Environmental modelling of paralytic shellfish toxins

A Report to SEATOR Partners

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Introduction

Harmful algal blooms (HABs) that produce paralytic shellfish poison (PSP) have occurred in Southeast Alaska for hundreds of years. Historically there have been several incidents of poisonings due to contaminated shellfish including Poison Cove on Baranoff Island in 1799, and the state of Alaska has recorded more than 250 cases of PSP since 1970. HABs that produce PSP in Alaska contain the dinoflagellate *Alexandrium* (Figure 1). *Alexandrium* has a complex life cycle, but in general phytoplankton such as *Alexandrium* bloom and proliferate in the spring, summer, or early fall in Alaska.

Knowing when these HABs are occurring and when it is safe harvest shellfish has been a challenge for Native Alaskans and subsistence harvesters for hundreds of years. HABs are caused by several complex interactions of water temperatures, sunlight, nutrient availability, and salinity and it is difficult to predict when and where conditions are going to favor a HAB that produces PSP.

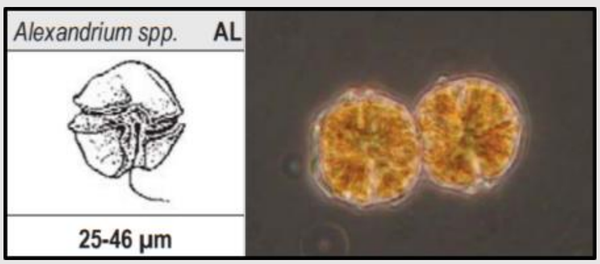

Figure 1 The dinoflagellate *Alexandrium* which produces PSP in Alaska.

Over the past 5 years the Southeast Alaska Tribal Ocean Research (SEATOR) network has collected more than 2,000 shellfish samples analyzed for PSP at the Sitka Tribe of Alaska Environmental Research Lab. These sample collections have been instrumental in developing our understanding of environmental drivers of HABs in Southeast Alaska. In addition to shellfish the partners have collected phytoplankton observations, temperature, and salinity data which have been incorporated into models that have enhanced our ability to understand PSP dynamics.

Many SEATOR partners monitor several species of shellfish, but blue mussels are the most informative when it comes to detecting HABs early. Blue mussels uptake and get rid of PSP toxins very quickly, and are widely used for monitoring programs around the world. Since 2015 the Sitka Tribe of Alaska Environmental Research Lab (STAERL) has analyzed more than 1200 blue mussel samples, which show a seasonal pattern (Figure 2).

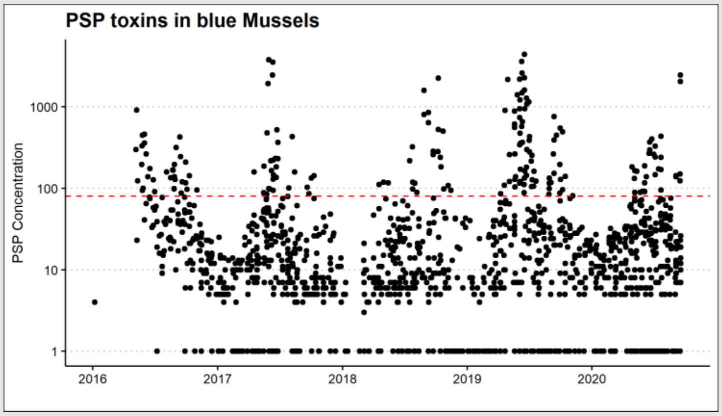

Figure 2 Concentrations of PSP toxins in blue mussels collected by SEATOR partners. Concentrations of PSP in blue mussels have exceeded the FDA threshold of 80 µg/100g^{-1} in each year in at least one community in Southeast Alaska. Note that the y-axis is on a log scale.

Methods

SEATOR partners have collected temperature and salinity data in addition to shellfish (Figure 3). Sea surface temperatures typically range from 2ºC (36ºF) to 16ºC (61ºF) in Southeast Alaska, although warmer temperatures have been observed in small protected bays during warm summer periods. Salinity also displays a seasonal cycle: surface water is the least salty in the summer time when melting snow and rain increase the amount of freshwater input into the ocean. Surface water is the saltiest in the winter time when storms drive mixing that brings up saltier water from the deep ocean.

I also brought in some other environmental variables to use for predicting HABs (Figure 4). These data were accessed mainly through the National Oceanographic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS). These included freshwater discharge from local streams and rivers, upwelling, precipitation, air temperatures, tidal flux, wind speeds, and photosynthetically active radiation (PAR), which is a measure of how much sun is reaching the surface of the ocean.

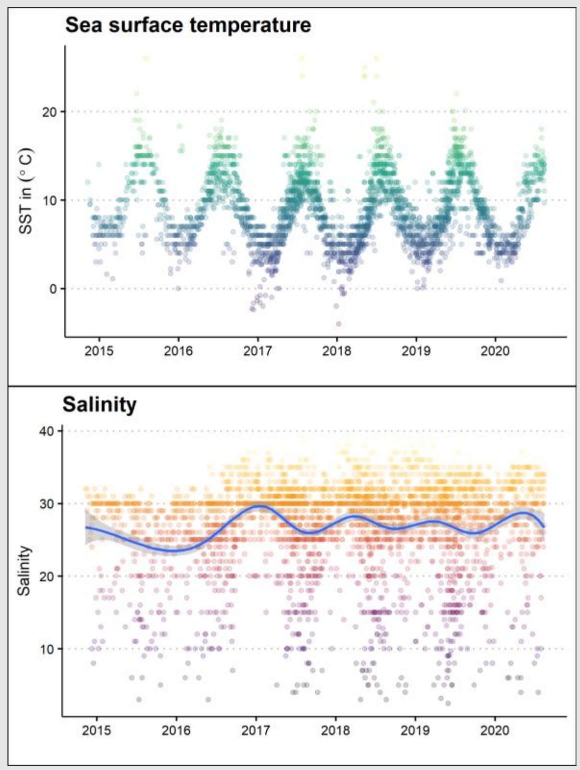

Figure 3 SST and salinity data collected by SEATOR partners since 2015.

Once I had all of the environmental data, I built a model using machine learning that tries to predict if mussels are going to be above or below the FDA threshold of 80µ 100g^{-1}. This random forest model is trained using a certain percentage of the dataset (70%) and then tries to predict the other 30%. In this way we can assess how accurate our model is, and how well it predicts things like the timing of PSP events. From this model, we can also figure out which variables are the most important to predict HABs in Southeast Alaska.

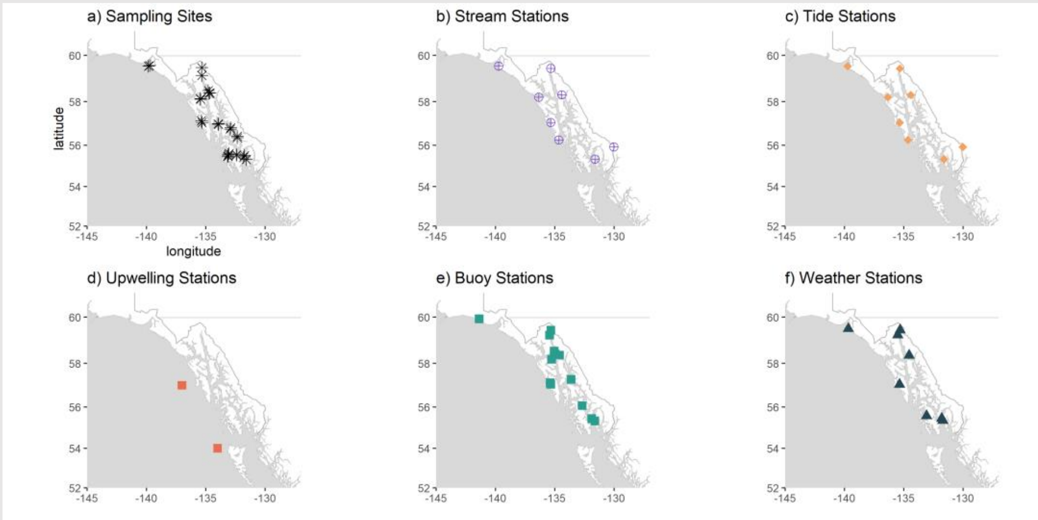

Figure 4 Stations from where environmental data for Southeast Alaska was accessed from federal agencies (NOAA, USGS).

Results

The model performed fairly well at predicting PSP concentrations in mussels in some cases. I had the model predict concentrations of PSP during the summers of 2017, 2018 and 2019 and it accurately predicted the timing of the spring blooms in 2017 and 2019. In the graph below (Figure 5), the black lines are the actual weekly average PSP concentrations from SEATOR partners, and the blue line is a proxy for the predicted concentrations from the model I created.

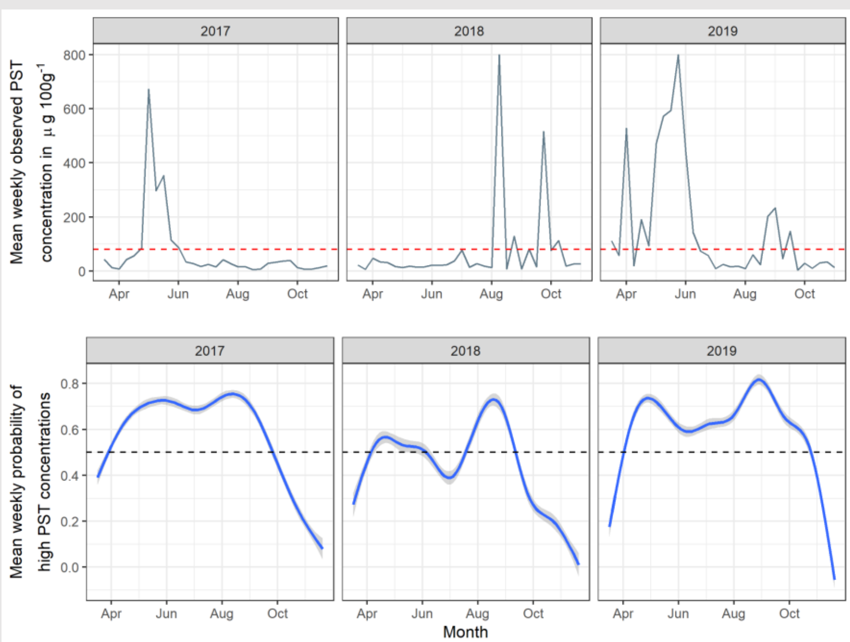

Figure 5 - PSP concentrations (top panels) and model predictions (bottom panels) from summers of 2017-2019.

There were two issues that affected the accuracy of these forecasts. Firstly, while the model did anticipate the spring bloom in 2017 and 2019, it also predicted a bloom in spring of 2018 which did not occur in most communities. You can see from the blue line in 2018 that the model was not confident about this prediction of a spring bloom, but nonetheless it incorrectly identified the period of mid-April to June as a bloom.

Secondly the model predicts that blue mussels will be 80µ $100g^{-1}$ for most of the summer May-October. While this is a conservative forecast option, it does not correctly pick up that blue mussels will often detoxify to below 80µ $100g^{-1}$ a few weeks after a

HAB. The environmental conditions are often right for a bloom throughout the summer, but the controls on whether a bloom happens are often dictated by variables which were not included in this model such as predation from zooplankton and nutrient availability.

The model also highlights which variables were the most important to predicting PSP concentrations (Figure 6). The three most important variables were sea surface temperatures (SST), air temperature, and salinity. This lines up well with studies from other regions – these variables seem to be the main drivers of HABs in regions such as British Columbia and Washington.

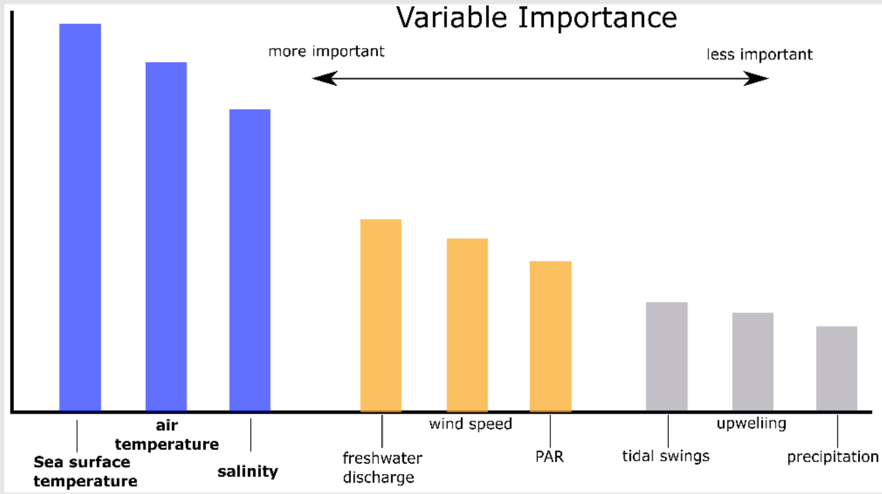

Figure 6 The importance of environmental variables to predicting PSP concentrations in blue mussels.

By looking further at these variables, we can describe the conditions under which we see high PSP concentrations in more detail. Below is output from the model which shows what values for these variables are likely to produce a bloom (Figure 7).

We see in increase in likely PSP concentrations at sea surface temperatures between 7.5 ºC (45 ºF) and 14ºC (57 ºF). Interestingly temperatures above 15 ºC, such as those seen in late June and early July, are not associated with HAB conditions. There are a few reasons why this might be, but in general by the time these temperatures occur in mid-summer the nutrient concentrations are lower and there are plenty of zooplankton grazers to reduce blooms of *Alexandrium*, Salinity also displays an optimal range of 25 to 28, which are values typically seen during the spring and summer in Southeast Alaska. Finally, with respect to air temperatures, the warmest temperatures were associated with HABs, with temperatures in excess of 20 ºC (68 ºF) are the most likely to produce a PSP event in blue mussels.

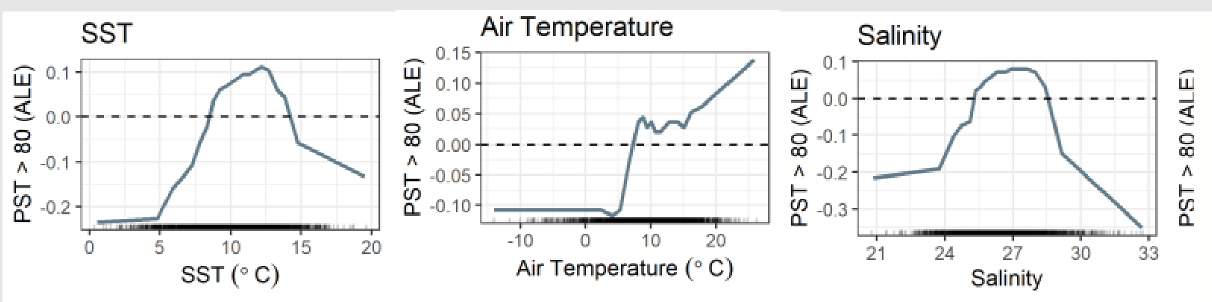

Figure 7 Positive values are associated with conditions more likely to produce a PSP forming HAB. Both SST and salinity display optimal values, while with regard to air temperature the warmer it is the more likely there will be a HAB.

Conclusions

HABs and PSP events in Alaska are difficult to predict, but the efforts of the SEATOR partners and the work presented here have laid the groundwork towards building a functional forecast model for Southeast Alaska. These types of models with daily resolution might be able to describe subtler dynamics of bloom formation which could lead to more accurate forecasts for harvesters and consumers. Models incorporating additional variables which may drive PSP dynamics (e.g., nutrients availability and cyst mapping) will further enhance our ability to predict and forecast HABs in Southeast Alaska.

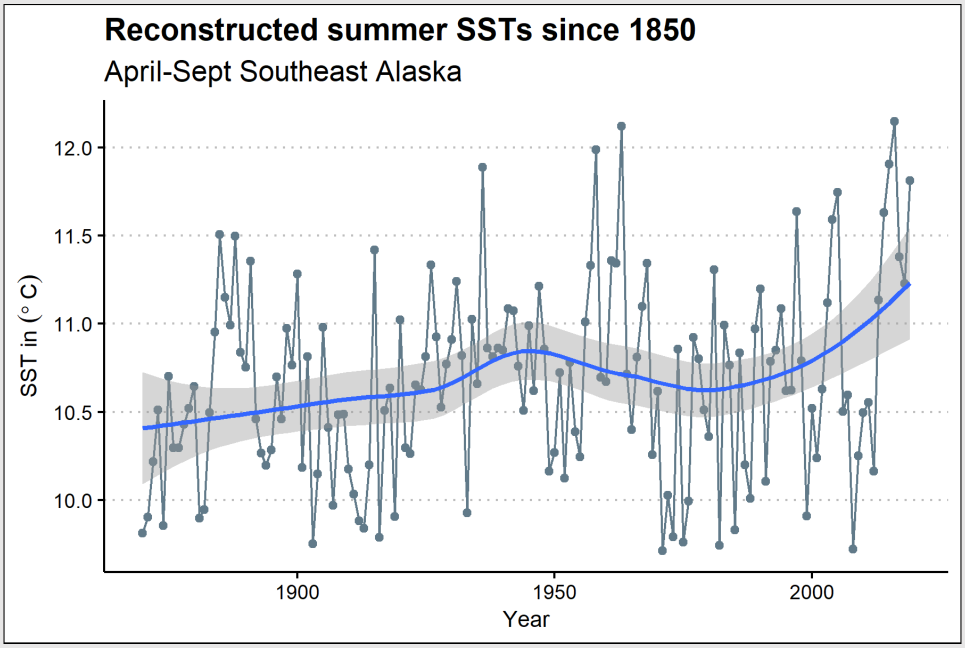

Figure 8 Historic summer sea surface temperatures (SSTs) for Southeast Alaska since 1850. Reconstructed SSTs from NOAA (HadISST).

The results of the environmental modelling can be paired with future climate scenarios to forecast HAB dynamics in the coming decades. In particular, rising ocean temperatures observed since 1850 (Figure 8) might increase the bloom window for HABs. In recent years many SEATOR communities have reached 8ºC in May, but with sea surface temperatures forecasted to increase by 0.1ºC - 0.5ºC per decade it's possible that this bloom window might shift earlier for many locations in Southeast Alaska.