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Health Risks and Benefits Among Surfers After Exposure to Seawater in Monterey Bay, Santa Cruz County, California, United States

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We investigated the health risks and benefits among surfers in Monterey Bay, Santa Cruz County, California, United States after seawater exposure. A total of 47 surfers enrolled and completed an online survey on the effect of the ocean environment on their well-being, physical and mental health, and provided their perspectives on ocean conservation. The majority of the surfers were white males, with a median age of 40 years, and a mean of 21 years surfing experience. Most of the participants spent over 5 h/week in the ocean. The most common health problems reported were adverse effects due to red tide exposure, surfer's ear, back and neck problems, and allergies. A total of 41% reported upper respiratory symptoms, and 8% of the participants reported gastrointestinal symptoms. All participants reported that the ocean benefited their emotional health, and 45/47 (>96%) reported that the ocean increased their life satisfaction, happiness, and decreased their stress level. All participants reported being engaged in ocean stewardship. This study suggests surfers were significantly more likely to report upper respiratory symptoms when they had experienced adverse health effects while surfing during a "red tide" and during a bloom of the microscopic, single-celled phytoplankter, *Akashiwo sanguinea*.

Keywords: upper respiratory symptoms, well-being, *Akashiwo sanguinea*, ocean stewardship, surfers

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INTRODUCTION

The global ocean ecosystem covers nearly 72% of the Earth. It sustains life through the hydrologic cycle and heat transfer through ocean current circulation. The majority of oxygen production on our blue planet is from oceanic photosynthetic phytoplankton, more than from the tropical rainforests on land (NOAA, 2020). Humans rely on healthy ocean ecosystems for seafood, medicines, marine employment, transportation, trade, recreation, and tourism. Approximately two-thirds of the world's 7 billion population live within 37 miles of the ocean coastal environment (United Nations Ocean Atlas, 2016). "Human health is intricately linked to ocean health" (Fleming et al., 2019).

The ocean provides numerous risks and benefits to human health (Bowen et al., 2014; Fleming et al., 2015). Time spent in the ocean has inherent risks, including accidents, drowning, illnesses from pathogenic bacteria, viruses, and harmful algal blooms (HABs), and dangerous marine

animals. Yet, for many people, the physical, emotional, and well-being benefits of being in the ocean outweigh the potential risks.

Globally, surfing is a popular sport. The growth of the sport of surfing was facilitated by the development of the wetsuit. In 1952, Hugh Bradner, a University of California Berkeley physicist, developed the wetsuit which provided prolonged access to the ocean for recreational activities, such as surfing and scuba diving (Rainey, 1998). The International Surfing Association, the governing authority for surfing, estimates there are 35 million surfers globally and 2.8 million surfers in the United States (Surfer Today, 2018). Surfing is a 10-billion-dollar global industry (Surfer Today, 2019). Although surfing is a popular activity, surfers may experience injuries from a variety of sources, such as being hit by their surfboard or another surfer's surfboard, maneuvering on a wave, hitting the seafloor (coral reef, sand, rocks), marine animals, and cold water temperatures (e.g., hypothermia). A systematic review of surfer injuries found that the body locations were the face, head, and neck (33.8%), legs (33.0%), arms (16.7%), torso (10.3%), and back/spine (4.5%) (McArthur et al., 2020).

Surfers are an ideal cohort to provide baseline information on health and wellness due to numerous hours of weekly seawater exposure year round. Water quality issues can have adverse health effects on surfers. For example, surfers are at risk from untreated urban runoff discharged into the ocean. These events include an increased risk of acute health problems with increased seawater exposure (Dwight et al., 2004). A recent meta-analysis by Leonard et al. (2018) concluded that people who swam in the sea had nearly twice the risk of ear and gastrointestinal problems than people who were not exposed to seawater. Similarly, the BEACHES study conducted in Florida evaluated the human health risk from seawater exposure with no known point source and found an association, nearly twice the risk between acute respiratory symptoms, gastrointestinal, and skin irritation among people who swam in the ocean compared to people who did not go in the ocean (Fleisher et al., 2010).

Harmful algal blooms (HABs) can also pose a health hazard for surfers. Globally, approximately 4,000 species of phytoplankton, microscopic floating unicellular algae, are the base of the marine food web (Sournia et al., 1991). Only a small number of genera of phytoplankton produce naturally occurring toxins, but these toxins can be transferred throughout the food web by accidental ingestion of cell-bearing water, inhalation of aerosolized toxins, or skin absorption of cells containing toxins. HABs have been demonstrated to cause morbidity and mortality in fish, seabirds, marine mammals, and humans (Anderson, 2009). Monterey Bay coastal waters contain a number of toxic microscopic phytoplankton, namely cells of *Pseudo-nitzschia*, *Alexandrium*, *Akashiwo, Margalefidinium fulvescens (previously Cocliodinium)*, *Chattonella*, *Fibrocapsa*, and *Heterosigma*, that under optimal environmental conditions can produce dangerous toxins. For example, the transfer of toxic domoic acid produced by *Pseudo-nitzschia* through the food chain can kill seabirds and marine mammals (Lefebvre et al., 1999; Scholin et al., 2000), and the surfactant-producing red tide of *Akashiwo sanguinea* can also kill seabirds (Jessup et al., 2009). *Heterosigma akashiwo*, a phytoplankton that produces brevetoxin, has also been identified in Monterey Bay coastal waters (O'Halloran et al., 2006). A shift in the Monterey Bay phytoplankton population from diatoms to dinoflagellates appears to be causing an increase in the frequency of red tide and HABs in this area (Jester et al., 2009). A cohort of Monterey Bay surfers were significantly more likely to have upper respiratory symptoms if they had a history of previous adverse health symptoms while surfing during a red tide (O'Halloran et al., 2017). Currently, anthropogenic activities and climate change conditions are increasing the geographic spread and abundance of HABs worldwide (Fleming et al., 2015).

Cold water temperatures, such as those in the coastal waters of Monterey Bay, which range between 10 and 16°C have been associated with exostosis of the external auditory canal (EAE) in previous studies (Kroon et al., 2002). EAE, more commonly referred to as "surfer's ear," is a slowly progressive disease involving irreversible bone growth of the tympanic ring due to long-term exposure to water temperatures of 19°C or lower (Attlmayr and Smith, 2015). Risk factors for EAE include surfing for more than 6 years, surfing more than five times per month, and not wearing earplugs or a hood while surfing in cold water. EAE is mostly benign but can cause conductive hearing loss and repeated otitis externa (Barbon et al., 2017).

There has been a considerable amount of research on the health benefits of exposure to "green" nature. Wilson (1984) biophilia hypothesis describes the innate connections people seek with other living organisms in terrestrial nature. More recent research has examined the health and well-being benefits associated with aquatic environments. The "Blue Gym Initiative" in the United Kingdom initiated a wave of research focused on "blue" (marine and aquatic) environments and their benefits to human health and well-being (Depledge and Bird, 2009; Gascon et al., 2017; White et al., 2019). "Blue space" environments are associated with greater feelings of restoration (feeling calm, relaxed, revitalized, and refreshed) and more positive feelings/emotions than places without water (White et al., 2010). People living along the coast of England reported better health than those living inland and greater feelings of restoration (White et al., 2014). A positive association was found between people who spent time in "blue" spaces engaged in recreational activities or lived close to the ocean with health and well-being with the findings being more pronounced in low income populations (White et al., 2019). A systematic review of 33 blue space studies suggested a positive association between blue space environments and health, mental health, and well-being (Britton et al., 2018).

Human survival depends on a healthy ocean ecosystem to sustain life through planetary systems. Numerous studies have documented humans reduced contact with nature in the past century due to urbanization (Klepeis et al., 2001; United Nations Ocean Atlas, 2016). When people feel disconnected from nature they can live unsustainable lifestyles. A connection with nature has been associated with pro-environmental behaviors (Capaldi et al., 2014).

The objective of the study was to investigate the health risks and benefits associated with seawater exposure in a surfer cohort in Monterey Bay, Santa Cruz County, California, United States. In this area, surfers are the dominant ocean recreational group due to yearly cold water temperatures and

great waves. Specifically, we investigated what association, if any, existed between surfer upper respiratory symptoms and phytoplankton bloom conditions. We examined the association of ocean exposure with surfer well-being (life satisfaction) and hypothesized that an ocean connection would lead to pro-environmental behaviors and ocean environmental stewardship. Additionally, we were interested in determining the prevalence of surfer's ear to determine if advocacy around preventative measures was warranted locally.

MATERIALS AND METHODS

This surfer health study was a prospective cohort study conducted between November 2018 and December 2019. Surfers submitted baseline surveys that included demographic and health information using the online survey tool, Survey Monkey[1]. Three additional follow up surveys on health, wellness, seawater exposure, acute health risks, and ocean conservation stewardship were requested in September, November, and December 2019. Reminder emails to complete surveys were sent to avoid missing data. The surfer health study was approved by the institution review board at of Ethical and Independent Review Services (#15102).

This study was conducted in the northern part of Monterey Bay, Santa Cruz County, CA, United States. Santa Cruz, CA is a famous surf location for recreational and professional surfers. In the cold coastal waters of Monterey Bay surfers wear wetsuits and surf year round.

Recruitment of surfer participants for the study occurred in various ways. Online advertisements were placed on the Surfline website (a website that specializes in surf reports and forecasts); e-mail messages to local surf clubs (Longboard Union and University of California Santa Cruz) and ocean non-profit organizations (Save the Waves, Surfrider Foundation, and Save Our Shores); and flyers at local surf shops. As an incentive to participate in the study, a $25 gift card was provided that could be redeemed by purchases from Patagonia or Amazon.com.

Surfers were eligible to participate in the study if they were 18 years or older, had internet access, and surfed at least 30 min per week (waves permitting) in the coastal waters of Monterey Bay in Santa Cruz County.

Participants provided informed consent using Survey Monkey. After providing consent, participants completed an online questionnaire with 24 questions about demographics (e.g., sex, age, race, marital status, education level, income), chronic and acute health issues, mental health, well-being, and amount of seawater exposure. Ocean exposure was self-reported in hours per day for the past 7 days.

Self-reported health outcomes included upper respiratory symptoms (defined as having one or more of the following symptoms sore throat, cough, runny nose, nasal congestion, or eye irritation), gastrointestinal symptoms (e.g., diarrhea, stomach pain, vomiting, and nausea), fever, EAE, surgery for EAE, and emotional problems that were previously diagnosed by a health care provider, such as anxiety and depression. A checklist of subjective well-being outcomes of time spent in the ocean included the following: life satisfaction, awe, happiness, feeling calm/relaxed, better sleep, pain relief, spiritual connection, and a connection with friends (the surveys can be accessed in the **Supplementary Material**).

Surfers were asked to complete three follow up questionnaires. The surveys were emailed during different marine environmental conditions and phytoplankton species seasonal variation to investigate a possible association of upper respiratory symptoms with phytoplankton bloom conditions. Follow up surveys were e-mailed on September 26, 2019 during a *Akashiwo sanguinea* bloom, November 19, 2019 during a *Margalefidinium fulvescens* bloom and December 11, 2019 when there was low phytoplankton cell density.

Environmental Data

The Monterey Bay opens to the Pacific Ocean with seawater temperatures ranging from 10 to 16°C. Monterey Bay is an area of high biological productivity with seasonal upwelling that brings nutrient-rich cold water to the sea surface. Seawater samples were collected weekly from the end of the Santa Cruz wharf (36.57°N, 122.01°W) in Monterey Bay from September 2018 to December 2019. Net tow samples were collected using a 1/4 m net with a 20 μm mesh that was hauled from 3 m depth to the surface. Surface seawater was also collected with a bucket to provide samples for immediate processing. An Olympus inverted microscope was used for the identification of the single-celled phytoplankton species composition obtained in the net. A 40-mL aliquot of the net tow sample was preserved in neutral Lugol's iodine for archival purposes. A Sedgewick Rafter Counting Chamber was used for cell counts of *Akashiwo sanguinea*. A digital thermometer was employed onsite to measure the temperature of the collected seawater. Weekly seawater quality data (i.e., *Enterococcus* counts) were obtained from the Santa Cruz County Department of Environmental Health Services website[2]. During our 3 follow-up study periods the bacterial water quality was acceptable in this location under the state of California's regulation of 35 enterococcus bacteria per 100 ml. Sea surface temperature and *Enterococcus* counts were considered potential confounders.

Statistical Analyses

Descriptive statistics, univariate and bivariate analysis, and generalized estimating equations (GEE) were used to quantify the strength of the associations between risk factors and the outcomes, upper respiratory symptoms, surfer's ear surgery, and life satisfaction (StataCorp, 2017). Data analysis was conducted using Stata 15 statistical software package (StataCorp LP, College Station, TX, United States). Univariate analyses included multiple variables: ethnicity, sex, age, marital status, annual income, smoking status, education level, frequency of weekly water exposure, years surfing, hours of exercise, and level of

[1]http://SurveyMonkey.com

[2]https://www.cityofsantacruz.com/government/city-departments/parks-recreation/parks-beaches-open-spaces/beaches-aquatics

concern about water quality. These variables were reported using descriptive statistics, such as means, ranges, and percentages.

Bivariate associations of potential predicators with upper respiratory illness were evaluated (i.e., sex, allergies, asthma, household exposures, smoking status, age, years surfing, college education, sea surface temperature, and *Enterococcus* counts). We recorded the dates surfed with the weekly phytoplankton community composition from the water samples. A regression analysis using GEE was used to estimate the association between potential risk factors or outcomes (upper respiratory symptoms, surfer's ear surgery, and life satisfaction) with other variables/characteristics (e.g., illness symptoms, socioeconomic characteristics, blooms in the last 7 days, well-being. . .). The relative risk (RR) of upper respiratory symptoms was estimated using GEE and adjusted for the following covariates: household respiratory illness, allergies, asthma, smoking status, rain in the past 7 days, bloom of *Margalefidinium fulvescens*, sex, age, years surfing, history of adverse health effects due to red tide exposure, seawater exposure in hours per week, presence of dinoflagellates, and bloom conditions of the dinoflagellate, *Akashiwo sanguiniea*. Variables with $p < 0.05$ in the bivariate regression analysis were included in the multivariate regression model. The final most parsimonious model included the covariates: previous history of red tide exposure with resulting adverse health effects and bloom of *Akashiwo sanguinea*. GEE accounts for the possibility that multiple weekly observations on the same surfer are correlated.

The RR for surfers' ear surgery was estimated using the regression analysis, GEE. Potential confounders included in the model were age, years surfing, ear plug use, education, and income. The final covariates included in the model were hours of ocean exposure in the past week and medical diagnosis of surfer's ear.

Regression analysis of the association of ocean exposure (years surfing) and life satisfaction included potential predictors happy, awe, surfer age, sex, hours of ocean exposure in the past week, life satisfaction, calm/relaxing. Descriptive statistics and summary tables were used to represent the perceived benefits of ocean exposure with the well-being, life satisfaction, of surfers.

TABLE 1 | Characteristics of the study participants ($N = 47$).

Variable	Frequency	%	Mean ± SD (range)
Sex			
Male	34	72	
Female	13	28	
Age (years)			40 ± 12 (18–64)
Race			
White	44	94	
Asian and Pacific Islander	1	2	
Latino	2	4	
Marital status			
Married	27	57	
Single	14	30	
Live with partner	6	13	
Divorced	0	0	
Highest level of education			
High School/GED	6	13	
AA degree	2	4	
Bachelor's degree	22	47	
Master's degree	11	23	
PhD or MD	6	13	
Household income			
Less than $40,000/year	7	15	
$40,000–100,000/year	12	26	
More than $100,000/year	18	38	
Prefer not to answer	10	21	
Time in the ocean—past week			
None	3	6	
<1	1	2	
1–2	4	8.5	
2–3	4	8.5	
3–4	4	8.5	
4–5 h	6	13	
5–6 h	7	15	
>6 h	18	38	
Years surfing			21 ± 12 (1.5–48)
Concern about ocean conservation			
Not concerned	0	0	
Moderately concerned	4	9	
Very concerned	43	91	

SD, standard deviation.

RESULTS

A total of 47 surfers took part in the study, with a total of 112 observations (Q1 $N = 47$ Q2 $N = 22$ Q3 $N = 27$ Q4 $N = 22$). Their characteristics are shown in **Table 1**. The majority of the participants were white (92%), male (72%), and married (57%). The median age was 40 years (range 18–64). Many of the surfers (53%) spent over 5 h per week in the ocean. Participants had surfed for a mean of 21 years. The majority of surfers reported being very concerned about ocean conservation issues (91%) (**Table 1**).

Acute and Chronic Health Issues

Upper respiratory symptoms (defined as 1 or more of the following symptoms: sore throat, cough, runny nose, nasal congestion, or eye irritation) were found in 41% of surfers, and 8% of surfers reported gastrointestinal problems (defined as 1 or more of the following symptoms: diarrhea, stomach pain, vomiting, and nausea) during the study. We asked the study surfer participants "Have you ever been told by a doctor, other health professional or counselor that you had (check all that apply)?" **Table 2** reports the self-reported acute and chronic health issues of the surfer participants. Twenty-six percent of the surfers in this cohort reported no chronic health problems. Nearly one-third of the surfers reported having neck and back problems, which could be due to the physical requirements of the sport, such as paddling prone. The prevalence of allergies in this surfer cohort was higher than the U.S. population (21 vs. 18%). It may be that the percentage of seasonal allergies is higher in this geographic area. On the positive side, coronary heart disease

TABLE 2 | Acute and chronic health problems in the study participants (*N* = 47).

Health problem	Frequency	(%)	US prevalence (%)
Adverse effects of red tide	17	36	
EAE–surfer's ear	15	32	
Surgery for EAE	7	15	
Back/neck problems	13	28	
Allergies	10	21	18
Anxiety	7	15	18
Asthma	6	13	13
Depression	4	9	9
Arthritis	3	6	
Alcohol abuse	3	6	6
Hypertension	3	6	32
Skin cancer	2	4	1.5
Ear problem other than EAE	2	4	
Eye problems	2	4	
Heartburn/GERD	2	4	18–28
MRSA	2	4	
Hypercholesterolemia	1	2	12
Cardiac problems	1	2	9
Substance abuse problems	1	2	
PTSD	1	2	
Diabetes	0	0	10
No chronic problems	12	26	

EAE, exostosis of the external auditory canal; GERD, gastroesophageal reflux disease; MRSA, methicillin-resistant Staphylococcus aureus; PTSD, post-traumatic stress disorder; US, United States.
Age standardized percentage of adults in US population (Cdc Data & Statistics, 2020).

(2 vs. 9%), high blood pressure (6 vs. 32%), and diabetes (0 vs. 10%) were lower in this surfer cohort than in the United States population[3]. The prevalence of skin cancer was higher in this cohort of surfers presumably due to increased sun exposure of surfing. Thirty-two percent of surfers reported EAE. Increased ocean exposure was associated with a greater risk of surfer's ear surgery (RR: 1.5, 95% CI: 1.09–1.96) (**Table 3**).

Health and Well-Being

The benefits of the time spent in the ocean on surfers' physical and mental health are shown in **Table 4**. The baseline questionnaire (*N* = 47) asked, "How does spending time in the ocean impact your health (check all that apply)." All the surfer participants reported that being in the ocean benefited their emotional health (100%). Ninety-six percent of surfers reported that spending time in the ocean increased happiness, reduced stress/anxiety, increased the experience of calm/relaxation, and improved life satisfaction. Surfer physical health benefits included better sleep (77%) and decreased physical pain (28%). Fifty-five percent reported spending time in the ocean, making them feel more generous. Additionally, 60% percent of surfers reported that surfing evoked feelings of awe. None of the surfers reported significant injuries (e.g., cuts, sprains, stitches, or concussions) during the study. Comments by surfer participants regarding health and well-being included the following: better

[3]http://cdc.gov

TABLE 3A | Association of surfer risk factors with upper respiratory symptoms using multivariate analysis—generalized estimating equations (GEE).

	Relative risk[a]	95% confidence interval
Previous episode of adverse health effects after surfing during a red tide	1.42	1.01–2.02
Surfing during a bloom of *Akashiwo sanguinea*	1.63	1.09–2.46

TABLE 3B | Association of surfer risk factors with surfer's ear surgery using multivariate analysis—generalized estimating equations (GEE).

	Relative risk[a]	95% confidence interval
Years surfing	1.5	1.09–1.96

The relative risk was calculated using generalized estimating equations to control for correlation due to multiple observations per participant.

productivity at work, spectacular marine life in Monterey Bay, spiritual connection, a place where things make sense, feeds my soul, and it's my refuge, demonstrating the importance of time spent in the ocean for this ocean loving cohort. The multiple regression analysis suffered from multicollinearity problems between covariates (e.g., life satisfaction, happy, calm). The authors decided not to include the non-significant findings in the results.

Harmful Algal Blooms

Our survey asked the question, "Have you ever had any symptoms or health problems due to a red tide (that discolored the water, for example, red, brown, green, or bioluminescent)? yes, no, no sure" In the survey, we used the term "red tide" rather than HABs because local surfers were more familiar with the term "red tide." Participates reported that they experienced itchy eyes, "sinus infection," "my nasal cavity will completely close up about

TABLE 4 | Self-perceived benefits of the ocean on participants' well-being and health (*N* = 47).

Benefit	Frequency	%
Emotional well-being	47	100
Increased happiness, "get stoked"	45	96
Calming/relaxing, decreases stress/anxiety	45	96
Improved life satisfaction	45	96
Improved mood	41	87
Connection with friends and other surfers	38	81
Sleep better	36	77
Awe-inspiring	28	60
Time feels more plentiful	26	55
Feel more generous	26	55
Decreased depression	19	40
Pain relief	13	28
No benefit	0	0
Other		
Spiritual connection	14/32	44
"It's my refuge."	17/32	53

8 h after surfing when red tide is present," and "severe reaction for months at a time for the last decade-plus." Thirty-six percent of surfers reported experiencing adverse health effects of "red tide" exposure, 38% said no and 26% said they were not sure if they had any adverse health effects due to red tide exposure (**Table 2**).

Risk factors for upper respiratory symptoms identified by the regression analysis, GEE, included a previous episode of adverse health effects after surfing during a red tide and surfing during a bloom or an abundance of the phytoplankton species, *Akashiwo sanguinea* (**Table 3**). Surfers who identified a history of previous adverse health symptoms after surfing during a red tide were 1.42 times more likely to have upper respiratory symptoms than surfers who had not experience any adverse health symptoms during a red tide (RR: 1.42, 95% *CI* = 1.01, 2.02). Surfers who surfed during a bloom of *Akashiwo sanguinea* were 1.63 times more likely to have upper respiratory symptoms than surfers who did not surf during an *A. sanguinea* bloom (RR: 1.63, 95% *CI* = 1.09, 2.46).

Ocean Conservation Actions

In the baseline study (N = 47) we asked "How concerned are you about ocean conservation issues? not concerned, moderately concerned, or very concerned." Four surfers reported being moderately concerned and 43 (91%) of the surfers reported being very concerned about ocean conservation. We hypothesized that concern for the ocean would lead to environmental action. In the second follow up survey we asked "How do you support ocean conservation?" Participants (N = 27) who completed the survey reported that they all engaged in ocean conservation activities. Pro-social behaviors included: talk with friends/family about ocean issues (93%), reduce use of plastic products (93%), reducing the carbon footprint (83%), vote in support of ocean conservation issues (78%), eat sustainable seafood, eat local fish, eat wild fish (74%), prevent chemicals, pesticides, and fertilizers at home from going down the storm drain (74%), donating money to ocean non-profits (43%), volunteering for an ocean non-profit organization (27%), and contact government representatives and lawmakers about ocean issues (22%).

DISCUSSION

The goal of this prospective cohort study was to examine the health risks and benefits of ocean exposure among surfers in Monterey Bay, a popular California surf location. The study found that upper respiratory symptoms (41%) and health effects of red tide exposure (36%) were the most common acute health concerns among study participants. Acute health effects after surfing during a "red tide" and surfing during a bloom of *Akashiwo sanguinea* were risk factors for upper respiratory symptoms. The most common chronic health issue reported was surfer's ear (32%). All participants reported the benefits of emotional health and wellness from time spent in the ocean. Additionally, surfer participants reported that they were actively engaged in ocean environmental stewardship.

Current anthropogenic environmental changes are increasing in the occurrence of red tide and HABs. The coastal waters of central California, including Monterey Bay, are home to several genera and species of phytoplankton that are responsible for red tide and their toxin production, namely single cells, floating genera of *Alexandrium, Pseudo-nitzshia, Akashiwo sanginea, Heterosigma akashiwo, Dinophysis, Fibrocapsa, Chattonella, Coccolidinium*, and *Microcystis*. However, none of these phytoplankton genera have been reported to be associated with upper respiratory symptoms or adverse health effects in surfers in Monterey Bay. Previous research did not find an association between upper respiratory problems and known toxic genera (e.g., *Alexandrium*) or species (such as *Pseudo-nitzshia australis*) and domoic acid in surfers in Monterey Bay (O'Halloran et al., 2017). However, along the Southeast coast of the Atlantic and the Gulf of Mexico coastal areas, *Karenia brevis* has been known to produce an aerosolized neurotoxin, brevetoxin, which is known to cause respiratory problems, especially among asthmatics and older adults (Kirkpatrick et al., 2004, 2011; Milian et al., 2007). *Karenia brevis* has not been identified in the cold coastal waters of Monterey Bay. In this study, we found an association between upper respiratory symptoms and surfing during a bloom of *Akashiwo sanginea*, a dinoflagellate in the seawater. Participants who previously experienced adverse health effects while surfing during a red tide were significantly more likely to have upper respiratory symptoms than those who had not experienced any adverse health effects during a red tide event.

To our knowledge, this is the first study to report upper respiratory symptoms associated with a bloom of the dinoflagellate *Akashiwo sanginea*. A previous study in Monterey Bay by Jessup et al. (2009) found mass stranding of sea birds caused by a surfactant-producing red tide due to *Akashiwo sanguinea*. Locally in Monterey Bay blooms of *Akashiwo sanguinea* have been found to have high seawater concentrations of dimethylsulfoniopropionate (DMSP), an organic sulfur compound that releases volatile sulfur into the air (Kiene et al., 2019). Further research on a possible mechanism of upper respiratory irritation in surfers is needed.

Surfer's ear was a common chronic health problem reported among this cohort of surfers, affecting almost one-third of participants. Past studies on EAE estimate the prevalence to range between 26 and 73% (Attlmayr and Smith, 2015). Kroon et al. (2002) found that cold water surfers were 5.8 times more likely than warmer water surfers to develop EAE and the prevalence was 38%. In this study, we assumed that surfers were aware of the association of EAE and cold water (Kroon et al., 2002) and methods of prevention. This may have been an incorrect assumption, however, given that 60% of surfers never wore earplugs. Locally these findings are of interest and may warrant public health awareness especially among young surfers. Future studies could examine the obstacles to using preventative measures, such as earplugs and/or a neoprene hood, which are protective but are an added expense.

Although time spent in the ocean has inherent risks, the surfer's in this study reported the ocean provided benefits of emotional health and well-being. The reported benefits of time spent in the ocean included increased happiness, relaxation, awe inspiring, increased life satisfaction, and a time to connect with friends and other surfers. The results of this study corroborates

existing evidence of the benefits of positive health and mental health from spending time in nature (White et al., 2020).

This surfer cohorts connection to the ocean through weekly ocean exposure presumedly motivated them to take ocean conservation action. Surfers had a pro-ocean mindset and engaged in environmental stewardship through recycling, reducing plastic use, leaving smaller carbon footprints, and eating sustainable seafood. Some surfers also engaged in political action by contacting legislators and voted for ocean conservation measures. During this time of anthropogenic climate change it is important for people to feel connected to nature and take positive action on behalf of the planet and ourselves. This study suggests that exposure to the ocean has a positive effect on promoting ocean conservation measures.

This study has both strengths and limitations. A strength was the prospective collection of exposure data over several months. On the other hand, the relatively small sample size (N = 47) was a potential study limitation with many of the surfers not completing all three follow up surveys. Selection bias is a concern because surfers who participated in the study may have different characteristics than those who chose not to participate in the study. The results of this small cohort of surfers cannot be generalized to other populations due to local seawater composition and community illnesses. Sources of other concurrent environmental allergens (e.g., pollen) were not available for this study. Additionally, other unmeasured possible confounding factors included occupational hazards (e.g., firefighters). Any of these other conditions may have had a positive association with upper respiratory symptoms.

Additional research is needed to identify the adverse health effects associated with bloom conditions of *Akashiwo sanguinea* and co-occurring toxins. In addition, the identification of co-occurring pathogenic bacteria and viruses during red tides to determine the role, if any, they play in human illness. Ongoing research focused not only on the risks but also on the benefits of the ocean environment will benefit ocean conservation endeavors during this time of anthropogenic environmental change.

CONCLUSION

This study highlights the interconnections between the ocean and human health, specifically addressing risks and benefits to surfers physical and mental health and their sense of well-being. There was an increased risk of upper respiratory symptoms among surfers with a history of adverse health effects of red tide and surfing during a phytoplankton bloom of *Akashiwo sanguinea*. Surfers reported emotional health and well-being benefits of time in the ocean. Additionally, surfers reported environmental stewardship and being engaged in ocean conservation endeavors. Future research in the interdisciplinary field of oceans and human health is necessary to focus on the importance of healthy ocean ecosystems for human health and a sustainable planet.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The study was approved by the Institutional Review Board of the Ethical and Independent Review Services (#15102). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CO'H and MS contributed to the concept and design of the study, revised the manuscript, and read and approved the final submitted version. CO'H performed the statistical analysis and wrote the first draft of the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.714831/full#supplementary-material

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