnesic shellfish poisoning, Paralytic shellfish poisoning, Cigatuera shellfish poisoning…) that are caused by harmful algal blooms. The modes of transmission of toxic algae are through ingestion, aerosolized particles, and skin absorption.

Several types of phytoplankton (Heterosigma, Chattonella, Fibrocapsa, Cocliodinium) can produce brevetoxin and or generate reactive oxygen species (ROS)- super oxide anions, hydrogen peroxides, hydroxyl radicals, and singlet oxygen. Environmental stress disturbs the balance of antioxidants and prooxidants, in some cases triggering the production of ROS (Cunningham et al. 1992 & Twiner et al. 2000). Wave and wind action can cause cell lyses and release aerosolized algal toxins. Backer et al. found that lifeguards in Florida complained of more upper respiratory symptoms after being exposed to aerosolized brevetoxin than during non-exposed brevetoxin times.

Internet surveys

Data collection of study participants can be conducted face-to-face, by mail, by telephone, by touchtone data entry on the telephone, or on-line. Different survey modes pose different challenges to survey quality. Questions are constructed in different ways in the different survey modes, which may result in different responses (Dillman 2007). On-line surveys have the advantage of being convenient, economical, and social desirability or acquiescence is less of a problem with sensitive data than with other survey modes (Dillman 2006).

Additionally, the Internet has been found to be an effective and low cost way to survey people for food borne as well as fresh and marine waterborne illnesses (Kuusi et al. 2004 & Turbow et al. 2008). Turbow et al. examined the Surfriders Ocean Health survey over an 11-year period. The findings from these surveys suggest that marine swimmers and surfers will volunteer information on health symptoms and illnesses online. Illness reports from marine exposure could assist in the development of a marine disease surveillance system (Turbow et al. 2008).

Materials and methods

The lifeguard health study was a cross-sectional study design. Ocean lifeguard participants provided informed consent online and completed a one-time survey online using Survey Monkey. The survey took approximately 10-15 minutes to complete. This prevalence study was conducted from early August through November 2010. The Lifeguard Health Study protocol was approved by the Institutional Review Board of the University of California, Berkeley (2010-05-1557).

Study population.

Eligibility

United States ocean lifeguards who were at least 18 years old and employed at least 20 hours a week were eligible to participate in the survey. Lifeguards needed to be able to read English and have Internet access to complete an online survey. Lifeguards were recruited for the study in a variety of ways. Recruitment occurred through personal contact with lifeguards, lifeguards telling lifeguards, fliers, Google ads, and the United States Lifeguard Association

(USLA) online message board. Individual lifeguard departments around the United States were emailed about the study with the online link. Lifeguard departments without email addresses were mailed information and the Internet link to the lifeguard health study. Ads using the key words “beach lifeguard” and “ocean lifeguard” were placed on Face book and Google.

The lifeguard health survey began with the informed consent section. The consent box had to be checked consenting to participate in the study to take the survey. The survey was comprised of 30 questions requesting demographic, health, acute stress, and beach environment questions. The survey asked several demographic information questions such as age, gender, location of beach where one lifeguards, and income. In addition, health and acute stress questions are asked in check box form as to whether a health care professional had ever identified that they had asthma, anxiety, diabetes, depression, and high blood pressure. Acute health care symptoms in the past week were requested. A few questions addressed the beach environment such as the presence of rip tides, sewage spills, oil spills, and red tides. The last question was qualitative requesting comments and concerns. The health outcomes measured were upper respiratory symptoms, gastrointestinal symptoms, ear symptoms, dermatological symptoms, fever and chills in the past week. Upper respiratory symptoms were defined as nasal congestion or runny nose or sore throat or eye irritation. Gastrointestinal symptoms were defined as having one or more of the following symptoms diarrhea, stomach pain, vomiting, or nausea.

The checklist guide lines for strengthening the reporting of observational studies in epidemiology (STROBE) for cross-sectional studies was followed for this study (appendix 6).

Environmental Data

Environmental data was tracked from the specific coastal areas that lifeguards were employed. Date, seawater temperature, pollen index, and air quality (PM2.5 and ozone) data were collected the same day that a survey was submitted using on-line weather information (http://www.wunderground.com/DisplayPollen.asp?Zipcode=28480).

Data Analysis

Descriptive statistics and multivariate logistic regression analyses were performed. Data was collected online using Survey Monkey statistical program and transferred to EXCEL files. The data analysis was conducted using STATA 11 statistical program. Demographic data has been compiled and presented in tables and charts. The continuous variables (*i.e.* age, height, weight, number of years as a beach lifeguard, seawater temperature, pollen index, number of rescues this past week, and water exposure this past week) are presented as averages with ranges. Categorical data (*i.e*. gender, ethnicity, income, beach closures, level of education, marital status, health insurance coverage, hours lifeguarding, level of concern about water quality, smoking status, physician diagnosed medical conditions, mental health symptoms, household illness, medications, health symptoms in the past week, weekly hours of physical activity, alcohol drinks per day, health effects due to oil exposure, and health effects due to harmful algal blooms) are presented in raw numbers and percentages. In addition, the frequency, percent, health and acute stress symptoms in lifeguard participants were presented. Multivariate logistic regression models included numerous potentially confounding factors. Those risk factors with a p-value<.25 were included in the logistic model. Upper respiratory and gastrointestinal health outcomes were measured as binary indicators of illness (0/1). Continuous variables were kept as continuous variables. Categorical variables were categorized as 0 or 1. Race was categorized as Caucasian or non-Caucasian. The risk and odds of upper respiratory symptoms and gastrointestinal symptoms were presented in adjusted risk ratios and adjusted odds ratios with the 95% confidence interval.

Results

One hundred and sixty eight ocean lifeguards completed the survey online using Survey Monkey. The socio-demographic characteristics of the lifeguards are presented in Tables 1 and 2. Among the 168 United States ocean lifeguards, the average age was 28 years old (range 18-59), the mean years lifeguarding were 8 years and ocean water exposure in the past week was 9.7 hours (Table 1). Seventy two percent of the lifeguards were male and 92% were Caucasian. Fifty one percent reported they did not drink alcohol and 73% made less than $40,000 a year (Table 2). Table 3 shows the geographic locations of the lifeguards. Sixty one percent lifeguarded on the Pacific Coast, 26% on the Atlantic Ocean, 9% from the Gulf of Mexico and 2% from the Hawaiian Islands. Lifeguard reports of previous health symptoms related to lifeguarding exposure during a harmful algal bloom or red tide is shown in Table 4. Sinus problems were the most commonly reported symptom at 13%. This table also shows a comparison of the surfer cohort (n=48) from the surfer health study. The same question was asked in each survey. The surfer cohort symptoms were greater than the lifeguards. Geographical location differences as well as more seawater ingestion or inhalation of aerosolized particles by surfers may explain the differences. Table 5 shows lifeguard reports of previous health symptoms related to lifeguarding exposure during an oil spill. Only 7 lifeguards reported lifeguarding during an oil spill. Five of seven lifeguards reported skin irritation as the most common health symptom. Table 6 compares health problems experienced by lifeguards (physician-diagnosed) in this study with the surfer health study and CDC United States prevalence. The most common health problems experienced by lifeguards were swimmer's ear (44%), allergies (22%) and surfer's ear (15%). The most common health symptom of the surfer cohort from the surfer health study was allergies (25%). The prevalence of allergies was higher in lifeguards and surfers in these studies than the US prevalence 9-16%. However, both lifeguards and surfers had a lower prevalence of high cholesterol or hypertension. Acute stress symptoms experienced after ocean rescues by lifeguards (n=167) are shown in Table 7. Approximately half of lifeguards in the study reported acute health symptoms after an ocean rescue. Among those reporting symptoms after a rescue flashbacks were the most commonly experienced symptom (26%) followed by sleep difficulties by 18%. Table 8 shows lifeguard acute health effects in the past week as well as the surfer cohort from the surfer health study. Among the lifeguard responses to the survey question 21% reported upper respiratory symptoms as defined as sore throat or cough or nasal congestion or runny nose or eye irritation. Ten percent reported gastrointestinal symptoms such as diarrhea or stomach pain or vomiting or nausea. Upper respiratory symptoms were the most common reported symptoms in both studies at 21% among lifeguards and 29% in surfers. Both groups reported 10% of GI symptoms in the past week.

Results of the multivariate logistic analysis are displayed in Table 9. In the unadjusted analysis, household upper respiratory illness, smoking, history of surfer's ear, and history of symptoms after exposure to a harmful algal bloom were risk factors included in the upper respiratory multivariate logistic model because they had a p-value <0.25 (Hosmer et al. 2000). In the adjusted multivariate logistic regression model lifeguards who had a physician diagnosis of surfers ear as compared to lifeguards with no history of surfers ear were 2.95 times more likely to have upper respiratory symptoms (95% CI = 1.33, 6.54). Additionally, lifeguards with a history of acute health symptoms after a HAB exposure were 1.57 times more likely to have upper respiratory symptoms than lifeguards without a history of acute symptoms due to a HAB (95% CI = .72, 3.47).

Among lifeguards with GI symptoms, in the unadjusted analysis, risk factors with a p-value<0.25 that were included in the multivariate logistic model were a history of symptoms after exposure to a harmful algal bloom, smoking, household GI, household UR, history of surfers ear. In the adjusted multivariate logistic regression model lifeguards with a history of symptoms after exposure to a HAB were 2.49 times more likely to have GI symptoms than lifeguards without a history of acute symptoms due to a HAB (95% CI = .76, 8.16).

The univariate analysis of lifeguards with acute stress symptoms after a rescue, included ocean rescues this week, ocean exposure this week, history of depression, history of anxiety, history of asthma, hours worked this week, gender, age, years lifeguarding, alcohol use, sea surface temperature and history of HAB symptoms after exposure to a HAB. Among lifeguards with acute stress symptoms after a rescue, in the unadjusted analysis, risk factors with a p-value<0.25 that were included in the multivariate logistic model were history of acute health symptoms due to HAB exposure, history of asthma, and history of anxiety. Forty eight percent of lifeguards reported acute stress symptoms after being involved in an ocean rescue. In the adjusted multivariate logistic regression lifeguards with a history of anxiety as compared to lifeguards without a history of anxiety had a 1.69 times increased risk of acute stress symptoms after a rescue (95% CI = 1.31, 2.17). Lifeguards with a history of having acute health symptoms after a HAB exposure had a 1.42 times increased risk of acute stress symptoms after an ocean rescue as compared to lifeguards without a history of acute symptoms due to a HAB (95% CI = 1.08, 1.86). In addition, lifeguards with a history of physician diagnosed asthma were 1.66 times more likely to have acute stress symptoms after a rescue as compared to lifeguards without a history of asthma.

Discussion

In this prevalence study 21% of the lifeguards reported upper respiratory symptoms, 48% reported acute stress symptoms after being involved in an ocean rescue and 10% had gastrointestinal symptoms during the past week. Adjusted relative risks were preferred to odds ratios in this study since acute health outcomes of upper respiratory symptoms and gastrointestinal symptoms are commonly experienced.

Upper respiratory symptoms were associated with a history of exostosis, surfers ear (RR = 2.95; 95% CI = 1.33, 6.54) and HAB exposure with subsequent acute health symptoms (RR =1.57; 95% CI = 0.72, 3.47). Exostosis, surfers ear, is caused by chronic coldwater exposure over numerous years. It is biologically plausible that this chronic ear problem increases susceptibility to upper respiratory symptoms thereby increasing the risk of cough, runny nose, nasal congestion and eye irritation. Lifeguards who responded to having acute health symptoms after exposure to HABs appear to be biologically susceptible to upper respiratory symptoms.

Gastrointestinal symptoms were reported by 10% of the lifeguards in the past week. There were no statistically significant associations identified. It is noteworthy, however, that the association between a history of HAB exposure and acute health symptoms with a relative risk of 2.49 suggests there is an association. However, the study lacks precision due to a small sample size (95% CI = 0.76, 8.16).

Acute stress symptoms due to ocean rescues were associated with a history of anxiety (RR =1.69; 95% CI =1.31, 2.17). This finding is consistent with the literature. Acute stress disorder is classified as an anxiety disorder in the Diagnostic and Statistical Manual of Mental Disorders (DSM) that is published by the American Psychiatric Association. Acute stress symptoms due to ocean rescues were also associated with a history of asthma (RR =1.66; 95% CI =1.30, 2.11). Stress his been linked as a biological trigger for asthma (Wright, 2011). Additionally, acute stress symptoms due to ocean rescues were associated with previous acute health symptoms after exposure to a HAB (RR = 1.42; 95% CI = 1.08, 1.86). This finding may be related to a stress response caused by potent neurotoxins of HABs. Some people are more vulnerable to stress and have a decreased rate of cortisol response to stress compared to people without a stress trigger (Iamandescu et al. 2008). Acute stress symptoms after being involved in an ocean rescue were reported by 48% of lifeguards. The length of acute stress symptoms and whether debriefings were offered at work after rescues are important questions for future prevention studies concerned about post-traumatic stress disorder.

Environmental factors

The coastal environmental parameters measured in this study were seawater exposure, sea surface temperature, beach closures, pollen index, ozone, PM2.5, and rip currents. None of the environmental variables were found to be associated with health risks among lifeguards. It was beyond the scope of this study to measure bacterial or viral indicators of water quality for point or nonpoint source runoff pollution at each beach location. Measurements of fecal indicator bacteria and male-specific coliphage would have been extremely helpful to examine the association with acute health risks. The risk of illnesses vary greatly in studies depending on geographical locations, point or nonpoint source ocean pollution, and the presence and type of harmful algal blooms (Cabelli et al. 1979, Colford et al. 2007, Wade et al. 2006, Pruss et al. 1998, Jiang et al. 2006, Kirkpatrick et al. 2008).

Strengths and limitations

There were several advantages and limitations to this cross-sectional study design. The advantages were that a number of acute health symptoms/illnesses and exposures could be investigated at the same time. The cost of the study was low compared to a prospective cohort study design. The time frame for carrying out the study was short. This prevalence study provided a snap shot of the health experience of U.S. lifeguards. It helped describe the patterns of health risks in this lifeguard population. The gold standard of study designs is the experimental study in which participants are randomized to exposure groups. In cross-sectional observational studies there is no randomization of exposure groups. There is only identification of existing or prevalent cases rather than incident cases over time. Another disadvantage of this study design is that an investigator cannot infer temporal sequence between exposure and disease. Therefore, one is unable to establish that exposure preceded disease.

Sources of bias were of concern in this study. Selection bias was a concern that would have underestimated the risks of acute health outcomes in this healthy physically fit lifeguard population. Differential misclassification due to lifeguards incorrectly answering a question could have underestimated or overestimated the measure of association.

Findings of other lifeguard studies

Occupational exposure to aerosolized brevetoxins during Florida red tide events is an occupational risk for lifeguards. Exposure to aerosolized brevetoxin is associated with upper respiratory symptoms. (Backer et al. 2005, Kirkpatrick et al. 2000)

Generalisability

This study of 168 lifeguards lacks the precision of a larger study. This study was a national cross-sectional study in which lifeguards volunteered to participate in the study. Ocean lifeguards were not randomized to participate in the study and therefore the findings are not generalisable to other ocean lifeguard populations.

Internet surveys

The Internet has been found to be an effective and low cost way to survey people for food borne as well as fresh and marine waterborne illnesses (Kuusi et al. 2004 & Turbow et al. 2008). Marine illness reports from seawater exposure could assist in the development of a marine disease surveillance system (Turbow et al. 2008). Additionally, on-line surveys have the advantage of being convenient, economical, and social desirability or acquiescence is less of a problem with sensitive data than with other survey modes (Dillman 2006).

Conclusions

The United States vast coastline is a beloved tourist and recreational resource of great economic value. Lifeguards with long hours of occupational exposure to the ocean were excellent participants for this study. Internet questionnaires proved to be an effective low cost way to survey lifeguards. Public health concerns of coastal water pollution and harmful algal blooms require monitoring for safe recreational conditions. This study established baseline information on HAB exposure and the association with acute health symptoms and acute stress symptoms among ocean lifeguards employed on United States beaches. Additionally, the findings of this study are helpful in generating hypotheses for future larger studies of ocean lifeguards.

Table 1. Demographic continuous data of lifeguards (n=168).

Characteristic	n	(average)	range
Age (years)	168	28	18 - 59
Years lifeguarding	168	8	1-30
Rescues in the past week	164	4	0-30
Hours in ocean this past week	168	9.7	0-60
Weight (pounds)	165	167.8	
Males	119	160.9	115-260
Females	46	166.8	98-180
Height	168	5’9”	
Males	121	6’0”	5’4”-6’6”
Females	47	5’6”	5’0”-5’11”

Table 2. Demographic categorical data of lifeguards (n=168).

Characteristic	n	(%)
Ethnicity		
Caucasian (non-Latino)	155	92
Latino	13	8
Gender		
Male	121	72
Female	47	28
Smoking status		
No	143	85
Some days	19	11
Every day	6	4
Education		
B.A./B.S.	72	43
High School diploma or GED	48	29
Health Insurance		
Private insurance	143	85
No insurance	23	14
Hours/week of physical activity		
6-10	54	33
11-15	49	30
16-20	30	18
Level of concern about the water		
Not concerned	52	31
Moderately concerned	74	44
Very concerned	43	26
Marital status		
Single	120	72
Married	39	23
Daily medications		
None	137	82
Prescription	30	18
Over the counter	9	5
Daily alcohol consumption		
0	84	51.2
1-2	59	36
3-4	12	7.3
5 or more	11	6.7
Annual income		
< 40K	124	73
40K-100K	40	24
100K	5	3

Table 3. Geographical location of lifeguards (n=168).

Region (state)	n	(%)
West Coast		
California	101	60
Oregon	2	1
East Coast		
Delaware	1	1
Florida	8	5
South Carolina	8	5
North Carolina	3	2
Maryland	4	2
Virginia	2	1
New Jersey	6	4
New York	12	7
Rhode Island	2	1
Gulf Coast		
Alabama	1	1
Florida	7	4
Texas	8	5
Pacific		
Hawaii	3	2

Table 4. Lifeguard reports of previous health symptoms related to lifeguarding exposure during a red tide (n=168), not mutually exclusive categories.

Symptom	n	%	% Surfer Health Study
Sinus problems	22	13	34
Sore throat	9	5	6
Skin rash	7	4	2
Respiratory irritation	4	2	4
Cough	3	1	6
Eye irritation	3	1	2
Allergies (non drug)	2	1	
Fever	2	1	2
Stomach ache	2	1	4
Ear infection	2	1	6
Flu	1	.5	8
Nausea	1	.5	4
Toxic shock	1	.5	

Table 5. Lifeguard reports of previous health symptoms related to lifeguarding exposure during an oil spill (n=7), not mutually exclusive categories.

Symptom	n
Skin irritation	5
Respiratory irritation	1
Eye irritation	1
Ear problem	1
Sinus problem	1
Anxiety	1
Frustration	1
Anger	1
Depression	1

Table 6. Health problems experienced by lifeguards (physician-diagnosed) (n=162).

Symptom	n	(%)	(%) CDC US Prev.	(%) Surfer Health Study
Allergies	36	22	9-16	25
Anxiety	14	9		
Asthma	20	12	7	17
Coronary Heart Dx.	0	0		
Depression	15	9	10	
Diabetes	0	0	8	0
High cholesterol	13	8	17	10
Hypertension	13	8	19	6
Skin Cancer	15	9		4
Other Cancer	0	0		2
Surfer’s ear	24	15		
Swimmer’s ear	71	44		
Other ear dx.	7	4		
Skin problems	11	7		6
Emphysema	0	0		
Crohn’s dx.	0	0		0
Irritable bowel	3	2		2
Hepatitis	1	0.6		
MRSA	1	0.6		
PTSD	3	2		
Alcohol dependence	1	0.6		
Drug dependence	0	0		
None	44	26		

Table 7. Symptoms experienced after rescues by lifeguards (n=167).

Symptom	n	(%)	US Prev. (%)
Flashbacks of rescue		43	26
Sleep difficulties	30	18	
Hypervigilance	26	16	
Recurrent dreams of rescue	26	16	
Recurrent recollections of rescue		18	11
Avoid thoughts or talking about rescue	17	10	
Difficulty concentrating	14	8	
Intrusive images	14	8	
Exaggerated startle response	11	7	
Irritability or outbursts of anger	4	2	
None	86	52	

Table 8. Lifeguard Acute Health Effects in the past week (n=168).

Symptom	n	% *	% * Surfer Health Study
Upper Respiratory (total)	35	21	29
Sore throat or cough	20	12	11
Nasal congestion or runny nose	25	15	23
Eye irritation	9	5	3
Gastrointestinal (total)	16	10	10
Diarrhea	13	8	7
Stomach pain	9	5	3
Vomiting	3	2	2
Nausea	4	2	2
External			
Ear	11	7	4
Skin	11	7	2
Fever	4	2	2
Chills	1	0.5	2
None	107	66	61

*not mutually exclusive categories

Table 9. Multivariable logistic regression models for upper respiratory symptoms and acute stress rescue symptoms.

Upper Respiratory	**RR**	**p-value**	**CI**
Hx exostosis	2.95	0.01	1.33, 6.54
Hx HAB sym	1.57	0.26	0.72, 3.47

Acute Stress	**RR**	**p-value**	**CI**
Hx Anxiety	1.69	0.00	1.31, 2.17
Hx HAB sym	1.42	0.01	1.08, 1.86
Hx Asthma	1.66	0.00	1.30, 2.11

Gastrointestinal	**RR**	**p-value**	**CI**
Hx HAB sym	2.49	0.13	0.76, 8.16

Dissertation Conclusion

This dissertation provides new baseline data for the emerging field of oceans and human health. It furthers our understanding of ocean exposure and acute health symptoms among surfers in Monterey Bay, California and United States ocean lifeguards. In addition, the meta-analysis provides an understanding of the association of acute health effects of nasal congestion, eye irritation, and cough due to brevetoxin that is produced by the phytoplankton, *Karenia brevis,* along the coast of Florida.

Beaches in the United States are tourist destinations and recreational resources of great economic value. Public health concerns of ocean point source and non-point source pollution and harmful algal blooms require monitoring for safe recreational access. Internet surveys of acute health symptoms and illnesses from seawater exposure can assist in the development of a marine disease surveillance system to assess our coastal water quality and assure the publics safety. Timely investigation or surveillance of HABs could provide a warning to beach goers and people who live close to the ocean and are susceptible to HAB toxins.

HAB exposure had a positive effect on acute health symptoms in the three studies. Acute health symptoms were identified among surfers and lifeguards who reported positive histories of acute health symptoms due to exposure to HABs. Additionally, acute stress symptoms in lifeguards were also associated with a history of acute health symptoms after HAB exposure.

Future research is required on the human health effects of specific HAB toxins as well as co-occurring pathogenic bacteria and viruses. This is important to assure the safety of the public as current global environmental changes favor the proliferation of HABs. Additional research is needed on susceptible populations and possible chronic effects of HAB toxins on humans. The findings of this dissertation establish baseline data for future research in the oceans and human health field. Additionally, the findings of these studies aid in the generation of hypotheses for future studies on ocean exposure and human health effects.

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Appendix 1. Meta-analysis summary RR & CI

RR Eye Irritation & HAB

author	RR	Cil	Ciu	weight	coef
Fleming 2007	1.9	0.8336	4.217	5.8	0.64
Fleming 2005	3	0.8545	10.5322	2.4	1.1
Backer 2005	29.5	1.9912	106.15	0.97	3.38
Backer 2003	9.9	0.9461	54.794	0.9	2.29
CDC 2008	10	1.5577	64.1979	1.1	2.3

Summary RR and CI

Sum. Wi	11.30
Sum. Wibi	14.42
bs	1.28
RRs	**3.58**
sqrt Sum. Wi	3.36
SE_s	0.30
1.96 SE_s	0.58
bs+1.96SE_s	1.86
bs - 1.96SE_s	0.69
lower CI	**2.00**
upper CI	**6.42**

Heterogeneity

X^2=	8.88
p=	**0.0641**
df =	4

Shore Adjusted CI	
SE_s	0.326
Var_s	0.106
X^2/df	1.321
Var_{adj}	0.141
SE_{adj}	0.375
1.96SE_{adj}	0.735
bs +1.96SE_{adj}	1.692
bs - 1.96SE_{adj}	0.222
lower CI	**1.25**
upper CI	**5.43**

Random Effects	
RRs	**2.83**
lower CI	**1.29**
upper CI	**6.24**

Nasal congestion & HAB RR

author, year	RR	CIlow	CIup	weight	coef
Fleming 2007	1.8	0.9213	3.588	8.3	0.59
Fleming 2005	2	0.8041	4.9742	4.6	0.69
Backer 2005	3.1	0.5909	16.4235	1.4	1.14
Backer 2003	14.4	2.0092	103.203	1	2.67
MMWR 2008	9	1.3859	58.443	1.1	2.2

Summary RR and CI	
Sum. Wi	16.42
Sum. Wibi	14.73
bs	0.90
RRs	**2.45**
sqrt Sum. Wi	4.05
SE_s	0.25
1.96 SE_s	0.48
bs+1.96SE_s	1.38
bs - 1.96SE_s	0.41
lower CI	**1.51**
upper CI	**3.98**

Heterogeneity

X^2=	6.03
p=	**0.1972**
df =	4

Shore Adjusted CI

SE_s	0.247
Var_s	0.061
X^2/df	1.506
Var_{adj}	0.092
SE_{adj}	0.303
1.96SE_{adj}	0.594
bs +1.96SE_{adj}	1.491
bs - 1.96SE_{adj}	0.303
lower CI	**1.35**
upper CI	**4.44**

Random Effects

D	0.1901
bs	1.0638
RRs	**2.90**
var	0.1173
lower CI	**1.48**
upper CI	**5.67**

RR Cough & HAB

author, year	RR	CIlow	CIup	weight	coef
Fleming 2007	1.7	0.9379	2.9617	11.6	0.53
Fleming 2005	1.7	0.7925	3.5053	7	0.53
Backer 2005	20.8	2.966	145.432	1	3.03
Backer 2003	6	0.7563	47.6033	0.9	1.79
CDC 2008	5	1.4475	17.2709	2.5	1.61

Summary RR and CI

Sum. Wi	22.98
Sum. Wibi	18.56
bs	0.81
RRs	**2.24**
sqrt Sum. Wi	4.79
SE_s	0.21
1.96 SE_s	0.41
bs+1.96SE_s	1.22
bs - 1.96SE_s	0.40
lower CI	**1.49**
upper CI	**3.38**

Heterogeneity

X^2=	8.93
p=	**0.0628**
df =	4

Shore Adjusted CI

SE_s	0.209
Var_s	0.044
X^2/df	2.233
Var_{adj}	0.097
SE_{adj}	0.312
1.96SE_{adj}	0.611
bs +1.96SE_{adj}	1.419
bs - 1.96SE_{adj}	0.197
lower CI	**1.22**
upper CI	**4.13**

Random Effects

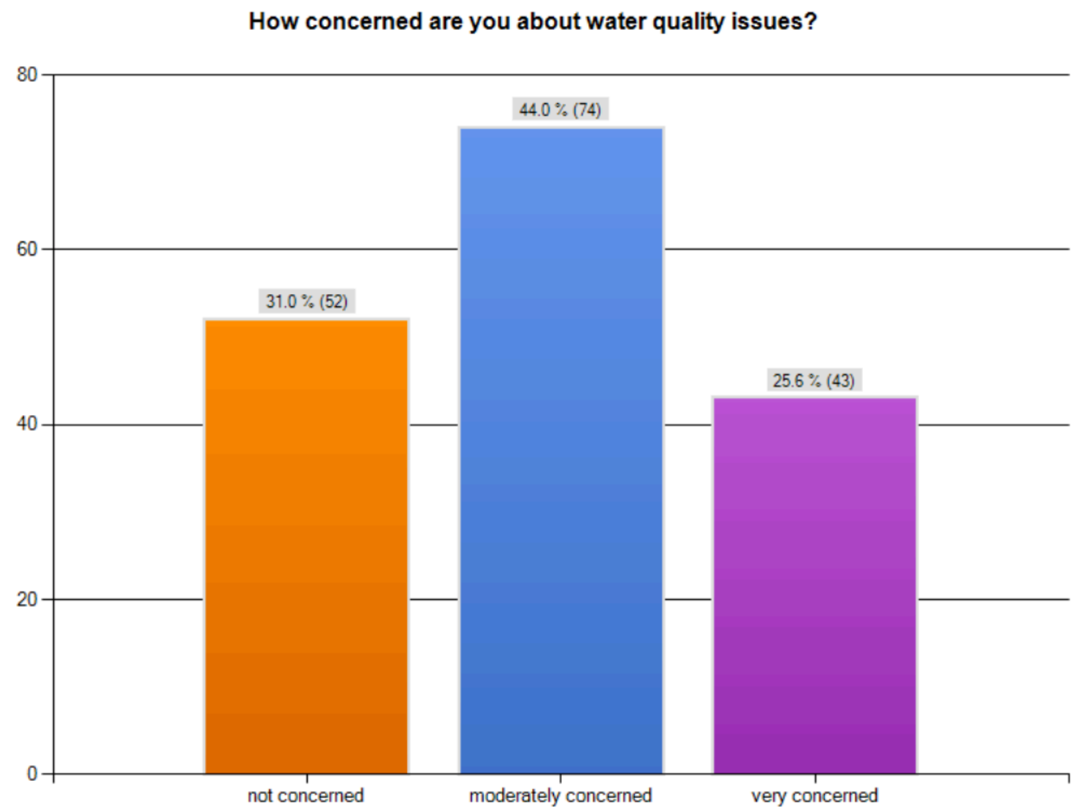
D	0.3366
bs	1.1136
RRs	**3.05**
var	0.1379
lower CI	**1.47**
upper CI	**6.31**

Appendix 2. STATA commands for GEE, GLM, and logistic regression in the surfer health study.

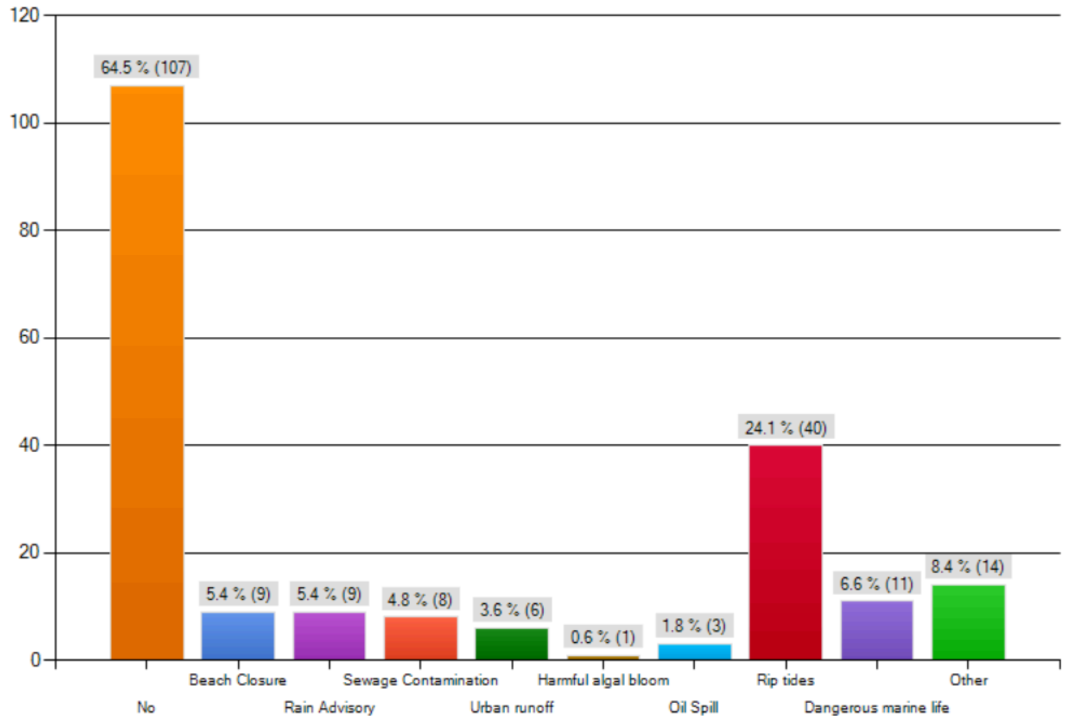
STATA commands
GEE
```
xtgee ur householdur redtideprb01 male0female1 allergies, family(binomial)
link(logit) t(date2) i(id) corr(exc) robust
xtgee, eform
```
For RR:
```
xtgee ur householdur redtideprb01 male0female1 allergies, family(binomial)
link(log) t(date2) i(id) corr(exc) robust iterate(25) eform
```

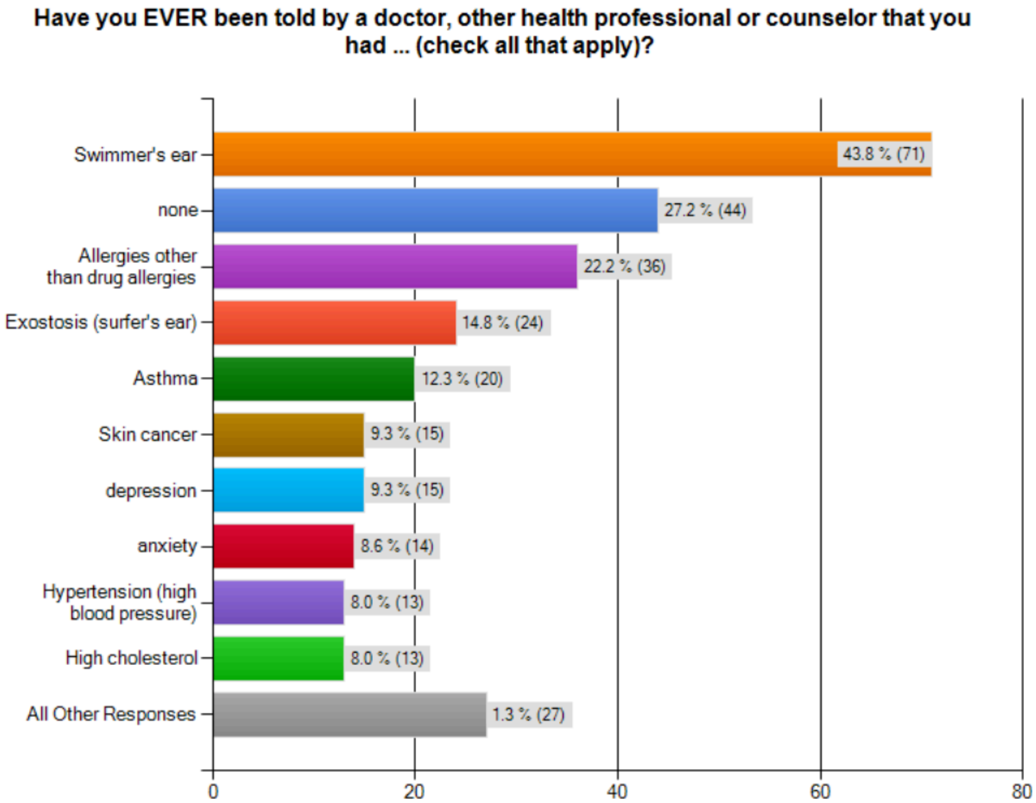
GLM
```
glm ur householdur male0female1 allergies redtideprb01, family(binomial)
link(logit) robust cluster(id)
glm, eform
```
GLM
For RR:
```
glm ur householdur male0female1 allergies redtideprb01, family(binomial)
link(log) robust cluster(id) iterate(25) eform
```
Logistic regression
```
logistic ur householdur redtideprb01 allergies male0female1
```

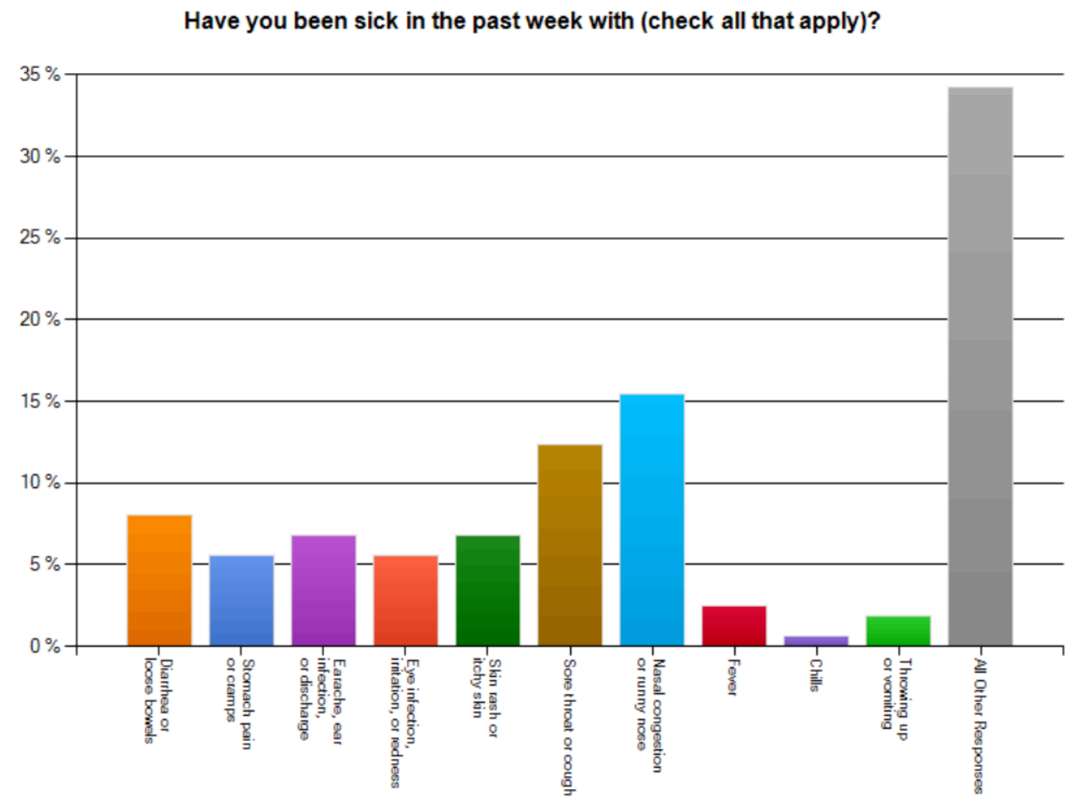
Appendix 3. Lifeguard Health Charts



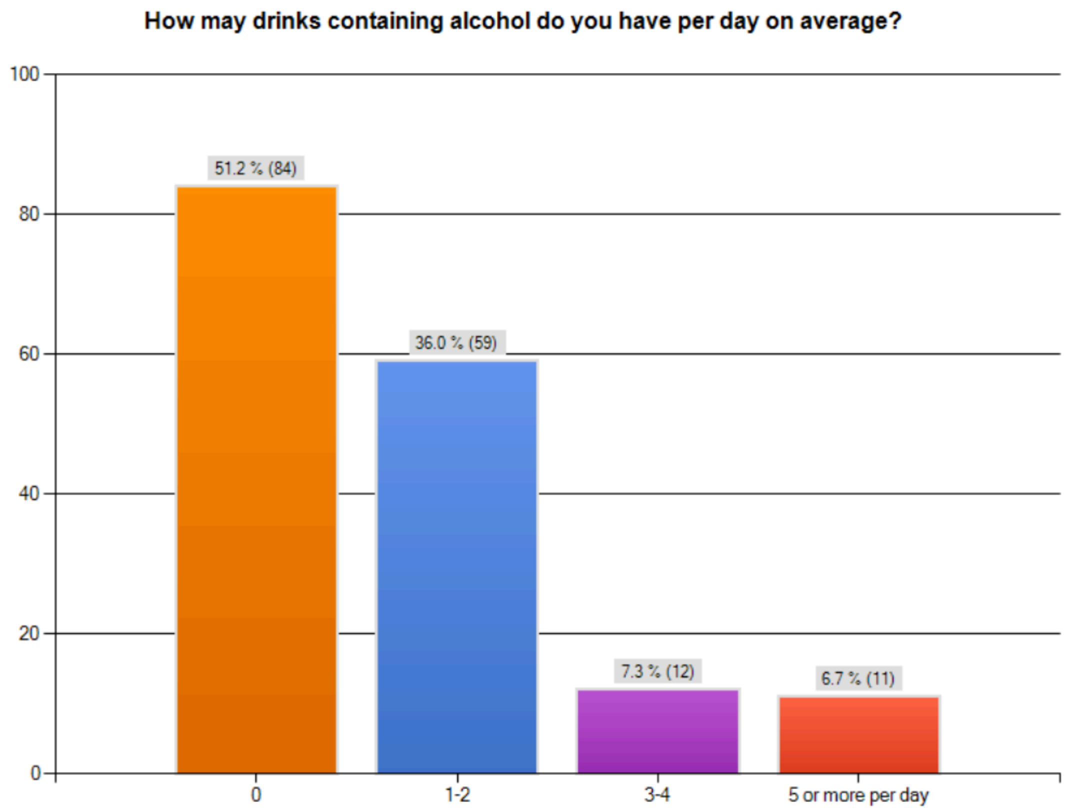
Were signs posted for advisories or closures at any of the beaches you worked this past week?

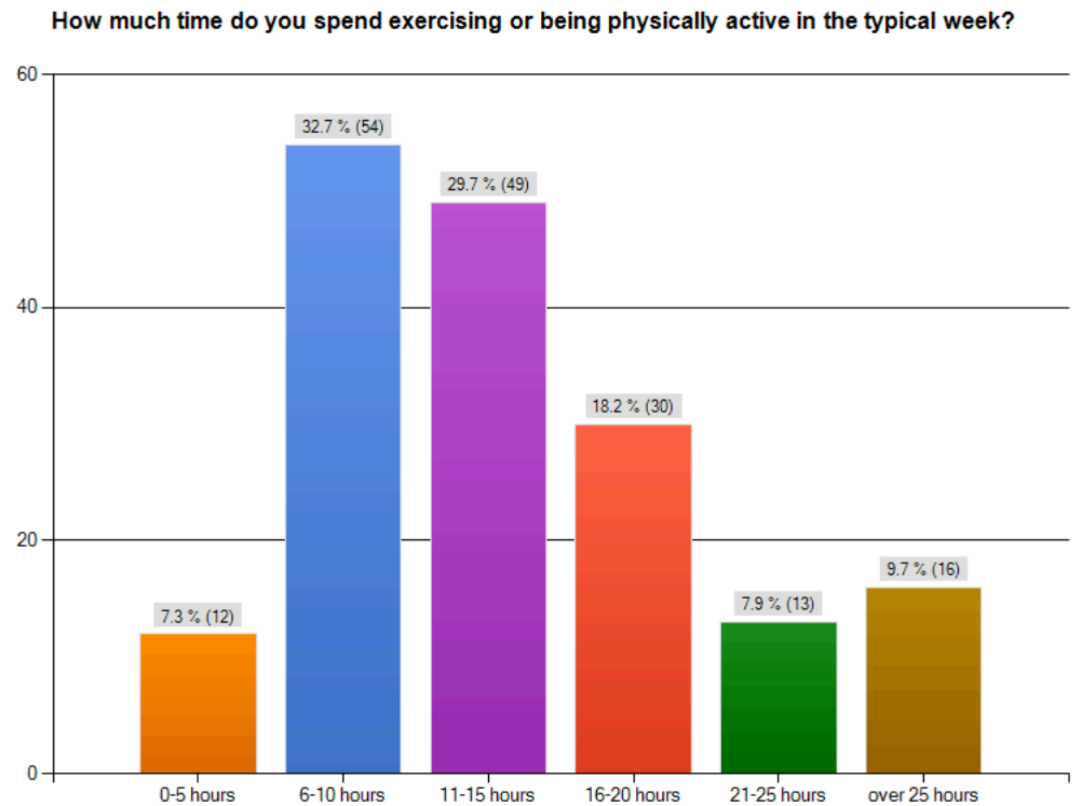



Have you EVER been told by a doctor, other health professional or counselor that you had ... (check all that apply)?
Swimmer's ear
43.8 % (71)
none
27.2 % (44)
Allergies other than drug allergies
22.2 % (36)
Exostosis (surfer's ear)
14.8 % (24)
Asthma
12.3 % (20)
Skin cancer
9.3 % (15)
depression
9.3 % (15)
anxiety
8.6 % (14)
Hypertension (high blood pressure)
8.0 % (13)
High cholesterol
8.0 % (13)
All Other Responses
1.3 % (27)
0
20
40
60
80



Have you been sick in the past week with (check all that apply)?
35 %
30 %
25 %
20 %
15 %
10 %
5 %
0 %
Diarrhea or loose bowels
Stomach pain or cramps
Earache, ear infection, or discharge
Eye infection, irritation, or redness
Skin rash or itchy skin
Sore throat or cough
Nasal congestion or runny nose
Fever
Chills
Throwing up or vomiting
All Other Responses


How may drinks containing alcohol do you have per day on average?
100
80
60
40
20
0
51.2 % (84)
36.0 % (59)
7.3 % (12)
6.7 % (11)
0
1-2
3-4
5 or more per day


How much time do you spend exercising or being physically active in the typical week?
60
40
20
0
32.7 % (54)
29.7 % (49)
18.2 % (30)
7.3 % (12)
7.9 % (13)
9.7 % (16)
0-5 hours
6-10 hours
11-15 hours
16-20 hours
21-25 hours
over 25 hours

Appendix 4. Lifeguard Health Questionnaire

Lifeguard Study

1. Lifeguard Health Study

Informed Consent to Participate in Research
Lifeguard Health Study

Purpose and Background
University of California Berkeley School of Public Health Professor Jack Colford and graduate student, Chris O'Halloran, would like to invite you to take part in our research study, which concerns the health of lifeguards. We want to examine what effect, if any, the ocean environment (i.e. water quality, air quality) has on lifeguard health.

Who Can Participate?
Ocean lifeguards who are at least 18 years old and are employed as lifeguards at least 20 hours a week on beach locations in the US.

Financial compensation
The first 100 lifeguards to complete the survey and provide an email address will receive a $10 gift card.
Lifeguards interested in the random raffle drawing to win one of five $100 gift certificates need to provide their email addresses to be contacted. Winners will be notified at the end of the study via email. Email addresses are voluntary and are only necessary for lifeguards who want to potentially receive gift cards.

Procedures: What will happen to me if I take part in the study?
You will be asked to complete a health survey. The survey includes demographic questions, questions pertaining to your health and to your job as a lifeguard.It takes about 10 minutes to complete the survey.

Benefits
There is no direct benefit to you for taking part in this study. It is hoped that the research will determine an association between the ocean environment and lifeguard health. A summary of the results of the study will be emailed to participants.

Risks/Discomforts
This study presents minimal risk to you. As with all research projects, there is a small chance that the confidentiality of the information collected could be compromised, but I will take care to prevent this from happening.

Confidentiality: Who has access to the data?
Participation in research may involve a loss of privacy, but your data will be handled as confidentially as possible. The information will be protected as follows. Data stored on a computer will be password-protected and encrypted. Your email address information will not be used in any reports, publications, or presentations related to this research. Your email address will only be used to contact you if you have won a gift certificate and to send you a copy of the study findings.

Retaining research records:
When the research is completed the data may be saved for use in future research done by myself or others. We will retain this study information for up to 10 years after the study is over. The same measures described above will be taken to protect confidentiality of this study data.

Taking Part in this Study
Participation in research is voluntary. You can decline to answer any questions and are free to stop taking part in the project at any time.

Questions
If you have any questions or comments about this research project please contact us at cohallo@berkeley.edu or lifeguardhealth@gmail.com

If you have any questions about your rights or treatment as a research participant in this study, please contact the University of California at Berkeley's Committee for Protection of Human Subjects at (510) 642-7461, or e-mail: subjects@berkeley.edu.

*** 1. Do you want to participate in the Lifeguard Health Study?**

- ◯ Yes, I am at least 18 years old and I agree to the above consent form.
- ◯ No, I don't agree to the above consent form.

Lifeguard Study

*** 2. Enter the beach name, county, and state where you lifeguard.**

Beach name where you lifeguarded this week. [ ]

County [ ]

State [ ]

3.

Enter your email if you want a gift card, the first 50 people to complete the survey receive a $10 gift card and you want to be entered in the random raffle to win one of ten $100 gift cards.Email addresses are voluntary.

[ ]

4. Were signs posted for advisories or closures at any of the beaches you worked this past week?

- [ ] No
- [ ] Beach Closure
- [ ] Rain Advisory
- [ ] Sewage Contamination
- [ ] Urban runoff
- [ ] Harmful algal bloom
- [ ] Oil Spill
- [ ] Rip tides
- [ ] Dangerous marine life
- [ ] Other

5. How old are you?

[ ]

6. Sex

- [ ] Male
- [ ] Female

7. How tall are you? (feet and inches)

[ ]

8. How much do you weigh?

[ ]

9. What race or ethnicity do you consider yourself (check all that apply)?

- [ ] Caucasian
- [ ] African American
- [ ] Mexican
- [ ] other Latino
- [ ] Asian
- [ ] Pacific Islander
- [ ] American Indian
- [ ] other

Lifeguard Study

10. Check the highest level of education completed.

- [ ] Not applicable (currently in school or dropped out)
- [ ] High school dipolma or GED
- [ ] College AA
- [ ] College BA or BS
- [ ] Master's degree
- [ ] MD, PhD, or doctorate degree

11. Marital status

- [ ] Single
- [ ] Married
- [ ] Divorced
- [ ] Live with partner

12. Are you covered by any type of health insurance or health care coverage?

- [ ] Yes, I have health insurance.
- [ ] No, I have no health coverage of any type.
- [ ] Don't know

13. How many hours did you lifeguard this week?

- [ ] 20-31
- [ ] 32-39
- [ ] 40 or more

14. How many years have you been lifeguarding?

15. How many rescues have you participated in this week?

16. How many hours have you spent in the ocean this week (swimming, paddling, rescuing people)?

17. How concerned are you about water quality issues?

- [ ] not concerned
- [ ] moderately concerned
- [ ] very concerned

18. Do you NOW smoke (cigarettes, pot, or anything) every day, some days or not at all?

- [ ] Every day
- [ ] Some days
- [ ] Not at all
- [ ] Don't know

Lifeguard Study

19. Have you EVER been told by a doctor, other health professional or counselor that you had ... (check all that apply)?

- ☐ Hypertension (high blood pressure)
- ☐ Diabetes
- ☐ Asthma
- ☐ High cholesterol
- ☐ Coronary heart disease
- ☐ Skin cancer
- ☐ Cancer (other than skin cancer)
- ☐ Allergies other than drug allergies
- ☐ Exostosis (surfer's ear)
- ☐ Swimmer's ear
- ☐ Other ear disorder
- ☐ Skin problems psoriasis or eczema
- ☐ Emphysema
- ☐ Crohn's disese
- ☐ Irritable bowel
- ☐ Hepatitis
- ☐ Methicillin-resistant Staphylococcus aureus (MRSA)
- ☐ depression
- ☐ anxiety
- ☐ post traumatic stress disorder
- ☐ alcohol dependence
- ☐ drug dependence
- ☐ none

20. Which of the following symptoms have you had after a rescue? (check all that apply)

- ☐ intrusive images
- ☐ flashbacks of the rescue
- ☐ recurrent distressing recollections of the rescue
- ☐ recurrent dreams of the rescue
- ☐ irritability or outbursts of anger
- ☐ hypervigilance
- ☐ exaggerated startle response
- ☐ difficulty concentrating
- ☐ difficulty falling or staying asleep
- ☐ efforts to avoid thoughts or conversations about the rescue
- ☐ none

21. Are you currently taking any medications (check all that apply)?

- ☐ No
- ☐ Yes, prescription medication
- ☐ Yes, over the counter medication

22. If yes, what medication(s) are you taking?

Lifeguard Study

23. Have you been sick in the past week with (check all that apply)?

- [ ] Diarrhea or loose bowels
- [ ] Stomach pain or cramps
- [ ] Earache, ear infection, or discharge
- [ ] Eye infection, irritation, or redness
- [ ] Skin rash or itchy skin
- [ ] Sore throat or cough
- [ ] Nasal congestion or runny nose
- [ ] Fever
- [ ] Chills
- [ ] Throwing up or vomiting
- [ ] Nausea
- [ ] None

24. If yes you have been sick this week, has anyone that you live with been sick in the past two weeks with any of the following (check all that apply)?

- [ ] Diarrhea or loose bowels
- [ ] Stomach pain or cramps
- [ ] Earache, ear infection, or discharge
- [ ] Eye infection, irritation, or redness
- [ ] Skin rash or itchy skin
- [ ] Sore throat or cough
- [ ] Fever
- [ ] Chills
- [ ] Throwing up or vomiting
- [ ] Nasal congestion or runny nose
- [ ] Nausea
- [ ] None

25. How much time do you spend exercising or being physically active in the typical week?

- [ ] 0-5 hours
- [ ] 6-10 hours
- [ ] 11-15 hours
- [ ] 16-20 hours
- [ ] 21-25 hours
- [ ] over 25 hours

26. How may drinks containing alcohol do you have per day on average?

- [ ] 0
- [ ] 1-2
- [ ] 3-4
- [ ] 5 or more per day

27. What is your approximate annual income?

- [ ] less than $40,000 per year
- [ ] between $40,000 - $100,000 per year
- [ ] more than $100,000 per year

Lifeguard Study

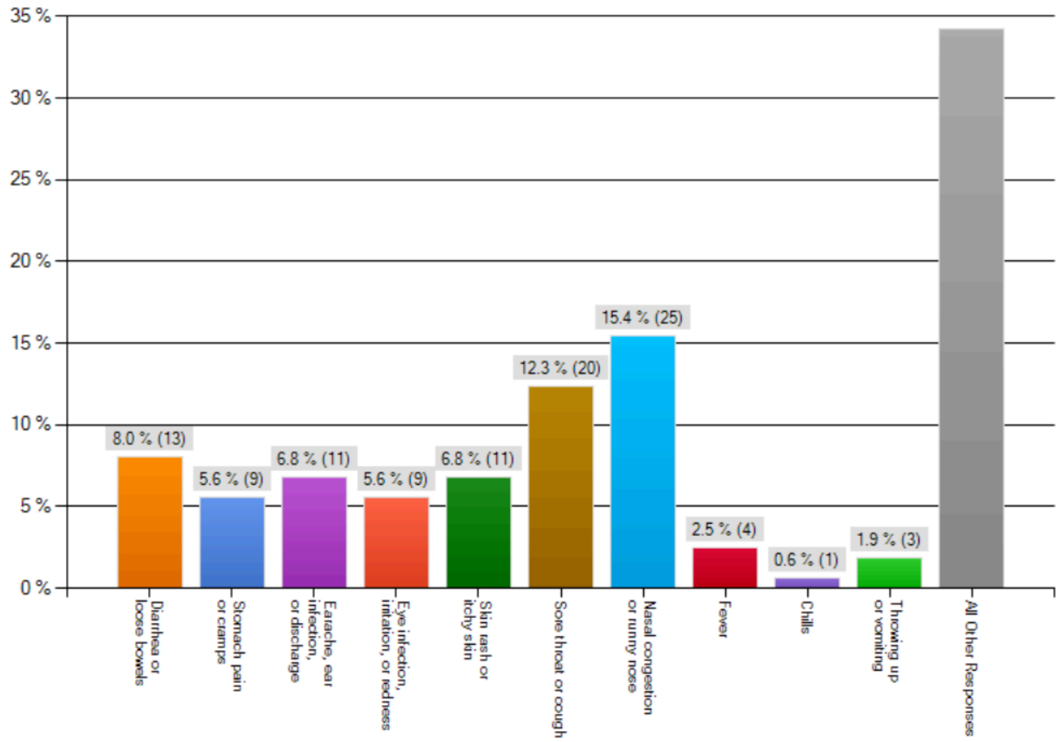
28. Have you had any health effects (e.g. skin irritation, respiratory problems, anxiety...) due to lifeguarding on a beach impacted by an oil spill?

29. Have you ever had any health problems lifeguarding during a red tide (e.g. appearance of water color that is red, brown, or purple)? If yes, please explain.

30. Comments/Concerns

How much time do you spend exercising or being physically active in the typical week?

Have you been sick in the past week with (check all that apply)?



Appendix 5. STROBE guidelines for cohort studies STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract Page 12	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background Page 13	2	Explain the scientific background and rationale for the investigation being reported
Objectives Page 16	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design Page 16	4	Present key elements of study design early in the paper
Setting Page 17	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants Page 17	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed
Variables Page 18	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement Page 17-18	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size Page 17	10	Explain how the study size was arrived at
Quantitative variables Page 18	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical method Page 18	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses

Results		
Participants Page 19	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data Page 19	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders

		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data Page 19	15*	Report numbers of outcome events or summary measures over time
Main results Page 20	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses Page 20	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations Page 22-23	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation Page 22	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability Page 23	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding Self funded	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

Appendix 6: STROBE guidelines for cross-sectional studies

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract Page 33	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background Page 34	2	Explain the scientific background and rationale for the investigation being reported
Objectives Page 34	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design Page 36	4	Present key elements of study design early in the paper
Setting Page 36	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants Page 36	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables Pages 38-39	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement Pages 37-38	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias Page 41	9	Describe any efforts to address potential sources of bias
Study size Page 38	10	Explain how the study size was arrived at
Quantitative variables Page 38	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods Pages 37-38	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants Page 38	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic,

Page 38	14*	clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data Page 38-39	15*	Report numbers of outcome events or summary measures
Main results Page 38-39	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses Page 39	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results Page 40	18	Summarise key results with reference to study objectives
Limitations Page 41	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation Page 40	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability Page 41	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding Self funded	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.