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Nicky Haigh

Harmful Algae Monitoring Program
Vancouver Island University, Nanaimo, BC, Canada
Email: Nicky.Haigh@viu.ca; Tel: 250-740-6354

Summary:

The effects of harmful algal blooms (HABs) on wild salmon in BC have long been underestimated and need to be addressed. We have shown that there is a strong correlation between naturally occurring blooms of the fish-killing alga *Heterosigma akashiwo* in the southern Strait of Georgia, during the time period when juvenile sockeye pass through this area after exiting the Fraser River, and poor returns of adult sockeye two years later (Rensel, Haigh, and Tynan, 2010. *Harmful Algae* 10: 98-115. doi:10.1016/j.hal.2010.07.005). The recurring and persistent HABs seen in this area may be responsible for a great deal of the low returns and decline of Fraser River sockeye since 1989, and in particular the disastrous return in 2009.

Introduction:

On the west coast of Canada there are approximately ten species of fish-killing algae that form blooms (naturally occurring thick assemblages) which can be widespread and persistent. These algae species are known to kill farmed salmon in BC every year. It has been commonly held that harmful algae species are not injurious to wild fish in BC, as the wild fish are not constrained by pens and so can swim below or away from the blooms, but this is an unproven assumption. Evidence of wild fish kills from toxic algae in other parts of the world, and a correlation seen between bloom timing of *Heterosigma akashiwo* (the most common fish-killing alga in BC) in the late spring in the southern Strait of Georgia and poor Fraser River sockeye returns two years later, indicate that HABs may affect wild salmon as much as farmed fish.

Harmful Algae Monitoring in BC:

There is only one program that directly monitors harmful algae in BC. The Canadian Food Inspection Agency monitors shellfish toxicity levels ("red tide", due to toxic phytoplankton) at sites around the coast, but does not test algae samples. The Harmful Algae Monitoring Program (HAMP), based at Vancouver Island University in Nanaimo, works with salmon farm companies on issues of harmful algae, and we have monitored from 11 to 27 sites around Vancouver Island for the past 12 years. During this time we have learned a great deal about the harmful algal species in our area and their fish-killing potential. The usual monitoring sites are at or near fish-farming operations, but because the program is based in Nanaimo we have also sampled at the Pacific Biological Station in Departure Bay for many years. At monitoring sites, water samples are taken weekly, usually from March or April to the end of October, and analysed for levels of known harmful algae species present, as well as other parameters.

HABs in Departure Bay:

Many harmful algae species are seen in Departure Bay. *Heterosigma akashiwo* is the most common, and is frequently seen at high concentrations, in two main periods: mid to late June and September. There is a great deal of interannual variation in timing and level; blooms are most frequently seen in June. These early *Heterosigma* blooms are associated with the Fraser River plume as it pushes across the

southern Strait of Georgia during the time of the spring freshet. Aquacultured fish mortalities have been reported at the Pacific Biological Station research farm due to *Heterosigma* blooms.

In 2007, *Heterosigma* was seen in three periods: an anomalously early and highly concentrated bloom in late May to early June, another bloom in July, and a smaller one in September. The early bloom, associated with the Fraser River plume, would have coincided with the peak of the juvenile sockeye migration from the river. There is a good possibility that these juveniles, already stressed from the transition from freshwater to the marine environment, would have been heavily impacted by this bloom. To a great extent, this could explain the extremely poor 2009 Fraser sockeye return.

Toxicity and ecology of* Heterosigma akashiwo*:

Heterosigma akashiwo is a toxic alga in the class Raphidophyceae that is known to kill fish in marine environments in many parts of the world, and it is the most frequent fish-killer here in BC. The exact toxic mechanism is not known; although a great deal of research has been done on this problem it appears there may be complex environmental interactions, plus variations in toxicity between strains of this species. The most common theory is that the alga produces reactive oxygen species which cause gill damage and respiratory failure, but other algal toxins have also been implicated. Acute toxic effects of *Heterosigma* on fish are very rapid: mortality is usually seen in a matter of minutes. In addition, there may be lower-level chronic effects on fish not killed in the bloom, or food web perturbations from toxicity or allelopathy of *Heterosigma* to other organisms.

Heterosigma is a very adaptable species that grows quickly and does well in low salinity environments, thus the often-seen association with river plumes and brackish water. Blooms may be extremely dense, frequently concentrated at the surface and down to a depth of 10 metres; this corresponds with the habitat of juvenile salmon near the Fraser River and throughout the Strait of Georgia.

During *Heterosigma* blooms, other algae and most zooplankton disappear, due to allelopathic substances produced by the alga, which slow growth or kill other organisms. This then impacts the food source of wild fish and may lead to starvation, particularly of fast growing juvenile fish that need to eat frequently. Blooms in the Strait of Georgia have been known to last the entire summer (four months, in 1993 and 1997) and in subsequent sockeye salmon return years (1995 and 1999) extremely low survival was seen. The evidence suggests that food web disruption may combine with direct toxic effects to adversely affect or kill wild fish. See Rensel et al. (2010) for an extensive literature review and discussion of these factors.

Evidence of wild fish kills due to HABs:

It has long been assumed that wild fish in BC are not affected by HABs. Reports of wild fish kills are uncommon, and these incidents can sometimes be explained by disease outbreaks, or low oxygen conditions in shallow or confined areas. In nearby Puget Sound, however, wild fish mortalities have often been seen associated with *Heterosigma* blooms.

If wild salmon were being killed by *Heterosigma* blooms near the Fraser River estuary, wouldn't the carcasses be evident in the Strait of Georgia? It appears not. In temperate waters the majority of dead salmon sink; studies of fish-kills in aquaculture operations report only about one percent of mortalities are seen floating in net-pens. In the case of mortalities of juvenile salmon it is possible that this one percent would be quickly scavenged by seabirds or other predators. The sinking mortalities, meanwhile, could be quickly dispersed and/or eaten by crabs or other fish.

Limited harmful algae monitoring in the past has made it difficult to link HABs with any observed wild fish mortality; reports in the past few years of mature wild salmon being affected by HABs have not been

followed up due to lack of funding. The remote and complex nature of the mainly uninhabited BC coastline makes investigation of fish kills very difficult. It is only the vigilance of aquaculture company personnel in these areas, and the companies' funding of harmful algae research through HAMP, that has enabled us to gain the insights we have in the past twelve years.

Evidence for HABs affecting juvenile salmon in the southern Strait of Georgia:

Examination of the harmful algae data available in the context of timing of juvenile sockeye migration from the Fraser River shows that there is a significant link between *Heterosigma akashiwo* blooms in the southern Strait of Georgia and poor sockeye salmon returns two years later. Marine survival of the Chilko stock of Fraser River sockeye averaged 2.7% in years when juvenile migration coincided with major *Heterosigma* blooms, versus 10.9% average survival in non-bloom or minor bloom years (Fig. 1).

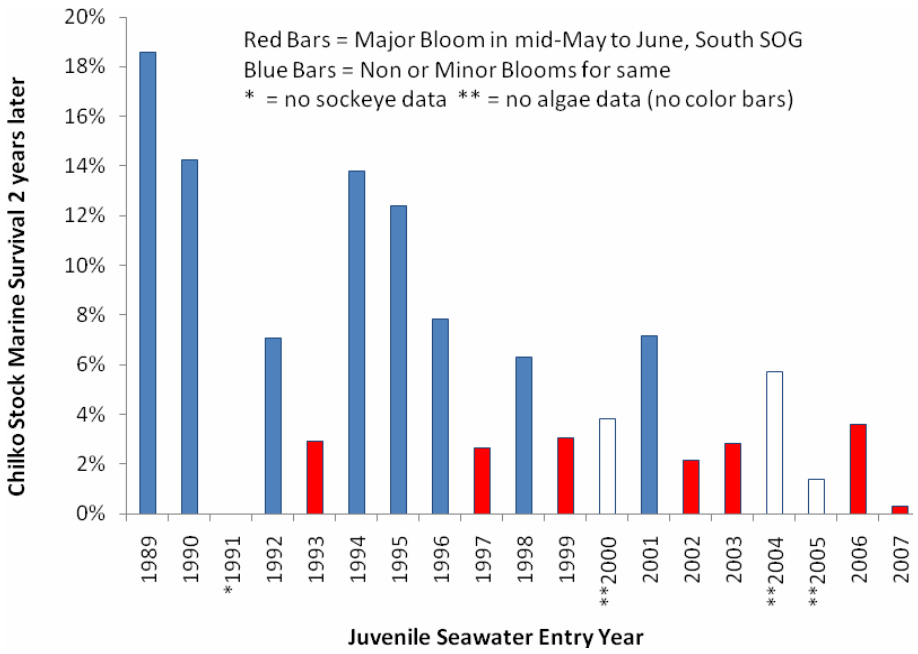

Figure 1: *Heterosigma akashiwo* blooms in the South Strait of Georgia 1989 – 2007 and marine survival percentage of Chilko stock sockeye salmon two years later. Red bar colour indicates years when major *Heterosigma* blooms were observed; bar length shows Chilko stock survival. From: Rensel et al. 2010.

There is also a highly significant correlation between survival rates for juvenile herring in 1997 – 2008 during their first summer in the Strait of Georgia and the marine survival for the Chilko sockeye salmon stock two years later (Fig. 2).

Clearly this indicates something is happening to both the juvenile herring and the juvenile salmon in the Strait in the six weeks they co-occur, before the salmon migrate from the Strait. This is the period when *Heterosigma* blooms are commonly seen in this area.

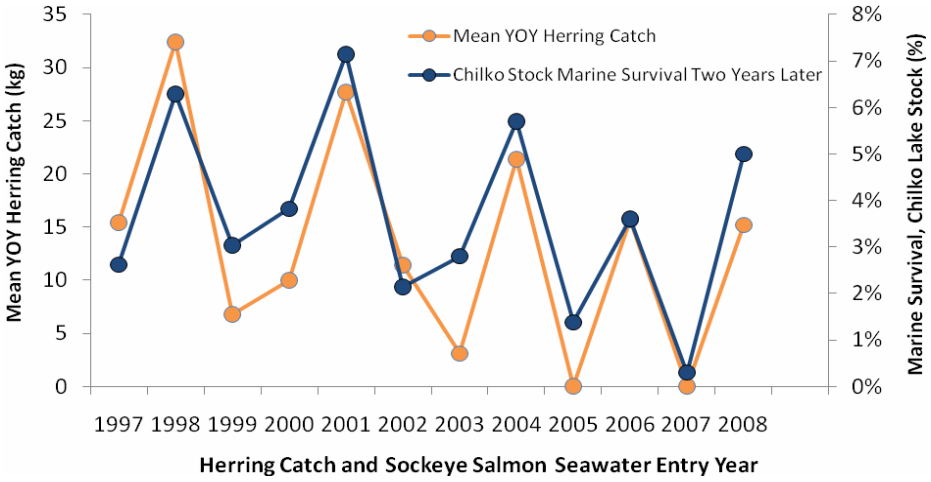

Figure 2: Marine survival of first year herring in the Strait of Georgia as measured in annual test fisheries (Schweigert et al. 2009), and Chilko stock Fraser River sockeye salmon two years later (2010 Chilko survival from PSC estimates, M. Lapointe pers. comm.). From: Rensel et al. 2010.

Conclusions:

There is a strong probability that harmful algal blooms are affecting wild salmon in BC. Toxic blooms of *Heterosigma akashiwo* co-occur with juvenile Fraser River sockeye in the southern Strait of Georgia, and poor returns on these runs can be linked to blooms two years prior.

More research needs to be done on the interaction of HABs and wild salmon in BC. Results from the Harmful Algae Monitoring Program, working with salmon aquaculture companies in BC, have shown that there are approximately ten species of harmful algae that affect farmed fish on the west coast, and it is probable that they also affect wild fish. This is one of the richest HAB environments in the world. While there are DFO research scientists working on harmful algae in the Maritime, Quebec and Gulf Regions, there is presently no government HAB research program on the west coast. It is time that government commits to research on this important biological oceanographic factor and its influence on Pacific salmon stocks.

References:

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Keywords:

HAB, harmful algae, *Heterosigma akashiwo*, phytoplankton, food web interactions