Oceanographic conditions and harmful algae in the Strait of Georgia, Canada – outcomes of seven years of monitoring with the citizen science program.

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Salish Sea Ecosystem Conference, April, 2022

Salish Sea Marine Survival Project

What affects juvenile Chinook, Coho, and Steelhead survival in the Salish Sea

SSMSP managed by the Pacific Salmon Foundation, Canada and Long Live the Kings, USA

5 years, 60 organizations, multimillion dollar project

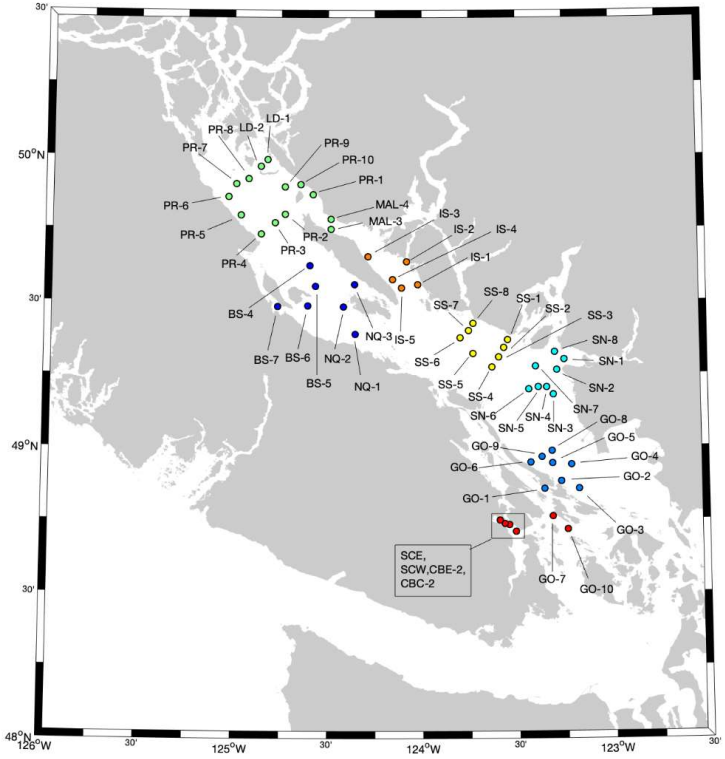
Full synthesis report – Pearsall, Schmidt et al., 2021

https://marinesurvival.wpengine.com/wp-content/uploads/2021PSF-SynthesisPaper-Screen.pdf

PSF Citizen Science Program (CitSci) 2015- ongoing

"scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions"

Pacific Salmon Foundation + Ocean Networks Canada + Department of Fisheries and Oceans



50-80 stations

20 trip/year
February – October: 2/3 times a months
November – January: once a month

CTD and Phytoplankton – each station
Nutrients ~30 stations
Zooplankton -3 stations
Secchi depth – each station

https://www.marinescience.ca/citizen-science-programs/

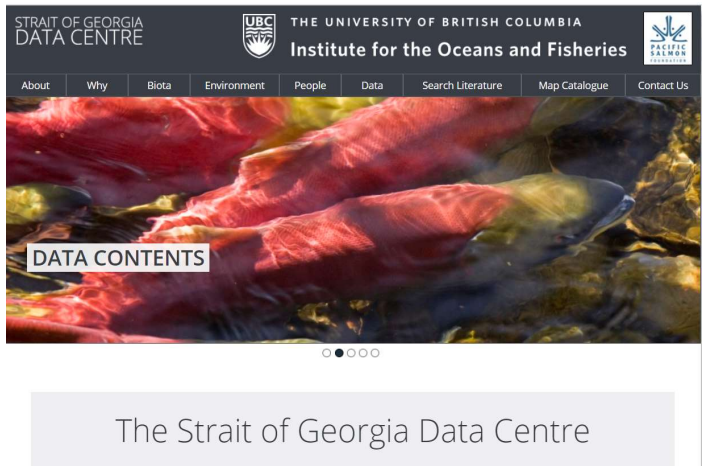
DATA

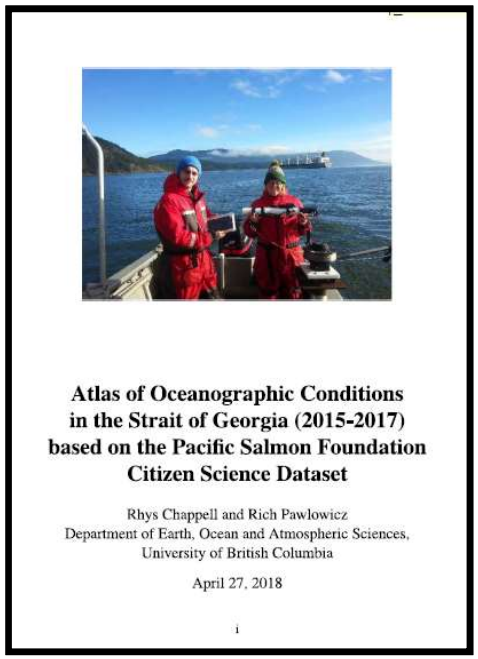
Raw data

http://www.oceannetworks.ca

http://sogdatacentre.ca/

pearsalli@psf.ca – Dr. Isobel Pearsall





Summary data

R. Pawlowicz, et al, 2020, **Atlas of oceanographic conditions in the Strait of Georgia (2015-2019) based on the Pacific Salmon Foundation's citizen science dataset**, Canadian Technical Report of Fisheries and Aquatic Sciences 3374

Digital atlas - updated annually

R. Pawlowicz and B. Boufford, **Atlas of oceanographic conditions in the Strait of Georgia**, https://sogdatacentre.ca/atlas/

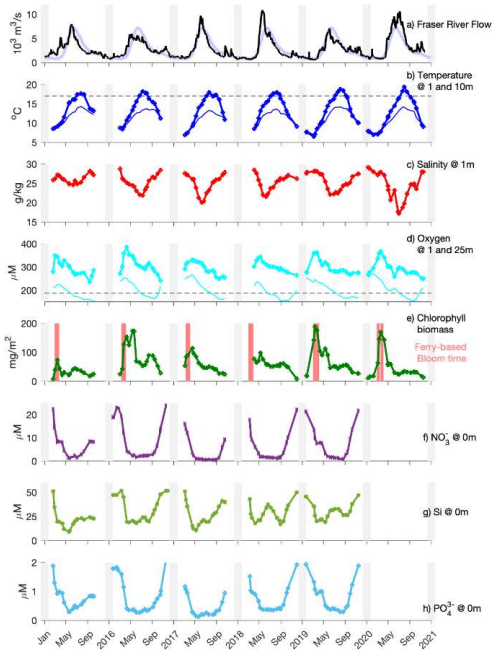
State of the Pacific Ocean -Can.Tech.Rep.Fish.Aquat.Sci.

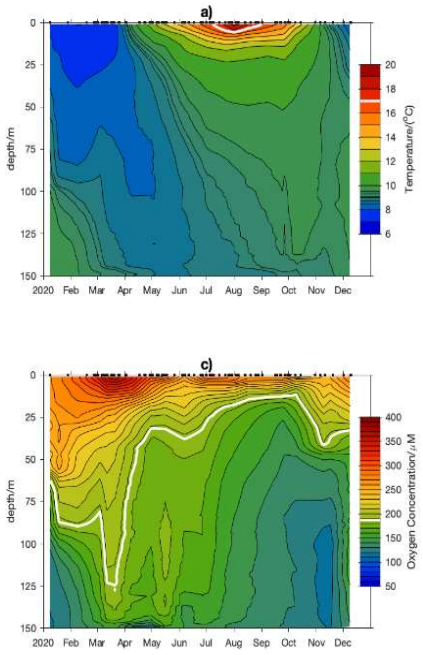
2019 - Esenkulova, S., Frederickson, N., Pearsall, I. Harmful algal blooms in the Salish Sea. https://waves-vagues.dfo-mpo.gc.ca/Library/40884569.pdf

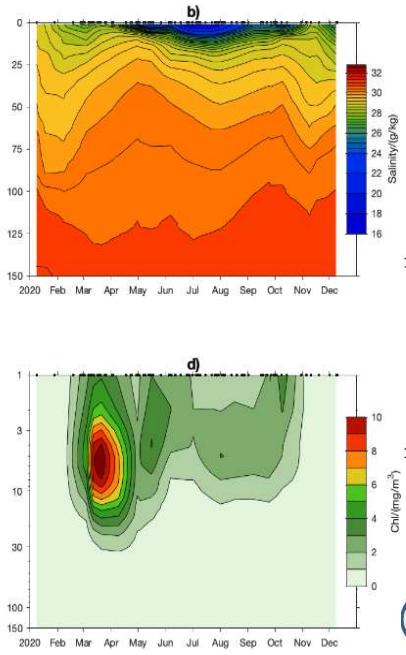
2018 - Esenkulova, S., Pearsall, I. Harmful algal blooms in the Salish Sea. https://waves-vagues.dfo-mpo.gc.ca/Library/4081306x.pdf

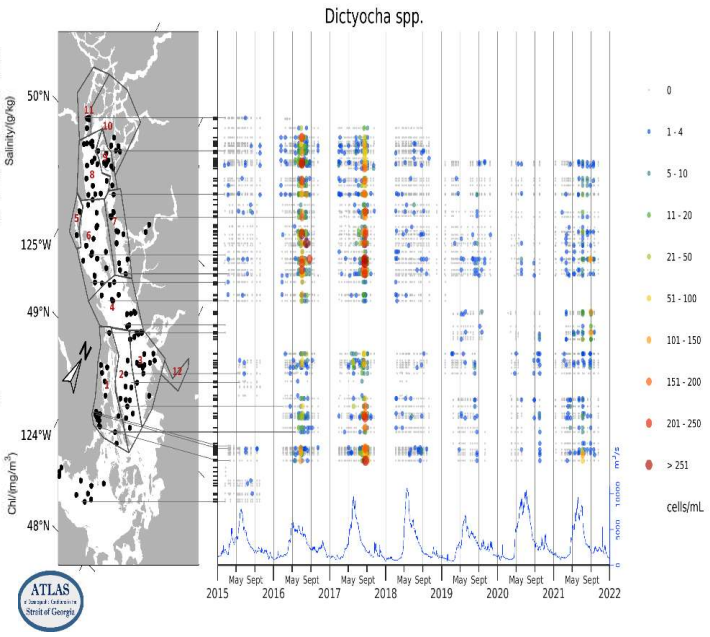
2017 - Esenkulova, S. Pawlowicz, R., Pearsall, I. Nutrients, the phytoplankton community and harmful algae in the Salish Sea. http://waves-vagues.dfo-mpo.gc.ca/Library/40717914.pdf

2016 - Esenkulova, S., Pearsall, I. The phytoplankton community in the Salish Sea. http://waves-vagues.dfo-mpo.gc.ca/Library/40617944.pdf







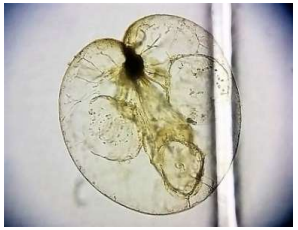


Highlights of SoG conditions on 2021

To be published in SOPO 2021

- Slightly warmer/fresher waters near surface in 2021
- There were thick blooms of *Noctiluca scintillans* in April; dinoflagellates *Alexandrium* spp. and *Dinophysis* spp. (PSP and DSP producing taxa) were very abundant.
- There were no *Heterosigma akashiwo* blooms; there were local summer *Dictyocha* spp. blooms and diatom blooms (*Rhizosolenia setigera*, *Pseudo-nitzschia* spp.), *Ditylum brightwellii* was unusually abundant in June and July.

Gabriola Island, Aril 20 2021; photo by P. Iverson



Noctiluca scintillans

Pseudo-nitzschia spp

Year	*Alexandrium*	*Dinophysis*
2015	15.2	2.1
2016	19.2	0.5
2017	21.4	1.8
2018	19.6	5.7
2019	14.6	4.1
2020	21.1	3.4
2021	20.6	6.7

% of surface samples containing algae, March-September, 4 areas: BS, CB, IS, PR

Harmful Algae News, UNESCO

Esenkulova, S., Pearsall, I., 2019: Citizen Science oceanography in the Strait of Georgia, Canada – an overview of five years operations. Harmful Algae News 63, 12-13. http://www.e-pages.dk/ku/1439

Ecology of Alexandrium spp. in the Strait of Georgia, British Columbia, Canada 2015. Esenkulova, Pearsall, Novak, 2017: Harmful Algae News 56, 7-8. http://www.e-pages.dk/ku/1276/

Observations of Heterosigma akashiwo bloom and associated wild salmon lethargic behavior in Cowichan Bay, Canada, 2014. Esenkulova, Luinenburg, Neville, Trudel, 2014. Harmful Algae News 50, 16-18. http://www.e-pages.dk/ku/1086/

Observations of *Heterosigma akashiwo* bloom and associated wild salmon lethargic behavior in Cowichan Bay, Canada, 2014

Heterosigma akashiwo is the most well-known and widely distributed fish killer and the main killer of farmed salmon in the Pacific Northwest region of Canada [1; Nicky Haigh, pers. com.]. In recent years (2009 - 2012), harmful algal blooms (HABs) caused $16 million of direct economic losses in farmed British Columbia (BC) salmon, with *Heterosigma* being the causative agent for the majority of these losses [2]. While the direct effects of *Heterosigma* on farmed BC salmon are evident, wild salmon losses and fish stress responses during *Heterosigma* blooms are currently understudied [3].

Over the past 20 years, there have been dramatic declines in the abundance of wild Chinook Salmon and Coho Salmon in the Strait of Georgia, BC. In response, the Pacific Salmon Foundation (PSF), an independent non-governmental organization, initiated the *Salish Sea Marine Survival Project (SSMSP)*. The SSMSP is a five year project of ecosystem research and habitat restoration designed to improve fisheries management and enhance economic and cultural benefits for Salish Sea communities. The current multi-disciplinary project team consists of over 20 federal and provincial agencies, First Nations tribes, academics and non-profit organizations [4]. The project seeks to improve our understanding of the causes of salmon mortality in the Salish Sea and explain wide fluctuations in salmon returns over the years. As part of the project, we initiated a pilot study to monitor HABs and investigate their possible effects on juvenile salmon (wild and hatchery) in the Cowichan Bay estuary and outer bay.

From the beginning of May to mid-July 2014, a team of technicians from PSF and Fisheries and Oceans Canada (DFO) collected fish samples using both beach seines (Fig. 1) and purse seines (Fig. 2). We also collected corresponding surface water samples at each set location for phytoplankton analysis. After collection, water samples were preserved with Lugol's Iodine solution; subsequent phytoplankton analysis was performed on a Sedgewick Rafter slide and dominant and harmful algae species were identified and enumerated under a light microscope.

During the late spring to mid-summer period, we observed three high phytoplankton biomass events or blooms. The first and third bloom were caused by *Pseudo-nitzschia* spp. (May 20, 21) and *Skeletonema costatum* (July 8, 9). During these blooms, the water was brown but the captured fish did not appear to be affected by the blooms. The second bloom was recorded during the first week of June and was caused by *Heterosigma* (Fig. 3); below we describe in detail this bloom development and associated changes in fish behavior.

The first few cells ($\leq$10 cells mL^{-1}) of *Heterosigma* were recorded on the north side of Cowichan Bay on May 26-27 while purse seining (Table 1, Fig. 4). Much higher concentrations (mostly in the range of 100-1000 cells mL^{-1}) were observed the next day when beach seining.

In the first week of June, *Heterosigma* concentrations did not exceed 100 cells mL^{-1} in both beach and purse seines (Table 1, 2).

On the beach seining day of the second week of June, all near shore areas were covered in a highly visible, thick orange bloom. *Heterosigma* concentrations reached 3-4 x 10^8 cells mL^{-1} at the north area of the Bay (Table 2, Fig. 4). During sampling, we did not notice any unusual fish behavior at these locations, though very few fish were caught at that time.

In the third week of June the water was brown/orange in color and most of Cowichan Bay was covered in swathes of highly visible phytoplankton bloom. Subsequent laboratory analyses of these water samples confirmed high concentrations of *Heterosigma*, ranging from 800 to 12 x 10^3 cells mL^{-1} on June 16, and 3.2-8 x 10^3 cells mL^{-1} on June 17. The highest concentration of 12 x

Fig. 1. Beach seine in Cowichan Bay, 2014.

Fig. 2. Purse seine in Cowichan Bay, 2014.

Citizen Science Oceanography in the Strait of Georgia, Canada – an overview of five years of operations

The Citizen Science Oceanography Program for the coastal waters of British Columbia (BC), Canada was proposed by Dr. Eddy Carmack, Fisheries and Oceans Canada (DFO). Carmack envisioned a 'mosquito fleet' of private boats collecting oceanographic data simultaneously throughout the Strait of Georgia (SoG). He said "[using] this citizen science approach, you can get into the shallow waters, you can get up the bays and estuaries. You can get around rocks. You get that quasi-three-dimensional perspective, almost four-dimensional". Such a program was funded in 2015 by the Pacific Salmon Foundation (PSF) and supported by the Oceans and Networks Canada (ONC) and DFO.

Keen volunteers from local communities were trained and their boats equipped with the necessary equipment (Fig. 1), and they have made oceanographic measurements and collected samples at ~80 defined locations on the same day approximately every two weeks between February and October, 2015-2019 resulting in complete coverage of the SoG. Oceanographic conditions were measured with CTDs (conductivity, temperature, depth) and water samples were taken for nutrient, phytoplankton, and zooplankton analysis. Samples were analyzed by skilled technicians at DFO, University of Victoria, and PSF. The data collected allows the examination of spatial and temporal variations in the physical and chemical oceanography, and plankton ecology throughout the entire Strait. This information has provided a unique high-resolution data series of the physical and lower trophic state of the SoG: this resolution is crucial for coastal waters as significant changes happen on a fine temporal scale in these areas, and only high frequency sampling can capture it.

Harmful algae monitoring is part of the Citizen Science Program. Some algae cause visible, high cell concentration blooms (that can be harmful or non-harmful) while some algae can cause harm (e.g. fish kills, shellfish poisoning) at very low concentrations. In the latter case, they are still called blooms because of their effects. These types of blooms can be invisible to the naked eye and only *in-situ* sampling can detect them. During five years of observations, the heaviest blooms were bright orange-red blooms of *Noctiluca scintillans* in 2018 and 2019 (Fig. 2) and the bright turquoise blooms of coccolithophorids in 2016 (Fig. 3). These blooms were visually striking and attracted a lot of public attention and news coverage. Other blooms, visually less prominent but potentially highly significant to marine life included blooms of: *Heterosigma akashiwo*, *Pseudo-nitzschia* spp. (Fig. 4), *Gonyaulax* spp., *Rhizosolenia setigera*, and *Dictyocha* spp. Phytoplankton time series obtained through the Citizen Science Oceanography Program showed clear seasonal and spatial patterns of some species. Investigation of the relationship between environmental factors and blooms will improve our understanding of regional bloom dynamics.

Citizen scientists sample areas close to where they live and to which they have emotional connections. Giving them the ability to measure their own waters is empowering. Carmack says that "if you look at bang for buck, value for money and engagement of people, and drawing kids into the game, it should be on every coast in the world". ONC states that "historically, oceanographic data collection relied on specialty research vessels and highly trained scientists in limited locations. These new tools reduce the high cost of sporadic data collection, increasing the geographic range of quality measurements." Spencer Taft, Tsleil-Waututh Nation adds that Citizen Science monitoring of the SoG "will allow us to precisely track changes as the waters are affected by climate change, development and restoration activities". October 2019 marks the end of the fifth year that the Citizen Science Oceanography Program has been carried out in the SoG: PSF hopes to raise funds to continue this program in 2020.

Authors

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Fig. 3. Bloom of Coccolithophorids, Maple Bay, 2016 (photo by Will Duguid)

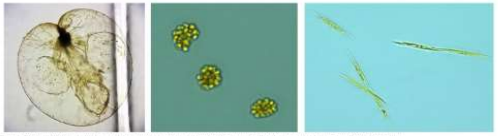
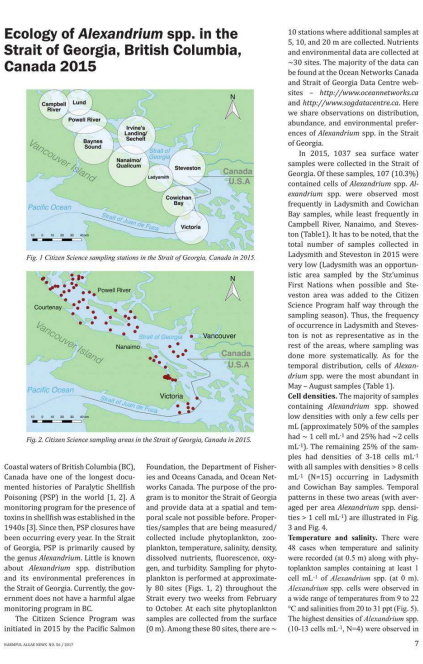


Fig. 4. Citizen Science samples: left, Noctiluca scintillans; middle, Heterosigma akashiwo; right, Pseudo-nitzschia spp.



Ecology of *Alexandrium* spp. in the Strait of Georgia, British Columbia, Canada 2015

Fig. 1 Citizen Science sampling stations in the Strait of Georgia, Canada in 2015.

Fig. 2. Citizen Science sampling areas in the Strait of Georgia, Canada in 2015.

Coastal waters of British Columbia (BC), Canada have one of the longest documented histories of Paralytic Shellfish Poisoning (PSP) in the world [1, 2]. A monitoring program for the presence of toxins in shellfish was established in the 1940s [3]. Since then, PSP closures have been occurring every year. In the Strait of Georgia, PSP is primarily caused by the genus *Alexandrium*. Little is known about *Alexandrium* spp. distribution and its environmental preferences in the Strait of Georgia. Currently, the government does not have a harmful algae monitoring program in BC.

The Citizen Science Program was initiated in 2015 by the Pacific Salmon Foundation, the Department of Fisheries and Oceans Canada, and Ocean Networks Canada. The purpose of the program is to monitor the Strait of Georgia and provide data at a spatial and temporal scale not possible before. Properties/samples that are being measured/collected include phytoplankton, zooplankton, temperature, salinity, density, dissolved nutrients, fluorescence, oxygen, and turbidity. Sampling for phytoplankton is performed at approximately 80 sites (Figs. 1, 2) throughout the Strait every two weeks from February to October. At each site phytoplankton samples are collected from the surface (0 m). Among these 80 sites, there are ~ 10 stations where additional samples at 5, 10, and 20 m are collected. Nutrients and environmental data are collected at ~30 sites. The majority of the data can be found at the Ocean Networks Canada and Strait of Georgia Data Centre websites – *http://www.oceannetworks.ca* and *http://www.ogdatacentre.ca*. Here we share observations on distribution, abundance, and environmental preferences of *Alexandrium* spp. in the Strait of Georgia.

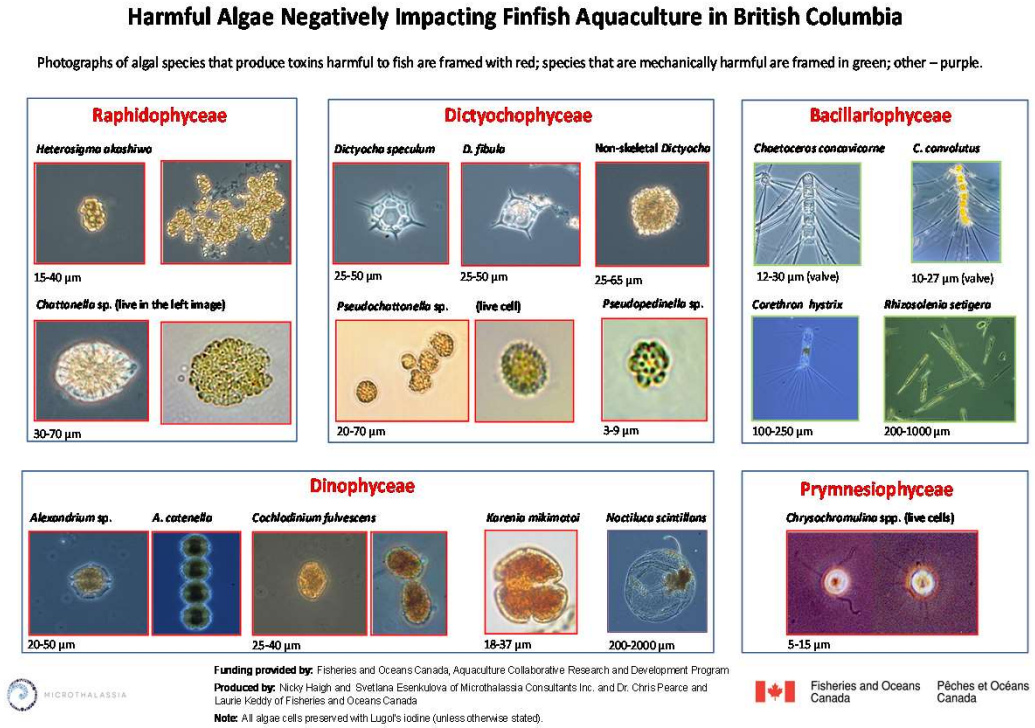
In 2015, 1037 sea surface water samples were collected in the Strait of Georgia. Of these samples, 107 (10.3%) contained cells of *Alexandrium* spp. *Alexandrium* spp. were observed most frequently in Ladysmith and Cowichan Bay samples, while least frequently in Campbell River, Nanaimo, and Steveston (Table1). It has to be noted, that the total number of samples collected in Ladysmith and Steveston in 2015 were very low (Ladysmith was an opportunistic area sampled by the Stz'uminus First Nations when possible and Steveston area was added to the Citizen Science Program half way through the sampling season). Thus, the frequency of occurrence in Ladysmith and Steveston is not as representative as in the rest of the areas, where sampling was done more systematically. As for the temporal distribution, cells of *Alexandrium* spp. were the most abundant in May – August samples (Table 1).

Cell densities. The majority of samples containing *Alexandrium* spp. showed low densities with only a few cells per mL (approximately 50% of the samples had ~ 1 cell mL^{-1} and 25% had ~2 cells mL^{-1}). The remaining 25% of the samples had densities of 3-18 cells mL^{-1} with all samples with densities > 8 cells mL^{-1} (N=15) occurring in Ladysmith and Cowichan Bay samples. Temporal patterns in these two areas (with averaged per area *Alexandrium* spp. densities > 1 cell mL^{-1}) are illustrated in Fig. 3 and Fig. 4.

Temperature and salinity. There were 48 cases when temperature and salinity were recorded (at 0.5 m) along with phytoplankton samples containing at least 1 cell mL^{-1} of *Alexandrium* spp. (at 0 m). *Alexandrium* spp. cells were observed in a wide range of temperatures from 9 to 22 °C and salinities from 20 to 31 ppt (Fig. 5). The highest densities of *Alexandrium* spp. (10-13 cells mL^{-1}, N=4) were observed in

First peer-reviewed paper on PSF CitSc Program

S. Esenkulova, K. Suchy, R. Pawlowicz, M. Costa, and I. Pearsall, **Harmful Algae and Oceanographic Conditions in the Strait of Georgia, Canada, Based on Citizen Science Monitoring,** Frontiers in Marine Science, 09 September 2021



Harmful algae are **very common** in the Strait of Georgia

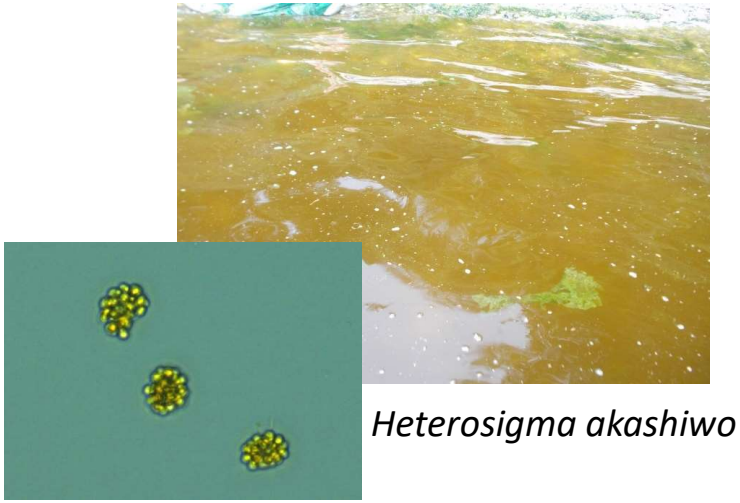
They are present in 9% (April) to 51% (August) of samples from February to October (n=5000)

They often reach concentrations associated with negative impacts in aquaculture (shellfish and salmon)

Harmful algae in the Salish Sea

Algae that formed dense blooms:
(> 1000 cells mL^{-1}) during 2015-2021 sampling seasons:

- *Heterosigma akashiwo* (2018, 2019, 2020)
- *Pseudo-nitzschia* spp. (2018, 2021)
- *Noctiluca scintillans* spp. (2018, 2021)
- *Rhizosolenia setigera* (2017, 2018)



Heterosigma akashiwo

Pseudo-nitzschia spp.

Noctiluca scintillans spp.

Harmful algae in the Salish Sea

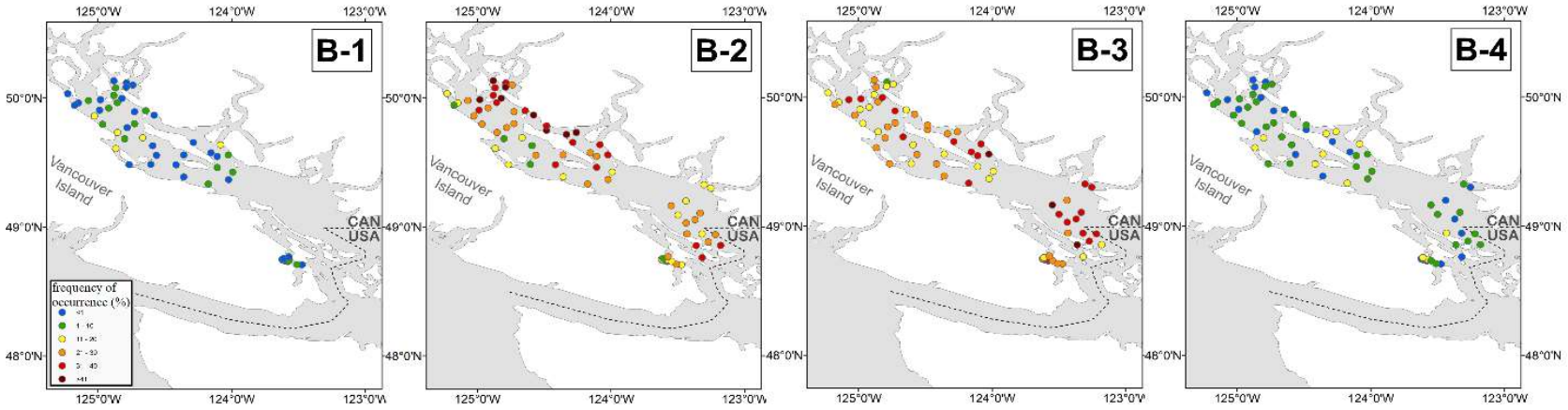
Spatial patterns

Temporal patterns

Statistically significant interannual and seasonal relationships between environmental drivers and the most common HA taxa

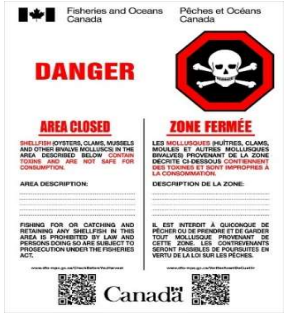
	Chaetoceros convolutus and *C. concavicorne*	*Rhizosolenia setigera*	*Alexandrium* spp.	*Heterosigma akashiwo*	*Dictyocha* spp.
Secchi depth	**0.429**	**-0.645**	**-0.497**	**-0.565**	**-0.406**
Temperature	**-0.509**	**0.665**	**0.753**	**0.58**	**0.498**
Salinity	0.368	-0.284	-0.363	-0.361	**-0.441**
Stratification	**-0.537**	**0.619**	**0.611**	**0.709**	**0.443**
Nitrate	**0.609**	**-0.477**	**-0.651**	**-0.541**	**-0.408**
Phosphate	**0.613**	-0.312	**-0.557**	**-0.383**	-0.3
Silicate	0.048	0.003	-0.205	0.04	0.062
Wind Speed	0.222	-0.074	-0.174	-0.217	-0.225
Rainfall	0.171	**-0.417**	**-0.505**	**-0.466**	-0.225
Cloud Cover	0.352	-0.362	**-0.653**	**-0.379**	-0.155
Fraser River Flow	-0.034	0.066	0.33	0.35	-0.01

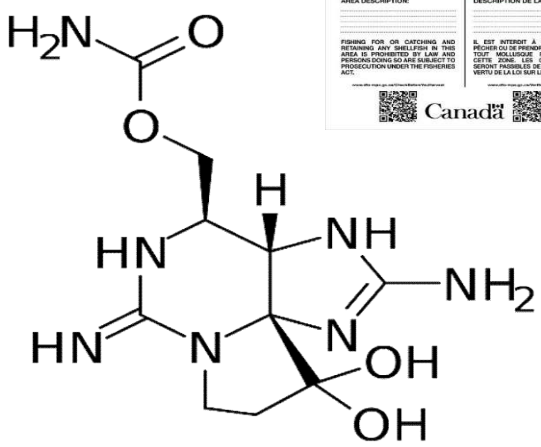
Average annual frequency of occurrence (%) of Dictyocha spp.



Harmful algae - shellfish

Year	Alexandrium %	PSP-total (ug STXdiHCl eq/100g)	Dinophysis %	TOX-DSP-LC (ug/g)
2015	**10.7**	**180**	1.7	0.12
2016	16.3	960	**0.7**	**0.008**
2017	**18.1**	**2100**	1.6	0.13
2018	15.7	900	**5.1**	**0.25**





Saxitoxin is produced by some *Alexandrium* species, cause Paralytic Shellfish Poisoning

Higher toxin concentrations of PSP (PSP-total) and DSP (TOX-DSP-LC) in shellfish flesh were detected in years when *Alexandrium* spp. and *Dinophysis* spp. were more prevalent (Esenkulova et al., 2021)

Harmful algae - salmon

Aquacultured salmon mortalities were reported in years with high concentrations of *Heterosigma* and *Dictyocha*.

There were four reports of salmon mortalities in 2016 (June 14, July 1 and 27, August 29) overlapping with high *Dictyocha* levels and five mortality reports in 2018 (at 2 sites on June 2, June 6, June 12, and August 19) overlapping with high *Heterosigma* levels.

DFO area	March 8, 2018	March 13, 2018	March 26, 2018	April 3, 2018	April 19, 2018	April 26, 2018	May 10, 2018	May 17, 2018	May 30, 2018	June 7, 2018	June 14, 2018	June 21, 2018	July 5, 2018	July 12, 2018	July 25, 2018	August 2, 2018	August 16, 2018	August 23, 2018	September 7, 2018	September 25, 2018	October 11, 2018
13	0	0	0	0	0	1	0	2	2	3	2	2	2	1	2	2	2	0	0	0	0
14	0	0	0	0	0	0	0	1	1	3	1	2	1	0	0	0	0	1	0	0	0
15	0	0	0	0	0	0	0	0	0	3	2	2	2	0	0	0	1	0	0	0	0
16	0	0	0	0	0	0	0	0	3	3	2	3	2	1	3	0	0	0	0	1	0
17	0	0	0	0	0	0	0	1		2	0	2	0		0	0	3	0			0
18	0		0	0	0	0	0	0	0	3	1	1	0	0	0	1	1	0	0	0	
29	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	

Heterosigma akashiwo levels in the SoG, 2018. Citizen Science data

250,000 salmon killed~ $4 M CAD losses

PSF Citizen Science contributing to other research

Stevens, S.W., Pawlowicz, R. and Allen, S.E., 2021. A study of intermediate water circulation in the Strait of Georgia using tracer-based, Eulerian, and Lagrangian methods. *Journal of Physical Oceanography*, *51*(6), pp.1875-1893.

<u>Additional studies and contributions</u>:
Biotoxins in water - harmful algae. In 2020 we added sampling for biotoxins for Dr. Andrew Ross, DFO

Zooplankton (SSEC 2018, 2 year data analysis showed large calanoid copepods and euphausiids was significantly positively correlated to the relative abundance of diatoms; small to dinoflagellates)

Fish studies (e.g. salmon and CitSc oceanography – SSEC snapshot, Paper #177)

WATCH program – sharing expertise

Ecosystem studies

Seasonal dynamics of oceanographic conditions, phytoplankton, and zooplankton in the Malaspina Strait, Strait of Georgia

Svetlana Esenkulova[1], Karyn Suchy[2,3], R. Ian Perry[3,4], Kelly Young[3], Maycira Costa[2], Ryan Flagg[5], Moira Galbraith[3], and Isobel Pearsall[1]

[1]Pacific Salmon Foundation; [2]Department of Geography, University of Victoria; [3]Institute of Ocean Sciences, Fisheries and Oceans Canada; [4]Pacific Biological Station, Fisheries and Oceans Canada; [5]Ocean Network Canada

Thank you
Questions?

Citizen Science Program

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Physical oceanography

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HABs questions Svetlana Esenkulova svesen@uvic.ca