A Tale of Two Species: An exploration into the effects of increased *Alexandrium* populations on shellfish harvesting in Kachemak Bay

Team: Persnickety Protoperidinium

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Abstract

Kachemak Bay has the optimum conditions for shellfish of all types. A wide tidal variation and nutrients from glacial runoff, provide a highly favorable environment for the growing of oysters, mussels, and clams. In addition, the region’s temperate summers discourage the development of *Alexandrium*, the dinoflagellate most commonly known to cause Paralytic Shellfish Poisoning (PSP). And as such, commercial and recreational harvesting has become one of the most productive in all of Alaska. However, this may not always be the case. The higher water temperatures and lower salinity levels caused by climate change are favored by *Alexandrium*. Furthermore, increased boat traffic and changing currents may lead to more frequent blooms of *Alexandrium*. This paper explores what an increase in *Alexandrium* would mean for Kachemak Bay’s burgeoning shellfish industry and investigates what can be done to solve the problem of PSP.
Physical Description of Kachemak Bay

Located in South-Central Alaska on the Kenai Peninsula is Kachemak Bay. The bay, like many others in the state, was shaped through the repeated advancing and retreating of glaciers. The Homer Bench, north of Kachemak Bay, and the Kenai Mountains to the south were respectively formed by glaciers during the last ice age within the boundaries of the bay (Field & Walker, 2003). Glaciation in Kachemak Bay also led to the formation of a 4 km long submarine-end moraine, an accumulation of stones and sediments moved by an advancing glacier. The Homer Spit bisects Kachemak Bay, leading to the two distinct basins of Kachemak Bay.

Currents

The currents of Kachemak Bay are rather complicated, as the Homer Spit acts as a barrier, dividing the freshwater fed inner basin from the marine outer basin. A major player in the currents of Kachemak Bay is the Alaska Coastal Current, which due to the extreme tides of Cook Inlet, is forced into the outer basin of Kachemak Bay. Nutrient rich water from the Gulf of Alaska enters the southern edge of Kachemak Bay’s mouth. The water exiting the northern edge of the bay is estuarine, with a low salinity and high turbidity, due to the high freshwater flow into Kachemak Bay. This makes the currents of the outer basin rather simple. The currents of the inner bay are more complicated, and not fully understood. Glacial runoff in the summer creates a layer of less dense fresh water over the salt water, resulting in a net flow of surface water from the inner bay to the mouth of the bay (Figure 1).

Changing Currents and Shipping Routes

With the ocean waters warming and arctic ice melting, new potential difficulties are presented, ones that could have local impact. The prospective Northwest Passage is a newly available shipping route from the Atlantic to Pacific Ocean, and a great opportunity for
commercial transport of goods as it saves approximately 4000 kilometers of travel (Zorzetto, May 2006). But it could also, subsequently, affect Kachemak Bay, leaving permanent repercussions. The Northwest Passage route coincides directly with the Alaska Coastal Current, which influences the bay (Figure 2). In addition, melt water from ice flows is contributing to the current (Buckelew July 17, 2013). These new changes, provoked by a changing climate, bring new waters and increased specie transport into Kachemak Bay; both potential dangers.

**Temperature and Salinity**

Kachemak Bay is glacial fed, leading to a highly estuarine ecosystem. The average temperature in Kachemak Bay during the winter is \(\approx 1.8^\circ \text{C}\) while the high is summer is \(\approx 10.5^\circ \text{C}\), the overall average being 6.5\(^\circ\) C (KBRR, 2010). Salinity in Kachemak Bay is highly stratified during the summer months, as there is a high input of glacial run off. Water quality testing by KBRR (2010) revealed that in the outer bay salinity did not significantly vary seasonally, nor in relation to depth. However, in the inner bay, it was found that salinities were highly stratified during the summer months. The extremes of the inner bay are caused by the Homer Spit. Freshwater is trapped within the inner bay, continually circulating. The outer bay is fed by the Alaska Coastal Current throughout the year, maintaining a stable salinity (Figure 3).

**Shellfish Harvesting**

The geology around the bay creates circulation patterns that sustain the productivity and diversity of the intertidal zones where marine invertebrates thrive. Incoming tides bring clear nutrient-rich water from the Gulf of Alaska on the south side of the bay and outgoing tides move sediment-loaded freshwater from the inner and north part of the bay. There is limited amount of inflow and change in salinity caused by water entering from outside the bay, which also limits the potential for contamination (Pegau, et al, 2006). Mild winter climate and large tidal ranges
create a healthy environment for marine invertebrates (Sigman, 2009).

Clams, mussels and oysters are the common shellfish harvested in Kachemak Bay. These have been harvested for centuries and are a traditional food source for the people living in the coastal villages around the bay. This food source is considered in subsistence harvest laws. Harvest limits are managed by the Alaska Department of Fish and Game. Littleneck clams, *Mercenaria mercenaria*, and butter clams, *Saxidomas gigantea* are harvested recreationally in Kachemak Bay. The commercial harvest of oysters and muscles has become a profitable maritime industry in Kachemak Bay.

**Shellfish Farms (Pacific Oyster)**

The waters of Kachemak Bay are well suited to the farming of shellfish, specifically Pacific Oysters, *Crassostrea gigas*. Currently, there are a total of 16 shellfish growing sites in Kachemak Bay. In addition, there are also nursery sites off the Homer Spit, and in Halibut Cove. In all of Alaska, there are a total of 28 farms selling shellfish; this means that over half of Alaska’s shellfish farms are found in Kachemak Bay (Alaska Department of Fish and Game, 2013).

**Paralytic Shellfish Poisoning**

The ingestion of non-commercially harvested shellfish is a danger. Paralytic shellfish poisoning (PSP) is a food born illness stemming from the ingestion of a highly potent marine toxin. This toxin is created by *Alexandrium* and can be present in all bivalves (clams, oysters, mussels, scallops and geoducks). After shellfish have filtered out the water, the toxin is absorbed in their bodies, and, in turn, ingested by humans. The typical symptoms occur three to four hours after ingestion. There is an initial tingling on the lip or tongue, which then progresses to the toes and fingers. Eventually, there is loss of muscle control in the limbs and breathing difficulty. Muscles in the chest and abdomen can eventually become paralyzed, sometimes resulting in
death within a two to twenty-five hour period. There is no known antidote for the PSP toxin but early identification can facilitate recovery (Alaska Division of Public Health, 2012).

The Alaska Department of Environmental Conservation only tests a few beaches in Alaska, some of which are located in Kachemak Bay. These test sites are only monitored because of commercial specie harvest in the local vicinity.

**Alexandrium**

Kachemak Bay supports a wide variety of marine invertebrates, including the bivalve molluscan shellfish (clams, mussels, oysters, geoducks and scallops), which can potentially contain the toxin that results in PSP. The presence of PSP is common in Southeast Alaska where the temperature of the sea is optimal for the growth of the dinoflagellate, *Alexandrium*, which is responsible for the toxin (SEARHC, 2010). Fortunately in Kachemak Bay there is limited evidence identifying human illness or death as a result of paralytic shellfish poisoning (Trainer, 2009). However the recreational and commercial harvest of shellfish in Kachemak Bay poses a potential danger to humans if *Alexandrium* establishes itself in Kachemak Bay.

**Alexandrium Life Cycle**

Understanding the life cycle of *Alexandrium* is an important factor in the management of harmful algal blooms and understanding environmental changes in the marine environment. There are several stages in the *Alexandrium* life cycle: motile vegetative cells, haploid gametes, diploid zygotes, resting cysts and temporary cysts (Anderson, 1998). *Alexandrium* is capable of reproducing both asexually and sexually. Asexual production begins by the division of two separate cells or binary fission. Each cell is capable of reproducing a duplicate copy of the DNA that allows for exponential growth of the species that take the form of motile vegetative cells. In sexual reproduction *Alexandrium* reproduces by two haploid gametes fusing together to form a
swimming diploid zygote. These zygotes become resting cysts. The formation of these cysts is essentially creating dormancy or hibernation in the organism. During this stage the cysts can be easily transported through the water by currents or can be present on non-animate objects such as ships and transported to other marine environments. They remain viable vegetative cells in this transport and under the right conditions can resume their life cycle. (Figure 4).

**Economic Impact of *Alexandrium***

The cyst formation of the life cycle is the link between *Alexandrium* and bivalves. When the phytoplankton cannot receive nutrients from the water or the environmental conditions change forcing them into a state of dormancy, they sink into the ocean bottom. All bivalve species are filter feeders and eat by pumping water through inlet siphons. They consume the *Alexandrium*. Toxins can be present in many of the organism’s tissues, but most commonly accumulate in the siphon (RaLonde, 1985). Through the consumption of the *Alexandrium* cells (alive, dormant or dead) the toxins can be transferred to the shellfish. Toxins have been found to be present in shellfish up to two years after consumption of *Alexandrium* (SEARHC, 2010).

Despite the large potential resource of shellfish harvesting, the commercial shellfish industry in Alaska remains small in comparison to other areas in the United States. If this were to expand, one obstacle to its success would be the prevalence of paralytic shellfish poisoning (Nosho, 1972). And this is a difficulty Kachemak Bay may soon have to face.

**Comparison to Puget Sound**

In order to correctly gauge what impact new water influxes could have on Kachemak Bay, it is important to look at occurrences elsewhere. Puget Sound and Kachemak Bay are easily comparable. Puget Sound is an estuary in Washington with fourteen major rivers feeding into its various basins. Figures for Puget Sound and Kachemak Bay can be seen in Figure 5.
Both fjords have similar winter and summer temperatures. Puget Sound ranges from approximately 6-13 degrees Celsius ("General Environmental Conditions in the Puget Sound Region"), and Kachemak Bay temperatures average at about 6 degrees Celsius ("Kachemak Bay Research Reserve System-Wide Monitoring Program Summary Report 2001-2011", pg. 10, July 2010). Puget Sound’s salinity averaging from 21-27 o/oo (Swenson, no date given) corresponds with the range of 15.2-33.3 psu in Kachemak Bay ("KBRR System-Wide Monitoring Program Summary Report 2001-2011", pg. 10, July 2010). In addition, Puget Sound and Kachemak Bay both have a semi-diurnal tide cycle, and relatively high tidal ranges of about 3.4 and 4.6 meters respectively ("Tides of Kachemak Bay" October 31, 2013) ("Puget Sound Facts.”, 2008).

However, perhaps the most important quality the two estuaries share is their high level of shellfish aquaculture. Though geoducks, *Panopea generosa*, are the primary source of income for Puget Sound, and oysters for Kachemak Bay, both places rely heavily on the shellfish industry to boost their economy.

The average value for Puget Sound’s shellfish is about forty-four million dollars ("Focus on Puget Sound" October 2008). Shellfish geoduck sales in the Sound add to the approximate yearly state revenue average of $7.2 million ("Puget Sound Facts.”, 2008). When fisheries are forced to close, these numbers drop drastically, and put a major dent in income. Little documentation of estimated profit loss in Puget Sound exists. However, closures elsewhere, caused by a single outbreak, have cost as much as $6 million (Boesch et al. February 1997). High toxin levels, 80 micrograms per 100 grams of meat as declared by the FDA ("Food Guidance Regulation Chapter 6: Natural Toxins", pg. 121), don’t yet plague Kachemak Bay, but shellfish harvest is of high import and any threat of closures is a cause for worry.

Although there were small amounts previously, *Alexandrium* didn’t flourish or cause much
distress in Puget Sound until 1978. The Sound claimed no past reported cases. That year, however, high levels of the paralytic shellfish toxin were found. The sudden issue was thought to have been caused by a large water flow containing high numbers of *Alexandrium* that swept through the area. Constant levels were found in later years leading up to the first needed closure of shellfish fisheries that occurred in 1988 (Nishitani, Chew & King, No date given). Since then, year-round monitoring is performed in the Sound, using websites and other means to update the public and commercial harvesters of closures ("Paralytic Shellfish Poisoning", no date given).

In contrast to Puget Sound, *Alexandrium* has not been much of a problem in Kachemak Bay. Based on the area’s past record of no fatalities, urgent hospitalizations, or harvest closures, the conclusion can be made that Kachemak Bay does not have an *Alexandrium* dilemma (Catie Bursch, personal communication, November, 2013).

Though Kachemak Bay is currently free of the burden of closed fisheries and toxins retained in the highly valued shellfish, the opening of the Arctic Passage could host numerous problems. With ships carrying ballast water, and even possible new currents affecting circulation within Kachemak Bay, *Alexandrium* could become an issue quickly. With just one massive surge of the dinoflagellate in the area, they could colonize and take root in Kachemak Bay’s once sparsely populated waters. All that is needed is one tide containing a high concentration of *Alexandrium*; not a difficult occurrence considering new water flows and specie transportation.

Puget Sound closely monitors shellfish in order to lessen danger of consumption, focusing on human health as the priority. Yet the Sound has found no real way to mitigate the economic damage of high toxicity levels, which is where Kachemak Bay should differ. Closure setbacks are something to be avoided. Unfortunately, there are no guaranteed methods to do so, but exploration of several ideas can only benefit Kachemak Bay. In conclusion, as far as a
comparison is concerned, oceanic changes could bring about a situation like that of Washington’s Puget Sound. Though the threat is not directly imminent, preparations need to be made and plans formed for the possible colonization of the harmful dinoflagellate, *Alexandrium*.

**Research and Monitoring**

Monitoring for *Alexandrium*’s presence is a piece of that preparation, and essential for the commercial harvest of oysters in Kachemak Bay as well as other bivalves, such as clams. This monitoring is also helpful in understanding the local ecosystems within the bay and new potential threats, brought about by change, to species in our waters. The best way to do this is to collect and monitor phytoplankton populations.

**Basic Overview of Phytoplankton Collection**

Collecting phytoplankton is simple. The most common method is the use of a very fine, cone-shaped net to filter the microorganisms out of the water (Figure 6). Plankton populations from several gallons can be contained within ounces, making the counting of the plankton both faster, and more effective. After a sample is taken, it is preserved for analysis. While there are other alternatives, the current Kachemak Bay HAB monitoring program uses an alkaline Lugol solution as a fixative. (Doroff, Ryan, Bursch & Hamilton, 2011).

In addition to the need for monitoring plankton populations, it is crucial that environmental factors be monitored as well. Nutrients, acidity, salinity, water and air temperature, weather conditions, wind speed; all of these variables affect plankton. Many species of phytoplankton require particular parameters in order to survive. When enough data is collected, models can be made to forecast plankton populations and predict when and where HABs are likely to develop.

**Phytoplankton Monitoring: Visual Assessment**

The most common way that plankton populations are quantified is simple microscope
based identification. This is also the method currently being used for the Kachemak Bay HAB monitoring program. In essence, an individual identifies and counts all of the phytoplankton found in a given sample of water.

However, the risk of human error cannot be ignored; misidentifications and miscounts are always possible. In one study, it was found that expert taxonomists identifying different species of the dinoflagellate *Dinophysis*, were 72% accurate (Culverhouse, Williams, Reguera, Herry & González-Gil, 2003). And while the species in this genus are quite similar, when compared to *Alexandrium*, there are also several non-toxic dinoflagellates in Kachemak Bay that bare a striking resemblance to *Alexandrium*.

**Phytoplankton Monitoring: Polymerase Chain Reaction**

A more experimental and potentially more accurate method of analysis is polymerase chain reaction (PCR). The first step in PCR is to extract the DNA from the plankton sample (preferably unfiltered). Once this is accomplished, the polymerase and nucleotides needed for amplification are added to the extracted DNA. Then, using a thermocycler, the DNA is synthetically replicated so that enough DNA is present to be genetically screened for *Alexandrium* and other phytoplankton. (Litaker & Sullivan, 2010)

**Shellfish Toxicity: Mouse Bioassay**

For testing the toxicity of shellfish, the usual practice is to perform a mouse bioassay. This procedure involves injecting a population of mice with liquid shellfish tissue and evaluating the sample’s toxicity based on mortality rates and the amount of saxitoxin present in the test subjects. (Ballentine & Ostasz, 1987) While this is a well-practiced and effective method, there are logistical difficulties to be considered. Currently, there is no facility capable of performing a bioassay in Kachemak Bay. Commercial shellfish farmers must go through the impractical
process of sending weekly samples to a lab in Anchorage for testing (Meyers, 2010). Furthermore, there is no way for recreational harvesters to test for PSP.

**Shellfish Toxicity: Enzyme Linked Immunosorbent Assay**

There is however a promising solution to the dilemma of rapid testing for PSP. Enzyme Linked ImmunoSorbent Assays (ELISA) provide a quick and relatively easy way to test for saxitoxin. Typically, an ELISA uses enzymes impregnated in a reagent strip that bind to the subject molecule (in this case the subject molecule is saxitoxin). If this subject molecule is not present, there will be a change in the reagent strip’s coloration. When the subject molecule is present, it inhibits the release of colorants. This method of testing for saxitoxin is both faster and more feasible than the bioassay (Jellett, Roberts, Laycock, Quilliam & Barrett, 2002). The only disadvantage to this method of testing is that it is dependent on subjective evidence, and as such, human error may lead to the reading of a false positive.

**Management Plan**

There is no practical way of modifying the environment to deter this dinoflagellate. Attempting to poison *Alexandrium* would put the entire ecosystem at risk. One could certainly try to dredge the cyst beds, but that would only send the cysts into the water column, and lead to an even larger algal bloom. In the end, there is no “silver bullet” for *Alexandrium*. The best that can be done is to try to detect, predict, and avoid this harmful dinoflagellate. In addressing possible management plans, it is important to address both the commercial and recreational harvesting of shellfish, in addition to *Alexandrium* itself.

**Test Kit for PSP**

It is important to keep in mind such strategies as ELISAs, because *Alexandrium* and its toxins could become increasingly problematic in Kachemak Bay. Perhaps the most promising
way to reduce the damage caused by PSP would be to distribute rapid test kits. Along with an ELISA test, important information such as symptoms of PSP and a phone number for the PSP hotline could be included. This way, not only can the general public be informed on the issue of PSP, but also they can inform themselves on how safe their shellfish is, even if it is recreationally harvested, and isn’t being screened by federal agencies.

**Changing Farming Practices**

The most common method of aquaculture in Kachemak Bay, is the use of “suspended culture”. This type of shellfish cultivation involves suspending the mollusks in cylindrical, lantern nets that are attached to a line of buoys. Typically, dinoflagellates thrive in the uppermost regions of the water column due to the fact that *Alexandrium* prefers the less saline, and nutrient rich environment provided by stream runoff. (Townsend, Pettigrew & Thomas, 2001). It may be possible to lower the lantern nets below the freshwater lens where an *Alexandrium* outbreak is most likely to occur, and hence avoid the impacts of a bloom event. This procedure has the potential to keep farms open for business, even during a bloom event.

While this plan of action has the potential to alleviate the economic impact of *Alexandrium*, there are several flaws that need to be addressed. The first is that it is unknown how deep the nets would have to be to completely avoid *Alexandrium*. It may be that the lantern nets would make contact with the seafloor, which would lead to abrasion of the nets and exposure to predators.

**Other Dinoflagellates in the Area**

Another possibility for management, which is only an idea to be contemplated, is tweaking other existing dinoflagellate species’ populations in order to increase competition for *Alexandrium*. Both *Protoperidinium* and *Ceratium* already reside in the waters of Kachemak Bay, and are potential species that could contend with the PSP causing agent (Catie Bursch,
personal communication, November, 2013). Dinoflagellate competition for nutrients and other vital life necessities could prove convenient in our attempt to control populations of *Alexandrium*. By either releasing high numbers of *Protoperidinium* or *Ceratium* into Kachemak Bay to discourage *Alexandrium* from taking root, or by releasing them only once there is a problem in order to aid in the dominance of a harmless dinoflagellate species over the area, attempts can be made to maintain the low level of contamination risk. However, this was only a consideration, as a solution such as species manipulation would be impractical at this point and should remain a conception only.

**Conclusion**

There is no doubt that oceanic changes have their benefits. The Northwest Passage is a great opportunity that opens up valuable options for shipping. But there is concern closer to home. Kachemak Bay is a healthy bay thriving in commercial and recreational aquaculture with a subdued *Alexandrium* population. Many people depend on the bivalves living in its waters. The successive occurrences leading from increased ship traffic to dense waves of *Alexandrium*, are a threat to our economy and lifestyle. Forced closures after few difficulties could prove a sudden, damaging likelihood. It is important to keep alert and aware of the potential complications that could soon be encountered in Kachemak Bay, and to plan ahead as best as possible. Unfortunately, there is no known key to defeating the PSP causing dinoflagellate. But there are notions to explore, ideas formulated around the regulation of shellfish farms, or testing kits. There is research that can be done, and actions should be taken in order to prepare against a threat that could soon be imminent. If and when *Alexandrium* colonizes local waters, Kachemak Bay needs to be ready for it.
Figures

Figure 1.

Generalized bathymetry and currents of Kachemak Bay, showing the influence of the Homer Spit on surface current patterns (Field & Walker, 2003).

Figure 2.

Salinity of Kachemak Bay from Seldovia Bay and the Homer Spit, note difference between Homer Deep and Homer Surface between June and October (KBRR, 2010).

Above is a diagram of the *Alexandrium* life cycle. (Woods Hole Oceanographic Institute)
Table of average water temperatures, salinities, area size, and depth of Puget Sound and Kachemak Bay.


<table>
<thead>
<tr>
<th></th>
<th>Average Water Temperature</th>
<th>Average Salinity</th>
<th>Approximate Area Size (in km²)</th>
<th>Average Depth (in meters)</th>
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<td>21-27 psu</td>
<td>2,642¹</td>
<td>137.16³</td>
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<tr>
<td>Kachemak Bay</td>
<td>6.6° C</td>
<td>15.2-33.3 psu</td>
<td>2,457²</td>
<td>41⁴</td>
</tr>
</tbody>
</table>

Figure 6.

A marine biologist collects phytoplankton using a plankton net. (Photograph ©2007 Ben Pittenger.)
References Cited


Bursch, C. Kachemak Bay Research Reserve, 95 Sterling Hwy, Homer, Ak, 99603, 907-226-4661.


http://www.psparchives.com/puget_sound/psfacts.html


SEARHC (Southeast Alaska Regional Health Consortium) (2010, June 22). *Paralytic shellfish poisoning (PSP) warning issued for Southeast Alaska.* Retrieved from
http://searhc.org/paralytic-shellfish-poisoning-psp-warning-issued-for-southeast-alaska


Zorzetto, A. ICE Case Studies, "Canadian Sovereignty at the Northwest Passage." Last