Exploring climate change impacts on respiratory illnesses arising from red tides in Florida Gulf Coast with economic analysis

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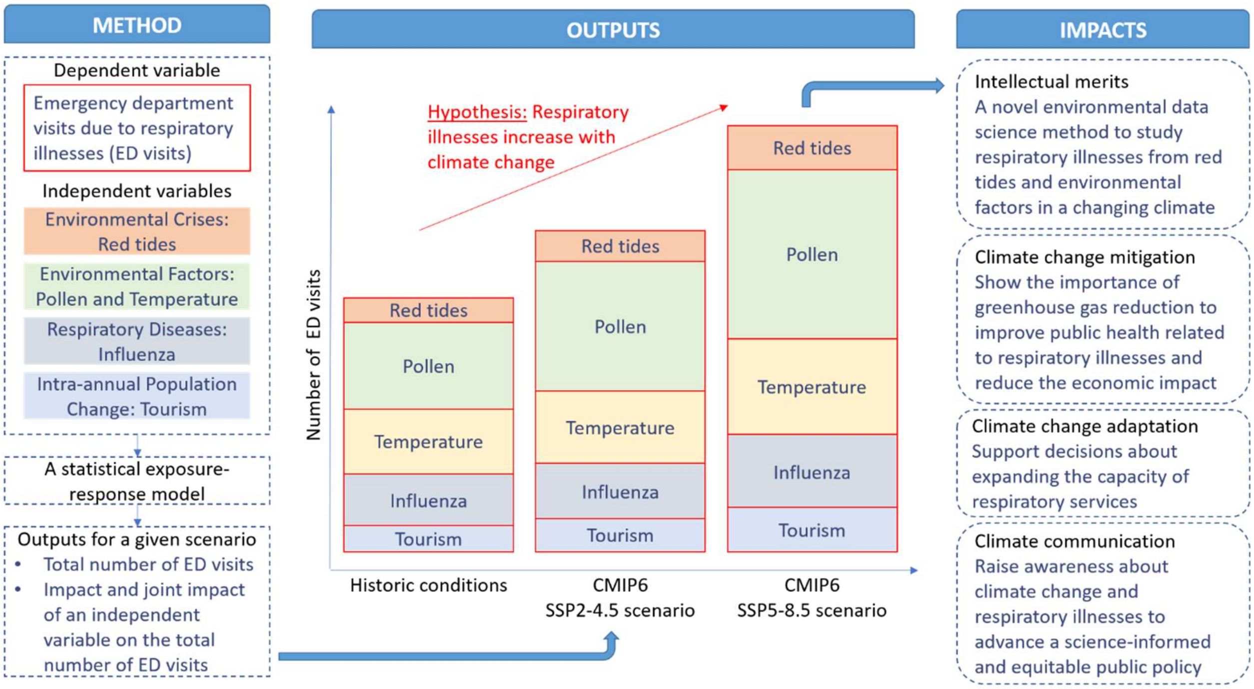
Visual Abstract



Project Summary

Background. Understanding impacts of climate change on respiratory illnesses arising from red tides, which are marine harmful algal blooms (HABs), is an important but challenging research. Red tides result in potent brevetoxins, which are linked to respiratory illnesses in humans. Epidemiologic studies show that aerosolized brevetoxins are linked to upper airway disease and chronic and acute bronchitis. Cost of illness due to red tide events leads to significant economic impacts on public health. Yet impacts of climate change on respiratory illnesses related to red tides (and HABs in general) have not been well understood.
Objective. The study objective is to understand the scale of increase of respiratory illnesses arising from red tides in a changing climate, given interactions with other environmental factors that are pollen and temperature. These enable assessment of economic impacts of respiratory illnesses associated with red tides and pollen, as these economic impacts have not been well understood and quantified.
Methods. To study respiratory illnesses associated with red tides under future climate scenarios, we will develop a statistical exposure–response model to express the relationships among respiratory illnesses with several variables that are red tide events, pollen, air temperature, influenza, and tourism. Our preliminary research results show that these variables can explain the number of respiratory-specific diagnoses in the emergency department. Based on the model, we will explore future conditions based on three scenarios of red tide bloom levels: low, medium, and high. We will also project pollen and air temperature under two shared socio-economic pathways (SSP) scenarios of the Coupled Model Intercomparison Project Phase 6 (CMIP6). These SSP scenarios represent different greenhouse gas scenarios as well as mitigation and adaption preferences. Subsequently, we will conduct an economic analysis based on the marginal costs and lost productivity of illness to quantify respiratory illnesses costs associated with red tides and pollen.
Outputs. This project will provide a novel approach of environmental data science that captures the interrelations between red tides, pollen, and temperature, and their individual contribution to respiratory illnesses under climate change scenarios. Future trends of respiratory illnesses arising from red tides and pollen will be produced for Florida Gulf Coast and the associated costs will be quantified under different climate scenarios. The project findings will be disseminated not only to the scientific community, but also to the public through a climate communication campaign.
Impacts. While the field of HABs and public health has matured with respect to historic conditions, health impacts due to HABs are unclear as climate change intensifies. The project will address this gap and consider the joint impacts of HABs and other environmental factors in alignment with the National Academy of Medicine's Grand Challenge on Human Health and Climate Change. The proposed environmental data science method will advance knowledge about respiratory illnesses arising from red tides and pollen in a changing climate, and can be readily adopted at many locations with red tide occurrence. The proposed research is needed for understanding how reduction in greenhouse gas emissions can improve public health with respect to respiratory illnesses arising from environmental factors such as red tides, pollen, and temperature. Understanding these future trends and the scale of associated economic losses is needed to make rational choices about climate change mitigation. Additionally, this will assist the health care sector to make informed decisions about expanding the capacity for respiratory services and other adaptation measures particularly for higher risk groups. Moreover, the project will train two graduate students at Florida Gulf Coast University and Florida State University. The students will work in an interdisciplinary project that connects climate change, environmental factors, epidemiology and public health, and economics. The project will help raise awareness about climate change and public health, which is imperative for advancing a sound science informed and equitable public policy.

Project Description

1. Introduction

Climate change is a major threat to public health. Due to fossil fuel burning, land-use change, and steel and cement production, the increase of greenhouse gasses (GHG) in the atmosphere is causing global warming. Climate change is rising the air temperature, increasing surface-ocean heat content, acidification and deoxygenation, rapidly melting glaciers and polar icecaps, accelerating sea-level rise, intensifying storms, increasing flood, drought and wildfire hazards, and changing vegetation patterns. As such, climate change is the single biggest health threat to humanity, as it affects basic determinants of public health such as clean air, safe drinking water, sufficient food, and secure shelter (World Health Organization, 2021). This proposal addresses the impacts of climate change on clean air and associated damage cost to public health in coastal regions. The proposal focuses on climate change impacts on respiratory illnesses arising from red tides, which are marine harmful algal blooms (HABs). The study location is west Florida shelf, which is ground-zero for sea-level rise in the United States (Maliva et al., 2021) and at very high risk of hurricane intensification (Balaguru et al., 2022) and exacerbation in extreme rainfall–surge hazard (Gori et al., 2022). HABs adds to the climate vulnerability of Florida (Heil & Muni-Morgan, 2021) through several pathways including public health impacts (Gobler, 2020). The **overarching goal** of this study is to understand to which extent respiratory illnesses arising from HABs can contribute to costs of public health due to climate change in west Florida shelf.

Epidemiologic studies suggest that aerosolized toxins from HABs are linked to respiratory illnesses in humans. Red tides, which is a common name of HABs occurring in Florida and worldwide, are caused by dinoflagellate Karenia brevis, a toxic single-celled protist. Karenia brevis produces potent neurotoxins, which are collectively called brevetoxins. Uptake of brevetoxins by humans can be through ingestion of shellfish causing neurotoxic shellfish poisoning, or inhalation of aerosolized brevetoxins carried in sea spray causing respiratory irritation. Aerosolized brevetoxins can exacerbate upper airway disease, chronic and acute bronchitis, pneumonia, and asthma (Abdullah et al., 2022; Fleming et al., 2009; Kirkpatrick et al., 2006). Respiratory illnesses associated with aerosolized brevetoxins lead to significant economic impacts in southeast Florida based on costs of illness of emergency department visits (Hoagland et al., 2009). However, while there is a reasonable amount of understanding about the influence of red tides on respiratory illnesses and associated economic impacts (Diaz et al., 2019; Hoagland et al., 2009, 2014; Kouakou & Poder, 2019), future impacts of climate change on respiratory illnesses arising from red tides are poorly understood, and economic costs have not been adequately quantified.

We hypothesize that respiratory illnesses arising from red tide will increase with climate change. Historic data analysis shows an increase in public health impacts from HABs since early 1980. As climate-driven changes in aquatic ecosystems are becoming substantial (Wells et al., 2020), there is a scientific consensus that public health impacts from HABs have increased over the past several decades (Gobler, 2020). According to an Intergovernmental Panel on Climate Change (IPCC) special report on ocean (Bindoff et al., 2019), HABs have increased in coastal areas since early 1980s in response to warming, deoxygenation, and eutrophication. For example, in the Gulf of Mexico, Tominack et al. (2020) show that the Texas Coastal Bend has experienced a significant increase in frequency of red tide blooms since mid-1990s. According to Bindoff et al. (2019), the increase in HABs has negative impacts on human health, and human communities in poorly monitored areas are among the most vulnerable. Increase in public health impacts from HABs could be attributed to increase of HABs frequency, intensity, toxicity, and duration (Heil & Muni-Morgan, 2021). There is a consensus that climate change is predicted to increase the frequency of coastal HABs (Hallegraeff, 2010).

We further hypothesize that the increase in public health impacts from red tides could be attributed to interactions with other environmental factors such as pollen and air temperature. Climate change with respect to increase in air temperature and pollen can increase respiratory illnesses in coastal regions.

Climate change represents a massive threat to respiratory health through directly prompting and aggravating respiratory diseases, and by increasing exposure to risk factors for respiratory diseases such as increase in temperature and pollen (D'Amato et al., 2014). For example, with respect to the impacts of temperature, Xie et al. (2017) show that a large diurnal temperature range can increase the incidence of childhood acute bronchitis in Hefei, China. Similarly, Figgs (2020) shows that emergency department chronic bronchitis diagnosis in Douglas County, NE, was higher during the 2012 heatwave compared to the same calendar period in 2011. Also, Pesce et al. (2016) suggest that climate change affects asthma in Italy such that higher and lower asthma prevalence are in dry-hot Mediterranean climates and rainy-cold northern climates, respectively. In addition to the increase in air temperature, climate change increases the amount of pollen produced by plants. For example, Zhang and Steiner (2022) show the projected climate-driven increase in the season length and magnitude of pollen over the continental United States. Projection of relevant environmental factors (i.e., temperature and pollen) that control respiratory illnesses such as pollen and air temperature is important for studying the public health impacts from HABs. For example, Hoagland et al. (2009) show that lagged red tide cell counts, low air temperatures, high pollen counts, influenza outbreaks, and intra-annual population changes due to tourism explain the number of respiratory-specific diagnoses in emergency department visits.

We propose **an environmental data science approach** to advance knowledge about respiratory illnesses arising from red tides under changing climate. Similar to Hoagland et al. (2009), we hypothesize that there is a relationship between respiratory illness visits to hospital emergency departments (ED visits) and red tides, environmental factors (pollen and air temperature in this study), influenza, and tourism. While analysis based on historic data provides evidence for increase in public health impacts from HABs in the past several decades, future impacts of climate change on respiratory illnesses arising from HABs are poorly understood. One **novelty** of this proposal is that we will consider respiratory illnesses arising from red tide based on advances in climate change research. Quantitatively projecting the distribution of red tides is a challenging task because large uncertainty remains about how integration of diverse climate drivers may alter red tides (Ralston and Moore, 2020). Thus, we will explore future conditions of red tides based on three framed scenarios of bloom levels: low, medium, and high. A framed scenario is an explorative scenario that describes "what could happen?" (Maier et al., 2016). The proposal addresses the challenge of projecting relevant environmental factors that control respiratory illnesses (i.e., pollen and air temperature) through using the shared socio-economic pathways (SSP) scenarios of the Coupled Model Intercomparison Project Phase 6 (CMIP6). SSP scenarios are trend scenarios, which are predictive scenario that describes "what will happen?"(Maier et al., 2016). We will project pollen and air temperature under two SSP scenarios of SSP2-4.5, and SSP5-8.5. The 4.5 and 8.5 are radiative forcing [W/m^2] terms that represent the difference between the amount of energy entering and leaving the atmosphere. SSP2 is the "Middle of the Road" scenario representing medium challenges to mitigation and adaptation; SSP5 is the "Fossil-fueled Development – Taking the Highway" scenario representing high challenges to mitigation and low challenges to adaptation (Riahi et al., 2017). This is one of the pioneering studies that use CMIP6 scenarios to study temperature and pollen in relation to respiratory illnesses. We will use a trend scenario and historic trend to present future conditions of influenza and tourism, respectively. This novel environmental data science approach will answer these research questions:

1. How significantly will climate change increase respiratory illnesses arising from pollen in Florida Gulf Coast?
2. What are the potential trends of respiratory illnesses in Florida Gulf Coast due to increase in air temperature under different climate scenarios?
3. Will climate change increase the costs of respiratory illnesses arising from red tides given different bloom levels?

In later projects that use trend scenarios for red tides, we can answer the following research question:

4. Will the reduction in GHG emissions improve public health with respect to red tides, and reduce the damage costs to public health from red tides?

2. Method

Methods. We will use a statistical exposure–response model to explore the hypotheses about the relationship between respiratory illnesses and bloom events based on ED visits (Hoagland et al., 2009)

$$ED_t = f(\mathrm{H}_{\mathrm{t}-1}, W_t, D_t, T_t, \varepsilon_t) \quad (1)$$

where t indexes time interval; ED is the number of ED visits due to respiratory illness in a local hospital; H is the red tide cells counts in the study area; W is a vector of environmental and weather variables, which are pollen and air temperature; D is a measure of regional respiratory disease outbreaks that is influenza; T is a measure of intra-annual population change, which is due to tourist visits; and ε_t is the residual errors. Granger causality test will be used is a statistical hypothesis test for determining whether one time series is useful in forecasting another. Equation (1) is solved using vector autoregression (VAR), which is a statistical model that captures the relationship between multiple variables change over time. We will use VAR(p) with automatic selection of lag p. All variables are endogenous variables, such that each variable is determined by its relationship with other variables. As such, we can estimate the contribution of each variable (i.e., red tide cell counts, pollen, and air temperature) to the total number of ED visits. We will conduct this analysis from 2005 to 2014 using historic data for all variables. Using a sample of one-year data and the Python module statsmodels for statistical modeling, we developed and tested the VAR(p) model in Eq.1 (https://bit.ly/HABs-Health). Historic data will be used to parameterize the statistical exposure-response model to be used for future projections, and Figure 1 shows the inputs and outputs of the projects.

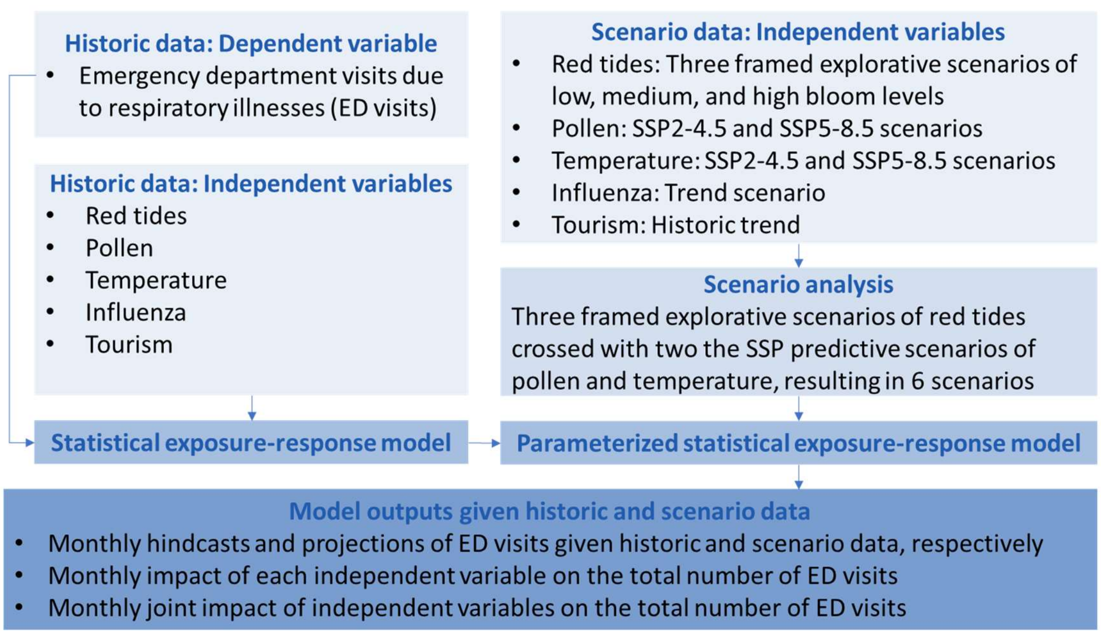


Figure 1. Data, models, and outputs of historic and scenario analyses

We will forecast monthly ED visits from 2015 – 2100, which will be aggregated as five-year averages. From 2015 to 2100 we will use three bloom levels of low, medium, and high, based on historic data with a five-year period. This is following the bloom level definition of Maze et al. (2015) and the concentration levels of Florida Fish and Wildlife Conservation Commission - Fish and Wildlife Research Institute (FWC-FWRI, 2022b). For air temperature and pollen, we will use CMIP6 scenarios of SSP2-4.5, and SSP5-8.5. We will use a five-year period of historic data to present future tourism activities. We will trend historic influenza outbreaks for future conditions based on data from Liu et al. (2020), which illustrates that in some regions of northern mid-latitudes in a warming climate, rapid weather variability in autumn will continue to strengthen. This suggests increased risk of 20% to 50% for influenza outbreaks in some highly populated regions (Liu et al., 2020). For future conditions, we will use a five-year corrected historic data of influenza. We will use non-trended influenza data for comparison. Using the model in Equation (1), we will forecast ED visits from 2015 – 2100 for the six scenarios that are three bloom level scenarios crossed with two CMIP6 scenarios for air temperature and pollen (Figure 1). As such, we can compare the future change in ED visit trends for the six scenarios.

To understand the economic impact of respiratory illnesses, we will estimate the cost of illnesses as the sum of marginal costs of ED visits and lost productivity during illness period based on hospitalized and recuperate days (Hoagland et al., 2009, 2014). We will consider respiratory ailments due to aerosolized brevetoxins during the historic period, and due to pollen during the historic and future periods. However, this model can be used in later projects to estimate future cost of respiratory ailments due to aerosolized brevetoxins, based on predictive red tide scenarios. As a proof-of-concept study, this project will only consider ED visits, and a in later study we can additionally account for hospital inpatient.

Data. The study area is Sarasota County, Florida. Data for implementing Equation (1) in the study area will be processed at a monthly interval for the historic period (2005-2014) and future period (2015-2100). We collected daily ED visit data from Sarasota Memorial Hospital (SMH), which is the closest hospital to the coastline in Sarasota County and serves about 63% of the county's population (Hoagland et al., 2009). Red tide data are referred to as cell counts of Karenia Brevis collected from 2005 to 2022. This publicly available data can be downloaded from NOAA Harmful Algal Blooms Observing System (HABSOS, 2022), and the continually updated database can be requested from FWRI (FWC-FWRI, 2022a). The fact that cell count data are generally based on event responses sampling and can be non-systematic and non-uniform, was considered in bloom data analysis (Elshall, 2021). We obtained pollen data as daily pollen counts, which is pollen grains per cubic meter of air for the period of 2005 to 2015 from the American Academy of Allergy, Asthma & Immunology. The data are collected using the Burkard 7-day pollen collector in the regional sampling station at the University of Florida, Gainesville. For future pollen data, we will extract the Sarasota County data from the dataset of Zhang and Steiner (2022), which is projected pollen magnitude over the continental US under the SSP2-4.5, and SSP5-8.5 scenarios. Daily average air temperature data was obtained from the New Pass Weather Station (27.19°N, 82.34°W), where the data are publicly available from 2004 to present (Mote Marine Laboratory, 2022). Near surface air temperature for scenarios SSP2-4.5, and SSP5-8.5 will be obtained for Sarasota County from the NASA Earth Exchange Global Daily Downscaled Projections archive (NEX-GDDP, Thrasher et al., 2022). We will use the outputs of all available downscaled projections for different global climate models with a simple ensemble average. For influenza data, we will obtain weekly influenza virus outbreaks data for the South Atlantic Region from the U.S. Centers for Disease Control and Prevention (CDC) from 2005 to 2015. The data is a measure of the percentage of specimens testing positive for influenza within a particular week, and the data is available for the epidemic period of October through May based on the assumption that the minimal outbreaks periods have little or no influenza cases(Hoagland et al., 2009). For tourism data, we obtained monthly data on Sarasota County monthly hotel occupancy rates and the number of units by lodging type from 2005 to 2015 from the Sarasota Convention and Visitors Bureau. Assuming two residents per unit, we obtained a monthly estimate of the temporary resident population by summing the number of occupants in all units. We will have access to all the data needed for the project.

3. Outputs, impacts, previous support, and timeline

Outputs. Expected deliverables are as follows: (1) dataset showing the trends of economic costs of respiratory illnesses arising from red tides in the study area from 2005 to 2100 given three bloom levels under SSP2-4.5 and SSP5-8.5 scenarios for the environmental variables that are pollen and air temperature, (2) datasets showing the trends of respiratory illnesses and associate economic costs arising from pollen in the study area from 2005 to 2100 with the future period shown under SSP2-4.5 and SSP5-8.5 scenarios, (3) at least one peer-reviewed publication in Science for the Total Environment or Environmental Health Perspectives, (4) a conference abstract to the American Geophysical Union (AGU) Annual Meeting, which is the most influential conference in Earth science research, and (5) public awareness and climate communication campaign around climate and human health through a blog post, ResearchGate project, 5-minute YouTube video about the project, seminars at Florida Gulf Coast University (FGCU) and Florida State University (FSU), and news sources through the media office in The Water School at FGCU.

Impacts. First, the project has several societal impacts. With a focus on respiratory illnesses, this project aligns with the National Academy of Medicine's Grand Challenge on Human Health and Climate Change. The project finding will help us understand to what degree the reduction in GHG emissions can improve public health with respect to respiratory illnesses arising from environmental factors such as pollen, red tides, and temperature. It is necessary to understand the scale of economic losses associated with climate change in relation to these environmental factors to make rational choices about climate change mitigation and adaptation. In addition, the results will help stakeholders and the health care sector to make science-informed decisions about expanding the capacity for respiratory services and mitigation measures particularly for higher risk groups such as individuals with preexisting conditions. Second, the project will also have multiple impacts on educational and professional development. The project will simulate growth for scholars from two public universities working in largely disconnected fields. Our project team members are Dr. Ahmed S. Elshall – an assistant professor in the Department of Bioengineering, Civil Engineering, and Environmental Engineering with joint appointment with The Water School at FGCU, Dr. Ming Ye – a professor in the Department of Earth Ocean and Atmospheric Science at FSU, and Dr. Julie Harrington – the director of FSU Center for Economic Forecasting and Analysis. The team will work together to make methodological contributions for studying the public health impacts of climate change. The project will train two graduate students at FGCU and FSU in environmental data science, Earth system modeling, and human health impact assessment. The students will get a chance to work in an interdisciplinary project that connects climate change, environmental factors, epidemiology and public health, and economics. Third, With respect to climate communication, the project will raise awareness about the impacts of climate change on human health through scientific evidence. This is imperative for advancing a sound science-informed and equitable public policy.

Previous support. This project will leverage on an existing National Science Foundation (NSF, Award # 1939994, 2019 - 2023) project about red tide modeling using Earth system models (Elshall et al., 2022a, 2022b, 2022c). The NSF project has a very limited scope with respect to health impact assessment. We collected and analyzed respiratory illnesses data from a regional hospital.

Timeline. The contribution of the PI at FGCU (Elshall), Co-PI at FSU (Ye), Co-PI at FSU (Harrington), one graduate student at FGCU (G1), and one graduate student at FSU (G2) are as follows.

Task	**2023**		**2024**	
	Q3	**Q4**	**Q1**	**Q2**
(1) Process red tide data (Elshall, and G1)				
(2) Process data of ED visits, influenza, and tourism (Ye, and G2)				
(3) Process pollen data (Elshall, and G1)				
(4) Process temperature data (Ye, and G2)				
(5) Conduct data analysis using VAR model (Elshall, Ye, G1, and G2)				
(6) Conduct economic analysis (Harrington, G1, and G2)				
(7) Prepare journal paper, conference abstract, outreach campaign (All team)				
(8) Prepare annual report (Elshall)				

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