Investigating Impacts of Ultraviolet Filters on the Cowichan River Ecosystem

Year 3

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EXECUTIVE SUMMARY

Ultraviolet filters (UVFs) are compounds added to chemical sunscreens, personal care products, and plastics to block or absorb ultraviolet radiation from the sun, protecting human skin or extending the usable life of a product. However, several different UVFs have been found to disrupt normal hormonal and genetic function in aquatic organisms at high doses. Scientific evidence also suggests that several UVFs bioaccumulate and can biomagnify within aquatic and terrestrial ecosystems at higher concentrations than found in ambient water.

The British Columbia Conservation Foundation (BCCF) oversaw collection of river and lake water, sediment, benthic macroinvertebrates, mussels, juvenile fish and adult fish from the Cowichan watershed over 3.5 years (2019-2022) as part of an investigation into the status of UVF contamination in the watershed. The purpose was to develop a baseline of information against which to compare future mitigation efforts. This monitoring was completed with the valuable assistance of community streamkeepers, volunteers, and angling guides.

In 2019 (Seed year), across 4 water samples, oxybenzone was found in all samples and ranged from 68 – 570 ng/L (Traynor 2019). This prompted an intensive and socially-distanced sampling protocol began in 2020, intended as Year 1 of a 5-year monitoring program to investigate and mitigate UVF contamination in the Cowichan River ecosystem. Sampling occurred at a range of sites along the length of the Cowichan River and at beaches around Cowichan Lake for the next three years. In 2020 (Year 1 of 5), across 64 water samples, oxybenzone ranged from <20 – 211 ng/L (Rodgers et al. 2021); juvenile fish, benthic macroinvertebrates, and freshwater mussels were collected and stored for future analysis. In 2021 (Year 2), across 105 water samples, oxybenzone ranged from <20 – 1,761 ng/L (Rodgers et al. 2022); sediment and fish were again collected and stored for future analysis.

In 2022 (Year 3 of 5), environmental samples were collected with the support of 7 volunteers and more than 48 volunteer hours. Samples were analyzed by Vancouver Island University's Applied Environmental Research Lab (VIU-AERL) using condensed phase membrane introduction mass spectrometry-liquid electron ionization with *in situ* liquid reagent chemical ionization (CP-MIMS LEI/CI), adapted to determine oxybenzone, enzacamene, octinoxate and octisalate in water. Efforts to further develop methods for analyzing sediment and fish tissue using CP-MIMS LEI/CI were also pursued. In Year 3, across 174 water samples, oxybenzone ranged from <20 – 2,076 ng/L; enzacamene ranged from <7 – 4,518 ng/L; octinoxate ranged from <27 – 17,869 ng/L; and octisalate ranged from <7 – 1,685 ng/L. Oxybenzone was not detected in appreciable amounts across 13 sediment samples. CP-MIMS LEI/CI was not able to be used for tissue analysis; alternate technologies were used. None of the four UVFs were observed in fish tissue using experimental alternate methods (gas chromatography); this method was outside of the intended scope of analysis.

Differences in river flow, precipitation, tourism and recreation patterns between years are likely factors affecting the year-to-year differences seen in oxybenzone (Rodgers et al. 2021). Similar to what was found in Years 1 and 2, sites sampled in Year 3 with high recreational use had relatively higher concentrations of oxybenzone than sites where wastewater inputs were present. Samples from the Town of Lake Cowichan wastewater outfall produced conflicting results. Some issues with QA/QC are present and discussed herein.

Recommendations include transitioning to an outreach and awareness education campaign in 2023, with a focus on peak use sampling as a comparison against past years to determine effectiveness of mitigation efforts. A UVF Mitigation Action Plan is summarized below, and should be used to guide further strategic outreach to help mitigate the introduction of contaminants to the watershed in Years 4 and 5.

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1.0 INTRODUCTION

"Ultraviolet filter" (UVF) is a term used to describe compounds added to chemical sunscreens that block or absorb ultraviolet radiation emitted from the sun. The presence and impact of UVFs in aquatic ecosystems is a rapidly emerging global issue, but information about UVF contamination in Canadian freshwater systems and potential impacts from chronic environmental exposure is currently limited.

Many UVFs have been demonstrated as dose-dependent endocrine disruptors, affecting reproduction and hormonal activity in several different aquatic species (Coronado et al., 2008; Fent, Kunz and Gomez, 2008; Gago-Ferrero et al., 2013; Molins-Delgado et al., 2017). Some UVFs are relatively stable against degradation in the aquatic environment, and certain UVFs may be prone to bioaccumulation and biomagnification within the aquatic food web (Fent, Zenker and Rapp, 2010; Gago-Ferrero et al., 2015). Both wastewater effluent and recreational inputs have been identified as major sources of UVF contamination worldwide (Semones et al., 2017; Tsui et al., 2014).

Located on southern Vancouver Island, the Cowichan watershed encompasses the traditional territory of the historic Cowichan Nation (present-day Cowichan Tribes, among others) (Cowichan Tribes, 2022). Significant cultural history is interwoven with the landscape. Today, listed as one of three Canadian Heritage Rivers in British Columbia (Madrone, 2013), the Cowichan River is an international destination known for drifting, angling, and fly fishing.

Besides supporting the lower Georgia Strait Chinook salmon (*Oncorhynchus tshawytscha*) indicator stock for the Pacific Salmon Treaty (Pacific Salmon Commission, 2020), the Cowichan watershed also provides critical habitat for hundreds of species of birds, fish, mammals, insects, and amphibians (BC Parks, n.d.), notably several populations of salmonid fishes including three species of trout: rainbow/steelhead (*Oncorhynchus mykiss*), coastal cutthroat (*O. clarkii clarkii*), and the introduced European brown trout (*Salmo trutta)*; along with four species of Pacific salmon: Chinook (*O. tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), and kokanee salmon (*O. nerka*). Many of these fish species have declined relative to historical abundances (LGL Ltd., 2005).

The Cowichan watershed currently faces extensive anthropogenic impacts such as urbanization, deforestation, and climate change (LGL Ltd., 2005), all of which can impact water quality. Additionally, each summer thousands of visitors seek out water-based recreational activities in the lake and river, which makes the water highly susceptible to UVF inputs from sunscreens and personal care products (Evans, 2019; Traynor, 2019). Considered most "at-risk" for UVF impacts in the Cowichan watershed ecosystem are those species spending a significant portion of their life in the freshwater environment, near areas of UVF contamination (e.g., freshwater invertebrates and fish such as rainbow trout, or anadromous fish spending part of their juvenile life cycle in freshwater during the summer, such as coho).

The British Columbia Conservation Foundation (BCCF) began investigating the issue of UVF contamination in the Cowichan River ecosystem in 2019 with Seed funding from the Habitat Conservation Trust Foundation, and partnership support from the Cowichan Lake and River Stewardship Society and the BC Ministry of Environment. Oxybenzone, a UVF added to many sunscreens and widely studied due to its estrogen-mimicking properties and propensity for bioaccumulation (Fent et al., 2008; Kim and Choi, 2014), was chosen as an indicator contaminant.

Additional financial support from the Habitat Conservation Trust Foundation, RBC Foundation, BC Ministry of Environment, Regional District of Nanaimo, Environment and Climate Change Canada, and Mitacs resulted in an annual sampling protocol undertaken in Year 1 (2020), Year 2 (2021) and Year 3 (2022), and continuous method development at Vancouver Island University's Applied Environmental Research Lab (AERL). The following report summarizes Year 3 activities and results.

2.0 GOALS AND OBJECTIVES

This project's overarching goals are to: 1) describe the nature and extent of UVF contamination within the Cowichan River ecosystem, 2) understand the potential impacts of UVF contamination on resident aquatic organisms, and 3) encourage public education, outreach and regulatory measures to help mitigate UVF inputs to the ecosystem. This study also aims to provide a project model for stewardship groups to undertake UVF investigations in other freshwater bodies of concern throughout BC and Canada.

The specific objectives for Year 3 were to:

- Continue describing the spatiotemporal distribution and interannual variability of oxybenzone, enzacamene, octinoxate and octisalate at select sites in the Cowichan watershed.
- Continue to assist Vancouver Island University (VIU) with sample collection and support student research to refine analysis methods for oxybenzone in sediment and tissue.
- Engage community stakeholders and volunteers in the project and its results by encouraging environmental learning and creating opportunities for active public involvement.
- Help guide the direction of mitigation efforts by comparing all water quality and public survey results 2019-2022, to help identify where targeted effort could be most effective.

3.0 METHODS

3.1 Study Area

The Cowichan watershed drains the Cowichan Valley basin, an area of approximately 940 km^2 on the southeast coast of Vancouver Island (LGL Ltd., 2005); the river flows east out of Cowichan Lake (elev. 180 m) for approximately 47 km before emptying into the Cowichan estuary and bay (Fig. 1).

The Cowichan Valley experiences a coastal Mediterranean climate, with warm-to-hot, dry summers and mild, wet winters (LGL Ltd. 2005). Since 2008, maximum summer temperatures in the region have reached between 30-36°C (Environment Canada 2020); increasingly warm mean annual temperatures, which have risen approximately 1.5°C since the 1980s, leave the valley prone to drought in the summer when water demand is highest (Smith et al., 2019; Westland Resource Group, 2007).

Several communities are located along the shores of Cowichan Lake, mainly concentrated towards its eastern end; the largest of these is the Town of Lake Cowichan (pop. ~3,000) (Statistics Canada, 2017a). Near its terminus, the Cowichan River flows through the City of Duncan (pop. ~23,000) and Cowichan Tribes First Nation (local pop. ~2,200) (Statistics Canada, 2017b and 2018).

Cowichan Lake is the drinking water supply for the Town of Lake Cowichan, which withdraws water directly from the lake upstream of the weir. Two wastewater treatment facilities currently discharge treated effluent into the Cowichan River: The Town of Lake Cowichan (TLC) outfall (located approx. 3.8 km downstream from the weir in Lake Cowichan) and the Joint Utility Board (JUB) sewage treatment plant outfall (located east of Duncan on Cowichan Tribes land, approx. 44 km downstream of the weir; slated for relocation to Cowichan Bay (North Cowichan, 2020).

Several sites along the Cowichan River are used as recreation areas. The most common summer recreation areas along the river include Cowichan River Provincial Park and campground facilities (including Stoltz Pool, Skutz Falls); Sandy Pool Regional Park; and Little Beach, a popular exit location for river tubers coming from the Town of Lake Cowichan. An additional site serving as a tubing take-out location in 2022 was Spring Pool. On the lake, beaches at Arbutus Park in Youbou and Gordon Bay Provincial Park are heavily used (Fig. 1).

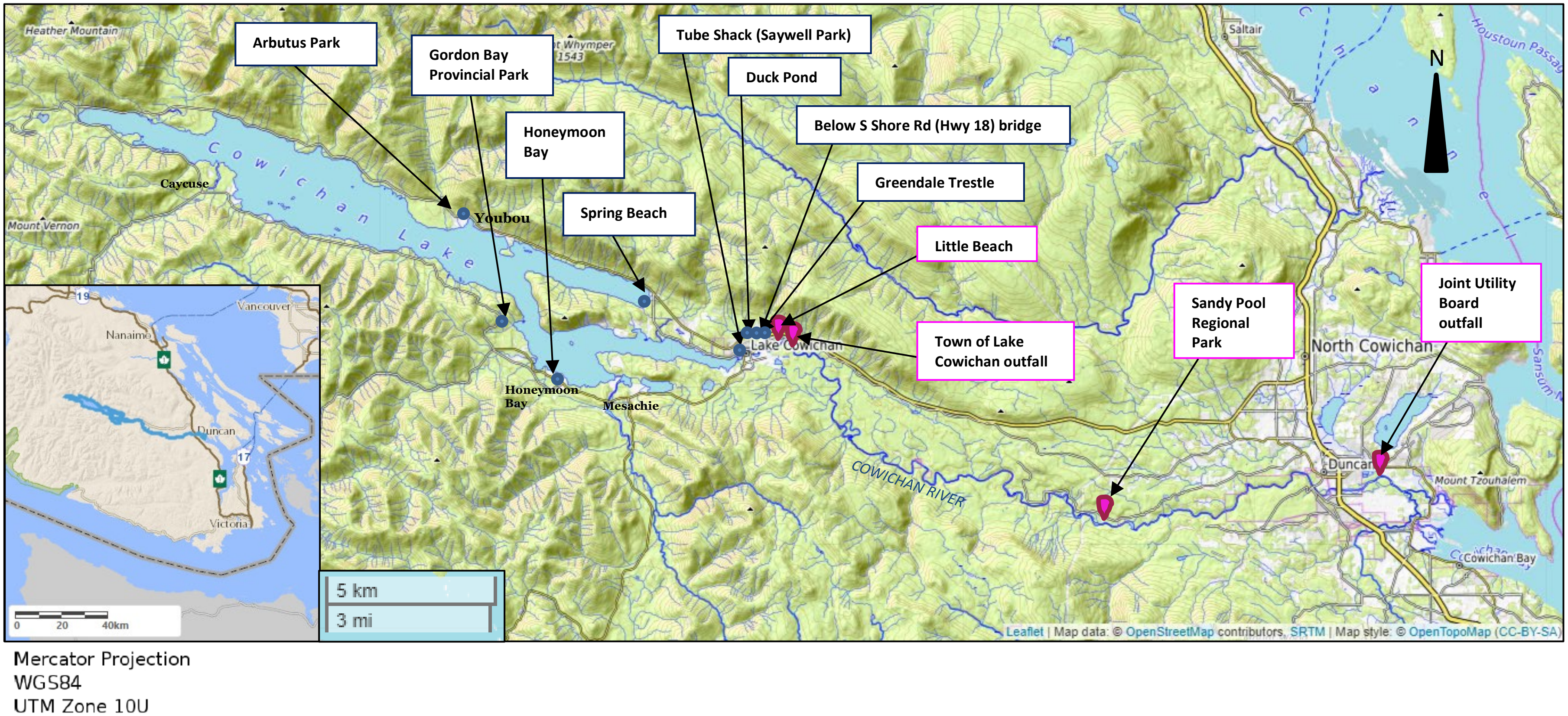

Figure 1. Cowichan Lake and River water sampling locations in Year 3, showing long-term Recreation vs. Wastewater monitoring sites (pink) and other Year 3 sampling sites (blue) (Image source: OpenTopoMap; Inset source: iMapBC).

3.2 Data Collection

3.2.1 River Discharge & Precipitation

Hourly water temperature and discharge data were downloaded from the Water Survey of Canada real-time hydrometric station database for Station ID “Cowichan River at Lake Cowichan” (08HA002), situated at 48° 49' 33" N, 124° 03' 10" W (ECCC 2022a). This hydrometric station monitors a total drainage area of 594 km^2 (ECCC 2021). Historical station data were downloaded using Cygwin DLL (3.3.4) terminal.

Daily air temperature and precipitation data were downloaded from Environment and Climate Change Canada’s historical database for Station ID “North Cowichan” (1015630), situated at 48° 49' 27" N, 123° 43' 08" W (ECCC 2022b). Data were downloaded using cygwin terminal. Data were used for North Cowichan station due to significant data gaps in the Lake Cowichan weather station.

3.2.2 Water Sampling

River water samples were collected at four long-term monitoring sites established in Year 1 (2020) (Fig. 1; in pink), on five weekends between July–August 2022. Additional river water samples spanning the length of the upper 5 km of the Cowichan River were collected on five weekends between July–August 2022 (Fig. 1). The upper 4 km of river was selected for close assessment in Year 3 (2022) due to the high recreational pressures in this area. Lake water samples were collected from five popular swim beaches (Fig. 1) on five weekends between July–August 2022 (Table 2). Samples at depth from the lake and river were collected using a Van Dorn on one date in Year 3 (2022) to compare with surface samples. Wastewater effluent samples were collected on three dates between June–September 2022 as an assessment of potential inputs from the TLCO outfall.

Equipment & protocol

Samples were collected by BCCF staff and trained community volunteers, following a similar sampling protocol to that established in Year 1 (2020) (described below). Volunteers were each provided with a sampling kit and pre-labelled sample bottles, a laminated manual, gloves, cooler, ice packs, pre-loaded data sheets, pencils, and thermometer. A review of sampling procedures was done during equipment drop-off. Volunteers also received one “field blank” vial with their kit for each scheduled sampling date. Wastewater effluent samples were collected using a modified protocol to allow for collection of treated effluent using a glass sampling jar and gloves.

Sample collection

The date, time, weather conditions, and real-time river discharge as listed on the Water Survey of Canada website for “Cowichan River at Lake Cowichan” and “Cowichan River at Duncan” stations were checked and recorded at the time of sampling. Water temperature was collected using one of several handheld thermometers calibrated to a known reference thermometer (YSI ProPlus). Samplers waded to knee-depth and faced upstream (in the case of river samples) or out toward the swimming area (in the case of lake samples), as close to the center of the river channel or swimming area as possible. In cases where wading was not possible, a dock or sloping bank was used to access the water.

Pre-cleaned, 50 mL amber glass vials with PTFE-lined polypropylene caps were uncapped, inverted, and submerged ~ 30 cm below the water surface, then righted to allow water to fill the vial. The rationale for sampling at depth (~ 30 cm) was to capture the ambient concentrations to which fish would be exposed to oxybenzone and other UVFs during rearing (Coronado et al., 2008; Ziarrusta et al., 2018; Labille et al., 2020). This water was discarded downstream behind the sampler, and vials were rinsed this way three times with river water before a sample was collected, then capped and immediately placed in a 9-quart field cooler with ice to keep cool and dark.

For wastewater effluent samples, treated effluent was sampled at the discharge point from the treatment pond. A clean glass measuring cup was dipped into the treated effluent and the contents used to rinse the sample vials three times. A second scoop of treated effluent was taken into the measuring cup and used to fill the duplicate sample vials together at the same time. Both vials were capped, sealed in two protective plastic bags, and placed in an isolated cooler with ice.

All samples were kept in the cold (~ 4°C) and dark after sampling (e.g., a volunteer's refrigerator) until they could be packaged and transferred to a larger cooler (Coleman Xtreme® 5 Marine Cooler, 26.4-L) for delivery to VIU-AERL in less than 48 hours.

Quality Assurance & Control

To reduce the risk of cross-contamination, samplers did not apply any sunscreen on the morning of sample collection. Sampling QA/QC in Year 3 (2022) involved collecting one field blank for each sampling day, and a duplicate for each sample. Field blank bottles were filled with deionized water in a sterile lab, then received, transported, uncapped, handled, stored, and shipped in the same manner as standard sample vials. Field blanks were poured from a clean vial to a regular sample vial while in the field. Duplicates were sampled simultaneously in one hand of the sampler; all samples were stored and handled under identical conditions until they underwent independent analysis.

3.2.3 Recreation Monitoring

Recreation monitoring was conducted for each site at the same time as water sampling. Samplers counted in-water users (*i.e.,* the number of people in the water upstream, and/or adjacent to the sampling location within the beach swimming area) at time of sample collection. This differs slightly from Year 1, when samplers counted in-water users for 10 minutes prior to sample collection. The method was consistent between Year 2 and Year 3. In-water user counts were not directly compared for Year 1 to Year 2 for this reason.

At recreation areas, public surveys were conducted with willing participants using a questionnaire. A copy of the questionnaire is found in Appendix A. Respondents were asked if they would like to participate in a survey. Positive respondents were read questions aloud, and asked to provide a response verbally; this response was marked on the questionnaire sheet. Answers were recorded by the interviewer using pencil and paper. Photos were taken of sunscreen products and linked to survey results, when available.

The Cowichan Lake District Chamber of Commerce (CLDCC), Town of Lake Cowichan, and Tube Shack local business were again contacted to request public engagement information for Year 3 (2022). The Town of Lake Cowichan Visitor Center, located beside Saywell park in the heart of downtown Lake Cowichan, was operated by the Town of Lake Cowichan. The Chamber of Commerce continued to operate its mobile outreach wagon. Data was also requested from BC Parks for Gordon Bay Campground and Stoltz Pool Campground. Available results were provided to BCCF via email. Recreation totals (by month) were able to be compared between project years.

3.2.4 Outreach

An outreach booth was set up with the goal of connecting with beach users face-to-face and sharing educational information. This outreach was intended to help learn the most effective strategies for outreach in Years 4-5, and was therefore spread out across several different locations. The booth was located at Arbutus Park, Gordon Bay Provincial Park, Youbou Market, Duck Pond, Honeymoon Bay Market, and Saywell Park on different dates.

The outreach booth contained educational information about UVFs and sunscreen products, sunscreen samples, UPF clothing examples, and ways to fill out the public questionnaire (in-person or digital). The main booth draws to engage with the public included: free samples, stickers, "business card" with key information about UVFs, and a bean bag toss game to learn about different product choices. Several other games were available and targeted towards youth (e.g. Fishing for Facts).

3.2.5 Sediment Sampling

Sediment samples were collected from two lake sites and five river sites in Year 3 (2022): Arbutus Park, Gordon Bay Provincial Park, Little Beach, Sandy Pool, the Tube Shack, Greendale Trestle, and 500 m d/s TLCO (Fig. 1).

Sample collection & equipment

All samples were collected from known swimming areas by scooping sediment into clean glass jars, collected either by hand (if near surface) or with an Ekman sampler (if at depth), and capped with inert foil under the metal cap. When used, the Ekman sampler was lowered to the sediment surface and, while resting open on the bottom, triggered to close using a messenger weight. A successful sample was raised out of the water, allowed to drain, then scooped into pre-labelled jars. Samples were kept cool and in the dark until delivery to VIU-AERL within 48 hours.

Quality Assurance & Control

To reduce the risk of cross-contamination, samplers did not apply sunscreen to their skin on the morning of sample collection. Two duplicate samples were collected at the Tube Shack and 500 m d/s TLCO locations to allow for comparison between results.

3.2.6 Fish Sampling

No additional fish sampling was done in Year 3 (2022) due to setbacks with analysis methodology. Processed samples from Year 1 and Year 2 were provided to VIU for further methodology development.

3.3 Analysis

3.3.1 Laboratory Analysis

Samples were transported to VIU-AERL on the first weekday morning after sampling, with an average transit time of 2 hours (total holding time <48 hours). Analysis was conducted using condensed phase membrane induction mass spectrometry with direct liquid electron/chemical ionization (CP-MIMS-LEI/CI).

CP-MIMS LEI/CI is a novel direct mass spectrometry technique developed by VIU-AERL researchers that eliminates sample preparation steps, requires less than 10 mL of sample for analysis, and provides parts-per-trillion detection limits for oxybenzone and related contaminants within minutes (Aplin et al. 2023, Vandergrift et al., 2022). This method was tested against more traditional commercial methods of analysis in Year 1 (2020) and found to be relatively comparable at a fraction of the cost.

The limits of quantitation and limits of detection for the CP-MIMS LEI/CI method varied both between sample runs and between compounds (Aplin et al. 2023). These analytical limits are summarized in Table 1. In previous years, only the limit of detection (LoD) was reported by the lab for oxybenzone results.

Table 1. Summary of detection/quantitation limits for the CP-MIMS LEI/CI method in Year 3 (2022).

UVF Compound	Year 1 (2020) LoD[1] (ng/L)	Year 2 (2021) LoD[1] (ng/L)	Year 3 (2022)	
			Limit of detection (LoD) (ng/L)[1]	Limit of quantitation (LoQ) (ng/L)[1]
Oxybenzone (Benzophenone-3)	20	20	5-20	15-101
Enzacamene (4-methylbenzylidene camphor)	-	-	6-37	7-930
Octinoxate (Octyl methoxycinnamate)	-	-	26-80	27-2383
Octisalate (Octyl salicylate)	-	-	7-23	7-73

[1] – Values provided by VIU-AERL lab

3.3.2 Method Development

Progress with method development at the end of Year 2 led to the addition of three new UVFs for analysis in Year 3; all water samples were analyzed concurrently for the four UVFs listed in Table 1. Octocrylene was also tested in Year 2 as part of method development, but the compound did not prove effective for analysis with the CP-MIMS LEI/CI method in Year 3 (2022).

Sediment analysis methods were also further pursued in Year 3. Because the membrane in a CP-MIMS experiment rejects solid particulates, heterogeneous processes such as sorption can be probed directly without filtration or extraction pre-processing steps (Aplin et al. 2023). Several sediment samples collected from the Cowichan watershed were tested as slurries in Year 3 (2022).

Extraction recovery experiments for oxybenzone in biotic tissue continued to encounter technical challenges. Alternate analysis methods were explored, including gas chromatography (GC-MS). Membrane permeate was collected offline and injected into the GC-MS using the same method as the sediment (Aplin et al. 2023). Two prepared tissue samples collected from the Cowichan watershed were run as part of method development in Year 3 (2022).

3.3.3 Data Analysis

Environmental data were processed and analyzed using Microsoft Excel (2016). All data were presented as values using descriptive analysis. Water sample results were summarized by site, type, and compared with river discharge between years; QA/QC results were presented for discussion. Recreation monitoring results were summarized by site, type, and compared between years. Public questionnaire and outreach results were tallied and presented as values.

In Year 3, more data was provided from the lab regarding method detection limits (LoD) and limits of quantitation (LoQ). The LoQ is calculate as 3x the signal-to-noise ratio (S/N) and is assumed to be the threshold above which there was adequate confidence in reporting data (Aplin et al. 2023).

Past reports assumed all values <LoD to be 0 ng/L due to the low presumed hazard of the compound at the LoD. For oxybenzone, no known chronic or acute risks to aquatic life have been found published in the literature at concentrations below the LoD of 20 ng/L. In Year 3 (2022), the LoD and LoQ varied between compounds and between sample dates (Table 1).

- The disadvantage of assuming <LoD or LoQ results are equivalent to 0 ng/L is an artificial lowering of the mean or median result, given the likelihood that some samples < LoD could have contained the compound of interest but were unable to be detected by the instrument using the specified method. Assuming 0 ng/L provides the user with a lowest-end estimation of real sample results; this has potential implications in situations where health risks exist at levels below the LoD or LoQ.

- The disadvantage of assuming <LoD or LoQ results are equivalent to the actual method LoD or LoQ is an artificial raising of the mean or median result, given the unlikelihood that *all* samples <LoD or LoQ are at the very threshold of detection by the instrument. Assuming the value of the LoQ value provides the user with a highest-end estimation of actual sample results, which is the most conservative approach especially in situations where a potential health risk exists at levels below the LoD or LoQ.

In practice, the sample value is often assumed to be the average between 0 and the reporting threshold limit (i.e., LoQ/2), under the assumption that the non-detect sample results are distributed normally and therefore an even number of high- and low-results exist across the samples.

Past analysis has shown that sample results appear stochastic and not normally distributed. Past reports assumed all values below laboratory limits of detection (<LoD) to be 0 ng/L for analysis. For this report, all values <LoD and <LoQ were assumed to be 0 ng/L for data analysis purposes and to remain consistent with the analysis done in previous years. For the purposes of duplicate comparisons of Relative Percent Difference (RPD), the actual LoQ value was used to avoid dividing by 0.

4.0 RESULTS

The Year 3 sampling period was intended to be from June 19 – September 8, 2022 (n=82 days). The sampling period was retroactively adjusted to July 24 – September 8, 2022 (n=47 days), due to a delay in obtaining lab results for the first two sample dates (as indicated by the black X's and red points on the x-axis of Fig. 2).

4.1 River Discharge & Precipitation

Mean daily river discharge (MDD) for the Cowichan River at Lake Cowichan (Station ID 08HA002) was relatively similar between Year 1 (2020), Year 2 (2021), and Year 3 (2022) for the month of July (>7.0 m^3/s). However, for the month of August the MDD was lower in the Seed and Year 2, but higher in Year 1 and Year 3 (Table 2). Although it is outside of the sampling period, of note is the drought period extended well into October in Year 3, which was not observed in past years (Fig. 2).

Table 2. Comparison of mean daily air temperature (North Cowichan Climate Station), river discharge and water temperature (Cowichan River at Lake Cowichan) for the months of July and August.

		Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Mean daily air temperature (°C)	July	16.7*	18.05	20.25	19.78
	August	19.0*	18.09	18.81	20.67
Mean daily water temperature (°C)	July	Not available	20.12	23.02	20.43
	August	Not available	21.74	22.35	22.96
Mean daily river discharge (m^3/s)	July	4.46	7.11	7.11	7.37
	August	4.45	7.08	4.92	7.22

*Data from nearby Station ID 1012055, Lake Cowichan (data missing for North Cowichan)

Hourly water temperature and discharge data were graphed for Cowichan River at Lake Cowichan (Station ID 08HA002) for the period May 1–October 31, 2022 (Fig. 2). The maximum discharge within this period was recorded on May 19 at 64.9 m^3/s. The maximum and minimum river discharges within the Year 3 sampling period only (July 24 to September 8), indicated by red points on the x-axis, were 8.10 and 6.87 m^3/s on September 4 and July 24-25, respectively; the MDD was 7.27 m^3/s (Fig. 2). The maximum and minimum river temperatures within the Year 3 sampling period were 25.51 and 20.73°C on July 30 and 26, respectively; the mean river temperature was 22.83°C (Fig. 2).

Daily air temperature and precipitation data were graphed for North Cowichan climate station (Station ID 1015630) for the period June 15–September 15, 2022 (Fig. 3). The maximum and minimum daily air temperatures within the Year 3 sampling period (July 24 to September 8), indicated by red points on the x-axis, were 36.5 and 5.9°C, on July 26 and September 8, respectively; the mean air temperature was 13.3 °C (Fig. 3). Precipitation events >5 mm occurred before, but not within, the Year 3 sampling period; the maximum precipitation recorded within the sampling period was 2.1 mm on September 4 (Fig. 3). Overall, precipitation was negligible during the Year 3 sampling period.

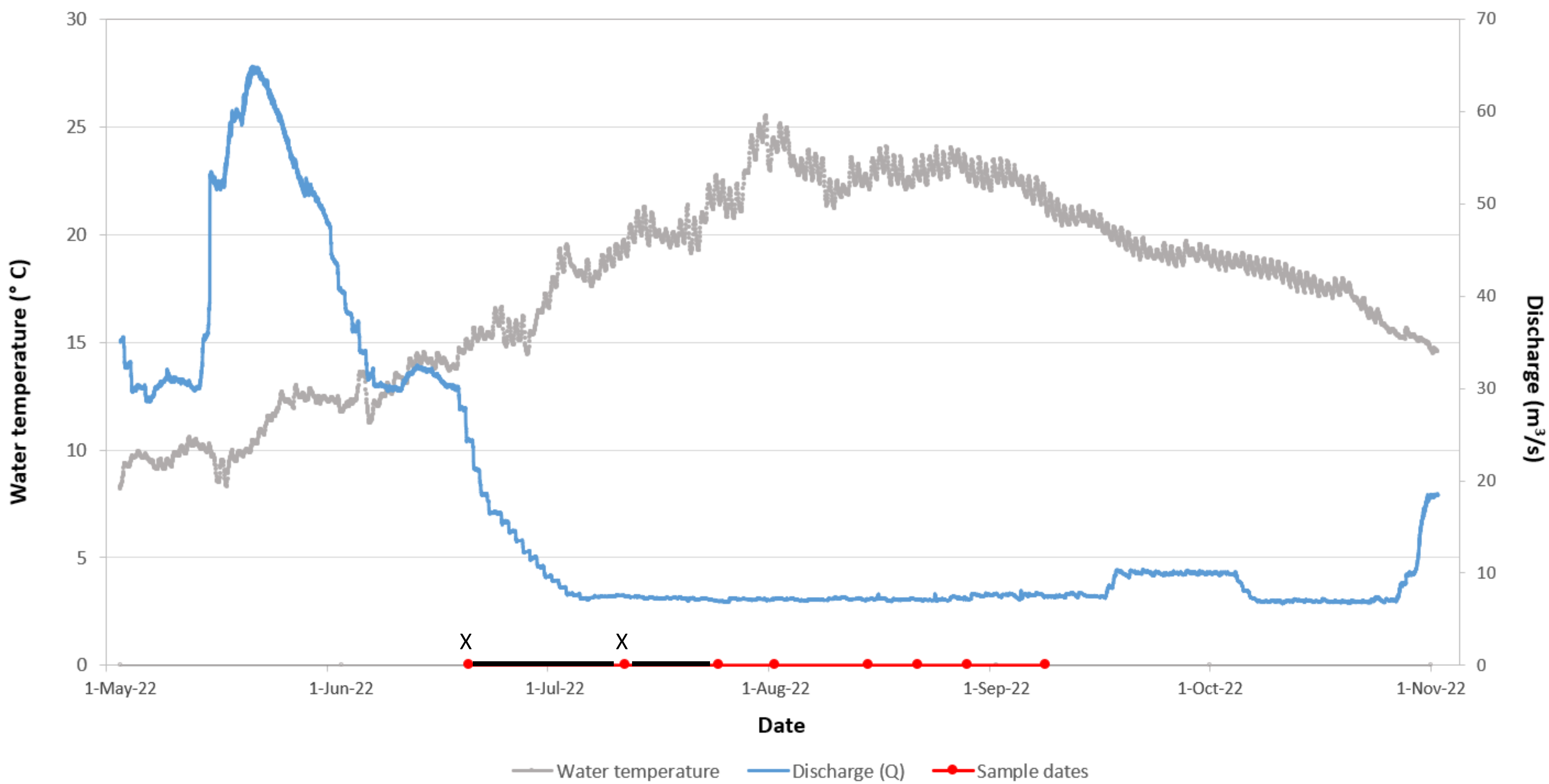

Figure 2. Water temperature (°C) (Gray; left-hand axis) and river discharge (m^3/s) (Blue; right-hand axis) for Cowichan River at Lake Cowichan (08HA002), May 1–Oct 31, 2022. Black X's denote collected but non-analyzed samples. Red sample dots denote Year 3 sampling period.

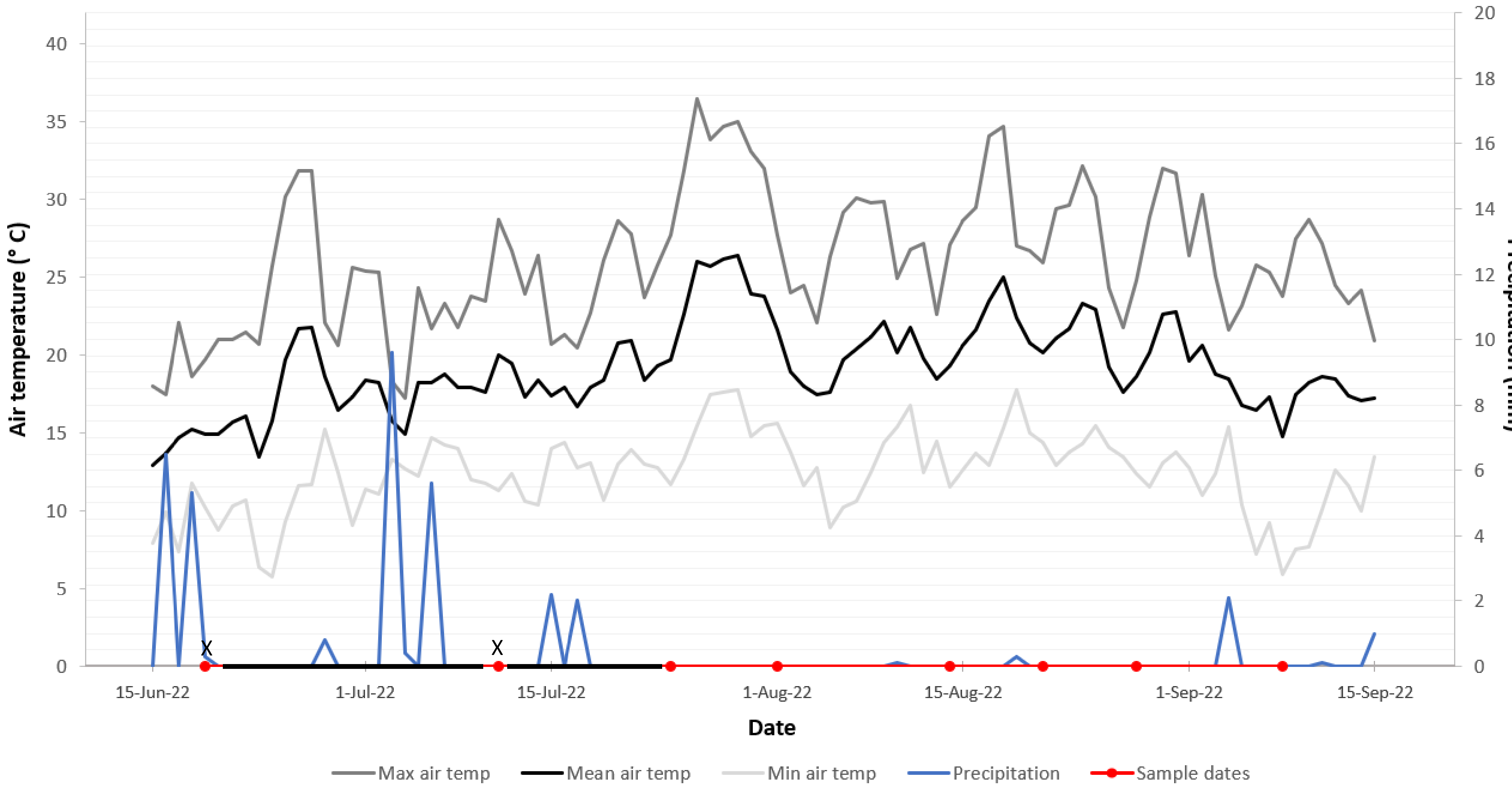

Figure 3. Maximum, mean, and minimum daily air temperature (°C) (black & gray; left-hand axis) and total daily precipitation (mm) (Blue; right-hand axis) for North Cowichan climate station, June 15–Sept 15, 2021. Black X's denote collected but non-analyzed samples. Red sample dots denote Year 3 sampling period.

4.2 Water Quality

4.2.1 Year 3 Results

A total of 174 water samples were collected at a range of sites throughout the Cowichan watershed in Year 3. This was comprised of 78 duplicates (156 samples), 16 field blanks, and 2 surface samples. All samples were submitted to VIU-AERL for analysis of the Ultraviolet Filters (UVFs) oxybenzone, enzacamene, octinoxate, and octisalate. 82% of all samples collected (n=143) were successfully analyzed by the lab at VIU-AERL. Of those samples analyzed in Year 3,

- 33% (n=47) were detectable for oxybenzone, while 67% (n=96) were below the method limit of quantitation (LoQ) for oxybenzone.
- 6% (n=9) were detectable for enzacamene, while 94% (n=134) were below the method limit of quantitation (LoQ) for enzacamene.
- 20% (n=28) were detectable for octinoxate, while 80% (n=115) were below the method limit of quantitation (LoQ) for octinoxate.
- 15% (n=22) were detectable for octisalate, while 84% (n=120) were below the method limit of quantitation (LoQ) for octisalate; 1% (n=1 sample) was not reported by the lab.

Quality Control

There were more apparent issues with quality control of sample results in Year 3 (2022) than in past years. There was a high occurrence of paired sample duplicates with non-detect (<LoQ) and detected results, especially for the compounds oxybenzone, octinoxate, and octisalate (Table 3). This resulted in a high incidence of Relative Percent Difference (RPD) between duplicates, far exceeding the QC threshold of 20% RPD used in Year 2 (2021).

The RPD percentages in Table 3 were calculated based on treating non-detect (<LoQ) samples as equivalent to the method LoQ provided by the lab at VIU-AERL for each compound (see Table 1). These RPD results are provided in Table 3 and represent the lowest (least conservative) estimate of RPD between sample duplicates; actual RPDs could be higher, as true < LoQ sample values are unknown.

Table 3. Comparison of the Relative Percent Difference (RPD) between sample duplicates for water samples collected during the Year 3 sampling period only (July 24 to September 8, 2022).

Reliability	RPD between duplicates	oxybenzone	enzacamene	octinoxate	octisalate
Excellent	0-5%	3	2	3	2
Good	6-10%	1	0	1	1
Fair	11-20%	4	0	3	1
	21-35%	6	2	6	0
Poor	36-50%	2	1	2	1
	51-100%	6	0	2	2
	101-200%	7	1	5	7
	NA	0	0	0	1
	Both duplicates indicate sample is < LoQ	33	56	40	48

Samples with RPD >20-35% should be treated with caution, and RPD >50% with extreme caution, as this indicates that sources of uncertainty exist regarding sample quality (CCME 2016; BC Ministry of Environment 2016). After a thorough review of sample and analysis methods, causes for this high RPD cannot be excluded from being due to one or several of the following reasons in Year 3 (2022):

- contamination during dry sample vial preparation and labelling at BCCF office or during handling in the field;
- contamination via airborne sources (e.g. aerosols) while at the field sampling location;
- differences in transport behaviour and fate of UVF compounds and/or particulate matter to which UVF compounds are adsorbed during sample collection in the field (i.e., environmental heterogeneity);
- natural degradation and breakdown of compounds at different rates between duplicates, due to varied concentrations of particulate and dissolved organic matter in samples.

While individuals handling sample vials did not wear sunscreen, it is possible that contamination could have occurred via use of other personal care products, such as lotions or lip balms, which are known to contain compounds such as octisalate. Environmental heterogeneity was aimed to be minimized due to the method of duplicate sampling (by keeping vials as close together as possible in space and time), but without more background knowledge about the chemical composition of the water being sampled (e.g. DOC, DOM), it is difficult to rule out environmental conditions of molecule transport or degradation as a factor leading to the significant differences seen between sample duplicates.

Further, 20% (n=3 of 15) of field blanks had reported detections of octisalate and octinoxate, at river sites only (no lake sites; Table 3), for the dates July 24, August 1, and August 28. These always occurred in situations where the corresponding duplicate samples had a matching non-detect (<LoQ) result, and could be the result of either contamination during dry sample vial preparation and labelling at the BCCF office, during sample handling, or contamination while in the field. Lab analysts also did not wear sunscreen and the instrument probe was cleaned between samples, so lab sources of contamination are relatively unlikely (C. Gill, pers. comm., March 2023).

For the purposes of this report, all duplicate sample values have been reported separately and presented for consideration and discussion. Readers should keep the bullets mentioned above in mind when interpreting high sample results for certain compounds. At VIU-AERL, laboratory accuracy generally ranged from 2-16% between repeat analyses (*M*=7.2%, n=7) with a level of acceptance for duplicates of +/- 20%. The maximum tolerance for RPD was determined to be 1.75x the laboratory acceptance of 20% due to the increased variability in sampling and handling between field duplicates (CCME 2016; BC Ministry of Environment 2016) and the relatively small sample volume collected. Sample results with a RPD >35% between duplicates have been marked with an asterisk.

Cowichan River

Of the water samples collected from the Cowichan River, point-in-time oxybenzone concentrations were highest approximately 0.6 km downstream of the weir, at Kinsmen Duck Pond beach on August 21, 2022 (2,076 ng/L*) (Table 4). The Duck Pond also had the highest median oxybenzone concentrations for all river sites sampled in Year 3 (*Mdn*=301, *IQR*=267, n=11).

Point-in-time concentrations for enzacamene, octinoxate, and octisalate were highest from the same sample at Spring Beach on August 1, 2022 (4,518 ng/L*, 17,869 ng/L*, and 1,685 ng/L*, respectively); however, this sample's duplicate was a non-detect (Table 4). This suggested that perhaps there was contamination or a significant difference between samples (e.g., a flocculated particle). For octisalate, the only detectable median concentration was for Gordon Bay Provincial Park Beach (*Mdn*=80, *IQR*=247, n=10). The median concentration of enzacamene and octinoxate for all sites was 0 ng/L.

Results were compared between the four long-term Recreation vs. Wastewater monitoring sites (Fig. 1, in pink) for Year 3. For the Recreation group, mean oxybenzone concentrations were almost the same between Sandy Pool (M=23.9 ng/L, SD=47.8, n=12) and Little Beach (M=23.1 ng/L, *SD*=35.0, n=14) although the median was below the LoQ. For the Wastewater group, mean oxybenzone concentrations were slightly higher downstream of the Town of Lake Cowichan Outfall (TLCO) (*M*=25 ng/L, *SD*=79.1, n=10) than the Joint Utility Board outfall (JUBO) (*M*=12.5 ng/L, *SD*=25, n=4) (Fig. 4) although the median was below the LoQ.

Cowichan Lake

Of the water samples collected from Cowichan Lake, point-in-time oxybenzone concentrations were highest at Arbutus Park Beach on August 1, 2021 (1,344 ng/L) (Table 5). Gordon Bay Provincial Park Beach had the highest median oxybenzone concentrations for all river sites sampled in Year 3 (*Mdn*=46, *IQR*=114, n=10); conversely, Honeymoon Bay had no detections of oxybenzone all season (n=10). All water samples from Year 3 were grouped by location (Lake vs. River) and plotted (Fig. 5) to compare oxybenzone concentrations between site type.

Point-in-time concentrations for enzacamene, octinoxate, and octisalate were highest at Gordon Bay Provincial Park Beach on August 1 and 28, 2022 (1,354 ng/L*, 3,848 ng/L*, and 1,189 ng/L*, respectively); however, this sample's duplicate was also a non-detect (Table 5).

4.2.2 Annual Variation

Since the project Seed year (2019), oxybenzone results have varied (Tables 6, 7, 8). In general, 2019 showed moderately high results for river sites (lake sites were not sampled), collected on just one date – the 2019 results are skewed due to a small sample size as a result. The maximum concentrations of oxybenzone seen to date were at the Duck Pond in 2022 (2,076 ng/L*) with 20 people swimming in the water and roughly a dozen more floating upstream, and at the lake in 2021 (1,761 ng/L), with 125 people swimming in the water (Table 8). Although variation between sites and sample dates is very high, with several sites exhibiting no detectable concentrations, oxybenzone was found to be present at varying concentrations across all sample years.

From Year 2 to Year 3, mean oxybenzone concentrations decreased at Little Beach, Sandy Pool, and downstream of the TLCO, whereas mean oxybenzone concentrations slightly increased downstream of the JUBO (Fig. 6); variance again remained high across years due to the very small sample size, with most samples returning as non-detects and a median value of 0 ng/L overall in Year 3. There was variation in the number of samples collected from Year 2 to Year 3 due to volunteer availability and duration of the sampling window.

For a year-to-year visual comparison, we plotted oxybenzone results from the four upper-river sites sampled consistently since the project Seed year in 2019 (Duck Pond, Greendale Trestle, Little Beach, and 500 m downstream of the TLCO). River discharge was graphed to show relative differences between years (Fig. 7). Across these four sites, the mean oxybenzone concentrations were highest in the Seed year (2019; *M*=325, *SD*=206, n=1), followed by Year 3 (2022; *M*=123, *SD*=335, n=4-6), Year 2 (2021; *M*=84, *SD*=110, n=1-6), and Year 1 (2020; *M*=71, *SD*=71, n=4-8). However, the variance ihigh and the number of sample dates for each site (n) is highly variable between years. Data for the other UVFs (enzacamene, octinoxate, octisalate) were not available for prior years, therefore are not summarized here.

4.2.3 Quality Assurance & Control

For an overview of sampling QA/QC, please refer to section 4.2.1 above. N=6 samples at VIU-AERL were tested in triplicate to confirm high readings. These values are provided as the mean with standard deviation between analyses in Tables 4 and 5.

Table 4. Ultraviolet Filter (UVF) concentrations (ng/L) in Cowichan River water at sites sampled in 2022.

Date	Location	Sample ID	Time	River km	Water temperature (°C)	River discharge (m3/s)	Oxybenzone (ng/L)	Enzacamene (ng/L)	Octinoxate (ng/L)	Octisalate (ng/L)	Group
6/19/2022	Little Beach	1	3:00:00 PM	2.8	15.3	22.3	No results from lab				Recreation
6/19/2022	Little Beach	2	3:00:00 PM	2.8	15.3	22.3	No results from lab				Recreation
6/19/2022	Sandy Pool	1	3:40:00 PM	28	15.9	22.3	No results from lab				Recreation
6/19/2022	Sandy Pool	2	3:40:00 PM	28	15.9	22.3	No results from lab				Recreation
7/8/2022	Wastewater effluent	1	1:30:00 PM	NA	20.3	7.49	No results from lab				WWTP
7/8/2022	Wastewater effluent	2	1:30:00 PM	NA	20.3	7.49	No results from lab				WWTP
7/11/2022	Tube Shack	1	2:47:00 PM	0.5	20.1	7.41	No results from lab				Recreation
7/11/2022	Tube Shack	2	2:47:00 PM	0.5	20.1	7.41	No results from lab				Recreation
7/11/2022	Duck Pond	1	3:00:00 PM	0.6	20.8	7.41	No results from lab				Recreation
7/11/2022	Duck Pond	2	3:00:00 PM	0.6	20.8	7.41	No results from lab				Recreation
7/11/2022	Below S Shore Rd (Hwy) bridge	1	3:16:00 PM	0.8	20.6	7.41	No results from lab				Recreation
7/11/2022	Below S Shore Rd (Hwy) bridge	2	3:16:00 PM	0.8	20.6	7.41	No results from lab				Recreation
7/11/2022	Greendale Trestle	1	3:35:00 PM	1.1	20.4	7.41	No results from lab				Recreation
7/11/2022	Greendale Trestle	2	3:35:00 PM	1.1	20.4	7.41	No results from lab				Recreation
7/11/2022	Little Beach	1	3:49:00 PM	2.8	20.7	7.41	No results from lab				Recreation
7/11/2022	Little Beach	2	3:49:00 PM	2.8	20.7	7.41	No results from lab				Recreation
7/11/2022	500 m d/s TLCO	1	4:07:00 PM	3.8	20.9	7.41	No results from lab				WWTP
7/11/2022	500 m d/s TLCO	2	4:07:00 PM	3.8	20.9	7.41	No results from lab				WWTP
7/11/2022	Sandy Pool	Blank	4:55:00 PM	28	NA	7.41	No results from lab				Blank
7/11/2022	Sandy Pool	1	4:55:00 PM	28	21.8	7.41	No results from lab				Recreation
7/11/2022	Sandy Pool	2	4:55:00 PM	28	21.8	7.41	No results from lab				Recreation
7/11/2022	Wastewater effluent	1	1:20:00 PM	NA	21	7.41	No results from lab				WWTP
7/11/2022	Wastewater effluent	2	1:20:00 PM	NA	21	7.41	No results from lab				WWTP
7/24/2022	Tube Shack	2	2:30:00 PM	0.5	21	6.94	84*	<LOQ	<LOQ	**75.5**	Recreation
7/24/2022	Tube Shack	3	2:30:00 PM	0.5	21	6.94	56 +/- 9*	<LOQ	<LOQ	**83.1**	Recreation
7/24/2022	Duck Pond	1	2:05:00 PM	0.6	21.9	6.94	130*	<LOQ	<LOQ	**<LOQ**	Recreation
7/24/2022	Duck Pond	2	2:05:00 PM	0.6	21.9	6.94	374 +/- 13*	<LOQ	<LOQ	**76**	Recreation
7/24/2022	Below S Shore Rd (Hwy) bridge	1	11:55:00 AM	0.8	21.7	6.94	162*	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Below S Shore Rd (Hwy) bridge	2	11:55:00 AM	0.8	21.7	6.94	<LOQ*	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Greendale Trestle	1	12:13:00 PM	1.1	21.7	6.94	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Greendale Trestle	2	12:13:00 PM	1.1	21.7	6.94	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Little Beach	Blank	12:30:00 PM	2.8	NA	6.94	<LOQ	<LOQ	<LOQ	105	Blank
7/24/2022	Little Beach	1	12:30:00 PM	2.8	21.9	6.94	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Little Beach	2	12:30:00 PM	2.8	21.9	6.94	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	500 m d/s TLCO	1	12:47:00 PM	3.8	22.3	6.94	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
7/24/2022	500 m d/s TLCO	2	12:47:00 PM	3.8	22.3	6.94	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
7/24/2022	Sandy Pool	1	1:38:00 PM	28	22	6.94	**62**	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Sandy Pool	2	1:38:00 PM	28	22	6.94	**<LOQ**	<LOQ	<LOQ	<LOQ	Recreation
7/24/2022	Quamichan Rd	1	4:30:00 PM	44.5	22.9	6.94	**<LOQ**	<LOQ	<LOQ	<LOQ	WWTP
7/24/2022	Quamichan Rd	2	4:30:00 PM	44.5	22.9	6.94	**50**	<LOQ	<LOQ	<LOQ	WWTP
8/1/2022	Tube Shack	Blank	2:11:00 PM	0.5	NA	7.23	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/1/2022	Tube Shack	1	2:11:00 PM	0.5	24.6	7.23	<LOQ	<LOQ	<LOQ*	496*	Recreation
8/1/2022	Tube Shack	2	2:11:00 PM	0.5	24.6	7.23	<LOQ	<LOQ	2246*	<LOQ*	Recreation
8/1/2022	Duck Pond	1	2:45:00 PM	0.6	24.4	7.23	497*	<LOQ	<LOQ	<LOQ	Recreation
8/1/2022	Duck Pond	2	2:45:00 PM	0.6	24.4	7.23	**301***	<LOQ	<LOQ	<LOQ	Recreation
8/1/2022	Duck Pond	3	2:45:00 PM	0.6	24.4	7.23	**394***	<LOQ	<LOQ	<LOQ	Recreation

8/1/2022	Below S Shore Rd (Hwy) bridge	2	2:26:00 PM	0.8	24.9	7.23	**75**	<LOQ	**<LOQ**	<LOQ*	Recreation
8/1/2022	Below S Shore Rd (Hwy) bridge	1	2:26:00 PM	0.8	24.9	7.23	**104**	<LOQ	**953**	85*	Recreation
8/1/2022	Greendale Trestle	2	2:43:00 PM	1.1	24.6	7.23	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/1/2022	Greendale Trestle	1	2:43:00 PM	1.1	24.6	7.23	*No results from lab*				Recreation
8/1/2022	Little Beach	2	2:57:00 PM	2.8	24.9	7.23	58*	<LOQ	<LOQ	<LOQ	Recreation
8/1/2022	Little Beach	1	2:57:00 PM	2.8	24.9	7.23	111*	<LOQ	<LOQ	<LOQ	Recreation
8/1/2022	500 m d/s TLCO	1	3:11:00 PM	3.8	25	7.23	250*	<LOQ	<LOQ*	<LOQ*	WWTP
8/1/2022	500 m d/s TLCO	2	3:11:00 PM	3.8	25	7.23	<LOQ*	<LOQ	1002*	208*	WWTP
8/1/2022	Sandy Pool	1	3:50:00 PM	28	24.7	7.23	160*	<LOQ	<LOQ*	<LOQ	Recreation
8/1/2022	Sandy Pool	2	3:50:00 PM	28	24.7	7.23	<LOQ*	<LOQ	1027*	<LOQ	Recreation
8/1/2022	Quamichan Rd	1	5:19:00 PM	44.5	24.8	7.23	<LOQ	<LOQ	<LOQ*	<LOQ*	WWTP
8/1/2022	Quamichan Rd	2	5:19:00 PM	44.5	24.8	7.23	<LOQ	<LOQ	1295*	98*	WWTP
8/1/2022	Wastewater effluent	Blank	8:00-8:30	NA	NA	7.23	<LOQ	<LOQ	<LOQ	109 +/- 7	Blank
8/1/2022	Wastewater effluent	1	8:00-8:30	NA	24	7.23	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/1/2022	Wastewater effluent	2	8:00-8:30	NA	24	7.23	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/14/2022	Tube Shack	Surface	3:48:00 PM	0.5	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Tube Shack	1	3:48:00 PM	0.5	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	10 m d/s Tube Shack	1	4:05:00 PM	0.51	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	10 m d/s Tube Shack	2	4:05:00 PM	0.51	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Duck Pond	Blank	3:15:00 PM	0.6	NA	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/14/2022	Duck Pond	1	3:20:00 PM	0.6	22.7	7.2	393.4*	<LOQ	710.6*	<LOQ	Recreation
8/14/2022	Duck Pond	2	3:20:00 PM	0.6	22.7	7.2	<LOQ*	<LOQ	<LOQ*	<LOQ	Recreation
8/14/2022	Below S Shore Rd (Hwy) bridge	1	16:30-16:40	0.8	23.7	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Below S Shore Rd (Hwy) bridge	2	16:30-16:40	0.8	23.7	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	30 m ds S Shore Rd (Hwy) bridge	1	16:30-16:40	0.83	23.7	7.2	**369.2**	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	30 m ds S Shore Rd (Hwy) bridge	2	16:30-16:40	0.83	23.7	7.2	**282.3**	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	30 m ds S Shore Rd (Hwy) bridge	Surface	16:30-16:40	0.83	23.7	7.2	<LOQ	<LOQ	**855.7**	<LOQ	Recreation
8/14/2022	Greendale Trestle	Blank	4:55:00 PM	1.1	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/14/2022	Greendale Trestle	1	4:55:00 PM	1.1	23.6	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Greendale Trestle	2	4:55:00 PM	1.1	23.6	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Little Beach	Blank	14:40-14:50	2.8	NA	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/14/2022	Little Beach	1	14:40-14:50	2.8	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Little Beach	2	14:40-14:50	2.8	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	500 m d/s TLCO	Blank	14:08-14:17	3.8	NA	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/14/2022	500 m d/s TLCO	1	14:08-14:17	3.8	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/14/2022	500 m d/s TLCO	2	14:08-14:17	3.8	23.4	7.2	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/14/2022	Sandy Pool	1	1:17:00 PM	28	21.6	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/14/2022	Sandy Pool	2	1:17:00 PM	28	21.6	7.2	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Tube Shack	1	1:39:00 PM	0.5	23.2	7	<LOQ	<LOQ	**<LOQ**	112*	Recreation
8/21/2022	Tube Shack	2	1:39:00 PM	0.5	23.2	7	<LOQ	<LOQ	**3206**	<LOQ*	Recreation
8/21/2022	Below S Shore Rd (Hwy) bridge	1	1:52:00 PM	0.8	23.6	7	<LOQ*	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Below S Shore Rd (Hwy) bridge	2	1:52:00 PM	0.8	23.6	7	121*	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Duck Pond	1	2:00:00 PM	0.6	22.8	7	2076 +/- 271*	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Duck Pond	2	2:00:00 PM	0.6	22.8	7	<LOQ*	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Greendale Trestle	1	2:08:00 PM	1.1	23.3	7	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Greendale Trestle	2	2:08:00 PM	1.1	23.3	7	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/21/2022	Little Beach	Blank	2:27:00 PM	2.8	NA	7	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/21/2022	Little Beach	1	2:27:00 PM	2.8	23.8	7	<LOQ	<LOQ	**694**	<LOQ	Recreation
8/21/2022	Little Beach	2	2:27:00 PM	2.8	23.8	7	<LOQ	<LOQ	**710**	*No result from lab*	Recreation
8/21/2022	500 m d/s TLCO	1	2:41:00 PM	3.8	23.7	7	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/21/2022	500 m d/s TLCO	2	2:41:00 PM	3.8	23.7	7	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/21/2022	Sandy Pool	Blank	3:16:00 PM	28	NA	7	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/21/2022	Sandy Pool	1	3:16:00 PM	28	23.3	7	<LOQ	<LOQ	<LOQ	<LOQ	Recreation

8/21/2022	Sandy Pool	2	3:16:00 PM	28	23.3	7	<LOQ	<LOQ	<LOQ	<LOQ	Recreation
8/28/2022	Tube Shack	1	4:05:00 PM	0.5	22.2	7.65	<LOQ	<LOQ	**<LOQ**	<LOQ	Recreation
8/28/2022	Tube Shack	2	4:05:00 PM	0.5	22.2	7.65	<LOQ	<LOQ	**2000**	<LOQ	Recreation
8/28/2022	Duck Pond	Blank	3:05:00 PM	0.6	NA	7.65	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/28/2022	Duck Pond	1	3:05:00 PM	0.6	22.6	7.65	**124**	<LOQ	**1991**	<LOQ	Recreation
8/28/2022	Duck Pond	2	3:05:00 PM	0.6	22.6	7.65	**130 +/- 7**	<LOQ	**<LOQ**	<LOQ	Recreation
8/28/2022	Below S Shore Rd (Hwy) bridge	2	4:20:00 PM	0.8	22.4	7.65	**75**	<LOQ	<LOQ	<LOQ	Recreation
8/28/2022	Below S Shore Rd (Hwy) bridge	1	4:20:00 PM	0.8	22.4	7.65	**80**	<LOQ	<LOQ	<LOQ	Recreation
8/28/2022	Greendale Trestle	1	3:50:00 PM	1.1	22.3	7.65	**79**	<LOQ	<LOQ	<LOQ	Recreation
8/28/2022	Greendale Trestle	2	3:50:00 PM	1.1	22.3	7.65	**101**	<LOQ	<LOQ	<LOQ	Recreation
8/28/2022	Little Beach	1	3:28:00 PM	2.8	22.4	7.65	**58**	<LOQ	**<LOQ**	<LOQ	Recreation
8/28/2022	Little Beach	2	3:28:00 PM	2.8	22.4	7.65	**61**	<LOQ	**1802**	<LOQ	Recreation
8/28/2022	500 m d/s TLCO	Blank	3:10:00 PM	3.8	NA	7.65	<LOQ	<LOQ	1988	<LOQ	Blank
8/28/2022	500 m d/s TLCO	1	3:10:00 PM	3.8	22.3	7.65	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/28/2022	500 m d/s TLCO	2	3:10:00 PM	3.8	22.3	7.65	<LOQ	<LOQ	<LOQ	<LOQ	WWTP
8/28/2022	Sandy Pool	1	12:58:00 PM	28	19.9	7.65	47*	<LOQ	**<LOQ**	<LOQ	Recreation
8/28/2022	Sandy Pool	2	12:58:00 PM	28	19.9	7.65	<LOQ*	<LOQ	**1627**	<LOQ	Recreation
9/8/2022	Little Beach	1	4:00:00 PM	2.8	21.8	7.42	**19.7**	**390.6**	<LOQ*	<LOQ*	Recreation
9/8/2022	Little Beach	2	4:00:00 PM	2.8	21.8	7.42	**16.9**	**522.6**	457*	26.2*	Recreation
9/8/2022	Sandy Pool	1	5:00:00 PM	28	19.8	7.42	**<LOQ**	**389.6**	490.7*	<LOQ	Recreation
9/8/2022	Sandy Pool	2	5:00:00 PM	28	19.8	7.42	**17.9**	**380**	192.2*	<LOQ	Recreation
9/8/2022	Wastewater effluent	1	3:32:00 PM	NA	22.1	7.42	**18.7**	**603.3**	**377**	**92.5**	WWTP
9/8/2022	Wastewater effluent	2	3:32:00 PM	NA	22.1	7.42	**16.4**	**579.1**	**481.5**	**96.6**	WWTP

Table 5. Ultraviolet Filter (UVF) concentrations (ng/L) in Cowichan Lake water at sites sampled in 2022.

Date	Location	Sample ID	Time	Water temperature (°C)	Oxybenzone (ng/L)	Enzacamene (ng/L)	Octinoxate (ng/L)	Octisalate (ng/L)	Group
7/11/2022	*Arbutus Park*	*1*	*12:10:00 PM*	*20*	*No results from lab*				*Beach*
7/11/2022	*Arbutus Park*	*2*	*12:10:00 PM*	*20*	*No results from lab*				*Beach*
7/11/2022	*Gordon Bay Provincial Park Beach*	*1*	*2:00:00 PM*	*20.5*	*No results from lab*				*Beach*
7/11/2022	*Gordon Bay Provincial Park Beach*	*2*	*2:00:00 PM*	*20.5*	*No results from lab*				*Beach*
7/11/2022	*Honeymoon Bay (Central Beach)*	*1*	*2:15:00 PM*	*22.8*	*No results from lab*				*Beach*
7/11/2022	*Honeymoon Bay (Central Beach)*	*2*	*2:15:00 PM*	*22.8*	*No results from lab*				*Beach*
7/11/2022	*Spring Beach*	*1*	*12:39:00 PM*	*20*	*No results from lab*				*Beach*
7/11/2022	*Spring Beach*	*2*	*12:39:00 PM*	*20*	*No results from lab*				*Beach*
7/24/2022	Arbutus Park	1	1:00:00 PM	21.3	<LOQ	<LOQ	<LOQ	<LOQ	Beach
7/24/2022	Arbutus Park	2	1:00:00 PM	21.3	<LOQ	<LOQ	<LOQ	<LOQ	Beach
7/24/2022	Gordon Bay Provincial Park Beach	2	3:15:00 PM	22.3	352*	<LOQ	**<LOQ**	**122**	Beach
7/24/2022	Gordon Bay Provincial Park Beach	1	3:15:00 PM	22.3	700*	<LOQ	**928**	**289**	Beach
7/24/2022	Honeymoon Bay (Central Beach)	1	2:55:00 PM	21.1	<LOQ	<LOQ	<LOQ	<LOQ	Beach
7/24/2022	Honeymoon Bay (Central Beach)	2	2:55:00 PM	21.1	<LOQ	<LOQ	<LOQ	<LOQ	Beach
7/24/2022	Spring Beach	1	1:35:00 PM	22.5	**62**	<LOQ	<LOQ	<LOQ	Beach
7/24/2022	Spring Beach	2	1:35:00 PM	22.5	**74**	<LOQ	<LOQ	<LOQ	Beach
8/1/2022	Arbutus Park	1	2:10:00 PM	22.1	**957**	<LOQ	<LOQ	**210**	Beach
8/1/2022	Arbutus Park	2	2:10:00 PM	22.1	**1344 +/- 34**	<LOQ	<LOQ	**249**	Beach
8/1/2022	Arbutus Park	Blank	2:10:00 PM	NA	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/1/2022	Gordon Bay Provincial Park Beach	1	2:00:00 PM	23.6	91*	<LOQ	3848*	631*	Beach
8/1/2022	Gordon Bay Provincial Park Beach	2	2:00:00 PM	23.6	<LOQ*	<LOQ	<LOQ*	109*	Beach
8/1/2022	Honeymoon Bay (Central Beach)	1	2:20:00 PM	23.4	<LOQ	<LOQ	<LOQ	<LOQ	Beach

8/1/2022	Honeymoon Bay (Central Beach)	2	2:20:00 PM	23.4	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/1/2022	Spring Beach	1	2:55:00 PM	24.5	<LOQ*	<LOQ*	<LOQ*	<LOQ*	Beach
8/1/2022	Spring Beach	2	2:55:00 PM	24.5	680 +/- 23*	4518*	17869*	1685*	Beach
8/14/2022	Arbutus Park	1	1:15:00 PM	21.6	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Arbutus Park	2	1:15:00 PM	21.6	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Arbutus Park	Blank	1:15:00 PM	NA	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/14/2022	Gordon Bay Provincial Park Beach	1	2:15:00 PM	22.8	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Gordon Bay Provincial Park Beach	2	2:15:00 PM	22.8	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Honeymoon Bay (Central Beach)	1	2:50:00 PM	22.5	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Honeymoon Bay (Central Beach)	2	2:50:00 PM	22.5	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Spring Beach	1	6:54:00 PM	21	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/14/2022	Spring Beach	2	6:54:00 PM	21	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Arbutus Park	1	12:48:00 PM	22.4	<LOQ	362*	<LOQ	<LOQ	Beach
8/21/2022	Arbutus Park	2	12:48:00 PM	22.4	<LOQ	<LOQ*	<LOQ	<LOQ	Beach
8/21/2022	Gordon Bay Provincial Park Beach	1	2:35:00 PM	22.3	121*	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Gordon Bay Provincial Park Beach	2	2:35:00 PM	22.3	<LOQ*	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Honeymoon Bay (Central Beach)	1	3:15:00 PM	22.8	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Honeymoon Bay (Central Beach)	2	3:15:00 PM	22.8	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Honeymoon Bay (Central Beach)	Blank	3:15:00 PM	NA	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/21/2022	Spring Beach	1	1:12:00 PM	23.2	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Spring Beach	2	1:12:00 PM	23.2	<LOQ	<LOQ	<LOQ	<LOQ	Beach
8/21/2022	Spring Beach	Blank	1:12:00 PM	NA	<LOQ	<LOQ	<LOQ	<LOQ	Blank
8/28/2022	Arbutus Park	1	1:48:00 PM	21.8	**21**	<LOQ	**<LOQ**	<LOQ	Beach
8/28/2022	Arbutus Park	2	1:48:00 PM	21.8	**<LOQ**	<LOQ	**1971**	<LOQ	Beach
8/28/2022	Gordon Bay Provincial Park Beach	1	2:00:00 PM	22.6	93*	<LOQ*	**1675**	1189*	Beach
8/28/2022	Gordon Bay Provincial Park Beach	2	2:00:00 PM	22.6	<LOQ*	1354*	**<LOQ**	51*	Beach
8/28/2022	Honeymoon Bay (Central Beach)	1	2:30:00 PM	23.1	<LOQ	<LOQ	**1706**	<LOQ	Beach
8/28/2022	Honeymoon Bay (Central Beach)	2	2:30:00 PM	23.1	<LOQ	<LOQ	**1520**	<LOQ	Beach
8/28/2022	Spring Beach	1	2:30:00 PM	22.6	<LOQ	<LOQ	**1511**	<LOQ	Beach
8/28/2022	Spring Beach	2	2:30:00 PM	22.6	<LOQ	<LOQ	**<LOQ**	<LOQ	Beach

<LOQ = Limits of Quantitation for CP-MIMS-LEI/CI; the highest LoQ for the specific date of analysis (see below). RPD>35% between duplicates marked with an asterisk.

Sampling Date	Oxybenzone	Enzacamene	Octinoxate	Octisalate
24-Jul	48	122	911	73
1-Aug	43	47	672	56
11-Aug	101	7	121	25
21-Aug	63	261	2383	26
28-Aug	15	930	1491	46
8-Sep	15	105	27	7

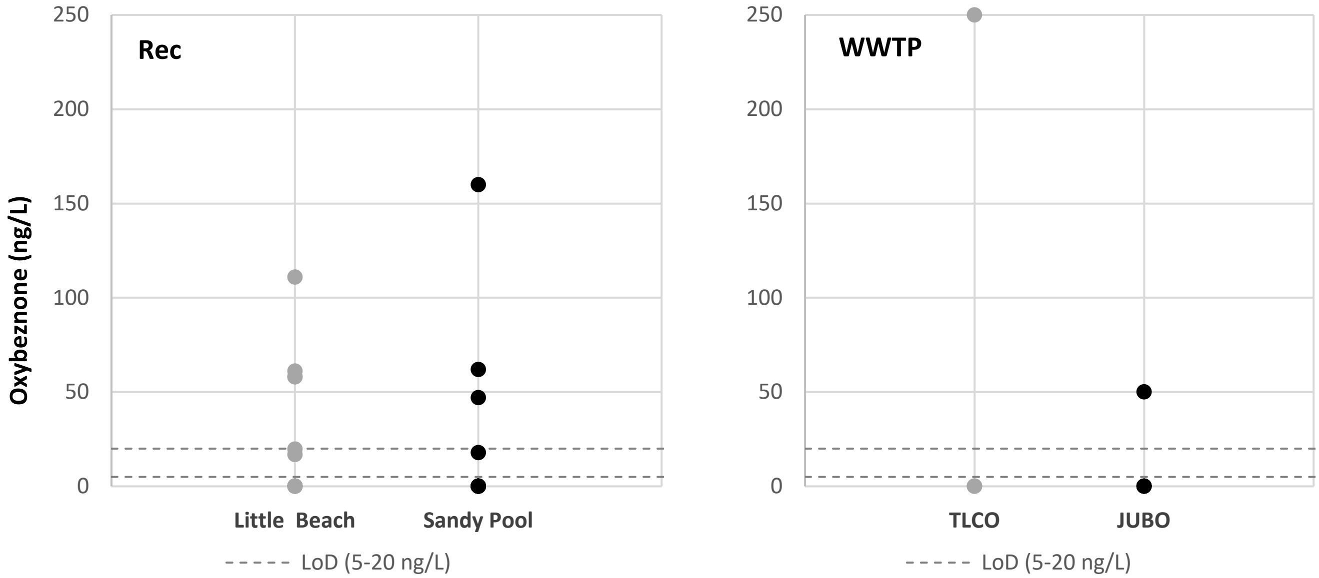

Figure 4. Comparison of oxybenzone results (ng/L) collected during the Year 3 sampling period only (July 24 to September 8, 2022) from Recreation (Little Beach (n=14) & Sandy Pool (n=12); left) and Wastewater (Town of Lake Cowichan outfall (n=10) & Joint Utility Board outfall (n=4); right) monitoring sites.

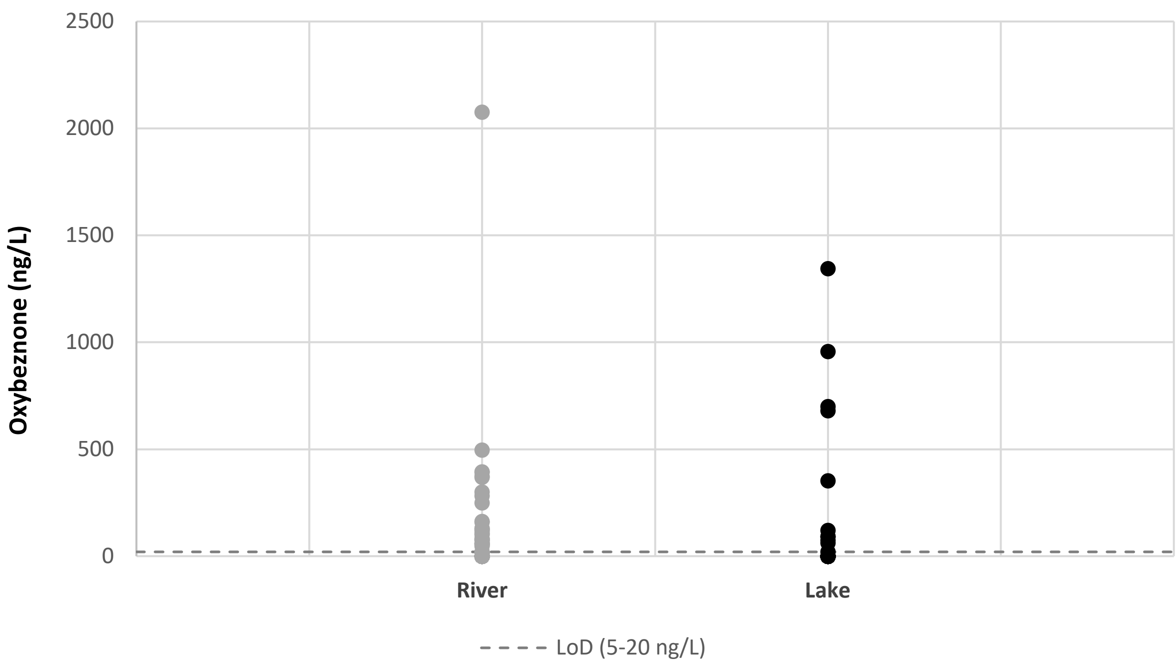

Figure 5. Comparison of oxybenzone results (ng/L) between River (n=87) and Lake (n=40) sites collected from the Cowichan watershed during the Year 3 sampling period only (July 24 to September 8, 2022).

Table 6. Maximum oxybenzone concentrations (ng/L), count of river swimmers and mean discharge at time of sampling in the Cowichan River at all sites sampled since 2019. Does not include wastewater adjacent sites.

		Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Maximum oxybenzone concentration (ng/L)	River (Recreation)	570	211	421	497
		n=3	*n*=36	*n*=60	*n*=85
Maximum count of people in water (#)		110	75	100	80
Mean River Discharge across sampling days (m^3/s)		4.5	7.3	6.1	7.9

Table 7. Maximum oxybenzone concentrations (ng/L), count of river swimmers and mean discharge at time of sampling in the Cowichan River at all sites sampled since 2019. Does not include recreational sites.

		Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Maximum oxybenzone concentration (ng/L)	River (WWTP)[1]	360	160	276	250
		n=1	*n*=19	*n*=13	*n*=24
Maximum count of people in water (#)		0	0	0	0
Mean River Discharge across sampling days (m^3/s)		4.5	7.3	5.9	7.3

[1] – Note: WWTP site (500 m d/s TLCO) is located < 5 km downstream from Little Beach (Recreation site).

Table 8. Maximum oxybenzone concentrations (ng/L) and count of beach swimmers at time of sampling in Cowichan Lake at all sites sampled since 2020 (no lake sites sampled in 2019).

		Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Maximum oxybenzone concentration (ng/L)	Lake	-	125	1,761	957
		n=0	*n*=5	*n*=28	*n*=48
Maximum count of people in water (#)		-	58	125	102

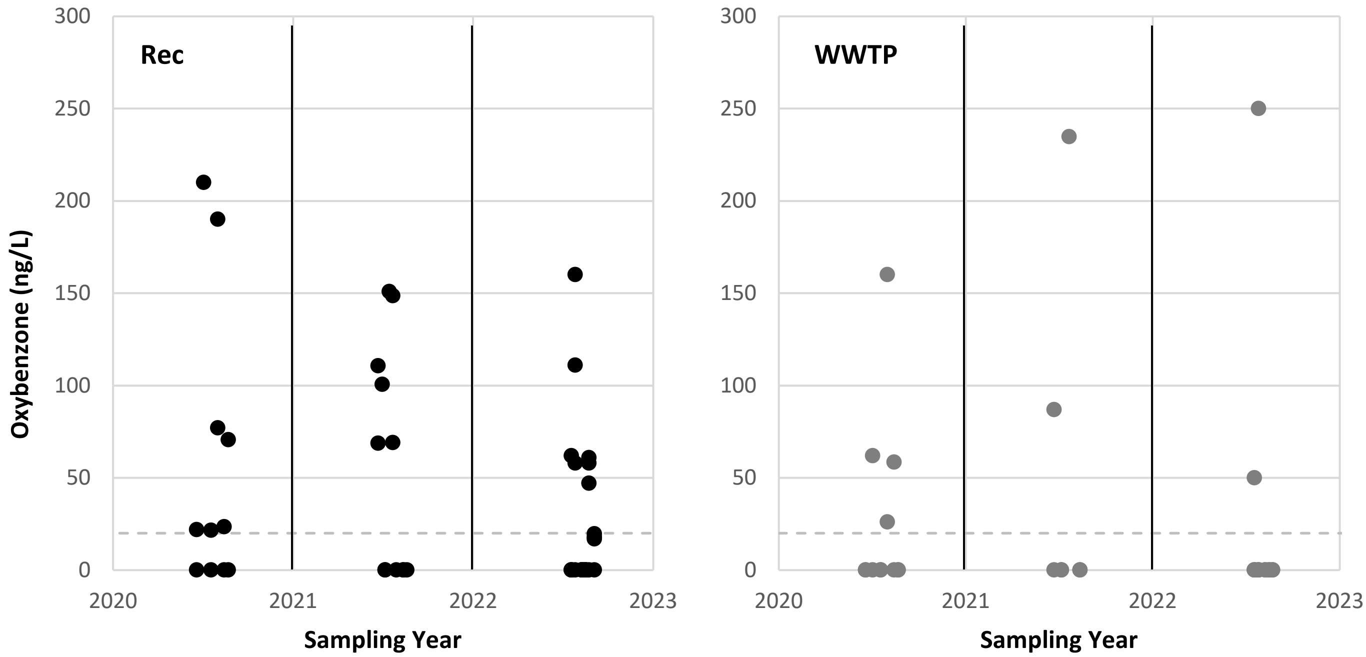

Figure 6. Comparison of oxybenzone concentrations (ng/L) between Year 1 (2020), Year 2 (2021) and Year 3 (2022), as collected from the same Recreation (Little Beach/Sandy Pool - left; n= 11, n=12 and n=12, respectively) and Wastewater (500 m ds TLCO/100 m ds JUBO - right; n=12, n=7 and n=14, respectively) monitoring sites. Dashed line shows average method limit of detection (LoD; 20 ng/L); values appearing as "0 ng/L" are <LoD.

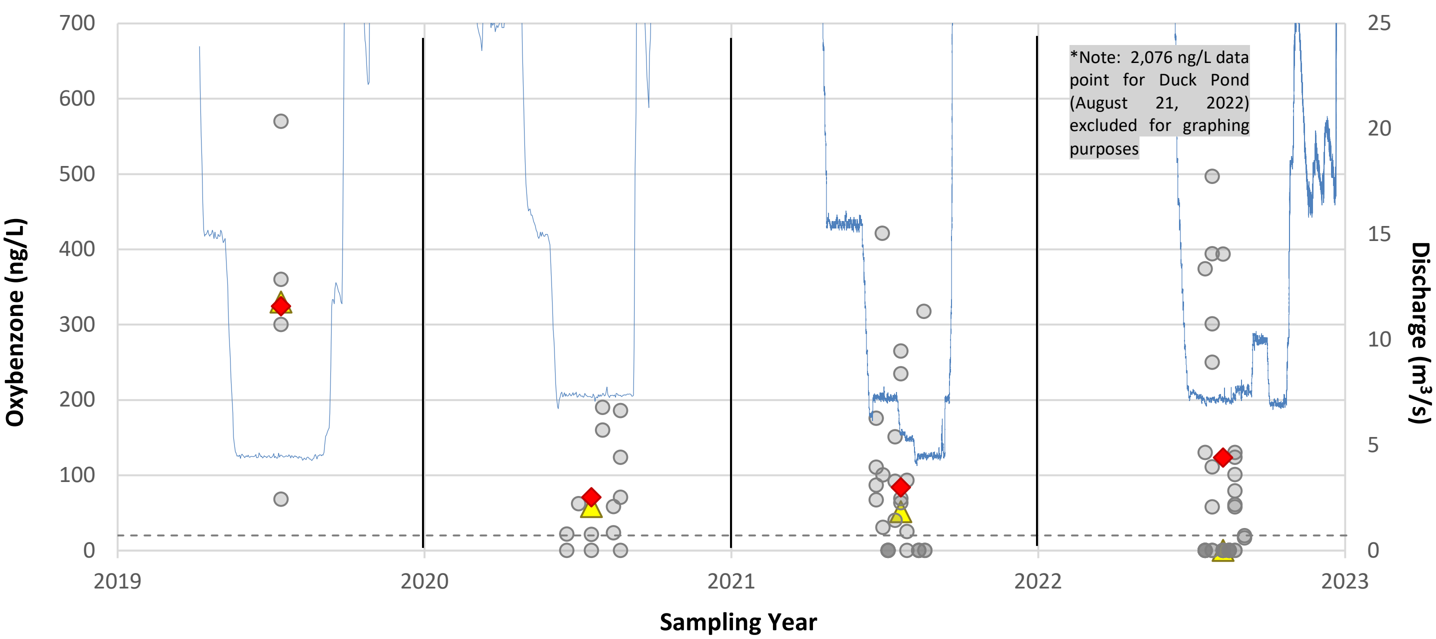

Figure 7. Oxybenzone concentrations (ng/L) as sampled across the same four sites in the upper Cowichan River, from the weir to 4 km below the weir (commonly referred to as the "Tubing Reach"), in 2019 (n=1 date per site), 2020 (n=1-6 dates per site), 2021 (n=4-8 dates per site), and 2022 (n=4 to 6 dates per site), shown in gray (left-hand y-axis). Mean across all samples shown as red diamond (left-hand y-axis); median shown as yellow triangle. Daily river discharge (m^3/s) for "Cowichan River at Lake Cowichan" (08HA002) shown in blue (right-hand y-axis). Dashed line shows average method limit of detection (LoD; 20 ng/L); values appearing as "0 ng/L" are <LoD.

4.3 Public Outreach

4.3.1 Year 3 Results

An outreach booth was set up on 11 dates throughout Year 3, on weekends from July 18 to August 27, 2022, with the goal of connecting with beach users face-to-face and sharing educational information. Additionally, roaming outreach occurred on 5 dates throughout Year 3, on weekends and weekdays from August 22 to August 29, 2022 at Arbutus Park, Saywell Park, Duck Pond, and Spring Beach.

A total of 299 people were spoken to during outreach in Year 3. Outreach involved face-to-face contact and communication with visitors to the swimming areas. The number of people spoken with varied based on the day of outreach, but ranged from 2-40 per day. An additional 160 people were reached through display and outreach support materials, but not directly spoken to about UVFs or the project goals. A summary of outreach numbers is in Table 9.

Table 9. Outreach impact during Year 3 (2022).

<table>
<tr><th></th><th>Adults spoken to</th><th>Adults stopped to look (not spoken to)</th><th>Youth spoken to</th><th>Youth stopped to look (not spoken to)</th><th>Number of free samples distributed</th><th>Survey responses received</th></tr>
<tr><td>Booth</td><td>145</td><td>40</td><td>56</td><td>120</td><td>45</td><td rowspan="3">87 paper / 17 online</td></tr>
<tr><td>Roaming</td><td>98</td><td>N/A</td><td>0</td><td>0</td><td>26</td></tr>
<tr><td>Total</td><td>243</td><td>40</td><td>56</td><td>120</td><td>66</td></tr>
</table>

The most effective event/location for a booth setup (i.e., the location with the most face-to-face engagements) was the Honeymoon Bay Market in Year 3 (43 people spoken to, approximately 11 people per hour). The least effective location was the Duck Pond (2 people spoken to, approximately 1 per hour).

Roaming outreach did reach fewer people overall (Table 9), but roaming successfully reached a greater number of people relative to the unit time spent (average of 9 people per hour) compared to the booth setup (average of 4 people per hour). Additionally, there were fewer total roaming days (n=5) than booth days (n=11) in Year 3.

Overall, the best performing outreach event was roaming at the Tube Shack/Saywell Park and Gordon Bay between 11:30 AM – 2:00 PM on August 23, 2022 (average of 16 people per hour).

4.3.2 Public Questionnaire

In Year 3, a total of 104 public questionnaires were received, on 12 different dates (Appendix A; Fig. A1). Questionnaire responses came from Arbutus Park beach, Gordon Bay Provincial Park beach, Youbou Market, Saywell Park, the Kinsmen Duck Pond, Honeymoon Bay beach, Sandy Pool, and the Tube Shack dock, as well as online submissions.

The majority of respondents were not wearing UPF clothing (66%) (Fig. A2). The majority (68%) of respondents assessed themselves as wearing sunscreen (Fig. A3). The most common amount of time waited between sunscreen application and bathing was 15 or fewer minutes (25%) (Fig. A4), followed by

30 minutes (23%). 71% of respondents felt they were aware of the environmental impacts of sunscreen use on the environment (Fig. A5). The main motivation for sunscreen product selection was Protection Factor for 52% of respondents, followed by personal health & safety (9%) and sensitive skin concerns (9%) (Fig. A6).

The total number of products assessed for active ingredient analysis was n=58 (Fig. A7). A total of 37% (n=21) contained Zinc Oxide as the primary ingredient. Only 14% (n=8) contained oxybenzone in the ingredients list; 0% (n=0) contained enzacamene, 3% (n=2) contained octinoxate, and 55% (n=32) contained octisalate. The breakdown was 61% (n=36) Chemical, 37% (n=21) Physical, and 2% (n=1) blend of both types of UVFs (Fig. A8).

The most common chemical UVF blend (i.e., non-physical) sunscreens contained a mix of Homosalate, Octocrylene, Octisalate and Avobenzone, in varying percentages. The most common sun protection factor rating was SPF 50 (Fig. A8), with the most common product application strategy being a cream (65%) vs an aerosolized spray (35%) (Fig. A9). Re-application times varied by respondent, but the most common re-application frequency was once per day (Fig. A10).

4.4 Recreation Monitoring

4.4.1 Year 3 Results

8 river sites and 4 lake sites were monitored on 8 dates in Year 3 (2022). The maximum number of in-water users observed during sample collection was 102 people swimming at Gordon Bay Provincial Park Beach on July 11, 2022 at ~ 2:00 PM – unfortunately, this set of samples were not analyzed by the lab, and thus fall outside of the Year 3 sampling window (July 24 – September 8, 2022). The second-highest observed number of in-water users was 80 people swimming/floating at the Little Beach tubing takeout on August 14, 2022 at ~ 2:45 PM.

Approximately 77% (n=63) of sites monitored had in-water users at the time of sampling, whereas 23% (n=19) had no in-water users at time of sampling (Table 11).

4.4.2 Annual Variation

In Year 3 (2022), the total number of engagements at the Cowichan Lake Visitor Center (CLVC) was just over 3,000 people; similarly, just over 3,000 people were engaged via the Chamber of Commerce's mobile outreach wagon, which continued to operate separate from the CLVC in Year 3. Total in-person engagements in Year 3 declined relative to past years: amounting to roughly 78% of engagements in Year 2, 61% of engagements in Year 1, and 12% of engagements in the project Seed year (Table 10)[1].

Table 10. Cowichan Lake Visitor Center and mobile outreach wagon engagements from 2019 – 2022[1].

	Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Visitor Center	35,125	9,945	2,866	3,143
Mobile Wagon	16,920	337	5,126	3,129
Total	**52,045**	**10,282**	**7,992**	**6,272**

[1] – Data supplied by the Cowichan Lake District Chamber of Commerce (K. Worsley, pers. comm., Feb 2021/2022/2023).

Table 11. In-water counts of recreational users at time of sample collection during Year 3.

RIVER

Date	Location	Time	# users
6/19/2022	*Little Beach*	*3:00:00 PM*	*0*
6/19/2022	*Sandy Pool*	*3:40:00 PM*	*0*
7/11/2022	*Tube Shack*	*2:47:00 PM*	*7*
7/11/2022	*Duck Pond*	*3:00:00 PM*	*27*
7/11/2022	*Below S Shore Rd bridge*	*3:16:00 PM*	*31*
7/11/2022	*Greendale Trestle*	*3:35:00 PM*	*10*
7/11/2022	*Little Beach*	*3:49:00 PM*	*41*
7/11/2022	*500 m d/s TLCO*	*4:07:00 PM*	*0*
7/11/2022	*Sandy Pool*	*4:55:00 PM*	*4*
7/24/2022	Duck Pond	2:05:00 PM	24
7/24/2022	Below S Shore Rd bridge	11:55:00 AM	32
7/24/2022	Greendale Trestle	12:13:00 PM	2
7/24/2022	Little Beach	12:30:00 PM	16
7/24/2022	500 m d/s TLCO	12:47:00 PM	0
7/24/2022	Sandy Pool	1:38:00 PM	5
7/24/2022	Quamichan Rd	4:30:00 PM	0
7/24/2022	Tube Shack	2:30:00 PM	34
8/1/2022	Tube Shack	2:11:00 PM	15
8/1/2022	Duck Pond	2:45:00 PM	12
8/1/2022	Below S Shore Rd bridge	2:26:00 PM	58
8/1/2022	Greendale Trestle	2:43:00 PM	9
8/1/2022	Little Beach	2:57:00 PM	22
8/1/2022	500 m d/s TLCO	3:11:00 PM	0
8/1/2022	Sandy Pool	3:50:00 PM	3
8/1/2022	Quamichan Rd	5:19:00 PM	0
8/14/2022	Tube Shack	3:48:00 PM	11
8/14/2022	Duck Pond	3:20:00 PM	10
8/14/2022	Below S Shore Rd bridge	16:30-16:40	27
8/14/2022	Greendale Trestle	4:55:00 PM	10
8/14/2022	Little Beach	14:40-14:50	80
8/14/2022	500 m d/s TLCO	14:08-14:17	0
8/14/2022	Sandy Pool	1:17:00 PM	3
8/21/2022	Tube Shack	1:39:00 PM	47
8/21/2022	Duck Pond	2:00:00 PM	20
8/21/2022	Below S Shore Rd bridge	1:52:00 PM	42
8/21/2022	Greendale Trestle	2:08:00 PM	20
8/21/2022	Little Beach	2:27:00 PM	32
8/21/2022	500 m d/s TLCO	2:41:00 PM	0
8/21/2022	Sandy Pool	3:16:00 PM	3
8/28/2022	Tube Shack	4:05:00 PM	7
8/28/2022	Duck Pond	3:05:00 PM	15
8/28/2022	Below S Shore Rd bridge	4:20:00 PM	30
8/28/2022	Greendale Trestle	3:50:00 PM	12
8/28/2022	Little Beach	3:28:00 PM	27
8/28/2022	500 m d/s TLCO	3:10:00 PM	0
8/28/2022	Sandy Pool	12:58:00 PM	0
9/8/2022	Little Beach	4:00:00 PM	4
9/8/2022	Sandy Pool	5:00:00 PM	0

LAKE

Date	Location	Time	# users
7/11/2022	*Arbutus Park*	*12:10:00 PM*	*27*
7/11/2022	*Gordon Bay Provincial Park Beach*	*2:00:00 PM*	*102*
7/11/2022	*Honeymoon Bay (Central Beach)*	*2:15:00 PM*	*6*
7/11/2022	*Spring Beach*	*12:39:00 PM*	*5*
7/24/2022	Arbutus Park	1:00:00 PM	2
7/24/2022	Gordon Bay Provincial Park Beach	3:15:00 PM	45
7/24/2022	Honeymoon Bay (Central Beach)	2:55:00 PM	15
7/24/2022	Spring Beach	1:35:00 PM	2
8/1/2022	Arbutus Park	2:10:00 PM	25
8/1/2022	Gordon Bay Provincial Park Beach	2:00:00 PM	50
8/1/2022	Honeymoon Bay (Central Beach)	2:20:00 PM	15
8/1/2022	Spring Beach	2:55:00 PM	2
8/14/2022	Arbutus Park	1:15:00 PM	16
8/14/2022	Gordon Bay Provincial Park Beach	2:15:00 PM	60
8/14/2022	Honeymoon Bay (Central Beach)	2:50:00 PM	0
8/14/2022	Spring Beach	6:54:00 PM	0
8/21/2022	Arbutus Park	12:48:00 PM	13
8/21/2022	Gordon Bay Provincial Park Beach	2:35:00 PM	50
8/21/2022	Honeymoon Bay (Central Beach)	3:15:00 PM	2
8/21/2022	Spring Beach	1:12:00 PM	14
8/28/2022	Arbutus Park	1:48:00 PM	6
8/28/2022	Gordon Bay Provincial Park Beach	2:00:00 PM	50
8/28/2022	Honeymoon Bay (Central Beach)	2:30:00 PM	3
8/28/2022	Spring Beach	2:30:00 PM	11

* Locations in italics did not have corresponding water samples analyzed by lab

Note: the CLVC changed operation from the Chamber of Commerce to the Town of Lake Cowichan in 2022, and was only operational from May to September[1]. Visitation trends for Year 3 suggest that total engagements peaked in July and August (Fig. 9), as expected for this lakeside destination community. It appears that visitations shifted slightly relative to pre-COVID 19 restrictions, peaking later in the season (August) as opposed to July (Figs. 8a, 8b)[2].

Tube rentals from the Tube Shack local business decreased in Year 3 relative to Year 2[3], suggesting the upper 4 km of the Cowichan River could have had a lower proportion of UVF inputs relative to past project years (Table 12). The business provided approximately 14 L of Stream2Sea "reef-safe" (oxybenzone-free) sunscreen to customers in Year 3[3]. Compared to the project Seed year (2019) when tube shack business was focused primarily on weekends, project Year 1 through Year 3 (2019-2022) saw steady visitation throughout the week and weekends[3].

Table 12. The Tube Shack visitor engagement and reef-safe sunscreen use from 2019 – 2022[3].

	Seed 2019	Year 1 2020	Year 2 2021	Year 3 2022
Total change year-to-year	Baseline year	+60%	+14%	-23%
Litres of Stream2Sea sunscreen used	No data	No data	19	14

Across all dates of monitoring, the average count of in-water users at River sites was 9 people (n=55) in Year 1; 17 people (n=66) in Year 2; and 16 people in Year 3 (n=48). This amounted to a net increase of nearly 1.9x from Year 1 to Year 2, and a net decrease of 0.9x from Year 2 to Year 3.

There is insufficient data to compare in-water users at Lake sites between Year 1 and Year 2; however, the average count of in-water users was 24 people in Year 2 (n=31), and 22 people in Year 3 (n=24). Similar to the River sites, this is a net decrease of 0.9x from Year 2 to Year 3.
Overall, Lake sites were approximately 1.4x busier than River sites, in both Year 2 and Year 3.

1 – Data supplied by the Cowichan Lake District Chamber of Commerce (K. Worsley, pers. comm., Feb 2021/2022/2023).

2 – Data retrieved from the Tourism BC statistics for the Town of Lake Cowichan Visitor Center (https://www.networkstats.tourismbc.com/ReportDefinition.aspx).

3 – Data supplied by the Tube Shack (A. Frisby, pers. comm., Sept. 2020/Feb 2021/Feb 2022/Feb 2023).

a)

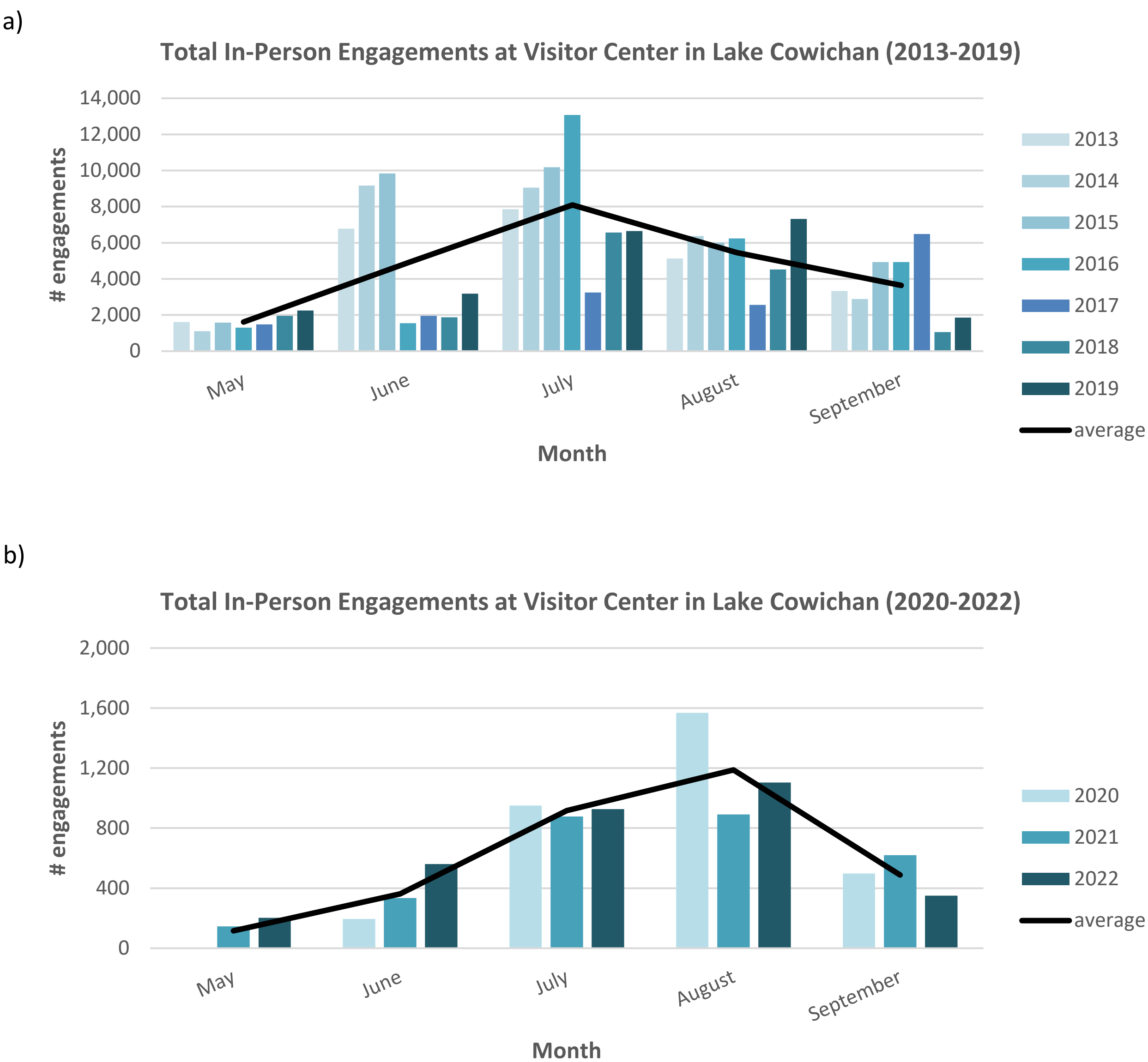

Figure 8. Total engagements at the Town of Lake Cowichan Visitor Center, for: a) the historical period with available data pre-COVID 19 restrictions (2013-2019), and b) the project Year 1 (2020) through Year 3 (2022)[1].

[1] – Data retrieved from the Tourism BC statistics for the Town of Lake Cowichan Visitor Center (https://www.networkstats.tourismbc.com/ReportDefinition.aspx).

4.5 Sediment Sampling

Continued method development for sediment analysis occurred in Year 3. Loading tests and exploratory analysis for oxybenzone in sediments were performed. This built upon the method development from Year 2.

A total of 13 sediment samples were collected from 5 River and 3 Lake sites in Year 3 and provided to VIU-AERL for exploratory analysis by both CP-MIMS LEI/CI and GC-MS. No oxybenzone signal was reliably detected in any of the sediment samples submitted to VIU-AERL, which suggests a sediment concentration of less than 10 – 20 µg/kg based on the earlier calibration tests and loading results (Aplin et al. 2023). The extraction efficiency could be lower in real-world sediments than in loading tests, however further analysis was beyond the scope of the lab method and agreement.

In Year 3, more sediment samples were collected that had a fine fraction (e.g. silt, mud, organics) compared to Year 2, however no physical analysis of grain size or % moisture was completed due to funding constraints. Grain size assessment was limited to qualitative descriptions (Table 13).

Table 13. Sediment samples collected in Year 3 (2022).

Date	Time	Location	Sample ID	Description (dominant grain size)
6/19/2022	3:30 PM	Sandy Pool	1	Sand
6/19/2022	2:45 PM	Little Beach	2	Sand & small gravel
8/14/2022	1:17 PM	Sandy Pool	3	Sand
8/14/2022	1:21 PM	Sandy Pool	4	Sand
8/14/2022	2:45 PM	Little Beach	5	Sand & small gravel
8/14/2022	2:50 PM	Little Beach	6	Silty Mud & organics
8/14/2022	2:15 PM	500 m d/s TLCO	7	Silty sand
8/14/2022	2:20 PM	500 m d/s TLCO	8	Mud & Organics
8/14/2022	3:48 PM	Tube Shack	9	Silty sand
8/14/2022	4:30 PM	Below S Shore Rd (Hwy) bridge	10	Sand
8/14/2022	6:54 PM	Spring Beach	11	Small gravel
8/14/2022	6:15 PM	Arbutus Park	12	Sand
8/14/2022	2:00 PM	Gordon Bay	13	Sand & small gravel

The n-Octanol/Water partition Coefficient (K_{OW}) of a compound – usually expressed as $\log K_{ow}$ – is a relative indicator of the tendency of an organic compound to adsorb to sediments, particulate matter, or living organisms. LogK_{ow} values "are generally inversely related to water solubility, and proportional to the molecular weight of a substance" (ChemSafetyPro 2016). Some properties of the four UVFs analyzed in Year 3 are presented in Table 14, including the $\log K_{OW}$.

Table 14. Chemical properties of the UVFs analyzed in Year 3.

UV FILTER	Molecular Formula	Average molecular weight MW	logKow[1]	pKa [2]	Bio-concentration Factor (BCF) [1]	Atmospheric Oxidation: Hydroxyl Radicals Reaction (@ 25 deg C), Half-Life (12-hour day) [1]	Volatilization from Water: Half-life Model River [1]	Volatilization from Water: Half-life Model Lake [1]	Removal in Wastewater Treatment [1]
		g/mol				*Hours (Days)*	*Hours (Days)*	*Hours (Days)*	*Total sludge adsorption (Total Removal)*
Oxybenzone	$C_{14}H_{12}O_3$	228	3.8	7.56	24	0.639 (0.053)	58,970 (2,457)	643,400 (26,810)	21.22% (21.47%)
Enzacamene	$C_{18}H_{22}O$	253	5.9	--	7,224	1.443 (0.120)	436 (18.2)	4890 (203.7)	91.01% (91.78%)
Octinoxate (Octyl methoxycinnamate)	$C_{18}H_{26}O_3$	289	5.8	--	5,856	2.483 (---)	119.4 (4.9)	1,445 (60.2)	90.31% (91.08%)
Octisalate (Octyl salicylate)	$C_{15}H_{22}O_3$	249	5.9	8.13	7,856	5.882 (0.490)	29.7 (1.2)	426.5 (19)	91.22% (92.03%)

[1] - ChemSpider, via Aplin et al. 2023

[2] - Wu et al. 2013, via Aplin et al. 2023

4.6 Wastewater Effluent Sampling

Year 3 (2022) was the first year we were able to sample treated wastewater effluent discharged from the Town of Lake Cowichan wastewater treatment plant. Unfortunately, two of the four samples collected were not analyzed by the lab (July 8, July 11). One sample, collected by a volunteer (August 1), was successfully analyzed but contained a contaminated field blank (with a hit for octisalate), and no result for any of the four UVFs tested in the vials labelled as effluent samples. The other successfully analyzed sample, collected by BCCF staff (September 8) had results for all four UVF compounds (Table 15), with RPDs between duplicates of 4.09 – 24.34%.

Table 15. Wastewater effluent sampling at the Town of Lake Cowichan wastewater treatment plant in 2022.

Date	Time	Sampler	Duplicate	Temperature (deg C)	Oxybenzone (ng/L)	Enzacamene (ng/L)	Octinoxate (ng/L)	Octisalate (ng/L)
7/8/2022	1:30 PM	BCCF	1 & 2	21.0	*Not able to be analyzed by lab*			
7/11/2022	1:20 PM	BCCF	1 & 2	20.3	*Not able to be analyzed by lab*			
8/1/2022	8:00 AM	Volunteer	1	24.0	<LoQ	<LoQ	<LoQ	<LoQ
8/1/2022	8:00 AM	Volunteer	2	24.0	<LoQ	<LoQ	<LoQ	<LoQ
8/1/2022	8:00 AM	Volunteer	Field Blank	24.0	<LoQ	<LoQ	<LoQ	109 +/- 7
9/8/2022	3:32 PM	BCCF	1	22.1	18.7	603.3	377	92.5
9/8/2022	3:32 PM	BCCF	2	22.1	16.4	579.1	481.5	96.6

4.7 Fish Sampling

The CP-MIMS-LEI/CI method has not proven to be applicable for tissue analysis, due to the high levels of fatty acids that have been found to damage the instrumentation. Sample pre-treatment to lower the fatty acid permeability is not an option due to the acid dissociation constants of the molecules in question limiting their recovery post-treatment (Aplin et al. 2023).

Alternate analysis methods using GC-MS were explored in Year 3 (2022), although they were outside of the scope of the standard VIU-AERL methods. Tissue samples from fish collected in Year 1 and Year 2 were provided to VIU-AERL for scoping and method development. Tissue samples showed weak or unstable signal intensity for the four target UVFs, unless loaded with a standard in the lab during the membrane extraction (Aplin et al. 2023).

No additional fish samples were collected in Year 3 due to the low recovery from historical frozen samples. Past samples collected have been summarized in the Year 1 and Year 2 reports.

5.0 DISCUSSION

To understand the potential impacts of contaminants, it is necessary to understand their sources and sinks within an aquatic ecosystem (Bashir et al. 2020). A confirmed, direct source of UVF contamination to the Cowichan River ecosystem is recreational use, while an indirect source is wastewater (Rodgers et al. 2021, Rodgers et al. 2022). Potential sinks or sources for degradation of UVF contamination include transport and/or transformation in air or water, adsorption to sediment, and/or uptake by biota.

5.1 Results to Date

In Year 1 (2020), we demonstrated that despite being a potential sink for oxybenzone, there was no build-up over time within the water of the Cowichan River; status remained unknown for swim beaches around Cowichan Lake and for other UVFs of concern. Although there was a very small sample size and high variance, we demonstrated a strong correlation between recreational swimming activity and the presence of oxybenzone in the water. Additionally, we demonstrated consistently little- to no- detection of oxybenzone downstream of the Joint Utility Board (JUB) wastewater treatment outfall in the City of Duncan. However, detection of oxybenzone was notable downstream of the Town of Lake Cowichan wastewater treatment outfall (TLCO). It was undetermined whether this was due to the TLCO directly, or caused by recreational activity upstream.

In Year 2 (2021), we continued to describe the presence and variability of oxybenzone throughout the watershed to build a baseline understanding of contamination in both river and lake water. We demonstrated there is a consistent presence of oxybenzone in recreational areas throughout the summer, but no gradual build-up of oxybenzone within the water column of either Cowichan River or Cowichan Lake.

Also in Year 2, we deployed a trial public questionnaire to better understand the use habits and barriers to adoption of river-friendly sun protection products by the public; through this questionnaire, we found that respondents strongly prefer creams and aerosolized sprays over bars, sticks or other methods of sunscreen application; many respondents waited 5 minutes or fewer after applying sunscreen before entering the water; and, two of the main factors considered when choosing a sun protection product were price and perception of personal safety. We also demonstrated there was a strong correlation between ambient air temperature and recreational use at lake and river recreational sites, with air temperatures above 28°C having the greatest potential influence on recreational use. We continued to add to our database of information about oxybenzone in the watershed, and method development progressed with the lab at VIU-AERL.

In Year 3 (2022), we aimed to continue describing the presence and variability of oxybenzone, as well as the UVFs enzacamene, octinoxate, and octisalate in water, for both Cowichan River and Cowichan Lake. We also aimed to determine whether oxybenzone or the other UVFs were detectable in a variety of river sediment, lake sediment, or fish tissue.

Below, we discuss the progress made towards these objectives and some of the specific results obtained in Year 3. We also address aspects of ongoing method development at VIU-AERL, some emerging studies about risks to aquatic life, and we provide updated information about contaminant regulations that have been applied around the world. Finally, we provide a synthesis of recommendations for continued project work in Year 4 (2023) and Year 5 (2024) in the form of a Mitigation Action Plan.

5.2 River Discharge & Precipitation

River discharge and water temperature data reflect the cool and wet spring and early summer season experienced across the east coast of Vancouver Island in Year 3. After the cool spring, a significant period of drought extended late into October. However, water levels remained above 7 m^3/s for the majority of the recreation season. Mean daily river discharge in August was similar to that seen in 2020, which was roughly 30% higher than in 2021. This may have been a contributing factor to the different oxybenzone results observed between years, as higher river discharge has greater potential to dilute contaminant inputs (Turunen et al. 2020).

Precipitation was also greater during the Year 3 sampling period than the Year 2 sampling period. Average summer precipitation is not expected to alter river discharge significantly due to flow control at the Cowichan Lake weir, but precipitation and air temperature both impact users' willingness to sunbathe or recreate in water, as well as users' perceived need to wear sunscreen when outdoors (Turrisi et al. 1999).

Historical data (2000 – 2019) indicates the mean daily discharge for the Cowichan River is lowest throughout the months of July – September, with August typically experiencing the lowest discharge (ECCC 2021a). This coincides with the occurrence of drought, high air temperatures, high UV index, and peak summer tourism in the Town of Lake Cowichan (ECCC 2021b; K. Worseley, pers. comm, Feb 2022).

5.3 Water Quality

In Year 3, water samples were collected with volunteer support. Unfortunately, due to instrument delays in early summer, the first three sample deliveries were not run by the lab.

Spatially, the highest concentrations of oxybenzone were detected at swim beaches around the lake and at sites in the upper river where recreation is concentrated. Studies worldwide have found that sunscreen by-products do accumulate in recreational swimming areas, and describe a contaminant "plume" which decreases with distance from the swimming area (Downs et al*.,* 2022; Labille et al*.,* 2020; Torres-Bejarano et al*.,* 2018).

Mean oxybenzone results were highest for swim beaches around Cowichan Lake, however the maximum point-in-time result was obtained from the Cowichan River at the Duck Pond (2,076 ng/L). This particular sample exceeded the 35% RPD threshold. The next highest point-in-time result was obtained from the Arbutus Park swim beach (1,344 ng/L) and had a RPD within threshold of 33.6%.
Other studies worldwide have reported oxybenzone values in the range of 0.3 – 5,390 ng/L in river water (up to 44,000 in vicinity of wastewater treatment plants (WWTP); 0.8 – 200 in lake water; 4 – 4,500 ng/L in swimming pool water; and 10 – 9,900 ng/L in shower water (Ramos et al. 2015). Values above 1,000 ng/L are typically associated with either direct recreational inputs, or WWTP discharges (Ramos et al. 2015).

The maximum results for enzacamene, octinoxate, and octisalate were all from the same sample (collected August 1, 2022 from Spring Beach Recreation Site). Unfortunately, this was an unreliable sample due to the high RPD% between duplicates (195.9%, 185.5%, and 187.1%, respectively). While high RPD could be due to sample contamination, it could also be due to environmental heterogeneity (CCME 2016). There may be stronger differences due to environment heterogeneity than previously expected. The small sample size of the 150 mL vials may further exacerbate this issue. Future comparison sampling could make use of a larger sample volume to see if the improves the high RPD between duplicates.

5.3.1 Comparison to past results

Across all water samples, the maximum oxybenzone concentration collected in Year 3 (2,076 ng/L) was slightly (~1.2x) greater than the maximum collected in Year 2 (1,760 ng/L), more than 9 times the maximum collected in Year 1 (211 ng/L), and more than 3 times the maximum collected in the project Seed year (570 ng/L). This result could have been influenced by the adjusted sampling plan developed for Years 2 and 3 (adjusted to capture peak use times, and more samples collected from Lake sites).

These differences can also be influenced by several other factors, including a smaller sample size in the Seed year, higher peak visitation clustered around weekends in the Seed year (pre-COVID-19 pandemic), changes to visitation trends since Year 1 due to COVID-19 pandemic restrictions, and variations in river discharge between years.

Year-to-year variation in weather patterns likely impacts the input and degradation of UVFs in the Cowichan River ecosystem as weather can influence recreational use and other environmental factors that affect molecule degradation (e.g., solar intensity) (Carstensen et al. 2022). Oxybenzone concentrations were observed to fluctuate significantly, both within and between sampling years.

Past findings suggest oxybenzone does not accumulate within the water column of the Cowichan River; the processes of molecule degradation were described in detail in the Year 1 report (Rodgers et al. 2021) in section 5.1.6. This was observed again in Year 2, at both River and Lake sites in the Cowichan watershed, giving confidence to the assumption that oxybenzone does not accumulate within the water column over time. While oxybenzone appears to have the lowest potential for removal via WWTP activity (Table 14), we did not find strong evidence of WWTP effluent as a source of oxybenzone inputs to the watershed.

5.3.2 Quality Assurance

The high variation in oxybenzone results can be attributed to a number of factors, including but not limited to: varied inputs over time (e.g., fluctuating numbers of people wearing oxybenzone-containing sunscreens), varied mixing within the water column (potentially influenced by site characteristics, river discharge, water temperature, human disturbances, etc.), and human error (e.g., having multiple samplers across multiple sites).

We attempted to understand the potential variation in ingredients by administering and collecting public surveys at select sampling locations (Appendix A); to control for mixing conditions by selecting a consistent sampling depth (30 cm) and location (middle of swim area (Lake), or downstream of target location as close to the point of obvious mixing as possible (River); and to control for human error by providing volunteer sample training, utilizing a standardized sampling protocol, and providing the same equipment, data sheets, and site directions to volunteers.

5.3.3 Quality Control

As addressed in Year 1, small sample sizes can skew results in favour of strong correlations. There is some difficulty in assessing results for the Cowichan watershed due to small sample sizes, different sampling designs and different analysis methods between project years.

Field blank samples were collected to determine the existence or magnitude of any contamination problem associated with sample containers, collection, handling, and transport (BC Ministry of Environment 2013). While three field blanks did present with a detectable result indicative of contamination, these were isolated to river sites only (no lake sites) which suggests there could be an environmental factor at play. Further isolated and trial tests with multiple field blanks is recommended to accompany any future sampling.

Duplicate samples were collected to measure the precision of sampling analysis, and environmental heterogeneity; a large difference between duplicate results usually indicates samples may not have been representative of the background water (BC Ministry of Environment 2013). Duplicates not close in value could indicate either: a) the compound was not adequately mixed throughout the water column during sampling, b) contamination between samples had occurred, or c) the analysis method was inaccurate between samples.

A threshold relative percent difference (RPD) of 35% was assigned to duplicate samples. RPD values >20% usually indicate a possible problem and >50% a definite problem, most likely either contamination or lack of sample representativeness (BC Ministry of Environment 2013). The moderate and high RPD for duplicate samples in Year 3 indicates a possible sample contamination, uneven mixing at time of sample collection, or variation in the analysis method. While in Year 2 (2021), duplicate samples collected from Cowichan Lake tended to have lower RPD (0-1%) than duplicates from the river (7-35%), the same was not true for Year 3 (Lake RPD from 1 – 196%; River RPD from 2 – 188%).

Further review of possible contamination and duplicate comparison scenarios are currently underway at the lab at VIU-AERL.

5.4 Recreation Monitoring

Data were requested from the Cowichan region public parks and campgrounds via BC Parks, but no data was supplied in time for publication in the report. Using results from the Chamber of Commerce data and the Tube Shack business, we can interpret an overall trend for recreational use in the summer. It appears that visitations to the region were highest in 2019, followed by 2021, 2022, and 2020 (in that order). The differences in visitation numbers could be related to lasting impacts from COVID-19 restrictions, a change in general visitation behaviour over time, or changes in the operation and location of the CLVC.

In past project years, the influence of air temperature on recreational behaviour highlighted the importance of sampling during anomalous periods of high air temperature that may fall outside of the standard summer sampling window (e.g., the "heat dome" event in June 2021). This may also help narrow target sampling times in order to capture peak instantaneous UVF inputs in future years.

In future, several factors will dictate total recreational pressure experienced in the watershed – including weather patterns and public health measures (e.g., travel restrictions, border closures). However, data from the past two years indicates that popular swim beaches around Cowichan Lake do experience higher recreational pressures, with only a few select sites (e.g., the upper tubing reach) on the Cowichan River experiencing levels of recreational pressure within range of the lake sites.

5.4.1 Potential UVF loading

Labille et al. (2020) performed public use surveys and found that 68% of surveyed beachgoers applied sunscreen while at the beach. The average user applied ~17.5 grams of sunscreen in a typical day, re-applying an average of 2.6 times. Labille et al. (2020) also calculated a recovery factor for the UVFs of concern released into water, which was about 30%. In Year 2 (2021), we attempted to develop a similar estimate of UVF loading for the Cowichan River. Through recreation monitoring and local business data captured as part of this project, we estimated that the upper 20 km of the Cowichan River sees between 20 – 1,000 tubers and swimmers per day, contingent on whether it is a weekend or weekday, and which month of the summer season it is. Throughout the peak recreation season (62 days, July – August inclusive), this amounts to between 1,240 – 62,000 recreational users (or an average estimate of ~30,500 people for the season).

Multiplying the estimated total number of river users by 17.5 g sunscreen each gives a range of 21.7–1,085 kg of sunscreen potentially applied; this amounts to approximately 6.5–325 kg of sunscreen potentially released (or an average of ~160 kg over one summer recreation season). With a UVF recovery factor of 30%, an average of 48 kg of UVFs could potentially be making their way into the Cowichan watershed each season.

However, it is necessary to consider that actual recovery values in the Labille et al. (2020) study were much lower than their modelled concentrations of UVFs, which they proposed could have been due to uptake through the skin barrier or partial photodegradation of UVFs in the environment. Understanding an approximate range for UVF loading, as in the above example, allows for the development of more informed outreach strategies, and improves quantification of mitigation impacts.

5.5 Sediment

No oxybenzone was detected in any of the sediments analyzed in Year 3. This suggests a sediment concentration of less than 10 – 20 µg/kg based on the results from VIU-AERL's in-house method experiments (Aplin et al. 2023). We expected to see presence of UVFs in the finer-grain sediments, such as those downstream of the TLCO. A review of existing literature (Ramos et al*.,* 2015) revealed a German study that sampled lake sediments and similarly had no detection of oxybenzone (Rodil & Moeder, 2008). The maximum detection was 27 ng/g dry weight (d.w.), collected from river sediments in Spain located downstream of a wastewater treatment plant (WWTP) (Gago-Fererro et al*.,* 2011).

Other UVFs of concern, including octocrylene and enzacamene, have also been detected in river sediments and found to range from 0.4 – 2,400 ng/g d.w. and 4 – 8 ng/g d.w., respectively (the highest values being located downstream of WWTP) (Ramos et al., 2015). Only oxybenzone was able to be tested for by the lab at VIU-AERL in Year 3.

Further sampling of additional UVFs in sediment may reveal information about potential UVF sinks in the Cowichan River ecosystem; however, at this time the data does not point to the sediment sampled as a strong sink for oxybenzone. Further detail is provided in Aplin et al. (2023). The higher $\log K_{OW}$ of the enzacamene, octinoxate, and octisalate compounds does suggest these have a stronger affinity for adsorption to sediment (and bioaccumulation) than oxybenzone. If method development continues, testing for the presence of these compounds may provide further information to help investigate the presence or impact of UVFs in sediment.

5.6 Fish Sampling

No additional fish were collected in Year 3. VIU-AERL completed an alternate analysis method for fish tissue samples using gas chromatography (GC-MS) in Year 3. However, this alternate method was not within the intended scope of the project agreement. With CP-MIMS, it has been found that high levels of free fatty acids and triacylglycerols can permeate the membrane and clog the instrumentation (Aplin et al. 2023), affecting further analysis for the entire AERL lab for several weeks. Attempts were made to adjust sample pH to mitigate issues encountered with fatty acids, but this was limited by the acid dissociation constants (pKa) of the UVFs oxybenzone and octisalate (Aplin et al. 2023). Due to the heavy reliance on equipment across all university courses and other clients, the risks of further membrane damage had to be mitigated. VIU-AERL has not been able to successfully analyze tissue using CP-MIMS LEI-CI to date, and have requested not to continue pursuing tissue methodology due to time and cost of the non-focus (GC-MS) instrumentation.

Through the GC-MS method, in Year 3 tissue samples were still not indicative of oxybenzone contamination (no appreciable signal intensity for the four target UV filters) unless fortified with a UV filter standard during the membrane extraction step (Aplin et al. 2023). The tissues in use had been frozen for 1-2 years. While this does not conclusively determine the presence or absence of UVFs in fish tissue for the Cowichan watershed, we have decided to pause the further pursuit of tissue methodology until additional funding or alternate methods become available.

The majority of resident rainbow, cutthroat and brown trout in the Cowichan River spend their entire lives within the freshwater environment (McPhail, 2007). Fish spending the majority of their life in freshwater are the focus for UVF impacts in the Cowichan River ecosystem, as there is a risk of exposure to UVFs from recreational use during periods of peak metabolism (e.g. during summer months when feeding and growth rates are highest) (Campana, 1999).

Past electrofishing surveys have indicated the upper 20 km of Cowichan River contains the highest densities of rainbow trout/steelhead fry and parr (McCulloch and Atkinson, 2019), with the highest concentrations occurring between 7–8.5 km (a few kilometres downstream from the most recreationally-intensive areas of the upper river (0–4 km). The majority of brown trout spawn in creeks that are tributary to the upper 2 km of the Cowichan River; fry, parr, and adults migrate to the mainstem at various ages (B. Anderson, pers. comm., 2021). Brown trout likely spend most of their lives rearing within the upper 20 km (B. Anderson, pers. comm., 2021). The upper Cowichan River is thus critical habitat for these two trout species, and there is overlap between resident trout rearing habitat and areas of significant recreation/UVF contamination.

Many studies have acknowledged the potential risks to aquatic life of long-term or chronic exposure to lower, environmentally-relevant concentrations of UVFs during sensitive life stages, e.g. juvenile rearing, or under conditions that enhance biotic stress response, e.g. high water temperatures (Campos et al., 2017; Kim et al. 2014; Muniz-Gonzalez and Martinez-Guitarte, 2020; Ozàez, Martinez-Guitarte and Morcillo, 2013; Scheil, Tiebskorn and Kohler, 2008). Due to a lack of primary literature about chronic exposure to UVFs at environmentally-relevant concentrations within freshwater systems, especially ecosystems within North America, developing a reliable method to assess UVF accumulation in fish tissues continues to be a major objective for this project. Further development work will require exploration of alternate methods or advancements in the CP-MIMS LEI/CI technology.

5.7 Wastewater Effluent

Further challenges were encountered with attempted effluent sampling in 2022. Due to instrument delays at the start of the sampling period, only two samples were able to be analyzed. One sample showed all no-detects while another sample showed all four UVFs to be present in the sample (Table 15). If possible, further sampling of treated effluent should occur in Year 4, but careful attention should be paid to:

a) ensure samples collected can be analyzed within the proper timeframes,

b) proper QA/QC protocols are followed, including the collection and analysis of sample duplicates, field blanks, equipment blanks and bottle blanks.

This will help ensure the questions surrounding concentrations of UVFs in treated effluent from the TLC wastewater plant are able to be answered. Efforts should be undertaken early in the season to secure access for sampling of influent and treated effluent from the Town of Lake Cowichan WWTP with the public works department.

5.8 Public Outreach

Year 3 (2022) was the first year where we specifically sought to conduct public outreach beyond just a public questionnaire. While we collected environmental samples to round out the environmental contamination baseline, we also used Year 3 to test several different methods of outreach and identify the most effective methods to pursue for a wide-scale education and awareness campaign within the community in Years 4 and 5.

5.8.1 Booth & Roaming Outreach

The outreach booth contained educational information about UVFs and sunscreen products, as well as samples and UPF clothing examples. The main booth draws to engage with the public in Year 3 included the free samples, stickers, “business card” with key information about UVFs, and a bean bag toss game to learn about different product choices. Other methods were used including other games and educational materials, but appeared to be less effective at resulting in an engagement.

In Year 4, focus should be targeted on reaching adult populations rather than youth (see section 6.0 below). Roaming is recommended over booth outreach for primary contact and gathering of information from the target audience. Booth outreach should still occur at large events, but the investment of time relative to effectiveness was highest at purpose-built events.

5.8.2 Public Questionnaire

We received 77 more responses to the public questionnaire in Year 3 than Year 2, partly as a result of the increased outreach. Responses also came from a wider variety of locations compared to Year 2. Results showed that the majority of respondents were not wearing sunscreen and not wearing UPF clothing (the questions were not mutually exclusive). This presents an opportunity to promote more diversions towards UPF clothing.

Respondents showed a relatively high (71%) awareness of the impacts of sunscreen use on the environment which is an increase over the result in Year 2 (64%). This could be due to the widespread awareness over growing concerns about potential impacts of UVFs in the environment, as well as a difference in response weight due to sample sizes being different between years (Year 2, n= 22; Year 3, n=104).

Ingredient analysis of the products reviewed showed some interesting results. Less than 20% of all products reviewed contained oxybenzone. The majority of products contained a blend of homosalate, octocrylene, octisalate and avobenzone. No products contained enzacamene, which was surprising. Enzacamene is approved for use in Canada, but not in the USA; this suggests there may be a strong impact of the USA market and EPA regulations influencing sunscreen ingredient blends even here in Canada. We were also surprised to see a “blended” product type that contained both physical (Titanium dioxide) and chemical (Octocrylene, Avobenzone) ingredients, which is not something we had observed in prior years.

5.8.3 Community-Based Social Marketing

We endeavoured to use Community-Based Social Marketing (CBSM) tactics in our outreach to best identify our target audience and to identify barriers to adoption of the behaviour change. CBSM was used as a preliminary guidance for the creation of the public questionnaire and sunscreen use survey. We contracted Lynne Betts and Crystal Klym to support a CBSM review of this project and provide suggestions for improved outreach. Unfortunately, due to a funding delay of 5 months, this review was not able to be completed or incorporated prior to the Year 3 outreach season.

The recommendations were founded in the principles of CBSM, which focuses on using behaviour change tools such as Commitments, Incentives, Prompts, Communication, and Recognition/Norms/Social Diffusion (Betts & Klym 2023). Five key steps were identified to refresh the outreach program heading into Year 4, which are summarized below in the UVF Mitigation Action Plan section.

6.0 Cowichan Watershed UVF Mitigation Action Plan for 2023 & 2024

Five key steps were identified to refresh the outreach program heading into Year 4:

1. Identify the specific behaviour you want to change.
    - Betts & Klym recommended listing all the behaviours related to UV filter use, from first point of contact to end destination (e.g., a person who is thinking about purchasing the product, purchasing the product, planning for a day out at the beach, bringing the product to the beach, applying the product, re-applying the product, swimming with the product on, etc.)
    - Identify which behaviour will have the most impact on reducing UV filter contamination if changed, and focus on those action(s) likely to have the most impact. Approaches to change behaviours should also be aimed precisely at one audience segment (e.g., children, adults, beach goers, etc.) – see below.

2. Identify who "does" that behaviour (i.e., the audience).
    - While activities aimed at young children may build stewardship awareness, they will likely not result in desired behaviour change; typically, the parent makes decisions about product purchasing, packing, application, and re-application.
    - Betts & Klym recommended diverting the time spent on youth outreach towards more direct adult outreach. Further scoping and understanding of the specific behaviours hoped to change will help narrow in on the target audience.
    - Further surveys or a focus group amongst just the target audience will help describe specific motivators for behaviour, and provide an opportunity to ask why people will – or will not – change their behaviour (i.e., a benefit or a barrier – see below).

3. Identify the barriers and benefits.
    - Once the target audience is identified, focused research with this audience is recommended to help identify the main motivators or barriers to changing behaviour. The specific behaviour change (e.g. switching to a different type of sunscreen or sunscreen alternative) also needs to be identified prior to doing this focused research.
    - The main factors people considered when purchasing sunscreen in Years 2 and 3 were Price and Safety. Information gathered through past surveys and questionnaires can be used to supplement additional targeted research for behaviour change in Year 4.
    - Betts & Klym recommended revising survey questions to reveal more about the target audience and their perceptions about alternatives, and continuing to deliver this survey in Year 4. For example, if the target audience applies sunscreen at the beach, a clear and effective prompt located in the parking lot or at the beach access point may be a good approach. If the target audience doesn't know where to buy alternatives, retail signage and in-store communications may help, along with dispensing stations at high-traffic locations.

4. Select the appropriate behaviour change tactics.
    - Betts & Klym found that past outreach approaches (e.g., educational poster, sun protective clothing fact sheet, games, colouring sheets) were not specific to one target audience and tended to lack clear and cohesive messaging.
    - The research completed in steps 1-3 above will help the project lead identify the most appropriate method to reach the target audience (e.g., prompts to help with forgetfulness, commitment statements and recognition to help with motivation, free samples to help with price barriers).
    - Outreach events where a booth is set up could be used as an opportunity to help with the commitment/recognition strategies, as a way to interact with the audience and trigger social diffusion of alternatives.

5. Pilot the approach / tactics and then consider large-scale implementation and evaluation.
    - Betts & Klym recommended to consider summer 2023 an opportunity to test some refreshed approaches to behaviour change, and monitor the behaviour change. Focusing on just 1-2 beach areas, to avoid diluting focus and allowing the messaging to stay strong and reach the greatest amount of people in the area targeted (e.g., Saywell Park for the upper river tubing reach, and Gordon Bay Provincial Park for the lake region).
    - Suggested considerations to incorporate in Year 4 include:
        - More cohesive messaging and branding across all materials and products distributed or displayed to the public. Contraction a graphic designer to help with this would be a helpful use of funds.
        - Dispensing stations with matching prompts and messaging to tie in with the outreach strategy.
        - Partnering with existing and new partners (e.g., retailers, agencies, tourism operators, accommodation providers, etc.) who align with the desired behaviour change and the target audience.
    - After further testing and refinement of these tactics, more widespread outreach at other beaches and areas can occur in Year 5.

Future project years should also incorporate intentional measurement/reporting by providing and tracking number of people engaged, amounts of sample products used, and compiling questionnaire responses. Effectiveness will be gauged by comparing a blend of the outreach metrics, product use data, and water quality results pre-and post- outreach efforts. All of this will contribute to the success of ongoing future project work and mitigation of contamination entering the Cowichan River watershed.

7.0 RECOMMENDATIONS

This report summarizes results from the third full year of collaborative UV Filter (UVF) monitoring in the Cowichan River watershed. Project goals include describing the nature and extent of UVF contamination within the Cowichan River ecosystem, improving understanding of potential impacts to resident aquatic organisms, and encouraging public education, outreach and regulatory measures to help mitigate UVF inputs to the watershed.

Specific objectives for Year 3 were to continue describing oxybenzone contamination at recreational sites in the watershed, to investigate other UVFs of concern in water, and to analyze both sediment and biotic tissues for oxybenzone. Partly a result of continued setbacks with method development for tissue analysis, these objectives were partially completed in Year 3 and have been summarized within this report. Methods are now established to analyze samples rapidly and at low-cost for oxybenzone and other UVFs of concern (enzacamene, octinoxate and octisalate) in water and sediment.

The focus for Year 4 is meant to be an outreach and awareness education program, with limited additional sample collection. Project roll-out in Year 4 should use the Mitigation Action Plan (section 6.0) and the recommendations below as a guide to project delivery.

1) An early-season workshop (e.g. before May Long Weekend) should be held with stewardship partners (e.g. past project volunteers, Cowichan Lake and River Stewardship Society executive, Cowichan Watershed Board representative, Cowichan Tribes representative), the Town of Lake Cowichan municipal staff, local businesses/Chamber of Commerce, and the summer outreach team. The workshop should focus on answering some of the questions listed in steps 1, 2 and 3 of the UVF Mitigation Action Plan.

2) Samples from major swim beaches, river recreation sites, and the wastewater treatment plant should, at minimum, all be collected during a "sampling blitz" over the August long weekend in Year 4. This will allow the August long weekend dataset to be compared for 2019 – 2023 as a relative comparison of mitigation effectiveness.

3) Data about visitation trends, recreational use, and river discharge conditions should continue to be collected in order to provide a more accurate comparison against past years' results.

4) While the results from tissue analysis in Year 3 do not definitively determine the presence or absence of UVFs in fish tissue within the Cowichan watershed, we do not recommend continued pursuit of analysis through the CP-MIMS LEI/CI method at this time. Further method development will be at significant cost through a commercial lab. Future academic partnerships can be explored, but will likely need to use an alternate method (e.g. GC-MS) of analysis.

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PERSONAL COMMUNICATION

Aaron Frisby — Owner, The Tube Shack. Lake Cowichan, BC.

- E-mail and text message communication with T. Rodgers, September 1-30 2020.
- E-mail communication with T. Rodgers, March 1 2022.

Brian Houle — Manager, Environment. Catalyst Paper Excellence Canada. Crofton, BC.

- E-mail communication with T. Rodgers, February 5 2021.
- E-mail bulletin: “Special update re: pumping from Cowichan Lake”, October 22 2019.

Brendan Anderson — Senior Fisheries Biologist, Fish and Wildlife. MFLNRORD Region 1. Nanaimo, BC.

- E-mail communication with J. Atkinson, February 5 2021.

Katherine Worsley Coordinator, Cowichan Lake District Chamber of Commerce. Lake Cowichan, BC.

- E-mail communication with T. Rodgers, February 6 2021.
- E-mail communication with T. Rodgers, February 18 2022.

APPENDIX A – PUBLIC SURVEY RESULTS

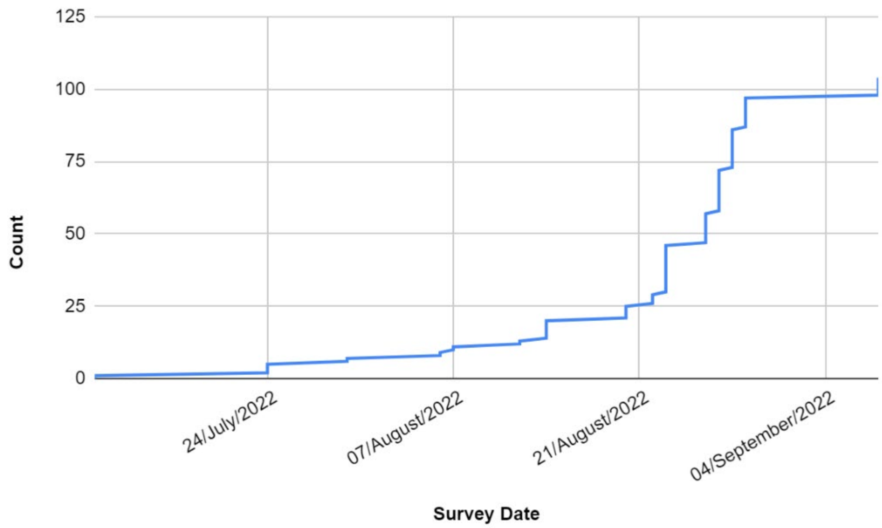

Fig. A1. Public questionnaire responses in Year 3.

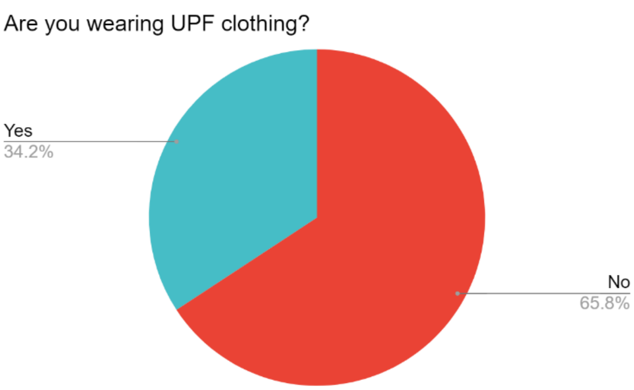

Fig. A2. Proportion wearing UPF clothing.

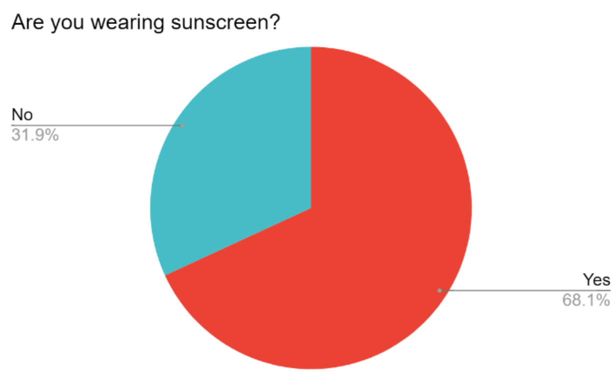

Fig. A3. Proportion wearing sunscreen.

Fig. A4. Amount of time before swimming.

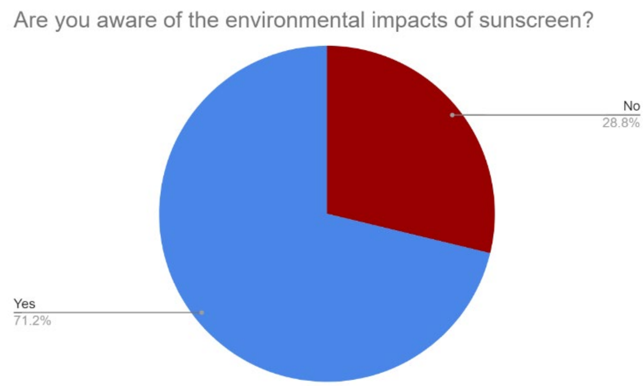

Fig. A5. Proportion aware of environmental impact.

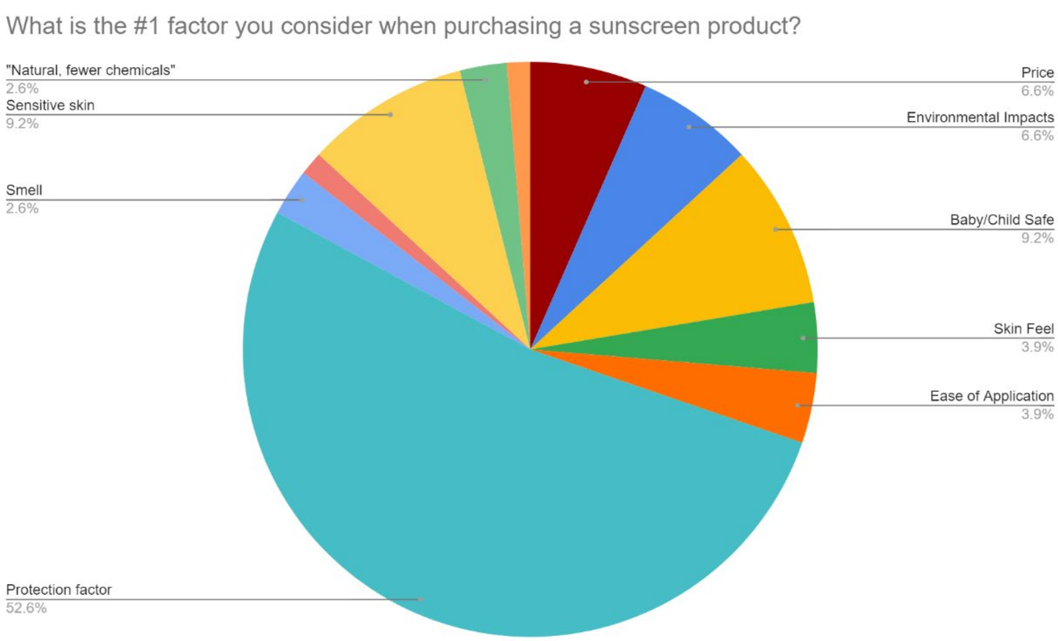

Fig. A6. Main consideration when choosing.

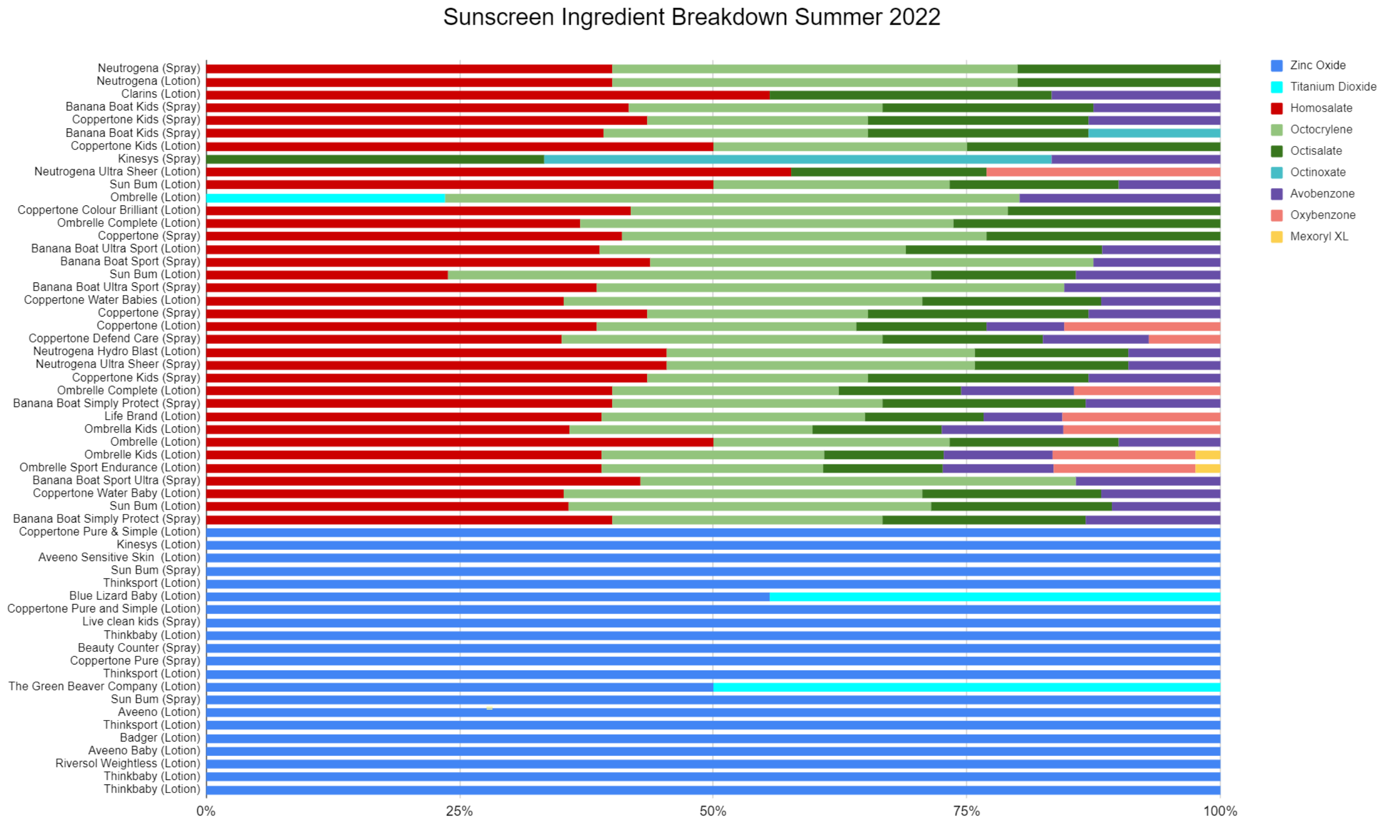

Fig. A7. Ingredients assessment.

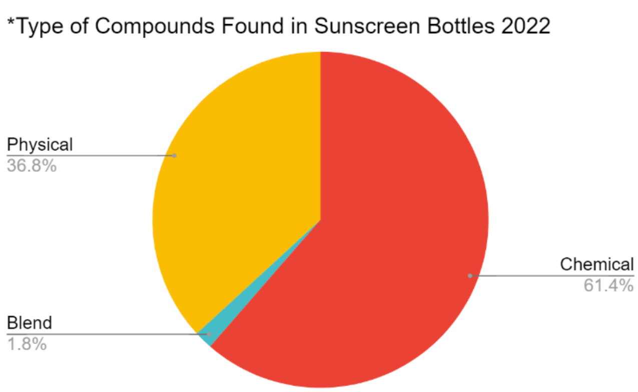

Fig. A8. Proportion of Chemical vs Physical products.

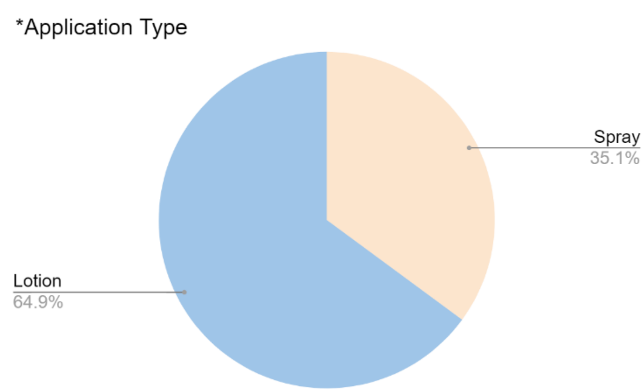

Fig. A9. Proportion of cream (Lotion) vs aerosol (Spray).

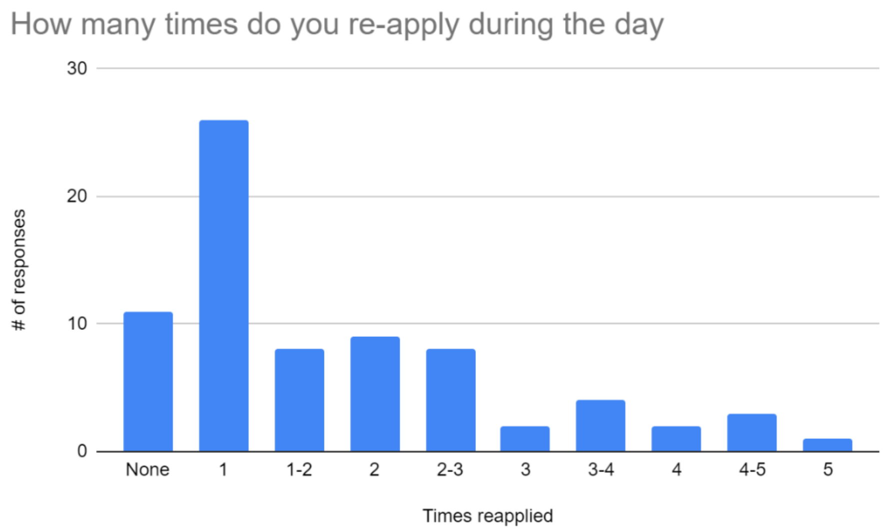

Fig. A10. Reapplication frequency.

APPENDIX B – PHOTOS

Figure B1. Example sampling positions at river sites (left; facing upstream into current) and lake sites (right; facing out toward swimming area).

Figure B2. Town of Lake Cowichan secondary treatment pond with discharge sampling hatch in foreground (left), and treated wastewater effluent sampling procedure (right) (photos: Thea Rodgers & Jessie Paras).

Figure B3. Volunteer conducting a recreation assessment under the Greendale Trestle in Year 3 (photo: Jessie Paras).

Figure B4. Outreach booth set up in various locations in Year 3 (photo: Jessie Paras).

Figure B5. Outreach booth set up in Year 3 (photo: Jessie Paras).