# WATER IS LIFE SCHOOLS 2026

MAURICK COLLEGE

# Research Papers

WATER IS LIFE SCHOOLS 2026
MAURICK COLLEGE

**Category 1 – "Nature & Aquatic Life"**
*Focus: aquatic and marine ecosystems, biodiversity, and ecological responses to environmental and human stressors*

1. How does thermal heat stress affect giant kelp growth
2. Trait – Environment Relationships and Morphological Variation in the Endemic Andean catfish *Trichomycterus bogotensis*
3. The impact of tourism on water and marine ecosystems in Curaçao
4. Tourism in The Wadden Sea
5. Microplastic in the Wadden Sea
6. Utilizing Game Theory to Determine the Grounds for Marine Cooperation
7. Detecting Newly Emerging Floating Vegetation Using Sentinel-2: The Novel Remote Sensing WARN for Monitoring Alligator Weed
8. Assessment of Water Quality in Bowker Creek for Implementation of a Salmon Egg Box to Restore Salmon Population
9. Chemical analyses of Gulbene city ponds

**Category 2 – "Clean Water, Smart Science & Health"**
*Focus: water quality, monitoring, purification technologies, and nature-based or technical solutions*

1. A Mangrove-Inspired Real-Time Water Quality Monitoring System
2. The Biofiltration Efficacy of Tanjung Pasir Mangroves in Mitigating Nitrate Loading and Stabilizing pH from the Cisadane River
3. Water is Life, Sustainability is Future: Green Photocatalyst from Rubberwood Biochar–$TiO_2$ for Wastewater Purification
4. Smart Water Monitoring: Automated Detection of Microplastics in Water Using Polarization Imaging and Machine Learning
5. Assessment of olive stone-derived biochar as a sustainable solution for reducing pharmaceutical pollution in wastewater
6. Hydro Credit Project
7. Microbial Contamination of Reusable Water Bottles Among Students of Different Age Groups
8. The mechanism of dehydration in the mouth, airway and lungs caused by vaping
9. Awareness of Estonian Companies Using Marine Raw Materials Regarding Environmental Impact Assessment and Data Availability

**Category 3 – "Water, Cities & Society"**
*Focus: governance, urban water management, social dimensions, policy, and human impacts*

1. Installation of Rain Gardens in Shibuya and Their Sustainable Maintenance System
2. Rainwater infiltration in city centers of Dutch cities
3. The Catalan Sponge; Potential measures to tackle a drought in Catalonia in 2040
4. Political participation in regional water management
5. Assessing Governance Model in Mangrove Management: A Case Study of State-Owned Enterprise (SOE) – Community Collaboration in Tanjung Pasir, Indonesia
6. Synergies. The Case of the Vanoi Torrent Dam.
7. Water Waste in Agricultural Practice

# Nature & Aquatic Life

Category 1

# How does thermal heat stress affect Giant kelp growth?

*Kelp Group*

*Oak Bay High School*

*British Columbia, Canada*

*Paisley Rodier, Isla Pilling, Ella Hostad, and Finn Ostermann*

**Abstract:**

This paper examines the effect of climate change and thermal stress on the growth of Giant Kelp (*Macrocystis pyrifera*) on the coast of British Columbia, Canada. Climate change has resulted in a rapid decline of Giant kelp forests, which has drastically affected the ecosystem. Our experiment examines how different temperatures affect the growth of Giant Kelp gametophytes and sporophytes. We hypothesize that the growth of Giant Kelp will be reduced when thermal stressed at 15℃ as compared to kelp grown at 10℃. The gametophytes were grown in an incubator supported by Blue Future Kelp for two weeks at the experimental temperatures. Then the light was switched from red to white to induce the growth of the sporophyte. We then transplanted the sporophytes to our school aquarium and measured their growth twice a week for an additional 4 weeks. We anticipated that the kelp grown at 10℃ would have larger growth than the kelp grown at 15℃. Unfortunately, our experiment was unsuccessful, and our kelp did not grow.

**Introduction:**

Giant Kelp, *Macrocystis Pyrifera,* is a perennial brown seaweed found worldwide in subpolar and temperate waters. Giant Kelp's ideal growing temperature is approximately 5-20°C, allowing it to thrive in the Northwest Pacific (Hutchins, 2016). It is common in the Pacific Northwest, Eastern North America, South America, South Africa, Oceania, Northeast Asia, and Northwest Europe. Giant Kelp is characterized by its root-like anchor, leafy blades, pneumatocysts, and incredible growth rate (Le et al., 2022). A pneumatocyst is an air bladder found in certain seaweeds to provide buoyancy. It averages a growth speed of 28 cm per day, but some blades can reach up to 60 cm per day. This rate of growth enables kelp to form dense forests, creating thick canopies despite a lifespan of only two to seven months.

These kelp forests provide shelter for a wide range of organisms, making Giant Kelp a keystone species. Giant Kelp reproduces through a two-stage life cycle called alternation of generations, allowing its microscopic gametophyte stage to drift long distances and seed new areas. These gametophytes then release sperm and eggs, which develop into the sporophyte stage, becoming the recognizable form of Giant kelp.

Giant kelp plays a crucial role in the marine life of the Pacific Northwest (*Giant Kelp Facts — SeaDoc Society*, n.d.). These kelp forests provide shelter for a wide range of organisms, making Giant Kelp a keystone species. Kelp provides shelter for fish and sea otters, food for marine snails, kelp crabs, and sea urchins, and serves as nursery grounds for fish. Aside from being home to marine life, giant kelp forests absorb and store an immense amount of $CO_2$ and convert it to biomass (*Kelp Forest Alliance*, n.d.). Giant kelp can soak up to 50 times more weight of $CO_2$ than a terrestrial forest, acting as a carbon sink even after the death of the plant. Additionally, Giant kelp forests slow down waves and capture some of their energy, thus protecting the coastline from harsh waves and erosion. The increased rate of global marine heat waves greatly affects kelp forests worldwide (National Marine Sanctuaries, n.d.). The localized temperature changes affect marine life and can lead to extinction. As the climate changes, the rise of ocean acidity and temperature degrades the health of kelp and other marine life. The increase in heat causes more algal blooms and lowers the rate of photosynthesis in the kelp species. Kelp tissues are more easily torn down, and blades are eroded during large wave events when in this weakened state, causing mass physical damage.

Additionally, Giant Kelp is incredibly important to the culture of the Indigenous Pacific Northwest tribes. Kelp was eaten, used in ceremonies, and made into hunting and fishing tools, including fishing lines, nets, hoses, and anchors. Not only has kelp been a valuable resource for Indigenous people dating back thousands of years, but it is also said that tribes followed the kelp beds along the coast of North America from places including Asia and South America during migrations (Whales, 2023). The decline of kelp forests not only affects marine life but also Indigenous communities that rely on it for their cultural identity.

**Methods:**

*Trial Run:*

Before starting our experiment, we ran a trial run to test it. We blended Giant Kelp gametophytes with an Erlemeyer magnetic stirrer before mixing them with a blend of F/2 nutrients and sterilized seawater. Then we poured the mixture into a sterilized spray bottle. We placed eight sterilized slides into our empty aquarium and sprayed the gametophyte mixture evenly across the slides. We then slowly filled up the tank with seawater and allowed the test slides to grow for two weeks. We used 90 umol photon grow lights on a 12-hour timer to simulate natural daylight cycles. We checked the microscope slides for growth after seven days and fourteen days. There was no sporophyte or gametophyte growth after the two weeks. We hypothesized that our flow rate was too strong for the gametophytes to attach securely to the microscope slides, and adjusted our methods.

*Main Experiment:*

After our trial run, we adjusted our experimental design based on what we learned. We took the blended gametophytes and added them to a spray bottle with the same nutrients and sterilized seawater as before. Instead of slides, we took rocks from a beach, rinsed them three times in fresh water, and placed them into two plastic containers with solid sides and an open top. We initially had planned to use porous containers, but chose solid containers instead to reduce disruption from water flow, with the plan of transferring the rocks once growth had been established. The gametophyte mixture was then sprayed equally onto the rocks.

*Figure 1. Finn, Ella and Isla spraying the gametophyte mixture onto the rocks.*

The containers were placed into two 30 umol photon red light incubators and grown at temperatures of 10 °C and 15 °C for four weeks. Our goal was to allow the gametophytes to solidly attach to the rocks in the incubator before adding them to the more disruptive aquarium environment.

*Figure 2. Isla and Clay Steel adding seeded gametophytes to the red light incubator.*

After their growth in the incubator, we transferred the containers to our aquarium. We slowly filled the containers with water from the aquarium, then carefully placed them in our full aquarium at the far end, away from the pump.

*Figure 3. Ella adding water to the gametophyte containers.*

The tank was then covered by a sheet of plexiglass, and white grow lights were placed on top on a 12-hour timer using 90u/mol photon light to simulate natural light cycles. We allowed for two weeks of growth before we removed a sample rock from both the 10°C and 15°C containers and measured the growth under a microscope. From there, we measured the kelp growth at one-week intervals for four weeks. Unfortunately, after four weeks of assumed growth, we discovered that our kelp had been unable to grow and that diatoms had grown in its place.

*Figure 4. Seeded rocks with gametophytes, the left container was incubated at 10℃ and the right container at 15℃.*

**Results:**

Unfortunately, our experiment was unsuccessful as the giant kelp gametophytes were unable to withstand our growing environment. We came to this unfortunate conclusion during week four when we pulled one rock from both batch one and two and found no gametophytes, only a large number of diatoms. The first batch grew enough diatoms to cover the rocks completely; the second batch grew none.

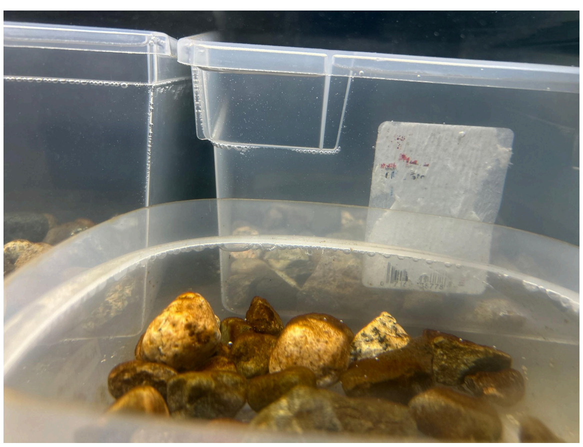


*Figure 5. Rocks overgrown with diatoms.*

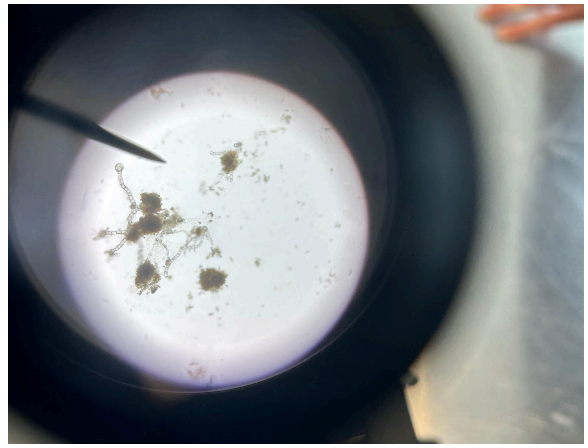


*Figure 6. Microscope slide showing gametophyte growth, but no sporophyte growth.*

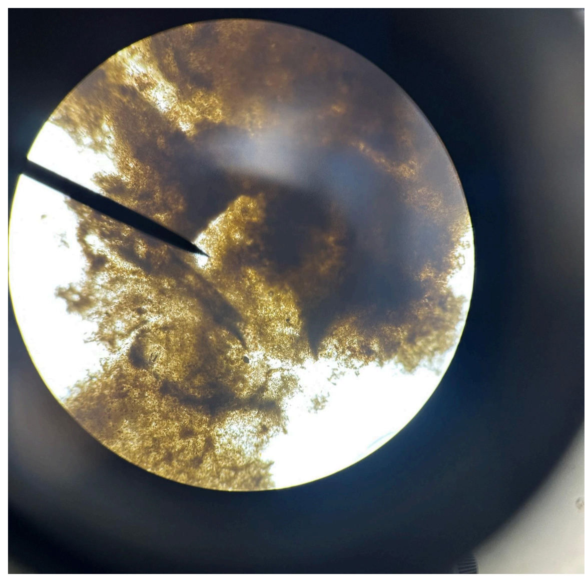


*Figure 7. Overgrowth of diatoms on rocks.*

Upon completion of our test run, which was also unsuccessful, we made many changes to our methods and hoped the results would be different. From the data we collected, we now believe the force of the water flow in the tank may have been our biggest source of error.

**Discussion:**

After studying our results, we are fairly certain that the turbidity of our growing tank dislodged the gametophytes from the slides and gravel, stopping them from properly anchoring themselves. Other potential causes include temperature, water purity, and nutrition. We are fairly certain these were not the primary issue, because we based our tanks' climate and nutrition on other successful studies (Simonson et al., 2015; Harden et al., 2024).

Our best hypothesis of the cause of the failure in our experiment was our high level of turbidity. Giant kelp gametophytes are very vulnerable to their environment (Harden et al., 2024). One giant kelp sporophyte releases billions of gametophytes, and out of these billions, very few survive to the sporophyte stage, sometimes none. Because of their inherent fragility, very small changes to their environment can be detrimental. The turbidity of our aquarium was higher and more powerful than expected, and pushed away all the gametophytes placed to grow before they could anchor properly, even after seeding them first in an incubator.

Scientists working alongside Blue Future Kelp are currently testing a gametophyte glue that will prevent this issue by securing gametophytes to their growth sites without causing turbidity. This ‘gameto-glue’ is still in the testing stages, though if we had been able to use the upcoming product, we hoped the gametophytes would have stuck and grown into the small kelp blades we had originally planned for. Other solutions for the issue could have been negatively charged algae being inside the tank, positively charged slides, or Poly-L-Lysine-coated slides for adhesion (BlueStar, 2025). In real life, climate change has affected turbidity levels in oceans and other water sources through increased storm frequency, coastal disturbances, and runoff and sediment from melting glaciers and mountains (Mi et al., 2019). These water increases cause a rise in turbidity, and mimics how our experiment can happen naturally without human fault in the wild. Another potential cause of failure could have been diatoms outcompeting the kelp gametophytes. In both our aquarium and the wild, kelp gametophytes have to compete with other organisms, such as diatoms and bacteria, to get the nutrients they need to survive and grow (National Library of Medicine, 2013). We believe that we did not have enough controlled variables within the environment of our aquarium, which led to the growth of unwanted species.

If we were to run this experiment again, we would dampen water flow, allow the gametophytes more time to anchor themselves, and use a higher ratio of gametophytes to water. Additionally, the water we used for our experiment was not sterilized. Sterilizing the water for the test run was extremely labour-intensive. If we were to run this experiment again and wanted to use sterilized water, we would have to come up with a more streamlined solution.

The decline in kelp forests is a worldwide issue, affecting countless people, but we believe these negative impacts may be disproportionately affecting indigenous First Nations. Kelp forests are vital food sources for many West Coast First Nations groups, including the Coast Salish, Haida, and Nuu-cha-nulth. The First Nations of Vancouver Island have deep historic and spiritual ties to these forests. The decline of Giant and Bull kelp is destroying ecosystems and food sources that these Indigenous Peoples have stewarded for thousands of years. Many First Nations are contributing to the research and restoration of kelp forests in BC, working in partnership with Oceanwise and other nonprofits. As climate change continues, this research will become increasingly important.

**Conclusion:**

Although we were unable to grow kelp, our negative results are still of value as we learned several methods and overcame many challenges associated with culturing giant kelp gametophytes in a controlled environment. Throughout our experiment, we discovered several new ways of doing research, identified our strengths and passions, and developed relationships with scientists like Clay Steell, a local biologist who works in applied kelp restoration science through Blue Futures Kelp.

**References:**

Blue Star Slides. (2025, July 7). *Applications and Benefits of Poly-L-Lysine-Coated Slides in Cell Biology*. Blue Star Micro Slides & Cover Glasses; Blue Star Slides. https://www.bluestarslides.com/applications-and-benefits-of-poly-l-lysine-coated-slides-in-cell-biology/

GiantKelpFacts—SeaDocSociety.(n.d.).SeaDocSociety. https://www.seadocsociety.org/giant-kelp-facts

Harden, M., Kovalev, M., Molano, G., Yorke, C., Miller, R., Reed, D., Alberto, F., Koos, D. S., Lansford, R., & Nuzhdin, S. (2024). Heat stress analysis suggests a genetic basis for tolerance in *Macrocystis pyrifera* across developmental stages. *Communications Biology, 7*(1147), 1-9. https://doi.org/10.1038/s42003-024-06800-7

Hutchins, R. (2025, August 22). *Marine protection boosts heatwave recovery for kelp forests - Oceanographic. Oceanographic.* *https://oceanographicmagazine.com/news/marine-protection-boosts-heatwave-recovery-for-kelp-forests/*

Le, D. M., Desmond, M. J., Pritchard, D.W., & Hepburn, C. D. (2022). Effect of temperature on sporulation and spore development of giant kelp (Macrocystis pyrifera). *PLoS ONE, 17*(12), 1-12. https://doi.org/10.1371/journal.

Mi, Huan, et al. "Climate Change Leads to a Doubling of Turbidity in a Rapidly Expanding Tibetan Lake." Science of the Total Environment, vol. 688, Oct. 2019, pp. 952–959, *https://doi.org/10.1016/j.scitotenv.2019.06.339*

Simonson, E. J., Scheibling, A., & Metaxas, A. (2015). Kelp in hot water: I. Warming seawater temperature induces weakening and loss of kelp tissue. *Marine Ecology Progress Series, 537,* 89-104. doi: 10.3354/meps11438

Steel, C. *Blue Futures Kelp.* (2025-2026). Support for experimental design and equipment rental.

The role of kelp forests in carbon dioxide removal and climate mitigation - Kelp Forest Alliance. (n.d.). https://kelpforestalliance.com/kelp-and-carbon

Whales, P. O. (2023, April 5). *BULL KELP: THE UNDERWATER TREE OF LIFE*. Prince of Whales. https://princeofwhales.com/bull-kelp-the-underwater-tree-of-life/

# Trait – Environment Relationships and Morphological Variation in the Endemic Andean catfish *Trichomycterus bogotensis* (Eigenman,1912)

Tabatha Samatha Echevarreneta Goldar, Alegría Gutiérrez Perdomo, Esther Sofía Vargas Lombana, Sara Aranzález De la Hoz, Isabel Acosta Jiménez, Luciana Rodríguez González.

*Colegio Claustro Moderno, Colombia, paolak@clasutromoderno.edu.co*

## Abstract

Freshwater ecosystems are essential for sustaining biodiversity, particularly within the Andean highlands of Colombia. The water bodies of the Zarauz estate, located on the Cundiboyacense high plateau, support populations of *Trichomycterus bogotensis*, an endemic freshwater catfish locally known as the "Capitán enano de la Sabana." Given its restricted geographic distribution and the limited scientific data available, this species may be particularly vulnerable to environmental changes and habitat disturbances.

This study examines the relationship between the dietary preferences, environment, and the distribution of biological traits of T. bogotensis to better understand its ecology and population status. We conducted environmental monitoring and collected biological data, using a mixed methodology approach, allowing for more robust inferences and the examination of the data from multiple perspectives [1], including passive sampling methods, morphometric measurements (standard length and weight), coloration patterns, and morphological features such as pelvic fin presence.

By exploring the interaction between the distribution and species traits, this research identifies optimal habitat conditions for the necessary study for its persistence. The inclusion of a trait-environment relationship provides a critical baseline for future ichthyological studies and conservation strategies for endemic freshwater biodiversity in the Colombian Andes.

## Keywords

Catfish, endemic, water bodies, Cundiboyacense high plateau, *Trichomycterus bogotensis*

## Introduction

Endemic species are a fundamental component of global biodiversity, as their restricted geographic distribution reflects specific ecological conditions and unique evolutionary processes. For instance, water bodies of the Cundiboyacense high plateau are inhabited by various endemic species; however, the lack of scientific information available puts the species in danger and makes them particularly susceptible to environmental changes and habitat disturbances[2]. For this reason, the objective of this project is to examine the biological characteristics of the freshwater catfish T. bogotensis located in Zaraus estate with the purpose of contributing scientific knowledge about its ecology and current state.

Environmental monitoring was carried out by analyzing the species, taking into account the factors and characteristics specific to it, such as coloration patterns and morphometric measurements. Furthermore, sampling was performed using both passive and active sampling methods, including traps and baits, as well as fishing nets, to capture specimens, which, according to Herrera Solano [3], is the simplest and most effective method. Moreover, as noted above, the importance of this study pertains to the conservation of species classified as endangered, threatened, or of special concern, which requires careful consideration [4].

Through the morphometric characterization, it is possible to infer potential distributions in the water column, providing a clearer understanding of how T. bogotensis interacts with and adapts to the various states of the water column, which is essential to ensure the proper conservation of the ecosystems and microecosystems of the Colombian Andes.

## Context

South America's aquatic ecosystems have specific characteristics that allow them to house the most diverse fish faunas on the Earth and to have the highest diversity of any region of comparable area, therefore it is essential to develop strategies to conserve habitats against all the threats to which they are exposed and put them at risk of extinction [5]

The created physical barriers that divided fish populations. This separation halted gene flow, leading to the independent evolution of extinct biodiversity hotspots, functioning like natural laboratories, fostering the evolution of new, isolated life forms [6]

The tropical Andes are a treasure of global biodiversity, specifically, the diversity of ichthyofauna, thanks to its extended riverine area, and altitudinal and latitudinal factors, which also favor the high estimated rate of endemism. Therefore, it is important to study these under-researched areas and endemic species characteristics to understand the relationship between them. [7]

There is an important relationship between the size of the water bodies and the diversity present there. For instance, in larger and isolated basins, extinction rates tend to be lower, and there's ample room for new species to evolve, which means these basins and also tropical areas in general, thanks to their long history of climate stability, boast a higher proportion of endemic s*pecies.[8]*

The Colombian Andean Region has a large biodiversity; nevertheless, there are not many studies or documents about the Andean fish fauna. This is why it is highly important to develop ichthyological inventories that allow us to study the spatial distribution of the biological elements involved and other systematic or genetic studies of specific species, and according to this study, there are many methods to capture species to develop them. [9]

## The purpose of the investigation

This research was conducted in a freshwater body with lentic and lotic microenvironments at Claustro Moderno school located in the eastern mountain range in Bogotá, Colombia, with the purpose of leaving a record of this endemic species located in an ecosystem characterized by a sandy substrate and freshwater vegetation, and surrounded by a nearby construction of artificial waterfalls that alters the water flow.

Furthermore, this study seeks to contribute to regional ichthyological scientific knowledge regarding the ecology and population status of T. bogotensis and provide an approach that aims to contribute to future conservation efforts. As well as to raise awareness in the community about the importance of caring for water bodies as a home for endemic species.

## Method of the investigation

### Study area

The study was carried out in a natural freshwater source located in Bogotá, Colombia (Fig. 1). This area belongs to the Bogotá savannah, which is characterized by a high-mountain climate with temperatures ranging from 10 to 18 °C. The substrate is mainly sand and, in some areas, covered with organic matter such as bark fragments, together with small aquatic plants (Fig. 2). This site is surrounded by secondary high- Andean forest. However, the margins of the aquatic ecosystem, although it is a natural freshwater body, it is currently exposed to anthropogenic disturbance.


Figure 1: Location of the study area.


Figure 2: Zarauz stated. Marked points indicate specimen collection sites.


Figure 3: A) Sampling site. B) Active collection site. C) General aspect of source - collection site.

### Data collection

Specimens analyzed in this study were collected through fishing activities conducted in the freshwater system. During the sampling process, each specimen was photographed from the dorsal view using a Canon EOS 600D (T3i) digital camera. A graduated ruler was incorporated as a scale reference in all images, and each specimen was assigned a unique identification code.

Additionally, morphometrics measurements were taken for each individual using a handmade ichthyometer, following scientific standardization. Finally, coloration patterns were also recorded using a standardized categorical classification system for consistent description and comparison among individuals.

## Methodology

### Sampling Design

The methodology was designed to characterize the meristic and morphometric traits of T. bogotensis through standardized field and laboratory procedures. Sampling was conducted to obtain representative specimens by systematically exploring two available microhabitats. A combination of active and passive sampling techniques was used.

Active sampling involved the hand, where the substrate was disturbed upstream to dislodge organisms that were carried by the current into the net. In low-flow conditions, manual collection of substrates such as stones and branches was also performed  as shown in Fig. 2.

Passive sampling included baited traps using two bait types (liver and dough of flour and egg), which showed differences in capture efficiency and selectivity. Sampling sites were classified according to flow type as low (L), moderate (M), or high (H).

### Specimen Processing

Collected specimens were processed in white trays under adequate lighting and handled with fine forceps. Each individual was recorded according to color pattern, maturity stage (approximated in relation to its size), and sampling site (Fig. 4)

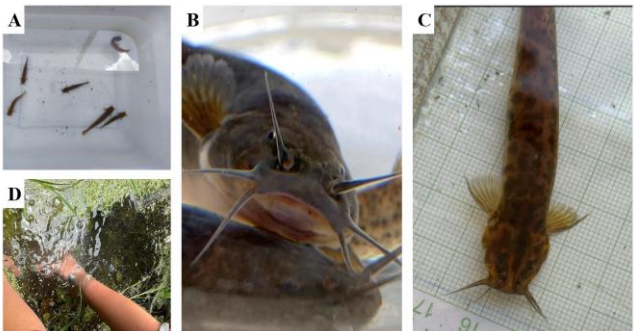



Figure  4: Specimen processing of T. bogotensis captured at Zarauz Farm, Bogotá, Colombia. (A) Capture of specimens; B) Dorsal, ventral and lateral photography of specimens; C) Morphometric measurement of a specimen. (D) Release into the sampling site.

Figure 4 shows the sampling site, representing the capture method used during fieldwork, consisting of a trap positioned within the water current of passive and active forms, using a fishing net. Representative individuals were photographed during the process to establish a reference record for morphological analysis and specimen documentation.. Together, these images summarize the main stages of specimen collection, handling, and biometric evaluation carried out during the study.

Coloration patterns were classified using a standardized coding system: U (uniform), S (spotted), B (banded), M (mottled), and C (camouflage). Sex was recorded as U (unknown), providing a basic approach to the population structure analysis of the sampling sites (Fig. 5)


Figure  5:  Collaboration pattern. A) Spotted; B) Mottled; C) Camouflage; D) Uniform; E) Bands

### Morphometric and Meristic Analysis

Morphometric measurements followed standard ichthyological protocols (Fig. 6). General body measurements included total length (TL), measured from the tip of the snout to the end of the caudal fin; standard length (SL), from the snout to the base of the caudal fin; head length (HL); head width (HW); and caudal peduncle length (CPL) as viewed in Fig. 6.

The obtained measurements showed variation among individuals and sampling events. Total length (TL) ranged approximately from 2.5 cm to 9 cm, while standard length (SL) varied between 1.6 cm and 7 cm. Head length (HL) ranged from about 0.4 cm to 2 cm, and head width (HW) from 0.6 cm to 1 cm. Body height (BH) showed values between 0.4 cm and 0.8 cm, and body width (BW) between 0.2 cm and 0.8 cm. These variations reflect differences in size, developmental stage, and possibly environmental conditions across sampling sites with different flow caudal water.

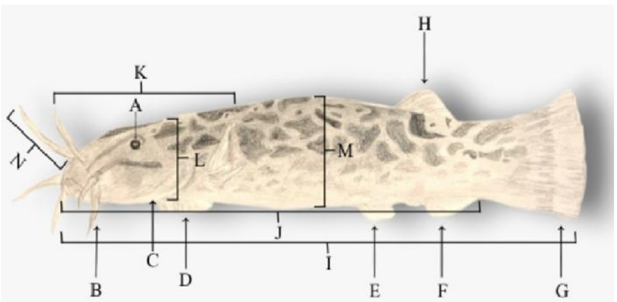



Figure  6:  Anatomy of T. bogotensis. Illustration: Alegria Gutierrez, technique: Analog drawing. Part 1: Morphology:  A) Eye; B) Barbel; C) Opercle; D) Pectoral fin; E) Pelvic fin; F)Anal fin; G) Caudal fin; H) Dorsal fin; Additionally, included the morphometric measurements: I) Total Length; J) Standard

Length; K) Head Length; L) Head Width; M) Body Width; N) Barbel Length.

## Data Analysis

From a qualitative perspective, the study focused on identifying specimens to the lowest possible taxonomic level, enabling the description of species presence, morphological variation, and assemblage composition. However, this approach is limited for comparisons between sites because it does not include standardized abundance data.

Therefore, a quantitative approach was also applied, counting individuals and relating them to sampling effort (area or time), which improves comparability and reduces variability. Additionally, semi-quantitative categories (abundant, frequent, scarce) were used when exact counts were not feasible.

Together, the integration of qualitative, quantitative, and semi-quantitative methods, along with standardized coding systems and detailed morphometric measurements, provided a robust framework for analyzing population patterns, habitat associations, and environmental conditions, supporting ecological assessment and monitoring.

## Results of the experiment

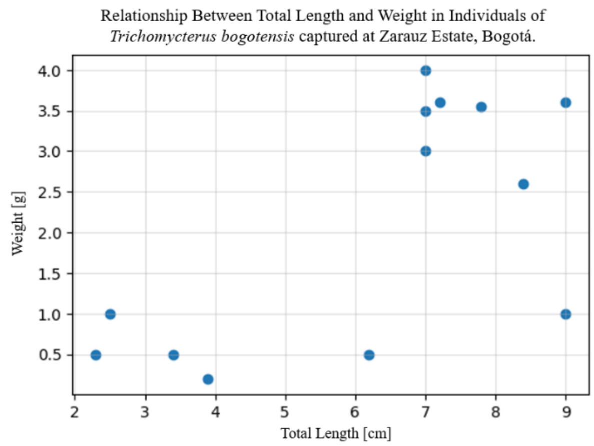
### Descriptive statistics

Total length ranged from 2.3 cm to 9.0 cm, with an average value of 6.21 cm. Weight values ranged between 0.2 g and 5.0 g, with an average of 2.43 g. The data revealed a positive relationship between total length and body weight. Larger individuals exhibited greater body mass, indicating possible proportional growth patterns (Table 1 and Table 2)

Table 1: Descriptive statistics of morphometric variables

| Variable | Minumum | Maximum | Mean ± SD |
|---|---|---|---|
| Total length (cm) | 2,3 | 9 | 6,21±2,38 |
| Standard length (cm) | 1,6 | 7 | 4,42±1,83 |
| Head length (cm) | 0,4 | 2 | 1,03±0,46 |
| Weight (g) | 0,2 | 5 | 2,43±1,65 |

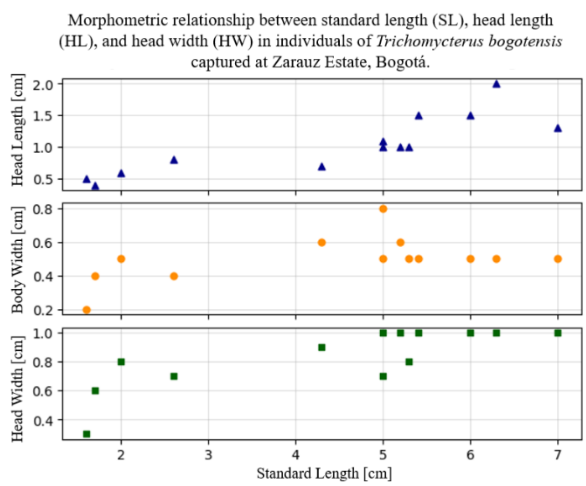
Table 2: Relationship Between Total Length and Weigh.

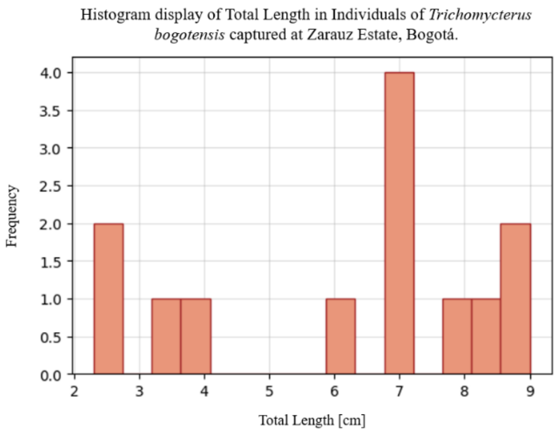



Sampling yielded a representative set of T. bogotensis individuals, allowing both qualitative and quantitative analyses. Although the sample size was limited, the collected data provided important information regarding the morphology and ecological distribution of the species.

Morphometric analysis revealed consistent proportional relationships among individuals. Total length (TL) ranged from 2.3 cm to 9 cm, with an average of 6.21 cm, while standard length (SL) varied between 1.6 cm and 7 cm. Body weight (W) ranged from 0.2 g to 5.0 g, with a mean value of 2.43 g. Head length (HL) ranged from 0.4 cm to 2 cm, indicating relative stability in cephalic proportions(Table 3), which showed low variability, suggesting morphological consistency within the sampled population. Slight increases in body robustness and fin dimensions were observed in larger individuals.

Table 3: Comparison of relationships in the measurements obtained.

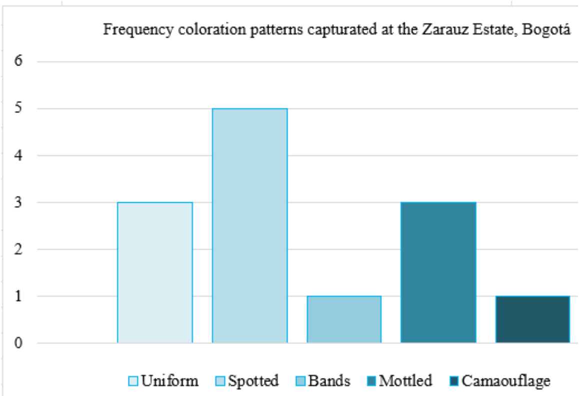





Meristic traits remained within expected ranges for the species, with minor intraspecific variation.

From a qualitative perspective, coloration patterns varied among individuals; the most frequent pattern was mottled (M), followed by spotted (S) and camouflage (C), whereas uniform (U) and banded (B) patterns were less common. These variations appear to be associated with substrate composition and environmental conditions, suggesting adaptive coloration linked to habitat characteristics (Table 4).

Table 4: Frequency coloration patterns captured at the Zarauz Estate, Bogotá




Different coloration patterns may be associated with substrate composition and cryptic adaptation strategies that reduce predation risk in benthic habitats. (Table 5). Among the captured specimens of T. bogotensis, five different coloration patterns were identified. The spotted pattern was the most commonly observed, representing 38.5% of the total organisms analyzed. Uniform and mottled patterns were also frequently recorded, each corresponding to 23.1% of the sampled individuals. In contrast, banded and camouflage patterns presented the lowest frequencies, with only 7.7% each (Figure 4). These results suggest the presence of noticeable chromatic variability within the studied population, which may be associated with adaptation to the rocky substrates and environmental conditions of the aquatic ecosystem where the organisms were collected.

Table 5: Relationships of the relative frequency of coloring patterns

| COLORATION PATTERNS | | |
|---|---|---|
| **Meaning** | **Frequency** | **Relative Frequency %** |
| Uniform | 3 | 23,08 |
| Spotted | 5 | 38,46 |
| Bands | 1 | 7,69 |
| Mottled | 3 | 23,08 |
| Camaouflage | 1 | 7,69 |

Qualitatively, capture efficiency differed according to the sampling method and bait type. Active sampling accounted for the majority of captures across different microhabitats. Passive sampling using baited traps showed differential selectivity: liver bait captured 0 individuals, whereas dough of flour-egg bait captured 1 individual. This method proved to be less effective due to the location and the bait.

The marked size disparity between habitats, where lentic specimens were significantly larger and heavier than those from lotic systems, suggests that environmental energy dynamics and habitat structure directly influence the phenotypic expression and age distribution of the population. These findings indicate that, while T. bogotensis maintains morphological consistency, its ecological distribution is sensitive to local environmental conditions and biological fitness.

Overall, the integration of qualitative, quantitative, and morphometric analyses indicates a morphologically consistent population of T. bogotensis, with ecological variation influenced by habitat type, environmental conditions, and sampling strategy.

## Conclusion

This study provides a preliminary characterization of the endemic Andean catfish T. bogotensis through the integration of morphometric, meristic, qualitative, and quantitative analyses. The results showed that the species presents relatively stable morphological proportions despite variations in body size among individuals, suggesting morphological consistency within the sampled population.

Coloration patterns varied among individuals, with mottled and spotted patterns being the most frequent. These patterns appear to be associated with substrate composition and environmental complexity, supporting the idea that coloration may function as an adaptive mechanism for camouflage and predator avoidance. Additionally, the higher efficiency of active sampling methods and the differential selectivity observed between bait types demonstrate the importance of combining multiple sampling strategies when studying freshwater fish assemblages.

These ecosystems are being threatened, which is why we should raise awareness of what the exploitation of these environments entails, which are key to maintaining the life of endemic species like the T. bogotensis. Most of the solutions for environmental problems start from their own knowledge; for this reason, it is important to continue with the deep searching and propagation, carrying out environmental monitoring and methodologies that can help conserve these resources and species.

## Acknowledgements

We are sincerely grateful to the professor of the Claustro Moderno School, Karen Paola Velandia Candil, for the mentorship, guidance, and patience throughout every stage of this study. Her knowledge in biology was very helpful along the way, making this project successful.

We want to express our sincere gratitude to our professor Carlos Mario Castaño Medina for his unwavering support during the writing, understanding, and development of the article, and for his invaluable assistance throughout the project processes and learning. His knowledge helped us to work faster and more correctly.

We are sincerely grateful to teacher Mariangélica Chávez-González from Colegio Claustro Moderno for her collaboration and support throughout the different writing processes we carried out during the development of the project. Her comments, suggestions, and corrections were fundamental to the article presented.

We would like to express our sincere gratitude to Colegio Claustro Moderno for providing the resources, facilities, and necessary support for the development of this research project. We especially thank our teachers and academic team for their guidance throughout the investigation process, as well as their contributions to the scientific and methodological development of the study.

## References

[1] Collen, B., Whitton, F., Dyer, E.E., Baillie, J.E.M., Cumberlidge, N., Darwall, W.R.T., Pollock, C., Richman, N.I., Soulsby, A.-M. and Böhm, M. (2014), Global freshwater species congruence. Global Ecology and Biogeography, 23: 40-51. [ 8]

[2] Herrera Solano, D. . (2014). Metodología para el muestreo de ictiofauna de aguas continentales con atarrayas. *Repertorio Científico*, *16*(2), 73–79. https://doi.org/10.22458/rc.v16i2.2517[ 4]

[3] Maldonado-Ocampo, J.A.; Ortega-Lara, A.; Usma O., J.S.; Galvis V., G.; Villa-Navarro, F.A.; Vásquez G., L.; PradaPedreros, S. y Ardila R., C. 2005. Peces de los Andes de Colombia. Instituto de Investigación de Recursos Biológicos «Alexander von Humboldt». Bogotá, D.C. - Colombia. 346 p [2,9]

[4] Meador, Cuffney, T., & Gurtz, M. (1993). Methods for sampling fish communities as part of the National Water-Quality Assessment Program. *Antarctica a Keystone in a Changing World*. https://doi.org/10.3133/ofr93104

[5] Moreno, J. M., Aguilar, F. A., Boada, N. S., Rojas, J. A., & Prieto, C.. (2019). Análisis morfométrico e índices corporales del capitán de la sabana. *Revista de la Facultad de Medicina Veterinaria y de Zootecnia*, *66*(2), 141-153. https://doi.org/10.15446/rfmvz.v66n2.82433 [10]

[6] Pole, K. (2009) "Diseño de metodologías mixtas. Una revisión de las estrategias para combinar metodologías cuantitativas y cualitativas". En Renglones, revista arbitrada en ciencias sociales y humanidades, núm.60. Tlaquepaque, Jalisco: ITESO[ 1].

[7] Plutarco Cala-Cala. Medio ambiente y diversidad de los peces de agua dulce de Colombia. Bogotá: Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 2019. 528 p. il. (Colección Álvarez Lleras No. 36)[ 7]

[8] Reis, R.E., Albert, J.S., Di Dario, F., Mincarone, M.M., Petry, P. and Rocha, L.A. (2016), Fish biodiversity and conservation in South America. J Fish Biol, 89: 12-47. https://doi.org/10.1111/jfb.13016[ 5]

[9] Schwarzhans, Werner & Radwańska, Urszula. (2025). 2025 Schwarzhans & Radwanska- The hidden fish diversity from the Langhian of the Central Paratethys-tales from an extinct biodiversity hotspot. [ 6]

# The impact of tourism on water and marine ecosystems on Curaçao

Valentina Antolin Vargas, Thiago Gougon, Damian Irausquin, Sam Kreling, Priyesh Punwasi

*Vespucci College, Willemstad, Curaçao, info@vespuccicollege.net*

## Abstract

Tourism on Curaçao has grown significantly in recent years, leading to increasing pressure on the water supply and the marine environment. This study analyzes the consequences of this growth for both the availability of drinking water and the quality of coastal and marine ecosystems. Curaçao naturally faces structural water scarcity due to a semi-arid climate, limited soil storage, and the virtual absence of natural freshwater sources. As a result, the island is entirely dependent on the desalination of seawater via reverse osmosis, an energy-intensive process that contributes to $CO_2$ emissions and local environmental impacts through the discharge of salt residue (brine). Additionally, inadequate wastewater treatment constitutes a serious environmental problem: a large proportion of wastewater is discharged untreated or insufficiently treated, leading to eutrophication, harmful algal blooms, oxygen depletion, and the spread of pathogens and toxic substances in coastal waters. These processes affect marine ecosystems, including coral reefs and seagrass beds. The health status of green sea turtles, particularly the increasing prevalence of fibropapillomatosis, is used as an ecological indicator of long-term environmental stress. The results demonstrate that the current growth of tourism exceeds Curaçao's ecological carrying capacity and emphasize the need for integrated and sustainable water and tourism policies to prevent further environmental degradation.

## Research themes

• Tourism growth and ecological carrying capacity on Curaçao.

• Structural water scarcity and drinking water supply.

• Seawater desalination and energy consumption.

• Wastewater treatment and water pollution.

• Consequences for marine ecosystems and indicator species.

## Introduction

In recent years, tourism on Curaçao has been growing at an unprecedented pace. Month after month, media and social platforms report on new records in the number of overnight tourists and cruise passengers. In 2025, the island received more than 1.7 million visitors, a 9 percent increase compared to the previous year, while Curaçao itself has only approximately 150,000 inhabitants and a surface area of 444 km$^2$.

This strong growth raises a fundamental question: can a small, dry island bear this increasing pressure?

Curaçao naturally suffers from structural water scarcity due to the warm, dry climate and the virtual absence of natural freshwater sources. At the same time, the growth of tourism is leading to a sharply increasing demand for drinking water and greater wastewater production, particularly in coastal areas where hotels, resorts, and recreational facilities are concentrated. This article examines the consequences of the explosive growth of tourism for water on and around Curaçao. It looks at the drinking water supply and the dependence on desalination, the treatment and discharge of wastewater, the role of geology and erosion, and the effects on the marine ecosystem. By considering these factors in conjunction, insight is gained into the ecological vulnerability of the island and the limits of sustainable tourism on Curaçao.

## 1. Water scarcity and dependence on desalination

Curaçao experiences structural water scarcity as a result of a confluence of climatic, geological, and hydrological factors. The island possesses virtually no natural freshwater sources such as rivers, lakes, or permanent streams. This absence is directly related to the geological structure of the island and the dry climate.

The climate of Curaçao is semi-arid, with an average annual rainfall of approximately 400–600 mm. This rainfall occurs primarily during a short rainy season between October and December. Outside this period, prolonged drought, high temperatures, and constant trade winds dominate. Potential evaporation is high and exceeds the amount of precipitation in many years, meaning that rainwater remains available for hardly any long periods.

Rain often falls in short, heavy showers. Due to the topography and limited vegetation cover, water flows rapidly to the surface via ditches towards the sea. This rapid runoff limits infiltration into the soil and intensifies erosion processes. As a result, structural groundwater replenishment remains minimal. The geological structure of Curaçao plays a central role in this issue. The island consists largely of limestone deposits and older volcanic rocks such as basalt and diabase. Limestone is porous and crisscrossed by cracks and karst structures, allowing water to flow away quickly towards the sea instead of being stored in aquifers. Volcanic rock, on the other hand, is hard and poorly permeable, meaning that infiltration hardly occurs.

The topsoil layer on Curaçao is often thin, calcareous, and stony. As a result, the soil's water retention capacity is low. Rainwater is barely retained and runs off quickly, taking soil particles with it. This leads to further soil depletion and intensifies erosion.

Moreover, the limited groundwater that forms is of poor quality. Due to the proximity of the sea and the limited recharge, saltwater intrusion occurs. Seawater penetrates the subsurface and increases the chloride content of the groundwater. Measurements show that salt concentrations in many wells are barely lower than those of seawater. High evaporation exacerbates this process, as salts remain behind when water evaporates.

Human interventions have further increased these natural limitations. Deforestation, agriculture, and urbanization have led to soil compaction and loss of vegetation, causing infiltration to decrease further. Although dams and reservoirs have been constructed over time to temporarily store rainwater, their effectiveness is limited by high evaporation, low storage capacity, and quality issues such as algal blooms and sedimentation.

Due to this combination of factors, Curaçao has been entirely dependent on seawater desalination for its drinking water supply since the beginning of the twentieth century. The first desalination plant was built as early as 1928, establishing a structural dependency on technological water production.


*Fig. 1: Seawater intake points*

## 2 Operation of reverse osmosis

Reverse osmosis is a desalination technique in which saline or brackish water is forced under high pressure through a semi-permeable membrane. Normally, water would move from a low to a high salt concentration through osmosis, but by applying external pressure, this process is reversed. The membrane allows water molecules to pass through, while salts, metals, and other dissolved substances are largely retained.

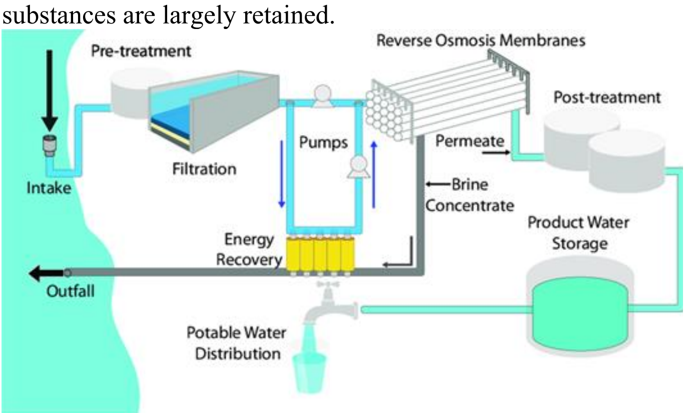



*Fig. 2: Schematic diagram of the desalination process using Reverse Osmosis, from seawater intake to freshwater production and brine discharge.*

The result is a separation into two water streams. The first stream consists of desalinated water suitable for consumption and distribution as drinking water. The second stream is a concentrated residual product, the saline residue or brine. This residue contains not only a high salt concentration but also traces of heavy metals and chemical substances resulting from membrane wear and periodic cleaning of the installations.

Generating the necessary pressure requires powerful pumps, making reverse osmosis an energy-intensive process. On Curaçao, desalination via reverse osmosis forms the primary source of drinking water. Aqualectra's modern installations provide the majority of the population, particularly in and around Willemstad, with reliable drinking water. This strong dependency makes the water supply vulnerable to disruptions in power supply and infrastructure.

### 2.1 Salt residue and ecological effects

The salt residue contains not only high salt concentrations but also traces of heavy metals and chemical cleaning agents originating from the desalination process. When discharged into the sea, this leads to a local increase in salt content. Research at desalination plants in the United Arab Emirates, among others, shows an average increase of approximately 5 ppt around discharge points.

Increased salinity reduces the amount of dissolved oxygen in the water. This process, salting out, occurs because ions attract water molecules.

*Fig. 3 : Pressure vessels and piping systems within a desalination plant on Curaçao.*

### 2.2 Energy consumption and $CO_2$ emissions

The desalination plants on Curaçao produce approximately 40,000 m³ of drinking water daily. The average energy consumption is approximately 3.9 kWh per cubic meter, which amounts to about 156,000 kWh per day. About 50 percent of this energy is sustainably generated; the remainder comes mainly from fossil fuel-fired power plants.

The combustion of diesel results in an emission of approximately 74.1 tonnes of $CO_2$ per terajoule. Taking into account an average efficiency of 37 percent, the daily energy consumption amounts to approximately $2.1 \times 10^5$ kWh, resulting in an emission of approximately 56.2 tonnes of $CO_2$ per day, or about 21,000 tonnes of $CO_2$ per year.

### 2.3 Effects of $CO_2$ on the Marine Environment

$CO_2$ emissions contribute to climate change and directly affect the marine ecosystem. Higher concentrations of $CO_2$ lead to warming of seawater, causing coral bleaching as corals lose their symbiotic algae. Additionally, $CO_2$ dissolves in seawater, leading to acidification. The decrease in pH hinders calcification in corals and shellfish and weakens reef structures.

Because of Curaçao’s great potential for solar and wind energy these problems can (partially)be resolved in the future.

These processes increase the vulnerability of marine ecosystems to erosion, storm damage, and biodiversity loss.

# 3 Wastewater issues on Curaçao


*Fig. 4: geographical location of the waste water treatment plants on Curaçao.*

In addition to desalination, wastewater constitutes a structural and growing source of environmental pressure on Curaçao. In 2018, only 16 percent of the produced wastewater was actually treated. Approximately 84 percent was discharged untreated into the terrestrial and marine environment. Only about 33 percent of the population is connected to the central sewage system. As a result, a large proportion of domestic and tourist wastewater reaches the environment without adequate treatment.

Furthermore, wastewater treatment plants process only about 50 percent of the wastewater supplied via the sewer system. The treated effluent is primarily used for irrigation, while a significant portion still ends up in the sea. The limited treatment capacity thus constitutes a structural bottleneck in water management on the island.

In areas without a sewer connection, cesspools and septic systems are widespread. These systems are often outdated, leak, and are inadequately monitored. Consequently, wastewater can infiltrate the soil and groundwater unhindered. In some cases, the contents of cesspools are transported by truck, but there are also situations where wastewater is discharged directly into the sea. This significantly increases the burden on coastal waters.

Sewage contains high concentrations of nitrogen, phosphate, bacteria, and organic material. Due to Curaçao's porous limestone soil, polluted water can sink into the subsurface relatively quickly and invisibly. As a result, pollution often remains undetected for a long time, while the effects only manifest themselves later in coastal waters and marine ecosystems.

## 3.1 Spread of pollutants via groundwater and surface water

In addition to wastewater, erosion and sediment transport play a significant role in the spread of pollution towards the coast. During heavy rainfall, water washes over bare and degraded soils, carrying along soil particles, nutrients, and pollutants. This runoff reaches the sea directly via ditches and drainage channels.

Furthermore, the porous limestone soil enables the underground spread of pollution. Research has shown elevated concentrations of nitrogen and phosphate in the groundwater, indicating long-term leakage of wastewater into the subsurface. Due to the natural slope of the groundwater system, this polluted water flows slowly towards the coast.

When groundwater reaches the sea, it does so through a process known as submarine groundwater discharge, in which groundwater flows beneath the seabed and enters coastal waters directly. As a result, pollution can appear in locations far removed from the original source.

Tides strongly influence these processes. During low tide, sea pressure decreases, allowing more polluted groundwater to move towards the sea. Measurements show that higher nutrient concentrations are observed in coastal waters specifically during low tide. During high tide, this outflow is temporarily slowed down.

Surface water currents and prevailing northeasterly trade winds ensure further dispersion along the coast. Enclosed or semi-enclosed bays, such as Piscadera and the Spanish Water, are particularly vulnerable. Limited water circulation here leads to the accumulation of sediment, nutrients, and other waste materials.

## 3.2 Consequences for marine ecosystems

Wastewater has far-reaching consequences for marine ecosystems around Curaçao. Nutrients such as nitrogen and phosphate cause eutrophication, leading to harmful algal blooms. These algae reduce light penetration, suffocate corals and seagrass, and lower the amount of dissolved oxygen in the water. Furthermore, feces in wastewater increase biochemical oxygen demand, creating oxygen-poor zones in which many organisms cannot survive.

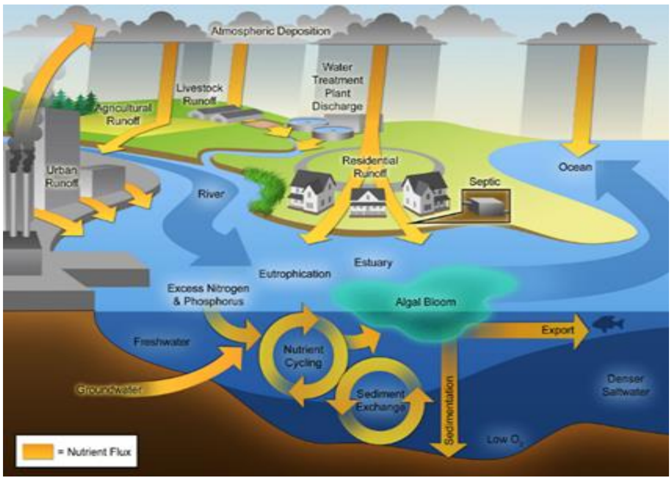



*Fig 5: eutrophication*

Wastewater also constitutes a major source of pathogens. Bacteria, viruses, parasites, and protozoa end up in the sea via discharges. Escherichia coli is used as an indicator of fecal contamination and is often found in excessively high concentrations, even in treated wastewater. Although this bacterium primarily poses risks to human health, marine mammals such as bottlenose dolphins can become infected with other resistant shared bacteria, such as MRSA.

Viral transmission via wastewater is also relevant. Although viruses are usually species-specific, coronavirus-like infections have been detected in marine mammals, demonstrating that transmission from polluted water is possible. Parasites and protozoa pose an additional threat to fish and marine mammals. Cryptocaryon irritans, the causative agent of White Spot Disease, can cause fish mortality. Protozoa such as Cryptosporidium spp. and Toxoplasma gondii can infect both humans and marine organisms and reach coastal waters via wastewater, among other means.

**Table A**

*Influent design parameters of wastewater treatment plant Klein Hofje combined with the effluent quality (June - November 2018) of wastewater treatment plant Klein Hofje to determine the specific treatment efficiency. [107]*

| Parameter | Influent Value | Effluent Value | Unit | efficiency |
|---|---|---|---|---|
| COD | 350 | 101.6 | mg/l | 70.97% |
| BOD | 870 | 43.1 | mg/l | 95.05% |
| Kjeldahl Nitrogen | 170 | 46.4 | mg/l | 72.7 % |
| TSS | 1040 | 12.1 | mg/l | 98.84% |
| Ammonium ($NH_4^+$) | Not specified | 25.5 | mg/l | - |
| Chloride ($Cl^-$) | Not specified | 196.6 | mg/l | - |
| E-coli | Not specified | >1000 CFU/100 | mg/l | - |
| EC | Not specified | 1341.8 | µS/cm | - |
| pH | 6.5 | 7.3 | - | - |

**Table B**

*Requirements for Wastewater Treatment Outflow*

| ***Parameter*** | ***Value*** | ***Unit*** |
|---|---|---|
| *Chemical Oxygen Demand (COD)* | *<100* | *mg/l* |
| *Biological Oxygen Demand (BOD)* | *<30* | *mg/l* |
| *Kjeldahl Nitrogen <40 mg/l* | *<40* | *mg/l* |
| *Total Suspended Solids (TSS)* | *<100* | *mg/l* |
| *Ammonium (NH+4)* | *<40* | *mg/l* |
| *Chloride (Cl−) <250 mg/l* | *<250* | *mg/l* |
| *E-coli* | *<1000CFU/100* | *mg/l* |
| *Electric Conductivity (EC)* | *<2250* | *µS/cm* |
| *pH* | *6-8.5* | *-* |

*CFU = colony-forming unit. [107]*

Chemical pollution exacerbates these effects. Oils and fats constitute approximately 10 percent of wastewater and cause suffocation, toxicity, and long-term pollution. They reduce the amount of dissolved oxygen and increase oxygen consumption in the water. Heavy metals such as mercury, cadmium, lead, chromium, and copper do not break down, accumulate in organisms, and affect the growth, reproduction, respiration, and immune systems of fish. This disrupts the food web. In addition, persistent chemical and organic substances occur, including polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins, and furans. These substances are highly toxic, bioaccumulative, and disrupt hormonal processes. Organic solvents and volatile organic compounds are also widespread. Research shows that solvents, in particular, are harmful and sometimes fatal to reef coral due to oxidative stress, disruption of cell membranes, and increased turbidity.

Changes in pH and electrical conductivity constitute an additional stress factor. A decreased pH inhibits calcification in corals and shellfish, while an increased pH and conductivity stimulate biological activity and algal blooms. Together, these processes lead to a deterioration of habitat quality and a decline in biodiversity.

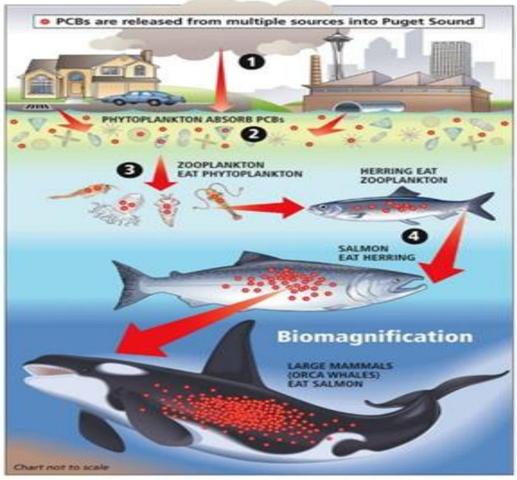



*Fig 6: bioaccumulation*

### 3.3 Tourism and additional environmental pressure

Tourism on Curaçao has increased significantly. In 2024 and 2025, approximately 700,000 tourists visited the island annually by plane and about 800,000 by cruise ship. This growth has led to higher wastewater production, particularly in coastal areas with a high concentration of hotels, resorts, and recreational facilities.

The existing wastewater treatment capacity is already insufficient for the habitants of Curaçao, and the tourism industry is adding an increased pressure to this system. This leads to the increase in the local accumulation of nutrients and pollutants.

## 4 Sea turtles as ecological indicators

Sea turtles play a key role within marine ecosystems and are considered important indicator species for the quality of the marine environment. In particular, the green sea turtle (Chelonia mydas) plays a regulatory role through its grazing behavior on seagrass beds. By grazing regularly, green sea turtles prevent seagrass and algae from becoming overgrown. This keeps seagrass beds productive, oxygen-rich, and ecologically stable. Healthy seagrass beds, in turn, form an important habitat and nursery for numerous fish species and invertebrates.

When green sea turtles decline in numbers or are in reduced health, this has direct consequences for the ecosystem. Seagrass beds can then become overgrown, die off, or lose their ecological function. The health status of green sea turtles is therefore used as a gauge for long-term environmental stress in coastal waters.

### 4.1 Fibropapillomatosis in green sea turtles

In recent years, green sea turtles with fibropapillomatosis have been found with increasing frequency in the waters around Curaçao. This disease is characterized by the formation of external and internal tumors, which can develop around the eyes, mouth, fins, and within organs. The tumors can severely impair vision, locomotion, and food intake, and often lead to death in advanced stages.

*Fig 7: Fibropapillomatosis*

Fibropapillomatosis is strongly associated worldwide with infection by the Chelonid alphaherpesvirus 5. This virus is considered a necessary condition for the onset of the disease. However, not every infected turtle develops tumors, suggesting that additional environmental factors play a significant role. The disease is therefore considered multifactorial.

### 4.2 Wastewater and environmental stress as exacerbating factors

Scientific studies show that fibropapillomatosis is most prevalent in coastal areas with high human pressure and reduced water quality. Wastewater discharges introduce large quantities of nutrients, heavy metals, and persistent organic pollutants into the sea. Nutrients such as nitrogen and phosphate cause eutrophication and algal blooms. This algal bloom can be accompanied by the production of biotoxins, which cause chronic inflammation and oxidative stress. These processes are known to promote tumors and can amplify the effects of an existing viral infection.

Heavy metals such as copper, zinc, cadmium, nickel, lead, and arsenic reach coastal waters via sewage, urban runoff, industrial activities, and shipping. These metals do not break down and can accumulate in sea turtles. Exposure to metals has been linked to immune system disruption and increased oxidative stress, making turtles less able to suppress viral infections.

In addition, persistent organic pollutants and per- and polyfluoralkyl substances play a role. These substances are bioaccumulative and weaken the immune system upon prolonged exposure. Although they are often not found in acutely toxic concentrations, they contribute to chronic environmental stress.

### 4.3 Local situation around Curaçao

Local observations and studies around Curaçao describe fibropapillomatosis as the result of prolonged environmental pollution. Heavy metals such as copper, zinc, cadmium, nickel, and arsenic are explicitly mentioned as problematic substances in coastal waters. Additionally, the presence of Sargassum seaweed plays a role, as this seaweed can absorb metals and, upon decomposition, can further deteriorate water quality.

Temperature is also mentioned as an influencing factor. Higher water temperatures increase both viral activity and physiological stress in turtles. In Caracas Bay, an area with high human pressure due to tourism, shipping, and coastal development, fibropapillomatosis was diagnosed in five of the eight green sea turtles examined. Comparable quantitative data is lacking for other bays around Curaçao, indicating a clear lack of knowledge.

## 5 Conclusion

The explosive growth of tourism on Curaçao has major and interconnected consequences for the water on and around the island. Due to the sharp increase in the number of tourists, the demand for drinking water has risen significantly, while Curaçao has virtually no natural freshwater sources due to its dry climate and geological structure. As a result, the island is entirely dependent on the desalination of seawater via reverse osmosis. This technique is energy-intensive and leads to high $CO_2$ emissions, which contributes to climate change, warming of seawater, and ocean acidification. In addition, the discharge of saline residue from desalination plants causes a locally increased salinity in the sea, resulting in a decrease in dissolved oxygen and disruption of marine ecosystems.

In addition to the pressure on the drinking water supply, tourism causes a sharp increase in wastewater production, particularly in coastal areas where hotels, resorts, and recreational facilities are concentrated. The existing wastewater treatment capacity is already insufficient and thus unable to accommodate this growth. As a result, this large amount of wastewater is discharged into the terrestrial and marine environment untreated or insufficiently treated. This leads to eutrophication, harmful algal blooms, oxygen depletion, and the spread of pathogens and chemical substances in coastal waters.

The consequences of this are clearly visible in the marine environment around Curaçao. Corals and seagrass beds are being degraded, biodiversity is declining, and ecological indicator species such as the green sea turtle are showing increasing health problems, including fibropapillomatosis. This points to long-term environmental stress strongly linked to human pressure in tourist areas. In summary, the explosive growth of tourism exacerbates both the quantitative pressure on the drinking water supply and the qualitative deterioration of the water and marine ecosystems around Curaçao.

## References


[1] Abdisa, T., Bula, B., Etana, M., & Getu, M. (2023). Epidemiology of helminthes, protozoans and ectoparasites of fishes: A review. *Journal of Veterinary Medicine and Animal Sciences, 6*(1), 1126. https://meddocsonline.org/journal-of-veterinary-medicine-and-animal-sciences/epidemiology-of-helminthes-protozoans-and-ectoparasites-of-fishes-a-review.html

[2] Adshead, D., Fuldauer, L., Thacker, S., Hickford, A., Rouhet, G., Muller, W. S., Hall, J. W., & Nicholls, R. (2018). *Evidence-based infrastructure: Curaçao*. United Nations Office for Project Services.

[3] Ahmadpour, E., Rahimi, M. T., Ghojoghi, A., Rezaei, F., Hatam-Nahavandi, K., Oliveira, S. M. R., De Lourdes Pereira, M., Majidiani, H., Siyadatpanah, A., Elhamirad, S., Cong, W., & Pagheh, A. S. (2022). Toxoplasma gondii infection in marine animal species, as a potential source of food contamination: A systematic review and meta-analysis. *Acta Parasitologica, 67*(2), 592–605. https://doi.org/10.1007/s11686-021-00507-z

[4] Alonso Aguirre, A., Balazs, G. H., Zimmerman, B., & Galey, F. D. (1994). Organic contaminants and trace metals in the tissues of green turtles (*Chelonia mydas*) afflicted with fibropapillomas in the Hawaiian Islands. *Marine Pollution Bulletin, 28*(2), 109–114. https://doi.org/10.1016/0025-326X(94)90547-9

[5] Amma, L. V., & Ashraf, F. (2020). Brine management in reverse osmosis desalination: A UAE perspective. *Department of Civil Engineering, University of Bolton RAK Academic Centre*, 1–6.

[6] Antilliaans Dagblad. (2025, mei). 1,5 miljoen toeristen op Curaçao: “Stranden worden privéstranden waarvoor je moet betalen”. https://www.ad.nl/nieuws/1-5-miljoen-toeristen-op-curacao-stranden-worden-privestranden-waarvoor-je-moet-betalen

[7] Australian Government, Department of Climate Change, Energy, the Environment and Water. (2022, June 30). *Polychlorinated dioxins and furans*. https://www.dcceew.gov.au/environment/protection/npi/substances/fact-sheets/polychlorinated-dioxins-and-furans

[8] Bauman, A. G., Burt, J. A., Feary, D. A., Marquis, E., & Usseglio, P. (2010). Tropical harmful algal blooms: An emerging threat to coral reef communities? *Marine Pollution Bulletin, 60*(11), 2117–2122. https://doi.org/10.1016/j.marpolbul.2010.08.015

[9] Beebe, K. (2023, June 29). *The vital link: Why water quality matters for coral reefs*. Coral Reef Alliance. https://coral.org/en/blog/the-vital-link-why-water-quality-matters-for-coral-reefs/

[10] Blue Halo Curaçao. (n.d.). *Sustainably manage ocean resources through marine spatial planning, marine reserves, and improved fisheries management*. United Nations Department of Economic and Social Affairs. https://sdgs.un.org/partnerships/blue-halo-curacao-sustainably-manage-ocean-resources-through-marine-spatial-planning

[11] Caribisch Netwerk. (2019, 28 februari). Afvalwater ziekenhuis Curaçao wordt al jaren geloosd in mangrovegebied. https://caribischnetwerk.ntr.nl/2019/02/28/afvalwater-ziekenhuis-curacao-vergiftigt-mangrovegebied-in-willemstad/

[12] Caribisch Netwerk. (2025, April 14). Curaçao zet eindelijk stappen richting EU-gelden voor waterbeheer. https://caribischnetwerk.ntr.nl/2025/04/14/curacao-zet-eindelijk-stappen-richting-eu-gelden-voor-waterbeheer

[13] Central Bureau of Statistics Curaçao. (2021). *Curaçao environmental statistics compendium 2020*. https://cuatro.sim-cdn.nl/cbscuracao/uploads/curacao-environmental-statistics-compendium-2020-a_0.pdf

[14] CARMABI. (2025, March 18). *World Recycling Day March 18*. https://www.carmabi.org/blog/

[15] CBM. (2020, June 20). Wastewater definitely not a waste of time. *Curaçao Business*. https://cbm.cw/wastewater-definitely-not-a-waste-of-time

[16] Chen, Q., Tang, K., Zhai, W., Zhu, Z., Yang, J. T., He, Z., Li, M., Kao, S., Yang, J., Zheng, Q., Lønborg, C., Thomas, H., & Jiao, N. (2025). Microbial responses to ocean deoxygenation: Revisiting the impacts on organic carbon cycling. *iScience, 28*(7), 112826. https://doi.org/10.1016/j.isci.2025.112826

[17] Cornell University. (n.d.). *Feces and urine—Human biological agent reference sheets (BARS)*. https://ehs.cornell.edu/research-safety/biosafety-biosecurity/biological-safety-manuals-and-other-documents/bars-other/feces-and-urine-human

[18] Curaçao Chronicle. (n.d.). Curaçao moves closer to securing €18.6 million EU grant for improved water management. https://www.curacaochronicle.com/post/local/curacao-moves-closer-to-securing-186-million-eu-grant-for-improved-water-management

[19] Curaçao Chronicle. (n.d.). Water quality in Curaçao’s bays worsens during rainy season, threatening coral reefs. https://www.curacaochronicle.com/post/local/water-quality-in-curacaos-bays-worsens-during-rainy-season-threatening-coral-reefs

[20] Curaçao.nu. (2025, June 10). Europese Unie helpt Curaçao met aanpak waterlozingen. https://www.curacao.nu/nieuws/nieuws-van-bonaire-curacao/49647/europese-unie-helpt-curacao-met-aanpak-waterlozingen

[21] Curaçao.nu. (2025, June 10). Nieuwe waterfabriek Hato West operationeel in 2026. https://www.curacao.nu/nieuws/economie/51539/nieuwe-waterfabriek-hato-west-operationeel-in-2026

[22] Curaçao.nu. (2025, November 6). Aqualectra haalt 50 procent duurzame stroom. https://www.curacao.nu/nieuws/algemeen/81680/aqualectra-haalt-50-procent-duurzame-stroom

[23] Curaçao.nu. (2025, November 9). Mangroven Curaçao onder druk door bouw en vervuiling. https://www.curacao.nu/nieuws/natuur/81787/mangroven-curacao-onder-druk-door-bouw-en-vervuiling

[24] Curaçao.nu. (2025, November 24). Onderzoek: Regen spoelt vervuiling vanuit Willemstad rechtstreeks naar koraalriffen. https://www.curacao.nu/nieuws/milieu/82575/onderzoek-regen-spoelt-vervuiling-vanuit-willemstad-rechtstreeks-naar-koraalriffen

[25] De Haan, L. (2023, 19 april). *Grijze stroom: Wat is het verschil met groene stroom?* HIER. https://www.hier.nu/klimaatverandering/grijze-stroom-wat-is-het-verschil-met-groene-stroom

[26] De Vries, A. J., & Department of Environment, Public Works The Hague. (2000). The semi-arid environment of Curaçao: A geochemical soil survey. *Netherlands Journal of Geosciences, 79*(4), 479–494. https://www.cambridge.org/core/journals/netherlands-journal-of-geosciences/

[27] Dijkstra, J. (2025, 11 april). *Zijn waterfilters met UV-technologie effectiever tegen bacteriën?* Pure Aqua. https://blog.pureaqua.nl/kennisbank/zijn-waterfilters-met-uv-technologie-effectiever-tegen-bacterien

[28] Di Mauro, V., Kamyab, E., Kellermann, M. Y., Moeller, M., Nietzer, S., Luetjens, L. H., Pawlowski, S., Petersen-Thiery, M., & Schupp, P. J. (2023). Ecotoxicological effects of four commonly used organic solvents on the scleractinian coral *Montipora digitata*. *Toxics, 11*(4), 367. https://doi.org/10.3390/toxics11040367

[29] Domingo, J., & Ashbolt, N. (2012). *Fecal pollution of water*. Encyclopedia of Earth. http://library.snls.org.sz/Encyclopedia%20of%20the%20Earth/

[30] Drechsel, P., Keraita, B., Seidu, R., & Abaidoo, R. C. (2014). Human health risks from wastewater-irrigated vegetable farming. In P. Drechsel & B. Keraita (Eds.), *Irrigated urban vegetable production in Ghana: Characteristics, benefits and risk mitigation*. International Water Management Institute. https://cgspace.cgiar.org/

[31] Drinkwater – Water- en energiebedrijf Bonaire. (n.d.). *Drinkwater*. WEB Bonaire. https://www.webbonaire.com/drinkwater/

[32] Drinkwater op Aruba volledig met osmosetechniek bereid. (n.d.). *NEMO Kennislink*. https://www.nemokennislink.nl/publicaties/drinkwater-op-aruba-volledig-met-osmosetechniek-bereid/

[33] Dujon, A. M., Schofield, G., Venegas, R., Thomas, F., & Ujvari, B. (2021). Sea turtles in the cancer risk landscape: A global meta-analysis of fibropapillomatosis prevalence and associated risk factors. *Pathogens, 10*(10), 1295. https://doi.org/10.3390/pathogens10101295

[34] Early desalination in the Caribbean with a focus on the Netherlands Antilles. (n.d.). American Membrane Technology Association. https://www.amtaorg.com/early-desalination-in-the-caribbean-with-a-focus-on-the-netherlands-antilles

[35] Eindredactie. (2025, October 24). Stromingen onthullen vervuiling rond Curaçao. *Antilliaans Dagblad*. https://antilliaansdagblad.com/nieuws-menu/31890-stromingen-onthullen-vervuiling-rond-curacao

[36] Eljaiek-Urzola, M., Romero-Sierra, N., Segrera-Cabarcas, L., Valdelamar-Martínez, D., & Quiñones-Bolaños, É. (2019). Oil and grease as a water quality index parameter for the conservation of marine biota. *Water, 11*(4), 856. https://doi.org/10.3390/w11040856

[37] Environmental Law Institute. (2016). *Sustainable fisheries & coastal zoning in Curaçao*. https://www.eli.org/sites/default/files/eli-pubs/eli-2016-sustainable-fisheries-coastal-zoning-curacao.pdf

[38] Environmental Literacy Council. (2025a, April 22). *What influences ocean pH?* https://enviroliteracy.org/what-influences-ocean-ph/

[39] Environmental Literacy Council. (2025b, May 5). *Why is pH important to sea life?* https://enviroliteracy.org/why-is-ph-important-to-sea-life/

[40] European Commission, Directorate-General for Climate Action. (2018). *Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions*. https://www.legislation.gov.uk/eur/2018/2066/data.html

[41] Faires, M. C., Gehring, E., Mergl, J., & Weese, J. S. (2009). Methicillin-resistant *Staphylococcus aureus* in marine mammals. *Emerging Infectious Diseases, 15*(12), 2071–2072. https://doi.org/10.3201/eid1512.090220

[42] Glibert, P. M., Maranger, R., Sobota, D. J., & Bouwman, L. (2014). The Haber Bosch–harmful algal bloom (HB–HAB) link. *Environmental Research Letters, 9*(10), 105001. https://doi.org/10.1088/1748-9326/9/10/105001

[43] Golomazou, E., Malandrakis, E., Panagiotaki, P., & Karanis, P. (2021). *Cryptosporidium* in fish: Implications for aquaculture and beyond. *Water Research, 201*, 117357. https://doi.org/10.1016/j.watres.2021.117357

[44] Govers, L. L., Lamers, L. P. M., Bouma, T. J., De Brouwer, J. H. F., & Van Katwijk, M. M. (2014). Eutrophication threatens Caribbean seagrasses: An example from Curaçao and Bonaire. *Marine Pollution Bulletin, 89*(1–2), 481–490. https://doi.org/10.1016/j.marpolbul.2014.09.003

[45] Green, E. J., & Carritt, D. E. (1967). Oxygen solubility in sea water: Thermodynamic influence of sea salt. *Science, 157*(3785), 191–193. https://doi.org/10.1126/science.157.3785.191

[46] Guenseley, M. (n.d.). *Curaçao* [Prezi presentation]. Prezi. https://prezi.com/0otgrqshvuiu/curacao/

[47] Hameete, C. (2025, March 18). *World Recycling Day March 18*. CARMABI. https://www.carmabi.org/blog/

[48] Health Canada. (2006, December 14). *PCBs*. Government of Canada. https://www.canada.ca/en/health-canada/services/healthy-living/your-health/environment/pcbs.html

[49] Health Canada. (2019, November 25). *Dioxins and furans*. Government of Canada. https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants/dioxins-furans.html

[50] Houten, J. G., & Gysels, H. (1984). *De Oosthoek encyclopedie van het milieu*. Oosthoek Uitgeversmaatschappij.

[51] International Energy Agency. (n.d.-a). *World: Sources of electricity generation*. https://www.iea.org/world/electricity

[52] International Energy Agency. (n.d.-b). *World: Total $CO_2$ emissions*. https://www.iea.org/world/emissions

[53] International Energy Agency, Taylor, P., Lavagne D'Ortigue, O., Trudeau, N., & Francoeur, M. (2008). *Energy efficiency indicators for public electricity production from fossil fuels*. https://iea.blob.core.windows.net/assets/

[54] Irausquin, D. (in press). *Drinkwaterzuivering op Curaçao*. PWS-manuscript gebaseerd op interview met algemene manager waterbeheer van Aqualectra.

[55] Ishii, S., & Sadowsky, M. J. (2008). *Escherichia coli* in the environment: Implications for water quality and human health. *Microbes and Environments, 23*(2), 101–108. https://doi.org/10.1264/jsme2.23.101

[56] Jager, C., De Boer, S., & Central Bureau of Statistics Curaçao. (2021). *Curaçao environmental statistics compendium 2020*. Central Bureau of Statistics Curaçao. https://cuatro.sim-cdn.nl/cbscuracao/uploads/

[57] Jin, J., Espino, M., Fernàndez-Garcia, D., & Folch, A. (2025). Coupling of numerical groundwater–ocean models to improve understanding of the coastal zone. *Ocean Science, 21*(4), 1407–1424. https://doi.org/10.5194/os-21-1407-2025

[58] Jones, K., Ariel, E., Burgess, G., & Read, M. (2015). A review of fibropapillomatosis in green turtles (*Chelonia mydas*). *The Veterinary Journal*. https://doi.org/10.1016/j.tvjl.2015.10.041

[59] Kakuschke, A., & Prange, A. (2007). The influence of metal pollution on the immune system: A potential stressor for marine mammals in the North Sea. *International Journal of Comparative Psychology, 20*, 179–193.

[60] Keller, J. M., Balazs, G. H., Nilsen, F., Rice, M., Work, T. M., & Jensen, B. A. (2014). Investigating the potential role of persistent organic pollutants in Hawaiian green sea turtle fibropapillomatosis. *Environmental Science & Technology*. https://doi.org/10.1021/es5014054

[61] Kent u de milieu-impact van pekelafvoer uit de ontziltingssystemen van zeewater? (n.d.). Guangdong Wteya Environmental Technology Co., Ltd.. https://nl.wteya.com/

[62] Kontas, A., Kucuksezgin, F., Altay, O., & Uluturhan, E. (2003). Monitoring of eutrophication and nutrient limitation in Izmir Bay (Turkey) before and after wastewater treatment plant. *Environment International, 29*(8), 1057–1062. https://doi.org/10.1016/S0160-4120(03)00098-9

[63] Kruijssen, T. P., Wit, M. R. J., Van Breukelen, B. M., Van Der Ploeg, M., Wageningen University & Research, & Delft University of Technology. (2024). Hydrogeological conceptualization of a small island groundwater system using historical data. *Netherlands Journal of Geosciences, 103*, e27. https://doi.org/10.1017/njg.2024.21

[64] Lorentzen, E. A. (2021, February 4). *Why fish are "immune" to coronaviruses*. Institute of Marine Research. https://www.hi.no/

[65] Machado e Silva, D. A., Costa, A. P., Rodrigues, A. C., Bem-Haja, P., Pires, S. S., Soares, A. M., Marques, C. R., Pacheco, M. G., & Rocha, R. J. (2021). Organic solvents alter photophysiological and oxidative stress profiles of the coral *Zoanthus* sp.: Towards an optimization of ecotoxicological protocols. *Science of the Total Environment, 777*, 146072. https://doi.org/10.1016/j.scitotenv.2021.146072

[66] Makhlouf, A. S. H., & Botello, M. A. (2018). Failure of metallic structures due to microbiologically induced corrosion and techniques for protection. In *Handbook of Materials Failure Analysis* (pp. 1–18). Elsevier. https://doi.org/10.1016/B978-0-08-101928-3.00001-X

[67] Marshall, T. (2025a, June 19). *The essential guide to understanding and fighting Brooklynella*. Manta Systems. https://www.mantasystems.net/

[68] Marshall, T. (2025b, October 2). *Disease identification in saltwater fish: A comprehensive guide for hobbyists*. Manta Systems. https://www.mantasystems.net/

[69] Marshall, T. (2025c, December 5). *Understanding marine velvet in saltwater fish: Comprehensive

*guide*. Manta Systems. https://www.mantasystems.net/

[70] Mathavarajah, S., Stoddart, A. K., Gagnon, G. A., & Dellaire, G. (2020). Pandemic danger to the deep: The risk of marine mammals contracting SARS-CoV-2 from wastewater. *Science of the Total Environment, 760*, 143346. https://doi.org/10.1016/j.scitotenv.2020.143346

[71] Mechanical water treatment. (2025, June 30). MITA Water Technologies. https://mitawatertechnologies.com/

[72] Ministry of Health, Environment & Nature, CARMABI, Green Force, DBB, University of Curaçao, UNESCO, MEO, Aqualectra, Selikor, BT&P, Meteo, SOAW, Amigu di Tera, Defensa Ambiental, Isena, G., & Narain, L. (2014). *National report of Curaçao for the Third International Conference on Small Island Developing States, Apia, Samoa, September 1–4, 2014* [Report].

[73] Moratal, S., Dea-Ayuela, M. A., Cardells, J., Marco-Hirs, N. M., Puigcercós, S., Lizana, V., & López-Ramon, J. (2020). Potential risk of three zoonotic protozoa (*Cryptosporidium* spp., *Giardia duodenalis*, and *Toxoplasma gondii*) transmission from fish consumption. *Foods, 9*(12), 1913. https://doi.org/10.3390/foods9121913

[74] Naturvårdsverket. (n.d.-a). *Dioxins and furans (as TEQ).* https://utslappisiffror.naturvardsverket.se/en/substances/chlorinated-organic-substances/pcdd--pcdf/

[75} Naturvårdsverket. (n.d.-b). *Polycyclic aromatic hydrocarbons (PAHs).* https://utslappisiffror.naturvardsverket.se/en/substances/other-organic-substances/polycyclic-aromatic-hydrocarbons/

[76] Nederlandse Vereniging van Zeepfabrikanten. (n.d.). *Hoe werkt zeep?* NVZ. https://www.nvz.nl/kennisbank/over-schoonmaakmiddelen/hoe-werkt-zeep/

[77] NetRegs. (n.d.). *What is an organic solvent?* https://www.netregs.org.uk/environmental-topics/air-pollution/solvent-emissions/what-is-an-organic-solvent/

[78] NOAA. (2024). *Toxoplasmosis and its effects on Hawai'i marine wildlife*. https://www.fisheries.noaa.gov/pacific-islands/endangered-species-conservation/toxoplasmosis-and-its-effects-hawaii-marine

[79] NOAA. (2025, September 25). *Ocean acidification*. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

[80] NOAA. (n.d.). *Caribbean region: National marine ecosystem status*. https://ecowatch.noaa.gov/regions/caribbean

[81] Nu.CW. (2025, March 21). Onderzoek duurzame toerismegroei gaat van start. https://nu.cw/2025/03/21/onderzoekduurzametoerismegroeigaatvanstart2/

[82] Nu.CW. (2025, July 17). Vervuiling kustwater vastgesteld bij ABC-eilanden. https://nu.cw/2025/07/17/vervuilingkustwatervastgesteldbijabceilanden/

[83] Oil contaminated wastewater treatment solution meets discharge standards. (2025, September 8). https://dainam-enviro.com/en/oil-contaminated-wastewater-treatment-solution-meets-discharge-standards-t642.html

[84] Olkowska, E., Ruman, M., & Polkowska, Ż. (2014). Occurrence of surface active agents in the environment. *Journal of Analytical Methods in Chemistry, 2014*, 1–15. https://doi.org/10.1155/2014/769708

[85] Omgekeerde osmose voor zuiver water: Waterdoctor legt uit. (2020, May 12). Waterdoctor. https://www.waterdoctor.be/waterbehandeling/omgekeerde-osmose/

[86] Ontzilting. (n.d.). *Climate-ADAPT: Adaptation options.* European Environment Agency. https://climate-adapt.eea.europa.eu/

[87] Othman, H. B., Pick, F. R., Hlaili, A. S., & Leboulanger, C. (2022). Effects of polycyclic aromatic hydrocarbons on marine and freshwater microalgae: A review. *Journal of Hazardous Materials, 441*, 129869. https://doi.org/10.1016/j.jhazmat.2022.129869

[88] Page-Karjian, A., Norton, T. M., Krimer, P., Groner, M., Nelson, S. E., Jr., & Gottdenker, N. L. (2014). Factors influencing survivorship of rehabilitating green sea turtles (*Chelonia mydas*) with fibropapillomatosis. *Journal of Zoo and Wildlife Medicine*. https://doi.org/10.1638/2013-0132R1.1

[89] Panagopoulos, A., & Haralambous, K. (2020). Environmental impacts of desalination and brine treatment: Challenges and mitigation measures. *Marine Pollution Bulletin, 161*(Pt B), 111773. https://doi.org/10.1016/j.marpolbul.2020.111773

[90] Patrick. (2025, November 5). *Wat is grijze stroom?* Om | Nieuwe Energie. https://www.samenom.nl/grijze-stroom/

[91] PCC Group. (2025, February 26). *Surfactants.* PCC Group Product Portal. https://www.products.pcc.eu/en/products/segment-1/surfactants/

[92] Pons-Bordas, C., Hazenberg, A., Hernandez-Gonzalez, A., Pool, R., Covelo, P., Sánchez-Hermosin, P., López, A., Saavedra, C., Fraija-Fernández, N., Fernández, M., & Aznar, F. (2020). Recent increase of ulcerative lesions caused by *Anisakis* spp. in cetaceans from the north-east Atlantic. *Journal of Helminthology, 94*. https://doi.org/10.1017/S0022149X20000115

[93] Pozzan, R., De Almeida Roque, A., Iwamoto, H., De Campos Guerreiro, F., Da Silva, A. P., Rubio-Vargas, D. A., De Marchi, M., De Oliveira, F., Martínez-Burgos, W. J., Prodocimo, M. M., & De Oliveira Ribeiro, C. A. (2025). Polycyclic aromatic hydrocarbons in marine environments

affect fish reproduction: A critical review. *Toxics, 13*(9), 747. https://doi.org/10.3390/toxics13090747

[94] PubMed. (2024). Effect of tourist activity on wastewater quality in selected wastewater treatment plants in the Balearic Islands (Spain). https://pubmed.ncbi.nlm.nih.gov/38289556/

[95] Regering van Curaçao. (2020). *De toekomst van water: Beleidsplan voor integraal waterbeheer.* https://www.publicpolicycuracao.com/wp-content/uploads/2020/05/Beleidsplan_water_v07.pdf

[96] Ren, A. (2017). Environmental pollutants and neural tube defects. In R. C. Gupta (Ed.), *Reproductive and developmental toxicology* (2nd ed., pp. 1139–1166). Elsevier. https://doi.org/10.1016/B978-0-12-804239-7.00061-5

[97] Rijksinstituut voor Volksgezondheid en Milieu. (n.d.-a). *Biociden.* Risico's van Stoffen. https://rvs.rivm.nl/onderwerpen/stoffen-en-producten/biociden

[98] Rijksinstituut voor Volksgezondheid en Milieu. (n.d.-b). *Staphylococcus aureus-infecties.* https://www.rivm.nl/staphylococcus-aureus-infecties

[99] Rumbaugh, E. (2025, October 14). Toxic impacts: Key chemicals that undermine wastewater treatment efficiency. Aster Bio. https://asterbio.com/toxic-impacts-key-chemicals-that-undermine-wastewater-treatment-efficiency/

[100] Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various types of water: A review. *IOP Conference Series: Earth and Environmental Science, 118*, 012019. https://doi.org/10.1088/1755-1315/118/1/012019

[101] Sanchez Barranco, V., Schellenberg, L., Mienis, F., Brussaard, C. P. D., Haas, A. F., & De Nooijer, L. J. (2025). Seasonal changes in bay water column properties and their influence on the distribution of dissolved and particulate substances along the south coast of Curaçao (Caribbean Sea). *Marine Pollution Bulletin*. https://doi.org/10.1016/j.marpolbul.2025.117545

[102] Sea Creatures. (2023, February 17). *Beautiful Curaçao*. https://www.beautifulcuracao.com/nature/beautiful-sea

[103] Seven Seas Water Group. (2024, September 5). *A deep dive into seawater reverse osmosis desalination*. Seven Seas Water Group. https://sevenseaswater.com/deep-dive-into-swro/

[104] Seven Seas Water Group. (2025, April 3). *Aqualectra signs 20-year Water-as-a-Service® BOOT agreement with Seven Seas Water Group*. https://sevenseaswater.com/aqualectra-20-year-agreement/

[105] Sharma, M., Kant, R., Sharma, A. K., & Sharma, A. K. (2024). Exploring the impact of heavy metals toxicity in the aquatic ecosystem. *International Journal of Energy and Water Resources, 9*(1), 267–280. https://doi.org/10.1007/s42108-024-00284-1

[106] Sivaranjanee, R. S., Senthil Kumar, P., & Mahalaxmi, S. (2022). A review on agro-based materials on the separation of environmental pollutants from water systems. *Chemosphere*. https://www.sciencedirect.com/

[107] Snijders, K., Van Breukelen, B. M., Langeveld, J. G., & Wit, M. (2023). *Urban wastewater management of Willemstad, Curaçao, and environmental implications*. Delft University of Technology. https://resolver.tudelft.nl/

[108] Soliman, M. N., Guen, F. Z., Ahmed, S. A., Saleem, H., Khalil, M. J., & Zaidi, S. J. (2021). Energy consumption and environmental impact assessment of desalination plants and brine disposal strategies. *Process Safety and Environmental Protection, 147*, 589–608. https://doi.org/10.1016/j.psep.2020.12.038

[109] Technische Universiteit Delft. (2021). *Onderzoek naar nutriëntenconcentraties en grondwaterstroming richting kustzones van Curaçao* [Rapport]. https://repository.tudelft.nl/

[110] Technische Universiteit Delft. (2024). *Nutrient transport through submarine groundwater discharge on Curaçao* [Rapport]. https://repository.tudelft.nl/

[111] Tech, G. W. (2023, September 18). *Ontzilt water: Sleutelfactoren die van invloed zijn op de waterkwaliteit*. Genesis Water Technologies. https://nl.genesiswatertech.com/

[112] Tharavathy, N., Krishnamoorthy, M., & Hosetti, B. (2013, July 14). Oxidation pond: A tool for wastewater treatment. *Journal of Ecology and Environmental Sciences*. https://www.rroij.com/

[113] Tomka, M., Kovacikova, E., Kovacik, A., Helczman, M., Jambor, T., Andreji, J., & Massanyi, P. (2025). Evaluation of trace metal effects on immunological parameters in freshwater fish. *Toxicology Letters, 411*, S107. https://doi.org/10.1016/j.toxlet.2025.07.279

[114] Tripepi, M., Van Veghel, I. J. R., & Vreugdenhil, A. D. (2025). First report of fibropapillomatosis and critical habitat use in green sea turtles in Curaçao. *Journal of Marine Biology*. https://doi.org/10.1080/24750263.2025.2539835

[115] Tryland, M., Lunestad, B.-T., Nesbakken, T., Robertson, L., Skjerve, E., Grahek-Ogden, D., & Norwegian Scientific Committee for Food Safety. (2011). *Human pathogens in marine mammal meat* (VKM Report 2011:09). https://vkm.no/

[116] United Nations Environment Programme. (2019). *Caribbean environment outlook*. UNEP. https://www.unep.org/resources/report/caribbean-environment-outlook

[117] United Nations Environment Programme. (2019). *Towards sustainable desalination*. https://www.unep.org/news-and-stories/story/towards-sustainable-desalination

[118] United Nations Environment Programme. (2022). *Marine pollution in the Caribbean: Coastal tourism pressures*. UNEP.

[119] United Nations Environment Programme. (n.d.). *PCBs: A forgotten legacy*. https://www.unep.org/topics/pollution-and-health/persistent-organic-pollutants-pops/pcbs-forgotten-legacy

[120] Understanding cesspools and septic tanks. (2025, February 28). A&L Cesspool. https://alcesspool.com/

[121] UNWTO. (2022). *Tourism and water use: Implications for coastal areas*. https://www.unwto.org/

[122] U.S. Department of Energy. (2020). *Curaçao energy snapshot*. https://www.energy.gov/

[123] U.S. Energy Information Administration. (n.d.). *Oil and petroleum products explained: Use of oil*. https://www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php

[124] U.S. Environmental Protection Agency. (2025a, January 28). *Vegetable oils and animal fats*. https://www.epa.gov/

[125] U.S. Environmental Protection Agency. (2025b, February 24). *What are volatile organic compounds (VOCs)?* https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs

[126] Van Sambeek, M., Eggenkamp, H., Vissers, M., Utrecht University, & DHV Milieu en Infrastructuur. (2000). The groundwater quality of Aruba, Bonaire and Curaçao: A hydrogeochemical study. *Netherlands Journal of Geosciences, 79*(4), 459–466.

[127] Vanstreels, R. E. T., Durant, A., Santos, A. P., Santos, R. G., Sarmiento, A. M. S., Rossi, S., Setim, F. E., Gattamorta, M. A., Matushima, E. R., Mayorga, L. F. S. P., & Uhart, M. M. (2023). Exploring the relationship between environmental drivers and the manifestation of fibropapillomatosis in green turtles (*Chelonia mydas*) in eastern Brazil. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0290312

[128] Veilig drinkwater dankzij bacteriën. (n.d.). TU Delft. https://www.tudelft.nl/

[129] Vertec BioSolvents. (2022, October 5). *What are organic solvents?* https://www.vertecbiosolvents.com/what-are-organic-solvents

[130] Vijf vragen over magnesium aan Jeroen de Baaij. (n.d.). Radboudumc. https://www.radboudumc.nl/

[131] Water desalination report. (n.d.). https://www.desalination.com/desalination-suppliers/aqualectra

[132] Water-Energy Nexus. (2017, March 20). International Energy Agency. https://www.iea.org/reports/water-energy-nexus

[133] Weese, S. (2020, November 3). *COVID-19 in animals review part 6: Marine mammals*. Worms & Germs Blog. https://www.wormsandgermsblog.com/

[134] Wit, M. R., Van Egmond, J., Kruijssen, T. P., Bense, V. F., & Van Breukelen, B. M. (2025). Hydrogeochemical signatures and human impact: A comprehensive analysis of groundwater quality on the semi-arid island of Curaçao. *Journal of Hydrology: Regional Studies, 60*, 102555. https://doi.org/10.1016/j.ejrh.2025.102555

[136] WOAH. (2021). *Fibropapillomatosis of sea turtles*. https://www.woah.org/

[137] Wood, C., Balazs, G. H., Rice, M., Work, T. M., Jones, T. T., Sterling, E., Summers, T. M., Brooker, J., Kurpita, L., King, C. S., & Lynch, J. M. (2021). Sea turtles across the North Pacific are exposed to perfluoroalkyl substances. *Environmental Pollution*. https://doi.org/10.1016/j.envpol.2021.116875

[138] Yao, C., & Benguang, Z. (2023). Research advances on the taxonomy of *Anisakis*, Anisakidae. https://doi.org/10.12140/j.issn.1000-7423.2023.04.014

[139] Zannotti, M., & Giovannetti, R. (2015). Kinetic evidence for the effect of salts on the oxygen solubility using laboratory prototype aeration system. *Journal of Molecular Liquids, 211*, 656–666. https://doi.org/10.1016/j.molliq.2015.07.063

[140] Zayat, H. E., Nasr, P., & Sewilam, H. (2021). Investigating sustainable management of desalination brine through concentration using forward osmosis. *Environmental Science and Pollution Research, 28*(29), 39938–39951. https://doi.org/10.1007/s11356-021-13311-z

# Tourism in The Wadden Sea

Marie Keller, Sofie Scholten, Hinrich Langer
*KGS Waldschule Schwanewede, Germany,*
*mareike.metschulat@waldschule-schwanewede.net*

## Abstract

The wadden sea attracts 20 millions of tourists annually, because of its wide beaches and unique tidal landscape. Tourism brings important income to the region, but this fragile ecosystem is struggling under the growing pressure of human activity. Therefore we wondered how big that impact on the environment really is and are going to consider factors such as littering or water pollution. We expect that busy tourist areas show greater signs of latter aspects and are going to analyze the relative correlation of tourism numbers to water quality and garbage quantity. In order to do the analysis we will conduct interviews with locals and look at informations from the city offices.

We hope to identify the main environmental problems connected to tourists and propose solutions to improve the welfare of the area, by raising awareness to the causes and finding possible spots for improvement.

## 1 Content

### 1.1 Purpose of the Investigation

The purpose of the investigation is to find out, how tourism affects the environment of the wadden sea, as there are around 20 million tourists a year, making it an important factor in the wellbeing of the area. Therefore we made the hypothesis; Places with more tourists have more litter and more pollution. The investigation is about the wadden sea as it is a very important ecosystem that is local to northern Germany. It has a wide diversity of fish, birds and seals to start with but also smaller organisms such as worms, insects or algae.

### 1.2 Method of the investigation

In order to conduct the investigation, we used an array of methods, such as interviews with local people to hear about their opinions, as they experience tourists everyday, meaning that they will have made observations regarding tourists. We also collected data from local city offices, such as tourist numbers and water quality and observed the litter on several beaches. Then we compared the data and looked for a correlation, if there is worse quality water or more litter on the beaches, our hypothesis would be confirmed.

### 1.3 Results

Tourism in the wadden sea is responsible for littering and pollution, but also disturbs wildlife in the area. Tourism still is important economically as around 20 million people visit a year contributing for a large part of the regions income, enabling the preservation for a part.

## 2 Conclusion

Tourism in the wadden sea brings too much benefits with it to ban it, as it is supplying a lot of jobs, but it still has drawbacks with the pollution, littering and the disturbance of wildlife. Therefore, as it cannot be banned, it should be made more environmentally friendly. In order to achieve that there are many possible solutions such as the installation of bins to enable tourists easier disposal. Furthermore tourists should be educated for a responsible use of the area during their stay. That way the area would be able to uphold the economical part of the equation whilst reducing the negative impact the tourists have by bad behavior. Then it might be helpful to have regular cleanups on the beaches and other affected areas to manually reduce the amount of waste the tourists leave behind them. If all of the aforementioned measures are successfully implemented the data should be overlooked again, if the improvements are enough, it can stay that way, if the problem is ongoing it might be necessary to limit the number of tourists allowed, or for there to be more measures taken in order to solve the ongoing problem.

## References

https://www.berger-touristik.de/cuxhaven-magazin/detail/wattenmeer-cuxhaven-eine-duestere-zukunft

https://wattmitmedien.kurs.jade-hs.de/25909/uebertourismus-am-wattenmeer-diversitaetsverlust-durch-zerstoerte-lebensraeume/

https://www.nationalpark-wattenmeer.de/wp-content/uploads/2023/11/NNL_Fachpublikation_Regionaloekonomische-Effekte-des-Tourismus_web.pdf

https://www.nationalpark-wattenmeer.de/wp-content/uploads/2023/11/NNL_Fachpublikation_Regionaloekonomische-Effekte-des-Tourismus_web.pdf

https://sdn-web.de/wp-content/uploads/Themen-95-04-14_Klimawandel-und-mögliche-Auswirkungen-auf-die-deutsche-Nordseeküste.pdf

https://www.nationalpark-wattenmeer.de/wp-content/uploads/2023/06/Prowad_Broschuere_DE_barrierefrei.pdf

# Microplastic in the Wadden Sea

Jarek Pietsch, Jule Haake, Mia Guzmann

KGS Waldschule Schwanewede, Germany,
mareike.metschulat@waldschule-schwanewede.net

## Abstract

Microplastic pollution is a growing threat to marine ecosystems worldwide. The Wadden Sea, a UNESCO World Heritage Site and important coastal habitat, is also affected. In our project, we focus less on the amount of microplastics and more on their cycle and their impacts on the ecosystem.

We examine how microplastics enter the Wadden Sea through human activities such as tourism and shipping, and how they are continuously transported, deposited and resuspended by tides, currents, and wind. This allows them to reamin the ecosystem for a long time. We also analyze the consequences for marine organisms and the food chain, as many animals ingest microplastics. Our aim is to better understand the ecological effects and highlight the importance of environmental protection.

## 1 Content

### 1.1 Purpose of the Investigation

In this investigation we want to find out where microplastics in the Wadden Sea come from and how they enter the environment. The Wadden Sea is a large natural area in northern Germany where many animals and plants live, such as seals, birds, fish, and small organism like worms and algae, We want to understand how microplastics get into this area.

### 1.2 Method of the Investigation

We visited the Wadden Sea Centre in Cuxhaven and conducted an interview with staff members to learn more about microplastics and their origins. After that, we went into the mudflats, observed the area carefully, and collected sediment samples.The sediment samples were then examined under a microscope to look for possible microplastic particles and fibres. We also looked for visible signs of plastic waste or pollution in the environment.In the end, we combined all the information from the interview and our field observations and compared them.

### 1.3 Results

The investigation shows that a large part of microplastics likely comes from shipping. This is also indicated by the blue plastic fibres we found in the sediment samples under the microscope. In addition, tourism and other human activities contribute to the pollution.

Microplastics enter the Wadden Sea through different pathways and are continuously transported, deposited and resuspended by tides, currents, and wind. As a result, they remain in the ecosystem for a long time.

Many marine organisms ingest microplastics, allowing them to enter the food chain. This can cause health effects such as inflammation or reduced fitness. In addition, microplastics can absorb pollutants from the environment and later release them again.

## 2 Conclusion

Microplastics are a long-term environmental problem in the Wadden Sea because they come from many everyday sources and break down very slowly. A key issue is that they accumulate in the environment over time and are therefore difficult to remove.

The investigation shows that microplastics are not just a single environmental issue but affect many parts of the ecosystem, especially marine environments and the animals living there. Therefore, it is important to reduce the amount of plastic entering the environment and to handle plastic products more responsibly in general.

## References

https://www.horiba.com/aut/scientific/resources/science-in-action/where-do-microplastics-come-from/
https://www.nationalpark-wattenmeer.de/news/gemeinsam-fuer-eine-plastikfreie-nordsee/
https://www.schutzstation-wattenmeer.de/naturschutz/gefaehrdungen/verschmutzung/muell/
https://www.stiftung-schutzstation-wattenmeer.de/aktuelles/beitrag/mikroplastik-detektive/

# Utilising Game Theory to Determine the Grounds for Marine Cooperation

Hikaru Kashihara, Ritsu Kobayashi, Hana Sato, Kaito Tojo

*Makuhari Senior High School, Japan, myoshida@shibumaku.jp*

***Abstract***

Marine resource management is key in an age where climate change, increased global demand and fierce competition exacerbates habitat destruction. This issue becomes increasingly challenging under contested ocean territories, in which individuals prioritise self-interest and deplete limited resources—a concept known as the "Tragedy of the Commons." A look into the specific elements that come into play in the signing of fishery agreements is essential for international cooperation and sustainable fishing. Even if territorial disputes persist, a shared agreement ensures continuous protection of the environment, economic viability of fishing, and diplomatic stability. Our research aims to clarify what circumstances, priorities, and relationships fishery agreements are established under. We will compound historical data from successful treaties, identifying the different variables that come into play. We will then assess those variables through simulations based on game theory and find the most impactful variables. These results could be generalized for not only fisheries, but for seabed mining and management for other resources. Through research in both historical and psychological fields, we can expect to find sufficient data to form a proposal on how to proceed with efforts in marine resource cooperation.

***Keywords***

Game theory, maritime cooperation, marine environmental treaties (METs), qualitative comparative analysis (QCA). Tragedy of the Commons

# 1 Introduction

## 1.1. Background

### 1.1.1 Maritime cooperation

Maritime cooperation involves efforts between organisations to manage, protect and utilise ocean resources sustainably. Globally, marine protected areas (MPAs) and other regulations of cooperation are reinforced through international fishing restrictions such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) [1]. However, in the high seas (international waters) outside of territorial waters and Exclusive Economic Zones (EEZs), restrictions are insufficient. Indiscriminate fishing in these areas will lead to the depletion of marine resources; to prevent this, maritime regulations must be enacted [2].

### 1.1.2 Maritime cooperation in disputed areas

However, establishing maritime regulations between nations engaged in territorial disputes is challenging. This is due to the ambiguity of border lines and ownership of marine resources. Overlapping claims are intensely linked to national sovereignty and security as well, impeding negotiation.

An example of a region with such dynamics is the South China Sea. In this area, which accounts for 12% of the world's fish catch, multiple countries such as China, the Philippines, Vietnam and Taiwan are asserting sovereignty over each other's EEZs. Total fish stocks in the South China Sea have declined by 70–95% since the 1950s [3]. However, poaching, illegal fishing in other countries' territorial waters and EEZs, and the construction of illegal artificial islands continue to occur. In 2011, the Declaration on the Conduct of Parties in the South China Sea (DOC), a set of preliminary guidelines for resolving disputes, was agreed upon by the disputing parties and their respective countries [4]. However, this agreement did not include provisions for the protection of marine resources or restrictions on the extraction of mineral resources. Overfishing continues to this day.

### 1.1.3 Tragedy of the Commons

The Tragedy of the Commons is an economic concept popularised by ecologist Garrett Hardin in 1968, that individuals with open access to a public resource (commons) will act in their own self-interest, depleting the resource.
In his essay *The Tragedy of Commons*, he describes a pasture that is open to all herders; each herder benefits by adding one more animal to the graze. However, the cost of overgrazing is shared by everyone, and the land degrades and eventually becomes unusable for all. While players understand protection of the commons is vital, the fear that other herdsmen will disobey and increase their profit prevents cooperation [5].
According to this theory, in maritime areas where territorial disputes exist, the focus shifts to maximisation of profit, leading to overfishing and the overexploitation of resources. The noble goal of marine environmental protection is not a prioritised factor in such situations.

## 1.2 Purpose

Hardin stresses that when private interest and collective rationality clash, "mutual coercion" is the solution [5]. However, in contested maritime regions, it remains unclear what conditions truly make cooperation possible. For instance, evolutionary biologist David Barash states that conservatives will acknowledge the necessity of private land ownership, claiming shared land is tantamount to unoccupied land, while liberals will call for social authority [6].
As climate change, population growth and global demand for resources accelerate, clarifying the foundations for successful agreements is vital. Especially for a country like Japan, which relies heavily on resources abroad, supply must be steady, even when economic competition and environmental protection overlap. Therefore, this study aims to determine the political, economic, and psychological conditions that effectively encourage the signing of maritime treaties.

# 2 R1 (Research 1)

## 2.1 Introduction

Examining the theories of international cooperation and examples of marine environmental treaties (METs), we discovered recurring variables that could come into play. Within the complex geopolitical context of the signing of METs, these variables interlink; a simple analysis of each variable may miss the broader nuances existing in negotiations. Therefore, utilizing Qualitative Comparative Analysis (QCA), we will derive a formula on what specific variables are necessary in the signing of bilateral METs, answering what the most significant combination of conditions is sufficient.

## 2.2 Methodology

### 2.2.1 Research design

To account for complexities, this study utilises two-step QCA to identify the combinations of conditions sufficient for the signing of bilateral METs. The two-step design follows the procedure developed by Schneider and Rohlfing. This separates structural conditions (unlikely to change in the short term) from proximate conditions (likely to change), removing the risk of comparing non-equivalent cases [7]. In stage 1, we passed cases through a necessary conditions test, using 0.9 as the threshold for allowing a dyad to pass. In stage 2, we created a truth table of proximate conditions, arranging all combinations of conditions and recorded which combinations are associated with the outcome across the empirical cases. Then, we used Boolean minimization to find a final solution on the required variables in the signing of METs. We applied the standard consistency score of 0.75 as a threshold [8].

### 2.2.2 Case selection

Our analysis listed dyads under the limitation that the two nations share an EEZ and that both have a reliance on fishing. Without these fulfilled, it is nonsensical for a treaty to be signed in the first place. We established these metrics before examining outcome variation to minimize selection bias. The final dataset has a total of 32 dyads (5 were excluded in stage 1, leaving 27 in stage 2), with an emphasis on geographic diversity, outcome diversity, and inclusion of variables that both do and do not fulfil structural conditions.

The outcome—whether a treaty was signed or not— was identified through the IEA database and other supplementary records such as Memorandums of Understanding.

### 2.2.3 Variables

#### 2.2.3.a Stage 1: Structural Conditions

These define the population of relevant cases. A dyad failing either condition was excluded from analysis as out-of-scope, rather than coded as a negative case, since the absence of these conditions renders treaty formation structurally implausible.

**DR (diplomatic relations)**

- 1: Both states maintain continuous formal diplomatic relations, including active embassies or equivalent missions, for at least 10 consecutive years.
- 0: Relations are absent, unrecognised, severed, or interrupted within that period.

**EF (Economic reliance or importance of fishing)**

- 1: Fishing or marine resource extraction constitutes a significant share of the economy or is important in one region and both states are active in the shared maritime zone.
- 0: Neither state has meaningful economic dependence on the shared zone. This is distinct from the initial case selection condition on the importance of fishing as this variable only applies in situations in which there is a particularly great reliance on fishing.

#### 2.2.3.b Stage 2: Proximate Conditions

These operate within the eligible population and explain variation in the outcome. All conditions were coded using publicly available data sources specified below.

**EC (Ecological Crisis)**

- 1: A significant pollution event, fish stock collapse, coral bleaching episode, or oil spill in the shared maritime zone is documented by IUCN, UNEP, or an equivalent body within the past twenty years.
- 0: Otherwise.

**TP (Third-Party Pressure)**

- 1: A documented international body, such as the UN Environment Programme, EU accession frameworks, or World Bank environmental conditionality has applied pressure or mediation specifically related to marine environmental governance of the dyad.
- 0: Otherwise.

**TR (Environmental Treaty Track Record)**

- 1: Both states have ratified UNCLOS and at least one major multilateral environmental framework and have a prior record of bilateral or multilateral environmental cooperation.
- 0: One or both states lack these commitments.

**ED (High Bilateral Economic Dependence)**

- 1: The other state ranks among the top five trading partners for at least one state in the dyad, or if significant bilateral investment ties exist, as verified against World Bank bilateral trade data.
- 0: Otherwise.

### 2.2.4 Variable justification

The variables included in R1 were identified through a review of the existing literature on international environmental cooperation and documented cases of MET formation, rather than derived from a single theoretical framework.

**EC — Ecological Crisis**

Ecological crises may encourage cooperation because they increase the costs of non-cooperation and create urgency for cooperation. Kingdon argues that unexpected crises can open opportunities for policy change [9]; Young states that environmental crises help overcome joint action problems in international negotiations [10]. Sprinz and Vaahtoranta also show that states facing high ecological vulnerability are more likely to support environmental agreements [11].

**TP — Third-Party Pressure**

Third-party pressure is based on the idea that international organizations encourage cooperation by changing the payoff structure of cooperation, reducing mistrust, and providing monitoring mechanisms that increase costs of noncooperation [12]. This is because nations would rather maximize mutual benefit over relative gains.

**TR — Environmental Treaty Track Record**

A history of environmental cooperation may make future treaties easier. Putnam's two-level games framework suggests that domestic institutional capacity shapes what international agreements are negotiable, and states with established environmental treaty records have demonstrated the capacity for future treaties [13]. From a game-theoretic perspective, Axelrod shows that repeated interaction builds trust and reciprocity that make cooperation self-sustaining [14].

**ED — Economic Interdependence**

Economic interdependence is based on the idea that strong trade and investment ties increase the costs of non-cooperation between states [15]. Neumayer further argues that economically interdependent states are more likely to commit to environmental agreements [16].

### 2.2.5 Hypothesis

While structural conditions such as diplomatic relations and reliance on fisheries define the potential for cooperation, the signing of an MET requires at least one of several proximate causal variables to be fulfilled, or a combination of them.

## 2.3 Results

### 2.3.1 Formula

In stage one, cases with major diplomatic disruptions or lack of reliance on marine resources were excluded, which are the following:

- China – Taiwan (DR=0)
- Saudi Arabia – Bahrain (EF=0)
- Israel – Lebanon (DR=0)
- North Korea – South Korea (DR=0)
- Pakistan – India (DR=0)
- China – Taiwan (DR=0)

We then inserted all other dyads into the table and derived a truth table out of it in stage 2.

Table 1: Stage 2 All Variables.

| | Dyad | EC | TP | TR | ED | O |
|---|---|---|---|---|---|---|
| 1 | US – Canada | 1 | 1 | 1 | 1 | 1 |
| 2 | US – Mexico | 1 | 1 | 1 | 1 | 1 |
| 3 | Chile – Peru | 1 | 0 | 1 | 0 | 1 |
| 4 | Brazil – Uruguay | 0 | 0 | 1 | 1 | 1 |
| 5 | Ecuador – Colombia | 1 | 1 | 1 | 0 | 1 |
| 6 | Norway – Russia | 1 | 0 | 1 | 0 | 1 |
| 7 | Norway – Iceland | 1 | 0 | 1 | 0 | 1 |
| 8 | Sweden – Finland | 1 | 1 | 1 | 1 | 1 |
| 9 | France – Spain | 1 | 1 | 1 | 1 | 1 |
| 10 | Greece – Italy | 1 | 1 | 1 | 1 | 1 |
| 11 | South Africa – Mozambique | 1 | 1 | 0 | 0 | 0 |
| 12 | Kenya – Tanzania | 1 | 1 | 1 | 0 | 1 |
| 13 | Senegal – Guinea-Bissau | 1 | 1 | 0 | 0 | 1 |
| 14 | Madagascar – Comoros | 1 | 0 | 0 | 0 | 1 |
| 15 | Australia – Indonesia | 1 | 1 | 1 | 1 | 0 |
| 16 | Australia – PNG | 1 | 0 | 1 | 1 | 1 |
| 17 | New Zealand – Fiji | 1 | 1 | 1 | 0 | 1 |
| 18 | Philippines – Malaysia | 1 | 1 | 1 | 0 | 1 |
| 19 | Philippines – Vietnam | 1 | 1 | 1 | 0 | 0 |
| 20 | China – Japan | 1 | 0 | 1 | 1 | 0 |
| 21 | China – Vietnam | 1 | 0 | 0 | 1 | 0 |
| 22 | Japan – South Korea | 1 | 0 | 1 | 1 | 0 |
| 23 | India – Sri Lanka | 1 | 0 | 0 | 0 | 0 |
| 24 | India – Maldives | 1 | 1 | 1 | 1 | 0 |
| 25 | Iran – UAE | 1 | 0 | 0 | 1 | 1 |
| 26 | Oman – Yemen | 0 | 0 | 0 | 0 | 0 |
| 27 | Eritrea – Djibouti | 0 | 0 | 0 | 0 | 0 |

Table 2: Truth table.

| EC | TP | TR | ED | Outcome | Representative Cases |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | US–Canada, US–Mexico, Sweden–Finland, Greece–Italy, India–Maldives |
| 1 | 0 | 1 | 0 | 1 | Chile–Peru, Norway–Russia, Norway–Iceland |
| 0 | 0 | 1 | 1 | 1 | Brazil–Uruguay |
| 1 | 1 | 0 | 0 | 1 | S. Africa–Mozambique, Senegal–Guinea-Bissau |
| 1 | 0 | 1 | 1 | **C (1/0)** | **Contradiction: Australia–PNG (1) vs. China–Japan, Japan–S. Korea (0)** |
| 1 | 1 | 1 | 0 | **C (1/0)** | **Contradiction: Ecuador–Colombia, Kenya–Tanzania (1) vs. Philippines–Malaysia, Philippines – Vietnam(0)** |
| 1 | 0 | 0 | 1 | 0 | China–Vietnam, Iran–UAE |
| 1 | 0 | 0 | 0 | 0 | Madagascar–Comoros, India–Sri Lanka |
| 0 | 0 | 0 | 0 | 0 | Oman–Yemen, Eritrea–Djibouti |

From the results of the table, we used Boolean Minimization to draw out a formula that represented the necessary combination of variables needed for success in the signing of METs. The initial formula was:

$$EC \cdot TR + {\sim}EC \cdot TR \cdot ED + EC \cdot TP \rightarrow O \qquad (1)$$

This can be simplified, as ED is redundant when EC and TR are both present.
The formula is as follows:

$$O=((EC\cdot TR)+(EC\cdot TP)+(TR\cdot ED)) \qquad (2)$$

Put into words, the QCA revealed that METs are successfully signed through the following three different models, under the assumption that diplomatic disruptions did not happen and fishing was significant to both states.

**1. Ecological Crisis + a Track Record of efforts in environmental protection (EC・TR)**

A stereotypical example of this pattern is the efforts by Canada and the United States in restoring the original conditions of Lake Erie. This lake had always been in "serious economic and ecological harm," and had multiple failed attempts for cooperation between the two countries in 1908 and 1946. This combination of variables led to the ultimate signing of the Convention on Great Lakes Fisheries [17].

**2. Ecological Crisis + Third Party Influence**

In 2025, Mozambique and South Africa signed the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement, which is a UN negotiated treaty. Before, the shared waters between these two countries were described as in the state of "full exploitation or depletion of coastal fishing grounds," and the UN's constant efforts in increasing cooperation between countries was a definitive factor in the signing of this treaty [18].

**3.Track Record of efforts in environmental protection + high Economic Interdependency**

Australia and New Zealand are heavily reliant on one another economically and signed the Treaty between the Government of Australia and the Government of New Zealand on Cooperation in Fisheries Surveillance and Law Enforcement in 1999. They had multiple treaties signed before, like the Convention on Biological Diversity in 1992, which indicates a healthy record of environmental protection.

### 2.3.2 Consistency, coverage and contradictions

#### 2.3.2.a Consistency and coverage

The overall solution achieves a consistency of 0.81, above the conventional threshold of 0.75, indicating that the formula reliably predicts treaty formation across the dataset. The raw coverage of each of the paths varies, with path 1 having the most coverage at 0.82. This shows that an ecological crisis combined with a history of cooperation is the way to reach a treaty. Path 3 has the lowest raw coverage, it has the highest consistency, showing how even though a track record of cooperation and economic interdependency is the hardest combination of variables to have amongst the three, if it does occur, the signing of a treaty is the most likely.

#### 2.3.2.b Contradictions

4 cases (China – Japan, Japan – South Korea, Philippines – Malaysia, and Philippines – Vietnam), produced contradictory results. Within QCA, contradictions usually signal a meaningful pattern that the current model does not account for [7]. All 4 contradictory dyads had the same structural feature of the existence of territorial disputes. One possible reason why a contradiction was born is because we based the study off the liberal hypothesis that all nations are aiming for absolute gains. Yet, within contested territories, this is not always the case as states try to gain a comparative advantage over the other, leading to the prioritization of relative gains [19]. We posit that in the context of contested territories; the absolute gains hypothesis does not apply.

Table 3: Consistency and coverage for all paths.

| Formula | Consistency | Raw Coverage |
|---|---|---|
| Path 1: EC·TR | 0.78 | 0.82 |
| Path 2: EC·TP | 0.8 | 0.71 |
| Path 3: TR·ED | 0.82 | 0.53 |
| Overall Solution | 0.81 | 1 |

## 2.4 Limitations of R1 and connection to R 2

The contradiction in R1 shows that under contested areas, the fundamental principle behind nations working together likely fails, as states stop prioritizing absolute gains. This means that our formula on cooperation only applies in situations without contested territories. In R2, we aim to fill in that gap by proving the ways in which cooperation can happen within them.

QCA is unable to model the specific decision-making process behind how treaties are signed and can only create models based off past treaties. We aim to specify conditions in which treaties are signed under contested territories in R2. All variables were coded by the researchers themselves, which introduces the risk of subjective judgement. To mitigate this, we grounded the variables with objective metrics. Additionally, the decision to include these 4 variables and exclude others reflects judgments made during the research design process that a different researcher might have made differently. Alternative conditions that were considered but excluded include regime type, power asymmetry between states, and changes in leaders.

# 3 R2 (Research 2)

## 3.1 Introduction

### 3.1.1 Background: Game Theory and the Tragedy of the Commons

Game theory is a branch of applied mathematics that provides tools to analyse interdependent decision-making. A game consists of players, strategies, and payoffs. Players are the decision-makers, ranging from countries to individuals and even plants. Strategies are the actions one can take, and payoffs are the outcomes for each combination of choices. Players have either similar or opposed interests, each considering the other's strategy to formulate the optimal solution [20].

Table 4: Payoff matrix for the Tragedy of the Commons.

| | | Other users: Protect land | Other users: Increase herd |
|---|---|---|---|
| Herdsman | **Protect land** | R R | S T |
| Herdsman | **Increase herd** | T S | P P |

R: reward, S: sucker, T: temptation, P: punishment

From a long-term perspective, the best scenario for both players clearly is the upper left corner, where both players receive an equal share and an infinite resource. Yet, as Hardin points out, mankind has a natural tendency of getting "locked into a system that compels him to increase his [share] without limit—in a world that is limited" [5]. To gain more fish than their opponent, Player A may betray the trust of Player B, shifting the situation to the bottom left box. Assuming they each have no way of knowing what action the other will take, the safest option for both players is to take 2 fish a day, as they will either gain more or an equal number of fish.

This is precisely how governments and fishing organizations progressively shift over to the bottom right box, exacerbating tension and destroying ecosystems.

### 3.1.2 Purpose

In R1, it became clear that whether a region was contested or not was incredibly significant to the signing of METs. Even if the situation fulfilled all requirements of the formula created in R1, the chances of the outcome being unsatisfactory were elevated. Therefore, in R2, we aim to define not only the most effective conditions for the signing of METs, but also the most effective conditions on the premise that the marine areas are being contested.

In our simulation, we have three different hypotheses:

1. The application, as well as the threat of punishments and rewards will encourage the mutual prioritization of the general public's interest.
2. Communication will encourage the mutual prioritization of the general public's interest.
3. A third party's influence, such as the UN, will encourage the mutual prioritization of the general public's interest.

Past attempts to get organizations to prioritize the greater good over their own self-interest include enforcing fisheries conservation regulations, designating MPAs, and signing international marine agreements, all of which use punishment as the primary motivator. We wondered if this truly was the only way to raise the chances of the signing of METs and thought also of increasing the frequency of conferences between nations, and the influence of third parties. Along with researching patterns in historical records of METs, to model real-time human thinking, which R1 was unable to do, we introduced a new perspective: psychology. The aim is to clarify the subjective requirements for the protection of the high seas and see how governments and fishing companies come to reasonable, fair, and effective agreements.

## 3.2 Methodology

### 3.2.1 Model

We created a simple model with 2 players and 8 fish in a pond. Each pair of fish gives birth to 1 fish every day. For example, if Player A continues taking 1 fish/day and Player 2 takes 2 fish/day, on the 2nd day, there would be (5 + 2 new =) 7 fish in the pond. When there are not enough fish, the remaining fish are split up according to the ratio of each player's demands (Table 5).

Table 5: Player A continues taking 1 fish/day, and Player B continues taking 2 fish/day.

| | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 |
|---|---|---|---|---|---|---|
| **Player A** | **Fish taken (1 or 2)** | 1 | 1 | 1 | 1 | (1→) 0.3 |
| | **Points (=total fish gained)** | **1** | **2** | **3** | **4** | **4.3** |
| **Player B** | **Fish taken (1 or 2)** | 2 | 2 | 2 | 2 | (2→) 0.7 |
| | **Points (=total fish gained)** | **2** | **4** | **6** | **8** | **8.7** |
| **Fish in pond at start of day** | | 8 | (5+7=) 7 | (4+2=) 6 | (3+1=) 4 | (1+0=) 1 |
| **Fish in pond at end of day** | | 5 | 4 | 3 | 1 | 0 |

Table 6: Payoff matrix ((ratio of) fish gained per day) for our model, assuming both players continue to take the same number of fish every day.

| | | Player B: 1/day | Player B: 2/day |
|---|---|---|---|
| Player A | 1/day | 1 1 | 1 2 |
| | 2/day | 2 1 | 2 2 |

Table 7: Payoff matrix for our model (total fish gained), assuming both players continue to take the same number of fish every day.

| | | Player B: 1/day | Player B: 2/day |
|---|---|---|---|
| Player A | 1/day | ∞ ∞ | 4.3 8.7 |
| | 2/day | 8.7 4.3 | 3.5 3.5 |

The highlighted boxes are examples of Nash Equilibriums, where no player can benefit by unilaterally changing their strategy (Tables 6, 7).

### 3.2.2 Games

We collected 18 students from Makuhari Junior and Senior High School (aged 13 to 17) and randomly assigned them into 9 pairs. 3 pairs were assigned to each gamemaster. Each pair played 2 games, the first of which was always Game 1. Each gamemaster directed a different second game: Game 2, 3 or 4.

Players were given the choice of taking up to 2 fish a day.

Excluding Game 3, the 2 players were put in different rooms to ensure that they truly would not know what their opponent was thinking. The gamemaster made sure that the choices were made without the influence of the opponent's choice.

The maximum length for all games was 10 days.

#### 3.2.2.a Game 1: Free Round (Control Round)

The players were told to "maximize their own profits." We hypothesised that players would act in their own self-interest and attempt to collect more fish than their opponent.

This was extremely crucial because the failure of this control round was meant to mimic that of disputed waters, and the Tragedy of the Commons itself. Although players knew taking 1 fish would be in everyone's best interest, they could not help being baited by the short-term, large profits that came with taking 2 fish every round.

#### 3.2.2.b Game 2: Rewards and Punishment

In Game 2, before players chose the number of fish to take, they had the option of declaring a reward or punishment to the opponent.

A reward was defined as taking away 1 point from oneself and giving 1 point to the opponent, as long as the opponent takes 0 or 1 fish. A punishment was defined as taking away 1 point from oneself and 2 points away from the opponent, but only if they choose to take 2 fish. The idea behind the punishment is that if a player wants to control their opponent, they must give up something of their own.

If there was only 1 fish left in the pond at the start of the day, punishment was applied for taking either 1 or 2 fish, and rewards were given if a player took 0 fish.

We hypothesised this would prevent the players from overfishing so as not to get punished.

#### 3.2.2.c Game 3: Discussion is allowed

The 2 players were placed in the same room, where they were free to discuss for 2 minutes before choosing how many fish to take. We hypothesized that most groups would realize "maximizing your own profits" meant keeping the fish stock alive and stable for as long as possible.

#### 3.2.2.d Game 4: Third party influence

A third party placed a pressure rating on each player. This is a model of consistent outside influence, such as pressure from the United Nations to follow international treaties on conservation. The existence of large treaty organizations, such as Biodiversity Beyond National Jurisdiction (BBNJ), is also an influential factor of the signing of METs.

If players took 1 fish, the percentage decreased by 5%. If players took 2 fish, the percentage increased by 15%. The ratio of change is different because in general, it is more challenging to regain trust or rebuild destroyed habitats.

All players began at 50%. The game ended if either of the players hit 100%. However, players were not notified of how much their rating is affected by their choices and only knew of the existence of a third party and a limit they could not cross.

## 3.3 Results and Discussion

The central assumption of the Tragedy of Commons is that depletion of resources in a free land is simply inevitable because humans have the tendency to act in their own self-interest even when they know that doing so is not in anyone's long-term interest. As a reflection of this idea, Game 1 had the shortest average lifespan, with most players acting in arbitrary greed. This also supports the hypothesis that we set out on why dyads that territorial disputes had failed as states and players prioritized relative gain as compared to absolute gain.

Although some pairs had to wait longer than others for their turn and therefore had more time to think of strategies, the average length of each game does not differ vastly.

All gamemasters noted that one aspect most players struggled with was guessing what their opponent would do.

### 3.3.1 Game 1 (Free Round) + Game 2 (Rewards and Punishment)

Table 8: Game 1 (Free Round) + Game 2 (Rewards and Punishment).

| | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Player 1 | Fish taken | 1 | 2 | 1 | 1 | | | | | | | 1.25 |
| | Points | 1 | 3 | 4 | 5 | | | | | | | |
| Player 2 | Fish taken | 2 | 2 | 1 | 2 | | | | | | | 1.75 |
| | Points | 2 | 4 | 5 | 7 | | | | | | | |
| Pond | | 7 | 4 | 3 | 0 | | | | | | | |
| Player 1 | Declaration / fish taken | × / 2 | R / 1 | P / 2 | P / 1 | P / 2 | P / 1 | | | | | 1.5 |
| | Points | 2 | 2 | 4 | 5 | 5 | 2.5 | | | | | |
| Player 2 | Declaration / fish taken | × / 2 | P / 0 | R / 1 | P / 0 | P / 1 | P / 1 | | | | | 0.833 |
| | Points | 2 | 3 | 4 | 4 | 4 | 1.5 | | | | | |
| Pond | | 6 | 6 | 4 | 4 | 1 | 0 | | | | | |
| Player 3 | Fish taken | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 0.5 | | | 1.56 |
| | Points | 1 | 3 | 5 | 7 | 9 | 10 | 12 | 12.5 | | | |
| Player 4 | Fish taken | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 0.5 | | | 1.18 |
| | Points | 1 | 2 | 3 | 5 | 6 | 8 | 9 | 9.5 | | | |
| Pond | | 9 | 9 | 9 | 7 | 6 | 4 | 1 | 0 | | | |
| Player 3 | Declaration / fish taken | × / 2 | × / 1 | P / 1 | P / 2 | P / 2 | P / 1 | P / 1 | P / 1 | | | 1.38 |
| | Points | 2 | 3 | 5 | 7 | 7 | 8 | 9 | 10 | | | |
| Player 4 | Declaration / fish taken | × / 1 | P / 1 | R / 1 | × / 1 | P / 1 | P / 1 | P / 1 | R / 0 | | | 0.875 |
| | Points | 1 | 2 | 2 | 3 | 3 | 4 | 5 | 6 | | | |
| Pond | | 7 | 7 | 7 | 6 | 4 | 3 | 1 | 0 | | | |
| Player 5 | Fish taken | 1 | 2 | 2 | 0.5 | | | | | | | 1.38 |
| | Points | 1 | 3 | 5 | 5.5 | | | | | | | |
| Player 6 | Fish taken | 2 | 2 | 1 | 0.5 | | | | | | | 1.38 |
| | Points | 2 | 4 | 5 | 5.5 | | | | | | | |
| Pond | | 7 | 4 | 1 | 0 | | | | | | | |
| Player 5 | Declaration / fish taken | × / 2 | P / 1 | R / 1 | R / 1 | P / 1 | P / 0 | P / 1 | R / 0 | P / 0 | | 0.778 |
| | Points | 2 | 4 | 4 | 6 | 7 | 8 | 9 | 8 | 7 | | |
| Player 6 | Declaration / fish taken | × / 2 | R / 1 | P / 1 | R / 2 | P / 1 | P / 1 | P / 1 | P / 0 | R / 1 | | 1.11 |
| | Points | 2 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 8 | | |
| Pond | | 6 | 6 | 6 | 4 | 3 | 3 | 1 | 1 | 0 | | |

- Light grey: Game 1
- Dark grey: second game

Fish in pond:

- Light red: decrease from previous day.
- Light blue: no change from previous day.
- Red: decrease from previous day; END OF GAME

Declaration: what each player declared to the opponent, not what the opponent declared to them.

- P: punishment
- ×: not applicable / no declaration
- R: reward

In all 3 pairs, the resource was preserved for an equal or longer number of days when rewards and punishments were allowed. Game 1 averaged 5.33 days per game, while Game 2 averaged 6.67 days per game.

All games ended before Day 10. This is because of the increased use of punishments as the game proceeds, which most likely results from both players' wish to gain more fish than their opponent. Real-life examples of this phenomenon include arms races and trade wars.

Interestingly, in our model, resources last longer with rigid punishment than unrestricted pursuit of profit.

### 3.3.2 Game 1 (Free Round) + Game 3 (Discussion is allowed)

Table 9: Game 1 (Free Round) + Game 3 (Discussion is allowed).

| | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Player 7 | Fish taken | 1 | 2 | 1 | 1 | 1 | 1.5 | | | | | 1.25 |
| | Points | 1 | 3 | 4 | 5 | 6 | 7.5 | | | | | |
| Player 8 | Fish taken | 2 | 1 | 1 | 2 | 1 | 1.5 | | | | | 1.41 |
| | Points | 2 | 3 | 4 | 6 | 7 | 8.5 | | | | | |
| Pond | | 7 | 6 | 6 | 4 | 3 | 0 | | | | | |
| Player 7 | Fish taken | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1.4 |
| | Points | 1 | 2 | 4 | 5 | 7 | 8 | 10 | 11 | 13 | 14 | |
| Player 8 | Fish taken | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1.4 |
| | Points | 1 | 2 | 4 | 5 | 7 | 8 | 10 | 11 | 13 | 14 | |
| Pond | | 9 | 10 | 9 | 10 | 9 | 10 | 9 | 10 | 9 | 10 | |
| Player 9 | Fish taken | 2 | 1 | 2 | 1 | 2 | | | | | | 1.6 |
| | Points | 2 | 3 | 5 | 6 | 8 | | | | | | |
| Player 10 | Fish taken | 2 | 0 | 2 | 0 | 2 | | | | | | 1.2 |
| | Points | 2 | 2 | 4 | 4 | 6 | | | | | | |
| Pond | | 6 | 7 | 4 | 4 | 0 | | | | | | |
| Player 9 | Fish taken | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1.3 |
| | Points | 1 | 2 | 4 | 6 | 8 | 9 | 10 | 11 | 12 | 13 | |
| Player 10 | Fish taken | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.2 |
| | Points | 1 | 2 | 4 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Pond | | 9 | 10 | 9 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | |
| Player 11 | Fish taken | 2 | 2 | 0 | 1 | 2 | | | | | | 1.4 |
| | Points | 2 | 4 | 4 | 5 | 7 | | | | | | |
| Player 12 | Fish taken | 2 | 1 | 0 | 2 | 2 | | | | | | 1.4 |
| | Points | 2 | 3 | 3 | 5 | 7 | | | | | | |
| Pond | | 6 | 4 | 6 | 4 | 0 | | | | | | |
| Player 11 | Fish taken | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1.8 |
| | Points | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | |
| Player 12 | Fish taken | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1.8 |
| | Points | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | |
| Pond | | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |

- Light grey: Game 1
- Dark grey: second game

Fish in pond:

- Light red: decrease from previous day.
- Light blue: no change from previous day.
- Light green: increase from previous day.
- Red: decrease from previous day; END OF GAME
- Blue: no change from previous day; END OF GAME
- Green: increase from previous day; END OF GAME

Similar results were seen in Game 1 with these pairs as the first 3 pairs, suggesting the normalcy of the players and consistency of the gamemasters. Game 1 averaged 5.33 days and Game 3 averaged 10 full days, displaying both a fruitful crop and long lasting, stabilized resource.

When given time to discuss and negotiate with the other player, all pairs made it to Day 10 with the fish stock extremely stable. Throughout the negotiations, all pairs asked each other to cooperate to sustain the number of fish. Therefore, it can be said that by establishing negotiations, both parties were able to understand each other's actions and achieve stable catches. There was 1 day where one player betrayed the other (Player 9 to 8) and took 2 fish, but the outcome remained satisfactory and unharmed. Interestingly, the number of fish in the pond rarely fluctuates, or the players follow a set pattern in the number of fish they take.

The fact that players could see each other's faces may have influenced their actions, however. It would seem more challenging to betray when one can see the opponent's expressions throughout the discussion, and their reaction when they discover they have been lied to.

### 3.3.3 Game 1 (Free Round) + Game 4 (Third Party Influence)

Table 10: Game 1 (Free Round) + Game 4 (Third Party Influence).

| | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Player 13 | Fish taken | 2 | 2 | 2 | 1 | 0.5 | | | | | | 1.5 |
| | Points | 2 | 4 | 6 | 7 | 7.5 | | | | | | |
| Player 14 | Fish taken | 1 | 1 | 1 | 2 | 0.5 | | | | | | 1.1 |
| | Points | 1 | 2 | 3 | 5 | 5.5 | | | | | | |
| Pond | | 7 | 6 | 4 | 1 | 0 | | | | | | |
| Player 13 | Fish taken | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1.4 |
| | Points | 1 | 2 | 3 | 4 | 5 | 7 | 9 | 11 | 12 | 14 | |
| | Pressure (%) | 45 | 40 | 35 | 30 | 25 | 40 | 55 | 70 | 65 | 80 | |
| Player 14 | Fish taken | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1.3 |
| | Points | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 11 | 13 | |
| | Pressure (%) | 45 | 40 | 35 | 30 | 25 | 20 | 35 | 50 | 45 | 60 | |
| Pond | | 9 | 10 | 12 | 15 | 19 | 24 | 30 | 39 | 54 | 75 | |
| Player 15 | Fish taken | 1 | 2 | 2 | 1 | 0 | 1 | 1 | | | | 1.14 |
| | Points | 1 | 3 | 5 | 6 | 6 | 7 | 8 | | | | |
| Player 16 | Fish taken | 2 | 1 | 2 | 0 | 1 | 1 | 1 | | | | 1.14 |
| | Points | 2 | 3 | 5 | 5 | 6 | 7 | 8 | | | | |
| Pond | | 7 | 6 | 3 | 3 | 3 | 1 | 0 | | | | |
| Player 15 | Fish taken | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1.3 |
| | Points | 1 | 2 | 4 | 5 | 6 | 8 | 9 | 10 | 12 | 13 | |
| | Pressure (%) | 45 | 40 | 55 | 50 | 45 | 60 | 55 | 50 | 65 | 60 | |
| Player 16 | Fish taken | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1.3 |
| | Points | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 10 | 12 | 13 | |
| | Pressure (%) | 45 | 40 | 35 | 30 | 45 | 40 | 35 | 50 | 65 | 60 | |
| Pond | | 9 | 10 | 10 | 12 | 13 | 15 | 19 | 24 | 31 | 43 | |
| Player 17 | Fish taken | 1 | 1 | 2 | 1.5 | | | | | | | 1.38 |
| | Points | 1 | 3 | 5 | 6.5 | | | | | | | |
| Player 18 | Fish taken | 2 | 2 | 2 | 1.5 | | | | | | | 1.88 |
| | Points | 2 | 4 | 6 | 7.5 | | | | | | | |
| Pond | | 7 | 6 | 3 | 0 | | | | | | | |
| Player 17 | Fish taken | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | | 1.56 |
| | Points | 1 | 2 | 3 | 5 | 7 | 8 | 11 | 13 | 15 | | |
| | Pressure (%) | 45 | 40 | 35 | 50 | 65 | 60 | 75 | 90 | 105 | | |
| Player 18 | Fish taken | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | | 1.44 |
| | Points | 1 | 2 | 3 | 5 | 6 | 8 | 10 | 12 | 13 | | |
| | Pressure (%) | 45 | 40 | 35 | 50 | 45 | 60 | 75 | 90 | 85 | | |
| Pond | | 9 | 10 | 12 | 12 | 13 | 15 | 16 | 18 | 22 | | |

- Light grey: Game 1
- Dark grey: second game

Fish in pond:

- Light red: decrease from previous day.
- Light blue: no change from previous day.
- Light green: increase from previous day.
- Red: decrease from previous day; END OF GAME
- Green: increase from previous day; END OF GAME

Pressure rating:

- Green: decrease from previous day.
- Red: increase from previous day.

Game 1 lasts 5.33 days and Game 4 lasts 9.67 days on average.

In Game 3, players were cautious in the first half of the game; if there was no pressure rating, the number of fish would continue increasing even if both players took 2 fish every day. However, as the game nears the end, their desires to maximise their profit surfaces, and they become more reckless.

## 3.4 Discussion

At this point, we had a large collection of data, but nothing to refute the claim that the data gathered, and the pattern of the data was all due to chance. Table 11 shows the amount of rounds the players lasted in each game, before the fish were all taken from the pond, or before the player was eliminated by third party pressure. Since we ran the control game a total of 9 times, the average number of rounds of the first three, second three, and third three games were written in the table. Table 12 is an ANOVA (Analysis of Variance) test of Table 11 and shows a p-value of 0.0004 (<0.05), proving that the results of the simulation were extremely statistically significant.

Table 11: (Number of rounds survived per game).

| Control | R/P | Discussion | TP Influence |
|---|---|---|---|
| 5.3 | 6.0 | 10 | 10 |
| 5.3 | 8.0 | 10 | 10 |
| 5.3 | 9.0 | 10 | 9.0 |

Table 12: (ANOVA of Table 11).

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 42.23583 | 3 | 14.07861 | 21.11792 | 0.000371 | 4.066181 |
| Within Groups | 5.333333 | 8 | 0.666667 | | | |
| | | | | | | |
| Total | 47.56917 | 11 | | | | |

We designed the Tragedy of Commons simulation to clarify the best grounds of cooperation on the premise that the shared waters are disputed, and in poor ecological condition. Although both the Game 3 (Discussion) and Game 4 (Third party) had significantly higher survival rounds than Game 1

(Free round), the Game 3 (Discussion) particularly had a remarkable, no-fail streak of 10 days per game.

The players of the Game 2 (rewards and punishments) were also observed to have more rational thought and high prioritization of public interest than in their previous control game, though not as fail-proof as the latter two games.

## 3.5 Limitations

A clear barrier in our experiment is the question of whether we can generalize our results to truly represent the status of marine resources, and the psychological logicality of governments. The participants from our study are all students from Makuhari Junior and Senior High School, which has a tight community. This naturally friendly atmosphere, along with their lack of true experience out in society, could have influenced the results of our simulation.

Moreover, the fish in the pond may have lasted longer because players simply became accustomed to how the game works. To test this, we must conduct a round where pairs play Game 1 in both the first and second games.

Some may also criticize this study as not accurately reflecting the sophisticated historical relationships countries have with each other in the motives for their actions, such as Japan and China, and that the high seas cannot be modelled into a simple simulation.

Although governments do face more complex circumstances in the face of maritime treaties, their situations share the same core pressures of competition and scarcity as the students in the simulation. Even if these results prove to be ungeneralizable to the real world, it undoubtedly helps in the understanding of specific concepts and mechanisms inside of it. Moreover, the participants were all unaware of who their opponents were and were also unable to see them, which lowered the risks of the simulation being influenced by familiarity and recognition.

Though satisfactory results were obtained in this simulation, it is also important to note that the little amount of data collected in this study may have been insufficient to build concrete facts upon. If this study was to be replicated, it is necessary to assemble more than 18 people.

# 4 Conclusion

## 4.1 R1

In R1, we tested out multiple hypotheses on the variables that matter in the signing of METs through QCA. After collecting data from 27 different pairs of countries, it told us that 3 routes were possible in the signing of METs.

1. Ecological Crisis + a Track Record of efforts in environmental protection (78% likelihood of MET)
2. Ecological Crisis + Third Party Influence (80% likelihood of MET)
3. Track Record of efforts in environmental protection + high Economic Interdependence (82% likelihood of MET)

All of these were dependent on stage 1's structural variables being fulfilled, where nations had undisrupted diplomatic relations for more than 10 years and marine resources were important for both nations. These results are significant and unique as they do not default to a one size fits all definition, but rather show the different complex combinations of variables that lead to the signing of METs along with a comparison of the likelihood that each one will lead to a MET. However, we also noticed that an important factor was missing from the QCA and was affecting the consistency of the formula and study: whether the region was contested or not. In most cases, if it was contested, the chances of METs being signed became lower, even if the situation between both countries fit the formula. We posited that this was because of the change in incentives from gaining absolute benefits to gaining relative benefits.

## 4.2 R2

In R2, we then decided to design a simulation in which participants' resources are shared and limited, leading to disputes and ecological decline. The same 2 players were to play a second game, where they were to do one of the following:

- Game 2: Apply rewards and punishments to their opponents.
- Game 3: Discuss with their opponents.
- Game 4: Be aware of third-party opinions.

After averaging survival times in all types of games, we were able to gain statistically significant data that proved the effectiveness of the conditions that were added in the second games. Compared to the control round, where participants tended to show aggressive and selfish behaviours, these conditions significantly lengthened the survival time of the fish in the simulation.

We can firmly state that in a previously contested maritime region, the following three variables, in order, are the most likely to bring success to the signing of METs:

1. Discussion
2. Third Party Influence
3. Rewards and Punishments

## 4.3 Overall

Overall, our research showed that the signing of maritime treaties happens under two different contexts: one where absolute benefit is prioritized and one where the existence of territorial disputes led to the prioritization of relative benefit. It also suggests that ecological crises alone are not sufficient to produce cooperation in contested maritime regions. Instead, sustainable environmental cooperation depends on the existence of mechanisms that encourage trust, communication, and mutual accountability between states.

Both our QCA and simulation demonstrated that when actors are placed in competitive situations involving shared and limited resources, cooperative structures—particularly communication and third-party influence, it significantly improves long-term sustainability outcomes. Therefore, the successful formation of METs appears to depend not only on environmental urgency, but also on the political and institutional conditions that enable cooperation to emerge despite conflict.

What makes this research interesting is that we can add nuance into the literary deadlock within international relations theory. We nuance incentive analysis between realists and liberals, by positing that the incentive analysis changes based on the circumstance. Without territorial disputes, liberal institutionalist theory holds, reflected in our R1 results. Yet, if territorial disputed to exist, realist invectives take over, as reflected in our R2.

# 5 Future Direction

While brainstorming different variables to test out in R2, we had multiple other options that we could not use simply because of the lack of availability of the researchers.

One of the alternative variables include exploring the usage of unequal power dynamics, which would better represent the real-world situation. If participants were aware of the power their opponent wielded, or lacked, we hypothesized that they would find it easier to predict what action they would take next, therefore making it easier to make their own decisions. However, the participants would have to find a balance between their own profit and the greater good.

Another variable we considered was the education and knowledge the participants were given beforehand, specifically about game theory. We initially hypothesized that this would open their eyes to the fact that having an infinite supply of food would be in both theirs and their opponent's best interest.

Adding in more players into one game is another option, as it would undoubtedly be more realistic. The increase or decrease in trust may be something worthwhile to study and would clarify which kinds of treaties are easier to sign.

In future replications of this research, it is important to keep in mind that the variables used in our simulation are far from being the only ones.

Instead of a two-step QCA as the one used in R1, future research can also try utilising temporal QCAs, which focuses on the effect a certain sequence or length of events has on the signing of METs, such as how long an environmental catastrophe lasts, how strong public pressure is applied, and if certain variables have the same results reversed.

As stated in R2, communication ended up being the most significant factor in the signing of MEDs in this study. In future research, it may be a promising approach to search for factors within communication, such as transparency levels, publicity, and levels of speaking power in discussions. Going a step further beyond our current results may reach more realistic and easier implementation into the real world.

Our research can not only be used to effectively sign METs, but it can also be used to monitor deep sea mining, a frequent topic in the news today. The data and simulation design can be utilised to predict territories that are at a risk of getting stuck in the Tragedy of Commons.

## 6 Acknowledgement

We would like to express our deepest appreciation to Mr Masahiro Yoshida of Makuhari Senior High School for supporting us through all aspects of this research, and students of Makuhari Junior and Senior High School for taking the time to take part in our experiment.

## 7 References

[1] "Marine Protected Areas." *OSPAR Commission*, https://www.ospar.org/work-areas/bdc/marine-protected-areas. Accessed 9 May 2026.

[2] "The tragedy of commons: Tips for sustainable co-existence." *GASCO news*, Sep. 2023 https://ngc.co.tt/wp-content/uploads/2023/10/GASCO-Q3-23-The-Tragedy-of-the-Commons.pdf

[3] South China Sea Expert Working Group. "A Blueprint for Fisheries Management and Environmental Cooperation in the South China Sea." *CSIS*, 13 Sep. 2017, https://www.csis.org/analysis/blueprint-fisheries-management-and-environmental-cooperation-south-china-sea#:~:text=Total%20fish%20stocks%20in%20the,over%20the%20last%2020%20years.

[4] "Declaration on the Conduct of Parties in the South China Sea." *ASEAN Main Portal*, 14 May 2021, https://asean.org/declaration-on-the-conduct-of-parties-in-the-south-china-sea-2/.

[5] Hardin, Garrett. "The Tragedy of the Commons." *Science*, vol 162, Issue 3859, 13 Dec. 1968, pp. 1243-1248. *Science*, https://www.science.org/doi/10.1126/science.162.3859.1243.

[6] Barash, David P. *ゲーム理論の愉しみ方：得するための生き残り戦術* [*The Survival Game: How Game Theory Explains the Biology of Cooperation and Competition*]. Translated by Rumiko Momoi, Kawade Shobo Shinsha, 2005.

[7] Schneider, Carsten Q, and Ingo Rohlfing. "Combining QCA and Process Tracing in Set-Theoretic Multi-Method Research." *Sage Journals*, vol.42, issue 4, 22 Mar. 2013. *Sociological Methods & Research*, doi:10.1177/0049124113481341.

[8] Schneider, Carsten Q, and Claudius Wagemann. *Set-Theoretic Methods for the Social Sciences*. Cambridge University Press, 2012.

[9] Kingdon, John W. *Agendas, Alternatives, and Public Policies*. Addison Wesley Longman, 1984.

[10] Young, Oran R. "Political Leadership and Regime Formation: On the Development of Institutions in International Society." *International Organization*, vol. 45, no. 3, Summer 1991, pp. 281–308. *JSTOR*, http://www.jstor.org/stable/2706733.

[11] Sprinz, Detlef, and Tapani Vaahtoranta. "The Interest-Based Explanation of International Environmental Policy." *International Organization*, vol. 48, no. 1, pp. 77–105, Winter 1994. *JSTOR*, http://www.jstor.org/stable/2706915.

[12] Keohane, Robert O. *After Hegemony: Cooperation and Discord in the World Political Economy*. Princeton University Press, 1984.

[13] Putnam, Robert D. "Diplomacy and Domestic Politics: The Logic of Two-Level Games." *International Organization*, vol. 42, no. 3, Summer 1988, pp. 427–60. *JSTOR*, http://www.jstor.org/stable/2706785.

[14] Axelrod, Robert. *The Evolution of Cooperation.* Basic Books, 1984.

[15] Keohane, Robert O. and Joseph S Nye. *Power and Interdependence*. Longman, 1977.

[16] Neumayer, Eric. "Do democracies exhibit stronger international environmental commitment?" *Journal of Peace Research*, vol. 39, issue 2, Mar. 2022, pp. 139–164. *Sage Journals*, doi:10.1177/0022343302039002001.

[17] Brant, Cory O, et al. "The History behind the Canada-U.S. Convention on Great Lakes Fisheries: A Seven-Decade Effort." *Laurentian*, Mar 2022. *ResearchGate*, doi:10.70227/SDJK2584.

[18] Bodiguel, Clotilde, and Stephen Cunningham. "Subregional review: Southwest Indian Ocean." *Food and Agriculture Organization*, July 2005, https://www.fao.org/4/A0477E/a0477e07.htm.

[19] Grieco, Joseph M. "Anarchy and the Limits of Cooperation: A Realist Critique of the Newest Liberal Institutionalism." *International Organization*, vol. 42, no.3, Summer 1988, pp. 485-507. *JSTOR*, http://www.jstor.org/stable/2706787.

[20] Brams, Steven J, et al. "Game Theory." *Britannica*, 5 May 2026, https://www.britannica.com/science/game-theory.

# Detecting Newly Emerging Floating Vegetation Using Sentinel-2: The Novel Remote Sensing WARN For Monitoring Alligator Weed

Karin Ito, Kanon Sugawara, Shixiao Liao

*Shibuya Makuhari high school, Japan, myoshida@shibumaku.jp*

# 1.Abstract

## Keywords

Alligator weed, Sentinel satellite data, Google Earth Engine, NDVI, MNDWI, Random Forest, remote sensing

# 2. Introduction

Invasive aquatic plants have become a serious environmental problem in lakes, rivers, wetlands, and agricultural waterways. These plants can reduce biodiversity, degrade water quality, block water flow, disturb native ecosystems, and interfere with human water use. Among them, alligator weed is especially difficult to manage because of its high reproductive ability and strong environmental tolerance.

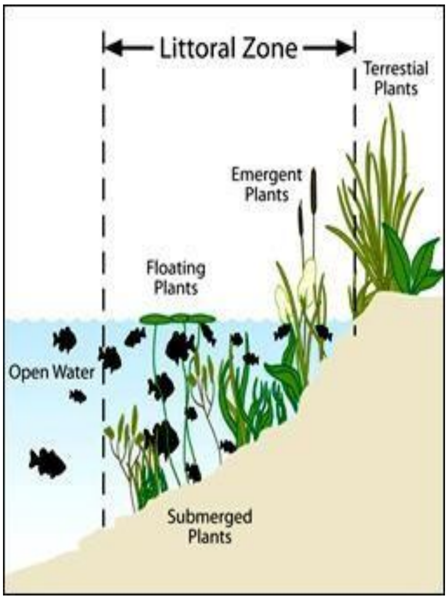



Figure 1. Aquatic vegetation structure and the position of emergent and floating plants in freshwater ecosystems

Alligator weed is a perennial invasive plant native to South America [1]. It is classified as an emergent to wetland plant, often growing in wetlands, rivers, lakes, and agricultural areas. A significant characteristic is that alligator weed forms mat-like colonies over the water surface. These colonies can block waterways, reduce the oxygen supply to aquatic ecosystems, interfere with irrigation, and create problems for flood prevention and water management. Their negative effects negatively affect a wide range of industries, from logistics to agriculture. In Japan, alligator weed has been designated as an invasive alien species, and its spread has been reported in multiple regions, including lake Inba in Chiba Prefecture [2].

The difficulty of controlling alligator weed makes early detection extremely important. Once the plant has expanded into large colonies, removal becomes costly and time-consuming. Attempts at physically removing the weed may adversely affect the situation if stem fragments break off and spread downstream. Chemical control[1] using chemical herbicides can affect non-target vegetation, while biological control[2] using natural predators of alligator weed is not always reliable in colder climates due to a mismatch in habitat. For this reason, detecting alligator weed growth before large-scale expansion is essential.

This study identifies the management problem of alligator weed and evaluates satellite remote sensing as a possible solution for wider, faster, and more continuous monitoring.

# 3. Purpose of Research

## 3.1 Current World Situation

### 3.1.1 Overview

Freshwater ecosystems are increasingly affected by invasive species, climate change, pollution, and human land-use changes. Invasive aquatic plants are especially problematic because they grow in areas that are often difficult to access directly, such as lakes, marshes, irrigation channels, and riverbanks. Once these plants spread across water surfaces, they can alter habitats and disrupt both ecosystems and human water systems.

Alligator weed is one example of this larger problem. Because it can grow rapidly and survive under difficult conditions, it can become dominant in invaded environments. Its ability to spread through stem fragments makes it particularly dangerous in waterways,

[1] Chemical Control is the use of herbicides to quell certain types of vegetation.

[2] The reduction of pest populations by natural predators that typically involves an active human role.

where broken stems can be carried downstream and establish new colonies.

### 3.1.2 The Management Problem of Alligator Weed

The management problem of alligator weed is not only that the plant is invasive, but that it is difficult to detect and remove before the plant spreads massively. Current management often depends on field surveys, reports from local authorities, or visual confirmation, but this detection can only be made when colonies have already become visible. By the time dense vegetation mats are detected from the ground, the plant has likely already spread to other areas.

### 3.1.3 Effects of This Issue

Alligator weed affects both ecosystems and human society. Ecologically, it can crowd out native plants, reduce biodiversity, alter aquatic habitats, and block sunlight and oxygen exchange in water systems [1]. Socially, it can interfere with irrigation, reduce crop yields, block waterways, increase flood risks, and raise management costs for local governments and communities [1].

Because the plant affects both environmental health and water management, the issue is not limited to conservation. It also impacts agriculture, disaster prevention, infrastructure maintenance, and local government planning. As an example, alligator weed colonies can make minor rivers unpassable, posing as an obstacle for boats, and in this way, can impede rescue operations in times of natural disasters.

## 3.2 Approaches to the Situation

### 3.2.1 Monitoring Methods and Limitations

Several monitoring methods can be used to detect and track alligator weed, but each has its own strengths and limitations.

#### 3.2.1.1 Field Surveys and Visual Inspection

Field surveys and visual inspection are the most direct methods and are also the methods that have been most often implemented in the past. They allow researchers and local officials to confirm the actual plant species and observe the condition of the site. This is important because satellite data alone cannot always identify species.

However, these methods require time, labor, transportation, and access to the site. They are difficult to conduct frequently over wide areas. In lakes, rivers, and wetlands, some areas may also be physically difficult or unsafe to reach. Therefore, field surveys and visual inspections are accurate but not always efficient for continuous large-scale monitoring.

#### 3.2.1.2 UAV-Based Aerial Photography

Unmanned Aerial Vehicles (UAVs)[3], or drones, can capture higher-resolution images than most free available satellite imagery. This makes them useful for detecting small patches of alligator weed and confirming vegetation patterns along shorelines. UAV imagery can also be useful for creating training data for machine-learning models.

However, UAV surveys still require field operations, flight planning, equipment, and permission. This raises concerns about cost efficiency and whether these large-scale methods can be implemented globally. UAVs are better suited for detailed local surveys than for continuous monitoring over large regions. UAVs are therefore useful as a validation tool, but less practical as the only monitoring system.

#### 3.2.1.3 Remote Sensing Technology

The limitation is that satellite data has lower spatial resolution than UAV imagery. Sentinel-2 imagery has a 10 m resolution for major bands, which means small patches may be mixed with water, soil, shoreline vegetation, or artificial surfaces [3]. In addition, vegetation indices such as NDVI can detect vegetation activity, but they cannot identify plant species by themselves. Because of this, remote sensing is powerful

[3] An aircraft that is guided autonomously, by remote control, or both and that carries sensors, and electronic transmitters.

for screening and monitoring, but it must be carefully validated.

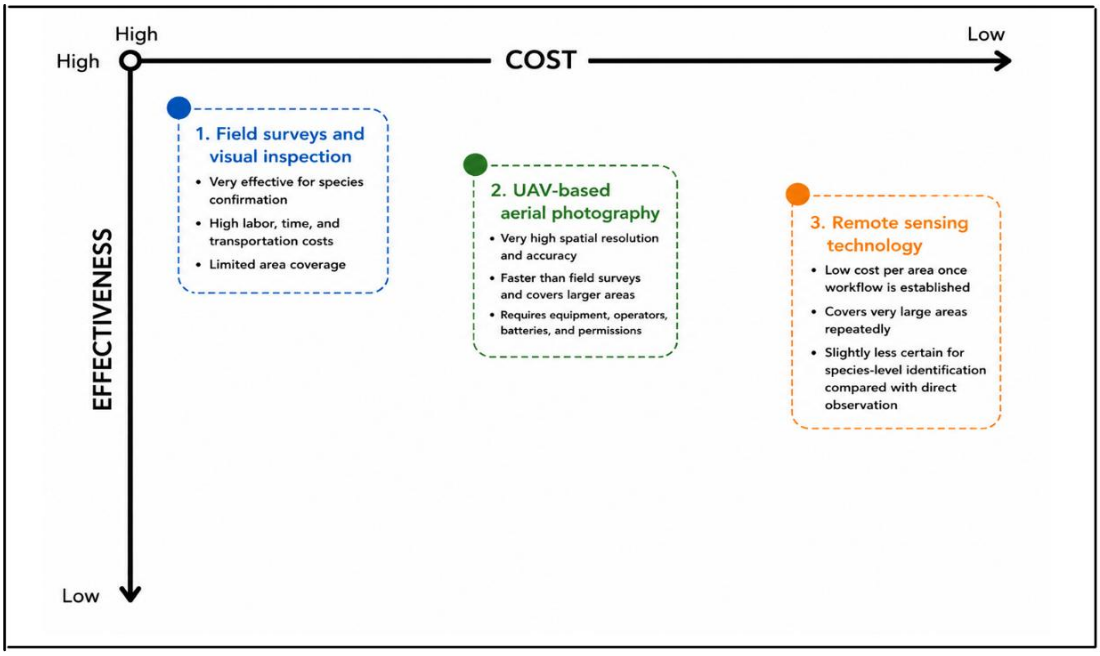



Figure 2: Relative effectiveness and operational cost of monitoring methods for alligator weed detection

Note: Effectiveness is only used in the context of definitiveness of disovery. Field surveys are very effective because it is directly possible to confim the existence of alligator weed while options 2,3 use indirect methods to discover alligator weed.

---

### 3.2.2 Past Research Example

Past research has shown that vegetation indices and satellite imagery can be used to monitor aquatic vegetation and algal blooms. In 2025, Shinohara and Kurida used Sentinel 2 data to visualize alligator weed in a river in Chiba Prefecture [4].

However, the specific detection of alligator weed remains difficult because it often grows near shorelines and can be spectrally similar to other vegetation. This means that a simple “green vegetation” detector is not enough.

### 3.2.3 Our Solution

Considering these considerations, we proposed the development of a staged satellite-based monitoring workflow. This was envisioned by first creating a rule-based NDVI–MNDWI Threshold Model on GEE that would analyze changes in NDVI indexes and MNDWI indexes to identify possible aquatic vegetation zones. Then, supervised machine-learning models are used to improve classification by learning from multiple satellite-derived variables. These methods will be explained later in this study.

The hypothesis of this research is:

Alligator weed-associated floating and emergent vegetation can be detected more reliably by combining vegetation indices, water indices, seasonal satellite composites, and supervised Random Forest classification than by using NDVI or MNDWI alone.

This hypothesis reflects the main weakness of index-only detection. NDVI and MNDWI are useful, but they describe surface conditions rather than species identity. A machine-learning model can combine more information, including seasonal change, optical bands (RGB color data), water indices, and radar variables, to create a more reliable classification of alligator weed.

## 3.3 Goals

### 3.3.1 Relation to SDGs

This research relates to several Sustainable Development The development of a satellite-based monitoring system for alligator weed provides a scalable technical solution that directly supports the targets of three United Nations Sustainable Development Goals.

Regarding SDG 6: Clean Water and Sanitation (Target 6.6), this research contributes to the protection and restoration of water-related ecosystems. By utilizing MNDWI and B11 (SWIR) spectral analysis to identify early-stage invasive mats, this study provides water management authorities with a tool to prevent the clogging of irrigation channels and the subsequent degradation of water quality caused by decaying biomass in Lake Inba.

In relation to SDG 13: Climate Action (Target 13.3), as rising temperatures and altered precipitation patterns accelerate the northern expansion of invasive aquatic species in Japan, there is an urgent need for adaptive monitoring. This project addresses climate-related resilience by establishing an automated, multi-temporal detection framework that allows for the long-term observation of invasive species migration in response to changing environmental conditions.

Finally, the study aligns with SDG 15: Life on Land (Target 15.8), which explicitly calls for the prevention and reduction of the impact of invasive alien species on land and water ecosystems. This research provides the spatial evidence required for rapid response efforts, moving beyond manual field surveys to a remote-sensing approach that can monitor vast, inaccessible marshlands. By improving classification accuracy through Sentinel-1/2 data integration, this study facilitates the conservation of native biodiversity in Japanese wetlands.

### 3.3.2 Our Goal

The main goal of this research is to evaluate whether satellite remote sensing can facilitate early detection of alligator weed. More specifically, the research aims to:

1. detect vegetation expansion over water surfaces using satellite indices;
2. evaluate the limitations of only using NDVI–MNDWI-based detection in terms of separating alligator weed and non-alligator weed;
3. compare the effects of using an increased number of data bands and machine learning Random Forest models to solely using NDVI MNDWI indices;
4. identify the model that provides the best balance of accuracy, simplicity, and ecological plausibility in detecting alligator weed growth;
5. provide recommend Big Query or the foundation for a future early-warning monitoring system to stop the spread of alligator weed.

---

# 4. Method of Our Research

Before explaining the detailed workflow, the following table defines the technical terms used in this study.

Table 1: technical terms used in this study

| Term | Meaning in this study |
|---|---|
| Alligator weed | An invasive aquatic plant species, *Alternanthera philoxeroides*, that can form dense floating or emergent mats over water surfaces. |
| Remote sensing | The use of satellite or aerial data to observe Earth's surface without direct physical contact. |
| Google Earth Engine | A cloud-based platform used to process satellite imagery, calculate indices, train models, and visualize spatial results. |
| Sentinel-2 | An optical satellite mission that provides visible, near-infrared, red-edge, and shortwave infrared imagery useful for vegetation and water analysis. |
| Sentinel-1 | A radar satellite mission that provides SAR data, including VV and VH backscatter, which can provide information about surface structure. |
| SAR | Synthetic Aperture Radar; a radar-based imaging method that can observe surface structure and is less affected by cloud cover than optical imagery. |
| NDVI | Normalized Difference Vegetation Index; a vegetation index used to estimate active green vegetation from satellite imagery. |
| MNDWI | Modified Normalized Difference Water Index; a water index used to identify |

| | |
|---|---|
| | water-related surfaces and separate water from land or vegetation. |
| NDWI | Normalized Difference Water Index; an index used to support water and moisture-related analysis. |
| Vegetation index | A calculated value from satellite bands used to highlight vegetation activity or plant condition. |
| Water index | A calculated value from satellite bands used to highlight water surfaces or water-related conditions. |
| Seasonal composite | A satellite image created by combining multiple images from the same season to reduce noise from clouds, short-term variation, and atmospheric effects. |
| Rule-based threshold model | A model that classifies pixels based on fixed conditions, such as NDVI greater than a set value or MNDWI below a set value. |
| Candidate vegetation-on-water | Pixels that satisfy the rule-based conditions for vegetation appearing over or near water surfaces. These pixels are not automatically confirmed alligator weed. |
| Connected-pixel filtering | A method that removes isolated pixels by keeping only pixels that are connected to a minimum number of neighboring pixels. |
| Random Forest | A supervised machine-learning model that combines many decision trees to classify data. |
| Training data | Labeled samples used to teach the model the difference between alligator weed-associated and non-alligator weed areas. |
| Validation data | Labeled samples not used during model training, used to evaluate model performance. |
| Validation accuracy | The proportion of validation samples correctly classified by the model. |
| Kappa | A metric that measures agreement between predicted and reference labels while accounting for agreement that could occur by chance. |
| False positive | A non-alligator weed sample incorrectly classified as alligator weed-associated vegetation. |
| False negative | An alligator weed-associated sample incorrectly classified as non-alligator weed. |
| Overfitting | A situation where a model performs very well on training data but may not generalize well to new or unseen data. |
| Overfit gap | The difference between training accuracy and validation accuracy, used as a simple indicator of possible overfitting. |
| Feature importance | A measure showing which satellite bands or indices contributed most to the model's classification decisions. |
| Probability map | A map showing how likely each pixel is to belong to the target class, rather than only showing a yes/no classification. |
| Field-verification priority layer | A map output that suggests where field surveys should be prioritized, but does not confirm species identity by itself. |

## 4.1 Study Area

The study focused on bodies of water in Chiba Prefecture, especially areas where alligator weed expansion has been reported, such as Lake Inba. This area was selected because it provides a relevant case study for testing whether known or suspected aquatic vegetation expansion can be detected through satellite imagery. Chiba Prefecture had published data based on field surveys on alligator weed colony dispersion and removal logs during the years 2020 and 2023 respectively. In the study, we focused on the circle area that had a five-kilometer radius from the coordinates [140.19, 35.75].

Lake and marsh environments are suitable for this research because alligator weed often forms vegetation mats over or near water surfaces. However, it cannot be overlooked that these environments also create classification challenges because shoreline pixels may contain mixtures of water, soil, vegetation, and artificial surfaces.

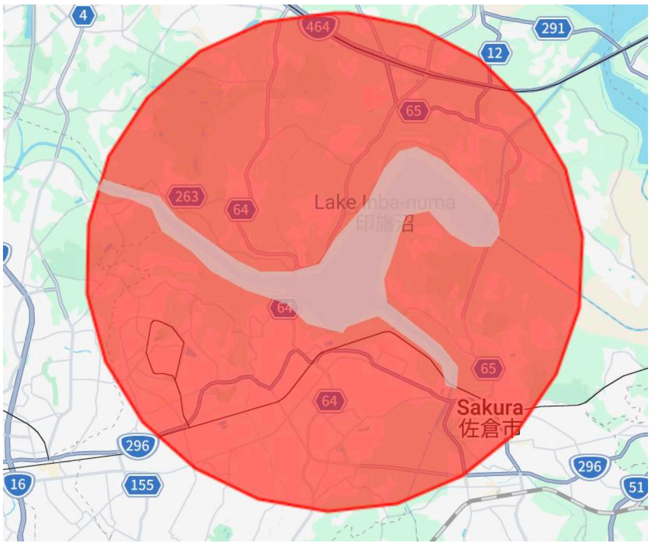



Figure 3: Research Area Map

## 4.2 Resources Used

### 4.2.1 Satellite Imagery

The final workflow used Sentinel-1 and Sentinel-2 data bands[4]. Sentinel-2 was used because it provides visible, red-edge, near-infrared, and shortwave infrared bands that are useful for vegetation and water monitoring. Sentinel-1 was used because SAR data can provide structural information and is less affected by cloud cover than optical imagery.

The Sentinel-2 variables included original optical bands and calculated indices such as NDVI, MNDWI, and NDWI. NDVI represented vegetation vigor, MNDWI represented water-related surface conditions, and NDWI provided additional water-related information.

### 4.2.2 Temporal Resources and Seasonal Composites

Seasonal composites were generated to reduce noise from individual images. The final model comparison used seasonal combinations from spring, summer, autumn, and winter. Spring was used to capture early vegetation growth, summer to capture peak growth, autumn to test late-season conditions, and winter to test whether all-season information improved classification.

Median composites were used to reduce the influence of clouds, temporary water-surface variation, and short-term atmospheric effects.

### 4.2.3 Google Earth Engine

Google Earth Engine was the main platform for satellite-image processing and final model creation. It was used to calculate indices, generate seasonal composites, sample training data, train Random Forest classifiers, create classification maps, produce probability maps, and analyze feature importance.

This was important because remote-sensing models must be evaluated in the context of spatial distribution, not only numerically. An efficient model must produce maps that are ecologically plausible and visually inspectable.

### 4.2.4 BigQuery and Tabular Machine-Learning Resources

BigQuery ML, an online data warehouse provided by Google, was used as an intermediate machine-learning exploration stage. Satellite-derived pixel values were exported from Google Earth Engine into a structured table. The cleaned dataset contained 8,237 sampled pixels, including 725 alligator weed pixels and 7,512 non-alligator weed pixels, with no removed pixels due to missing values.

This stage showed that spatial satellite data could be converted into a tabular dataset and utilized for training a machine learning model to classify alligator weed. However, it also revealed limitations because spatial visualization was difficult, and some high-performance results raised overfitting concerns.

### 4.2.5 Training and Reference Resources

Training samples were divided into two classes: alligator weed and non-alligator weed. Alligator weed was labeled as class 1, and non-alligator weed was labeled as class 0. These samples were extracted at 10 m resolution and randomly split into training and validation subsets. Seventy percent of the samples were used for training, while thirty percent were reserved for validation.

Reference information, including field-related data and local reports, was used to evaluate whether satellite-based results were spatially plausible. However, the research still recognizes that field validation remains necessary for stronger species-level confirmation.

## 4.3 Research Stages

The model names used in this study are as follows in the table:

Table 2: Model names in this study

| Stage | Model name used in this paper | Inputs | Output |
|---|---|---|---|
| Stage One | Model 1: Rule-Based NDVI–MNDWI Threshold Model | Sentinel-2 NDVI, MNDWI, water adjacency, connected-pixel condition | Candidate vegetation-on-water mask |
| Stage Two | Model 2: BigQuery ML Exploratory Classification Model | Exported Sentinel-2 and supplementary Sentinel-1 variables | Preliminary classification results and feature importance |
| Stage Three | Model 3: Seasonal Random Forest Classification Models | Seasonal Sentinel-2 variables and supplementary Sentinel-1 SAR variables | Final model comparison, probability map, and feature importance |
| Stage Three: selected model | Model 3B: Spring–Summer Random Forest Model | Spring + summer seasonal variables | Preferred early-warning classification model |

### 4.3.1 Stage One: Rule-Based NDVI–MNDWI Threshold Model in Google Earth Engine

The first stage was to use a Rule-Based NDVI–MNDWI Threshold Model. NDVI was used to detect active vegetation, while MNDWI was used to identify water-related surfaces. By combining these indices, the model attempted to detect vegetation appearing over or near water surfaces. In simplified form, pixels were highlighted as candidate vegetation-on-water only when they satisfied all rule-based conditions simultaneously:

Candidate vegetation-on-water=$(\text{NDVI}>0.35) \wedge (\text{MNDWI}<0) \wedge (\text{Water adjacency}=1) \wedge (\text{Connected pixels}\geq 3)$

The model used thresholds such as high NDVI, low MNDWI, adjacency to water, and minimum connected pixel count. The minimum connected-pixel condition was used because alligator weed often forms mat-like colonies rather than isolated pixels. This helped reduce random noise and false positives and focus on coherent vegetation patches.

### 4.3.2 Stage Two: BigQuery-Based Machine-Learning Exploration

The second stage tested whether BigQuery ML could improve classification by using multiple satellite-derived variables. This stage was designed to move beyond fixed thresholds and allow a supervised model to learn patterns from optical bands, infrared bands, water indices, radar bands, and predefined class labels.

However, BigQuery ML created challenges for spatial interpretation. The model could produce predictions numerically, but it was difficult to prevent overfitting the model. This made it difficult to judge whether the model was detecting realistic alligator weed patches or simply classifying broad shoreline areas as positive.

### 4.3.3 Stage Three: Creating Comparable Random Forest Models in Google Earth Engine

The third stage used Random Forest classification in Google Earth Engine. Four seasonal model options were tested:

Table 3: Seasonal model options

| Model | Seasonal Inputs | Purpose |
|---|---|---|
| Option A | Summer only | Test the simplest peak-growth model |
| Option B | Spring + summer | Test early-growth and peak-growth combination |
| Option C | Summer + autumn | Test whether late-season information improves classification |
| Option D | All seasons | Test whether maximum seasonal information improves performance |

Each model used Sentinel-1 and Sentinel-2 variables. The Random Forest classifier was trained with 150 samples and a fixed point of comparison. This made the models comparable and allowed accuracy, overfit gap, confusion matrix values, and feature importance to be examined.

### 4.3.4 Model Selection

The model-selection process did not rely only on the highest accuracy. Instead, the models were evaluated based on validation accuracy, kappa, overfit gap, false positives, false negatives, number of input bands, and interpretability.

This was important because a model with many bands may produce slightly higher accuracy but may also be more complex and less practical. The best model should be accurate, simple enough to interpret, using the least amount of information.

## 5. Results and Interpretations

### 5.1 Stage One

The Rule-Based NDVI–MNDWI Threshold Model was useful as an exploratory screening method. It allowed possible aquatic vegetation zones to be visualized quickly and showed that satellite-derived vegetation and water indices could capture broad patterns of vegetation over or near water.

However, the model had a major limitation. NDVI can detect vegetation, but it cannot determine whether the vegetation is alligator weed. MNDWI can help separate water surfaces from land surfaces, but it cannot distinguish between plant species. Therefore, the Stage One model was not sufficient as a final detection method.

The result of Stage One was still important because it confirmed that index-based detection can identify candidate areas. In other words, it can function as a first screening layer, but not as proof of alligator weed presence.

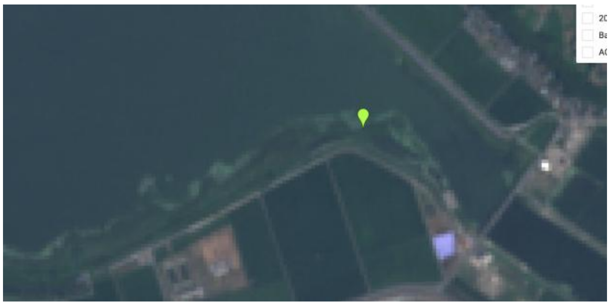
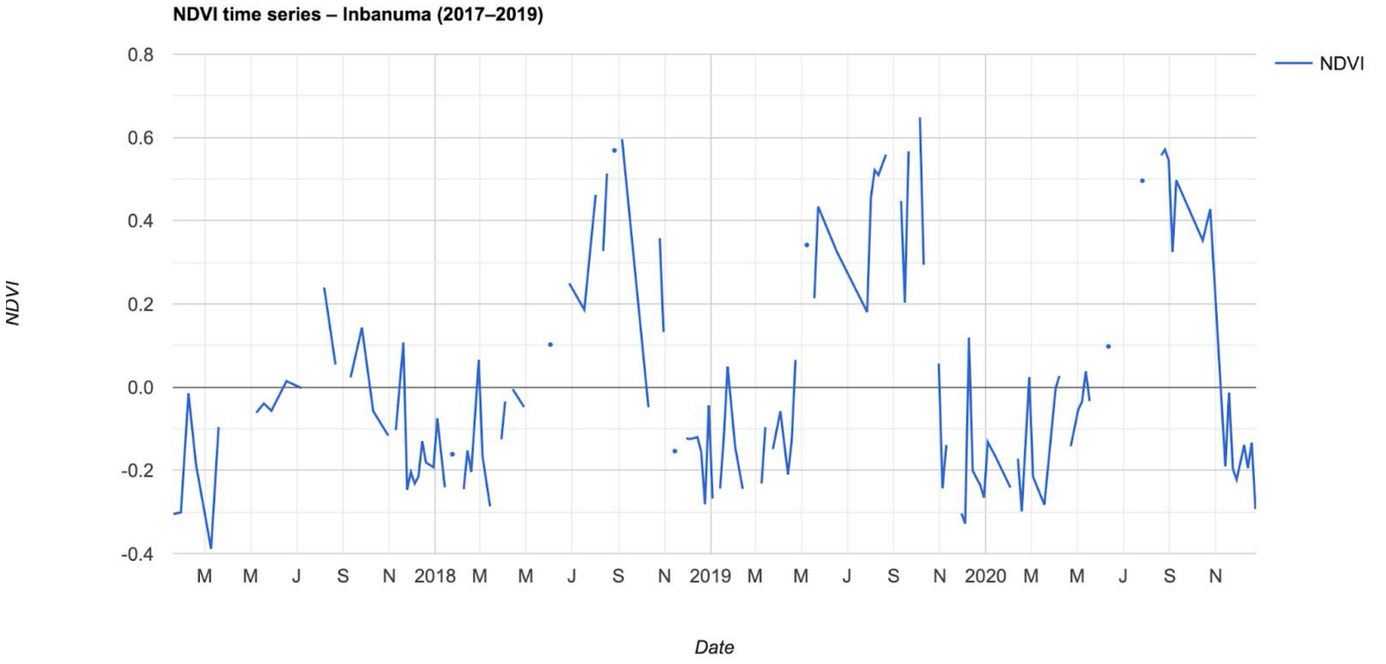


Figure 4. The Coordinate Plane Used to Observe NDVI Increase




Graph 1: Sustained Increase Following Alligator Weed Infestation From 2018

## 5.2 Stage Two

The BigQuery-based machine-learning exploration showed that supervised classification was possible using exported satellite-derived data. The dataset was successfully exported, with 8,237 valid sampled pixels. This demonstrated that Google Earth Engine and BigQuery could be connected for tabular machine-learning analysis.

To evaluate the contribution of specific spectral variables to the classification process, an analysis of **Importance Gain** was conducted on the final model. The results revealed a highly structured hierarchy of predictors, with four primary variables dominating the model's decision-making process: **Shortwave Infrared (B11)**, **NDVI**, **MNDWI**, and **Near-Infrared (B8)**.

The Shortwave Infrared band (B11) emerged as the most significant predictor, followed closely by the Normalized Difference Vegetation Index (NDVI). The Modified Normalized Difference Water Index (MNDWI) and the Near-Infrared band (B8) also showed substantial gain, collectively forming a "core" set of features. This ranking indicates that the model's predictive power is derived from a clear multi-dimensional signal: the interplay between vegetation health, leaf-structure reflectance, and surface moisture content. The reliance on these specific bands suggests that the classification logic is rooted in the physical contrast between the dense, moisture-rich canopy of Alligator Weed and the high-absorption characteristics of the surrounding water surface.

However, this stage also revealed a key weakness. Numerical accuracy alone was not enough. Because spatial visualization was difficult, it was again not possible to fully confirm whether the model was identifying actual alligator weed patches or simply learning shoreline characteristics. This was especially concerning because alligator weed often grows in shoreline or wetland environments. If the training data were spatially biased, the model could learn the habitat background rather than the target species itself.

Therefore, Stage Two helped clarify the need for a final workflow that could combine classification, mapping, probability output, and feature-importance analysis in the same environment.

## 5.3 Stage Three

The Stage Three Seasonal Random Forest Classification Models all achieved high validation accuracy, meaning that a large proportion of the held-out validation samples were correctly classified. However, validation accuracy alone is not sufficient to judge model quality, because it does not show the balance between false positives and false negatives or whether the model can generalize to new locations.

Among the four Seasonal Random Forest variants, Model 3B / Option B (spring + summer) and Model 3D / Option D (all seasons) performed better than Model 3A / Option A (summer only) and Model 3C / Option C (summer + autumn). Table 2 summarizes the training accuracy, validation accuracy, overfit gap, and kappa value for each mode.

Table 4. Seasonal Random Forest model comparison

| **Model** | **Seasonal input** | **Band count** | **Training accuracy** | **Validation accuracy** | **Overfit gap** | **Kappa** | **Interpretation** |
|---|---|---|---|---|---|---|---|
| Model 3A / Option A | Summer only | 16 | 0.9996 | 0.9953 | 0.0044 | 0.9184 | Strong, but lower than spring-summer and all-season models |
| Model 3B / Option B | Spring + summer | 32 | 1.0000 | 0.9978 | 0.0022 | 0.9653 | Best balance of accuracy and simplicity |
| Model 3C / Option C | Summer + autumn | 32 | 1.0000 | 0.9953 | 0.0047 | 0.9284 | Similar to Option A, but weaker than Option B |
| Model 3D / Option D | All seasons | 64 | 0.9998 | 0.9979 | 0.0020 | 0.9662 | Highest metric values, but most complex model |

Model 3D / Option D achieved the highest validation accuracy and kappa value, but the difference between Model 3D and Model 3B was extremely small. Model 3D used 64 input bands, while Model 3B used only 32. Therefore, Model 3B was selected as the preferred model because it achieved nearly the same performance with half the input complexity.

Model 3B achieved a validation accuracy of 99.78%, a kappa value of 0.9653, and an overfit gap of 0.0022. The overfit gap was calculated as the difference between training accuracy and validation accuracy. A smaller overfit gap suggests that the model performed similarly on training and validation samples, while a larger gap may indicate overfitting. In this study, the small overfit gap of Model 3B suggests limited overfitting within the pixel-based validation design. However, because nearby pixels from the same training polygons may have similar spectral characteristics, these metrics should be interpreted as initial validation results rather than final proof of species-level generalization.

Model 3B also achieved a high recall score and F1-score. Recall is important for early-warning monitoring because it measures how many alligator weed-associated validation samples were correctly detected. The F1-score combines precision and recall, making it useful for evaluating overall classification balance. These results suggest that the spring-summer model performed strongly while avoiding the unnecessary complexity of the all-season model.

## 5.4 False Positives and False Negatives

False positives and false negatives were examined because overall accuracy alone does not show the type of classification error. A false positive occurs when a non-alligator weed sample is incorrectly classified as alligator weed-associated vegetation. A false negative occurs when an alligator weed-associated sample is incorrectly classified as non-alligator weed.

For early-warning monitoring, false negatives are especially serious because they represent missed possible infestations. Missing a true infestation could delay field response and allow the plant to continue spreading. False positives are also problematic because they increase the number of unnecessary field-check locations and may reduce management efficiency. However, in an early-warning system, a limited number of false positives may be more acceptable than missing an actual invasion.

The confusion matrix showed that all four models produced very few classification errors. Model 3B / Option B produced 0 false positives and 5 false negatives in the validation set. Model 3D / Option D also produced 0 false positives and 5 false negatives, but it required twice as many input bands as Model 3B. This supports the selection of Model 3B as the preferred model because it achieved nearly identical practical classification performance with lower complexity.

Table 5: Confusion Matrix for the seasonal Random Forest models

| Option | True Negatives | False Positives | False Negatives | True Positives | Precision | Recall | F1-score | Balanced Accuracy |
|---|---|---|---|---|---|---|---|---|
| Option A: Summer only | 2247 | 0 | 11 | 64 | 1.0000 | 0.8533 | 0.9209 | 0.9267 |
| Option B: Spring + summer | 2243 | 0 | 5 | 72 | 1.0000 | 0.9351 | 0.9664 | 0.9675 |
| Option C: Summer + autumn | 2276 | 0 | 11 | 74 | 1.0000 | 0.8706 | 0.9308 | 0.9353 |
| Option D: All seasons | 2261 | 0 | 5 | 74 | 1.0000 | 0.9367 | 0.9673 | 0.9684 |

These results in Table 5 show that Option B performed almost identically to Option D in practical classification terms, while remaining simpler. This supports the selection of Option B as the preferred model. However, because the separation of decisions of training pixels and evaluation pixels was pixel-based, nearby pixels from the same training polygons may have similar spectral characteristics. Therefore, these metrics should be interpreted as an initial validation result rather than final proof of species-level generalization.

## 5.5 Comparison with Reference Information

The satellite-based results were compared with available reference information from Chiba Prefecture (see Figure 4) and a simple on-site survey conducted by our team on March 26, 2026..The Stage One model showed vegetation expansion patterns that corresponded with known vegetation growth areas, but it could not confirm species identity. The Random Forest model improved classification by using multiple seasonal and spectral variables.

However, comparison with reference information also highlights an important limitation. The available reference information was useful for contextual comparison, but it was incomplete and not sufficient for fully independent spatial validation. Therefore, the model evaluation may overestimate performance. The current results are promising, but stronger validation using field surveys, UAV imagery, or high-resolution satellite imagery is needed before the model can be considered fully reliable for official monitoring. Instead,

it can be used as a tool to reduce the necessary area and scope of in-person monitoring and utilized as an early-warning system.


Figure 5. Red indicated alligator weed patches, while orange indicates removed alligator weed patches as of 2023.

## 6. Discussion

The most important finding of this research is that simple index-based detection and machine-learning classification play different roles. The Rule-Based NDVI–MNDWI Threshold Model is useful for screening for increased vegetation patches, but not for final species classification. It can identify possible aquatic vegetation areas, but it cannot determine whether the vegetation is alligator weed.

Feature-importance results (see Table 5) showed that the boosted-tree models relied mainly on vegetation indices, water-related indices, infrared optical bands, and Sentinel-1 radar backscatter. In the simpler models, MNDWI, NDVI, B11, and B8 were repeatedly selected as important variables, indicating that the model was learning the contrast between water, vegetation, and moisture conditions. In the seasonal models, summer vegetation indices such as EVI summer, GARI_summer, and NDVI_summer became especially important, suggesting that growing-season vegetation signals were useful for separating alligator weed-labeled pixels from non-alligator weed pixels. Sentinel-1 radar variables, especially VV_summer and VV_winter, also appeared among the important
VV_winter, also appeared among the important
features, indicating that radar backscatter provided additional structural information beyond optical reflectance.

Table 6 : Band importances

| Band | Importance |
| --- | --- |
| B12_summer | 14.1851 |
| VH_summer | 12.2862 |
| NDVI_spring | 11.4945 |
| NDWI_summer | 11.3612 |
| NDVI_summer | 10.9526 |
| B8_summer | 9.8246 |
| B11_summer | 9.7751 |
| VH_spring | 9.6898 |
| B12_spring | 9.1680 |
| B11_spring | 9.0639 |

Image 6 Red indicated high probability (p>0.7) area of alligator weed, blue indicates other possibilities. In total, the area classified as high-probability alligator weed patches were 87.9 ha in size.

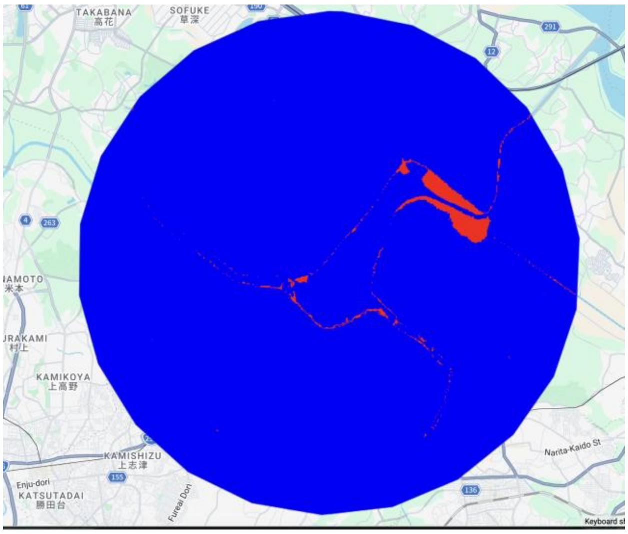



Image 6. The Probability Scale of Alligator Weed.

The prominence of $B11$, $NDVI$, $MNDWI$, and $B8$ in the feature importance rankings provide a strong physical validation of the model's logic, yet it also highlights the ecological limitations identified during the BigQuery ML stage. These variables effectively create a "vegetation-on-water" filter, identifying high-biomass clusters within aquatic environments; however, the BigQuery results demonstrated that high numerical accuracy can be misleading if the model is learning the tabular performance metrics habitat's context rather than species-specific traits. Because these spectral bands are broad indicators of moisture and chlorophyll, there is a significant risk of the model identifying "shorelines" as a general ecological zone rather than alligator weed as a unique species. This discrepancy reveals that while the model is statistically robust, it remains susceptible to "habitat leakage," where terrestrial or riparian vegetation at the water's edge is incorrectly flagged due to spectral similarity. Consequently, these results suggest that cannot be the sole measure of success. Spatial interpretation and visual inspection are mandatory to ensure the model is detecting the target biological entity rather than simply mapping the lake's geomorphological boundaries.

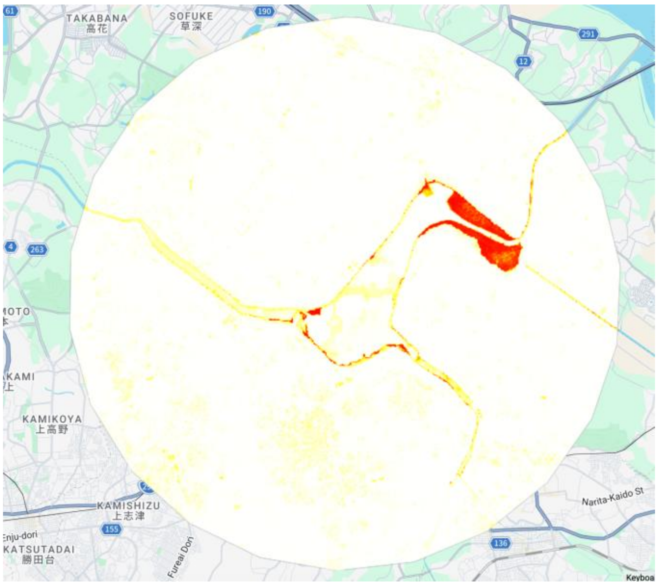



Figure 7: Probability layout
(red being higher probability of alligatorweed)

The final Random Forest workflow combined the flow of classification, mapping, probability output, and feature-importance analysis in one code script on Google Earth Engine. This made it easier to evaluate both numerical performance and ecological plausibility.

Option B was selected because it represented the strongest balance between accuracy and simplicity. Spring data may capture early vegetation emergence, while summer data captures peak vegetation growth. Together, these seasons provide useful information about the growth cycle of alligator weeds. Option A, C were passed over because of their limited convenience while Option D was passed over due to complexity.

This supports one of the key interpretations of the study: more data is not always better. A practical monitoring model should not only maximize accuracy, but also remain interpretable, efficient, and transferable.

## 7. Conclusion

This study evaluated a staged remote-sensing workflow for detecting alligator weed. The Rule-Based NDVI–MNDWI Threshold Model from Stage One successfully identified possible vegetation zones over or near water surfaces, making it useful as a first screening method. However, because NDVI and MNDWI are not species-specific, the index-based model could not serve as a final alligator weed detection model.

The BigQuery ML from Stage Two showed that satellite-derived variables could be used for supervised classification, but it also revealed problems related to spatial visualization and overfitting. These issues led to the final Google Earth Engine Random Forest workflow in Stage Three.

Among the four seasonal models, Option B, using spring and summer data, was selected as the best overall model. As explained in the Discussion, although Option D had slightly higher numerical performance, Option B achieved nearly identical validation accuracy with half the number of input bands. Option B also produced strong recall, high F1-score, no false positives in the validation set, and only five false negatives.

Overall, this research suggests that satellite remote sensing can support early-warning monitoring of invasive aquatic vegetation. At the current stage, the model should be described as detecting likely alligator weed-associated vegetation rather than definitively identifying alligator weed in every pixel. With better validation data and higher-resolution imagery, the workflow could become a practical tool for local environmental monitoring.

## 8. Future Directions

Future work towards this project focuses on improving training data, validation quality, and spatial resolution.

First, more balanced training samples are needed. In particular, the model should include more negative samples from non-alligator weed shoreline vegetation. This would reduce the risk that the model learns shoreline conditions instead of alligator weed identity.

Second, validation should be improved. The current random split provides an initial estimate of performance, but it does not fully test whether the model can generalize new locations. Future validation should include spatially separated test areas, field-confirmed alligator weed locations, and comparison with UAV or high-resolution satellite imagery.

Third, higher-resolution data should be introduced. Sentinel-2 is useful for wide-area monitoring, but its 10m resolution makes it difficult to detect small or narrow patches. UAV imagery or commercial satellite imagery with 3–5m or finer resolution could improve early-stage detection.

Fourth, the model should be tested in other regions where alligator weed has been reported. This would show whether the workflow is specific to Lake Inba or can be applied more generally.

Finally, the long-term goal is to develop an automated early-warning system. By combining satellite monitoring, seasonal classification of alligator weeds, probability mapping, and alert functions, local governments and environmental managers could detect possible alligator weed expansion earlier and respond before large colonies become established.

In conclusion, this study highlights both the promise and current limitations of using satellite imagery to detect invasive aquatic plants. By building toward improved data quality, validation, and resolution, the proposed approach moves closer to a practical early-warning system. Ultimately, it demonstrates how advances in remote sensing and machine learning can contribute to more timely, efficient, and scalable management of ecological threats.

## 9. Acknowledgements

We would like to express our sincere gratitude to Mr. Masahiro Yoshida of Shibuya Makuhari High School for his continuous guidance and support throughout this research. We also thank Dr. Tomoaki Kasuga at the Remote Sensing Technology Center of Japan (RESTEC) who provided technical advice on remote sensing, Google Earth Engine, and environmental monitoring. Finally, we acknowledge the public data sources and previous studies that supported the development of this research.

## 10. Author Contributions

Conceptualization, K.I., K.S., and S.L.; methodology, S.L.; software, S.L.; validation, K.I., K.S., and S.L.; investigation, K.I., K.S., and S.L.; resources, K.I., K.S.; writing—original draft preparation, K.I., K.S., and S.L.; writing—review and editing, K.I., K.S., and S.L.; visualization, S.L.. All authors have read and agreed to the final version of the manuscript.

## 11. References

[1] National Invasive Species Information Center, *Alligator Weed.*

[2] Chiba Prefecture, *Overview of Invasive Aquatic Plants in Lake Inba and Lake Teganuma*.

[3] Google Earth Engine, *Sentinel-1 and Sentinel-2 Data Catalog*.

[4] K. Shinohara and H. Kurita, “Distribution of Invasive Species Alternanthera philoxeroides in the Hakken River, Chiba Prefecture Visualizing by Satellite Data.”

The related SDGs GOALS mentioned:

Goal 6 | Department of Economic and Social Affairs.

United Nations, United Nations, sdgs.un.org/goals/goal6.

Accessed 27 May 2024.

Goal 13 | Department of Economic and Social Affairs.” United Nations, United Nations, sdgs.un.org/goals/goal13.
Accessed 7 May 2026.

Goal 15 | Department of Economic and Social Affairs,” United Nations. Accessed: May 7, 2026.

# Assessment of Water Quality in Bowker Creek for Implementation of a Salmon Egg Box to Restore Salmon Populations

*Dog Salmon Group*

Luc Hodkinson, Sophie Goodman, Mason Pite, Juliette Schmaltz

Oak Bay High School

British Columbia, Canada

djshrubsole@sd61.bc.ca

## Abstract

Bowker Creek was once a diverse ecosystem, providing spawning grounds for salmon species. Now flowing through three municipalities before emptying into the ocean, the creek no longer harbors salmon due to rapid urbanization around Oak Bay and the Greater Victoria area in the past century. In hopes of reclaiming this urban waterway, we are continuing the work to reintroduce Chum salmon (*Oncorhynchus keta*) to Bowker Creek in support of the 'One Hundred-Year Plan' to revitalize the creek. Between the months of October 2025 and February 2026, we monitored two locations weekly to determine which site was the most suitable for a salmon egg box. We tested levels of dissolved oxygen, turbidity, stream flow, air and water temperatures, and pH. This project is in continuation of work done by Friends of Bowker Creek, an organization that previously added a salmon box in 2022. We expect our findings will tell us which site can provide the best environment to restore a Chum salmon run in the creek. We hope that the addition of a second box will strengthen the relationship between the Oak Bay community and Bowker Creek ecosystem.

## 1. Introduction

### 1.1 History of Bowker Creek

Bowker Creek is a complex urban waterway that flows through the municipalities of Victoria, Saanich and Oak Bay on Vancouver Island, in the Province of British Columbia. This waterway stretches over 3.4 kilometres above ground and 4.5 kilometres in underground pipes or tunnels. In total, the creek path is over 10 kilometres in length. While it used to be a stream with a consistent flow, now roughly fifty percent of the creek is covered by hard, impermeable surfaces, such as roads, roofs or parking lots, and over sixty percent of the water runs through culverts, pipes or tunnels [4]. Prior to 1914, Bowker Creek was ecologically diverse, housing an array of species, including Chum salmon (*Oncorhynchus keta*) and Cutthroat trout (*Oncorhynchus clarkii*). This rich ecosystem and healthy salmon habitat thrived for centuries until European settlers began to arrive in the late 1700s and in larger numbers in the 1800s. The local First Nations, the Lək̓ʷəŋən people, relied on these salmon as a main food source [2, 8].

### 1.2 Chum Salmon Life Cycle

Pacific salmon are widely recognized as a keystone species, as their life cycle links both British Columbia's salt and freshwater ecosystems [5]. The Chum salmon are the poorest jumpers of the salmon fish family and as a result they tend to lay their eggs in the lowest portions of streams when compared to other species of salmon. Three to five years after hatching, Chum salmon return to lay their own eggs in their home creek. Compared to other salmon species, Chum salmon tend to spawn further downstream as they struggle to progress much further inland and upstream. The females dig the egg resting places by sweeping the gravel with their tails, while the males fertilize the eggs.

During the winter months, the eggs will incubate within the gravel beds. In early spring, these eggs will hatch to form "alevins" with their yolk sacks attached. When the yolk sack disappears, they emerge as fry. The Chum salmon fry spend only a few weeks in these fresh water streams before they head back into the cold salt water ocean. However, before the Chum salmon leave their home streams, they undergo a physical change called smoltification. They spend some additional time in the estuaries to acclimatize their bodies, which allows them to navigate the ocean salt waters. It is at this stage that the fish are known as smolts and they begin to imprint the stream, by taking in the smells and tastes so they are able to return to the same stream to reproduce [6]. Chum smolts spend the least amount of time in the creek, which is one reason why they are considered a better species to choose for urban stream restoration projects. Upon leaving the creek, they spend three to five years in the ocean growing before making their journey home to create the next generation of Chum salmon [6, 12].

## 1.3 Restoration Efforts

As Victoria urbanized, the welfare of Bowker Creek and other natural ecosystems were prioritized less than the need for housing. As a part of this development, many creeks that ran through the area became a part of the storm water system, where they carried precipitation out to the ocean. While this was good for the towns, it caused immense strain on the natural environment. After precipitation falls on the town, it gets mixed with the dirt, chemicals and other artificial substances that flow into the urban waterways, thereby unbalancing this delicate ecosystem [3, 4].

Established in 2004, the Bowker Creek Initiative ("BCI") is a collaborative effort between local government, volunteer organizations and citizens to protect the Bowker Creek's ecological, social and economic health [4]. In 2011, the 100 Year Plan was created by the representatives from three municipalities (Saanich, Oak Bay and Victoria) [1]. It has taken one hundred years for Bowker Creek to find itself in its current degraded state and the expectation is that it will take the same amount of time to restore the creek to its former healthy state. Working together, municipalities and school districts developed a draft plan of different objectives to focus on to support the creek's restoration. This plan developed a list of goals, such as effectively managing the water flow, achieving and maintaining acceptable water quality in the watershed, improving and expanding public access to natural areas and increasing the overall biodiversity of the Bowker Creek watershed. The intention of this 100 Year Plan is to restore Bowker Creek's water quality to the point where Chum salmon are able to reproduce in this watershed. This plan has an important role connecting many different groups to a common and shared vision for the healthy future of Bowker Creek. The Oak Bay High School project will focus on continuing the restoration efforts by assessing the viability of a potential second placement site for Chum salmon eggs in Bowker Creek and the comparison of Bowker Creek to other local salmon bearing streams to assess future restoration efforts.

## 1.4 Comparable Urban Salmon Waterways

This paper will analyze the potential salmon hatching success in Bowker Creek with two other urban salmon bearing watersheds: Goldstream Provincial Park and the Colquitz River. Our team members conducted numerous chemical and physical water quality tests in two potential salmon bearing locations in Bowker Creek. The purpose of these tests was to determine which location would provide the best potential survival rate for Chum salmon eggs [9]. This project is being completed in collaboration with the Friends of Bowker Creek, a local environmental organization, which has previously conducted water quality tests and added Chum salmon eggs in a different stretch of the creek [15].

In early 2022 the Friends of Bowker Creek received approval from the Department of Fisheries and Oceans, who manages salmon fisheries throughout Canada, to place a salmon egg box in Bowker Creek [11]. This original egg box was intentionally placed in a very natural location, out of the sight and reach of the general public. Our project tested two potential locations for a second salmon egg box: one at our high school's outdoor classroom, adjacent to the creek, and the other slightly downstream in a restored wetland area. The objective is that the establishment of a second egg hatching location will be a critical step forward in the efforts to restore Bowker Creek to its natural state. Both the potential box locations would be more visible to those, who are interested in knowing more about the efforts to bring salmon back to Bowker Creek. Having the second salmon box located in a highly visible location will make it an effective way to teach both the general public and Oak Bay High School students about the life cycle of Chum salmon, and how to care for both the wildlife and the creek moving forwards.

In heavily urbanized areas, local salmon populations face environmental stressors such as altered hydrology, habitat fragmentation, shoreline development and pollution. Despite these obstacles, several greater Victoria watersheds continue to support active annual salmon runs. Goldstream River Provincial Park and the Colquitz River are examples of how salmon spawning habitats can successfully co-exist within municipal locations, if the appropriate natural habitat features are present or created by deliberate human restoration efforts [7, 13]. The persistence of these groups of spawning salmon provides a compelling case study for how aquatic ecological resilience can be fostered within metropolitan environments. This study will focus on comparing and contrasting those two urban salmon bearing watersheds with Bowker Creek. Each of these flowing bodies of water has experienced varying degrees of anthropogenic modification, including extensive use of culverts, storm water diversion, riparian vegetation removal, channel straightening and human use impacts. Prior to urban development, these waterways contained naturally meandering channels, floodplains, coarse gravel beds, and intact, mixed riparian forests, which are all necessary features for salmon spawning and juvenile fish development.

A key contributor to the local salmon enhancement is the Goldstream Volunteer Salmonid Enhancement Association hatchery, which was established in 1982. This local hatchery incubates eggs from caught salmon and promotes their growth through the alevins and smolt stages. Once the fish reach the smolt stage, they are released into local streams to make their journey to the ocean. Three of the streams that this hatchery supports are Goldstream River Provincial Park, the Colquitz River, and Bowker Creek [7].

Goldstream Provincial Park is located about 16 km from downtown Victoria, in the Province of British Columbia in Canada. This park runs along the busy Trans-Canada Highway and it has various streams, which interconnect prior running into the estuary. It is nestled within a mixed forest, which includes 600 year old Douglas Firs, Western Cedars, low lying vegetation and wild flowers. Goldstream Park is well known for its annual autumn salmon runs, which occur during late September to early December [14]. It is vital for the Chum, Coho and Chinook salmon species, who return from the Pacific Ocean to spawn there. This stream system also provides a natural floodplain with riffles, pools, and forest vegetation that contributes a varied and enriched food source for the juvenile salmon to feed from. Despite its idyllic setting, Goldstream Park has undergone extensive restoration efforts to address human usage and the water runoff effects of the nearby commuter highway [7].

The Colquitz River is part of a watershed system that flows through Copley East Park in the municipalities of Saanich and View Royal. Prior to large-scale urban development, the Colquitz was a naturally meandering waterway with side channels and floodplains. With urbanization, the creek was straightened and heavily modified. Natural gravel beds were washed away or removed, wetlands were drained for farming and native vegetation was cleared. As a result, the river and the surrounding park area have experienced decades of ecological degradation. This includes the impacts of storm water runoff, which introduced pollutants, increased water temperatures, and subjected the stream beds to more flooding and soil erosion. All these factors have contributed to the loss of this salmon spawning habitat [13].

Although the area was once unsuitable for successful salmon spawning, restoration efforts have created an opportunity to re-establish salmon runs in the Colquitz watershed. Since 2019, the Peninsula Streams Society and the District of Saanich have been working in partnership to restore sections of the Colquitz River [13]. The state of this riparian area prior to 2019 is very similar to the current environmental conditions found in Bowker Creek.

Collectively, the Goldstream River and Colquitz River illustrate both the vulnerabilities and resilience of urban salmon habitats in the Greater Victoria region. While urban development presents many challenges, targeted restoration, community involvement and hatchery programs have assisted in rebuilding the local salmon populations [7, 13]. These efforts demonstrate that with continuous monitoring and human assistance in optimizing the natural environment, the salmon will continue to thrive within human communities.

## 1.5 Goal of the paper

By examining local urban watersheds, this paper explores how adaptive management, habitat engineering, and volunteering efforts can mitigate negative human impacts on the surrounding watersheds. The goal for Oak Bay High School is to assess the viability of a potential second site for the placement of Chum salmon eggs in Bowker Creek and to compare Bowker Creek to other local salmon bearing streams.

## 2. Methods

Water quality surveys are used to provide information about the chemical composition of water. The background of the water chemistry can determine what kinds of plants and animals can live there. The water quality was tested as a way to assess the suitability of the creek for supporting Chum salmon eggs. The Advanced Streamkeeping Habitat Survey published by the Department of Fisheries and Oceans Canada (DFO) was used as the basis for our methods to collect data for our project [16]. In order to avoid a significant difference in data between sites, sampling was done within 24 hours of each other. This module provided instructions on how to use and measure dissolved oxygen, pH, temperature, and turbidity with materials readily available to high schools [17].

### 2.1 Water Quality Survey

**Temperature:** Read the temperature of the air on the thermometer after letting it sit for two minutes, then put it below the water surface and make sure it is fully submerged for another two minutes. Read the temperature while the thermometer is still in the water. Record the temperature in the Data Sheet [17].

**Dissolved oxygen:** Follow the instructions of the dissolved oxygen test (LaMotte Company). Collect the water sample carefully, without introducing air or bubbles to the sample. Add the reagents in the water sample to stabilize the oxygen, then fill the titration tube and insert the titrator into the top of the titrating solution. Add drops from the titrating solution to the titration tube until the color becomes a very pale yellow, afterwards add drops from the starch indicator. Continue the titration until the blue color disappears and the solution becomes colorless. Finally, read the level on the titrator, and record it as the dissolved concentration (see Figure 2) [17].

**pH (API):** Follow the directions of the pH kit. Fill the 5ml sample. Add three drops of the pH indicator and match the color to the chart included with the kit (see Figure 1 and 2) [17].

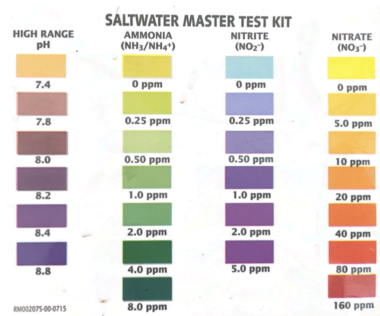



Figure 2: pH Color Chart

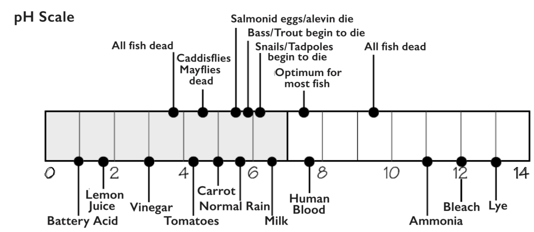



Figure 3: pH Scale

**Turbidity:** Fill the tube with water to the 1.2 metre line, then look from the top down the tube. If the black-and-white disk is visible, stop there and mark the turbidity as 120cm. If it is not visible, release water from the bottom valve and stop once the disk comes into sight. Read the level on the scale, then record the measurements in the data table [17].

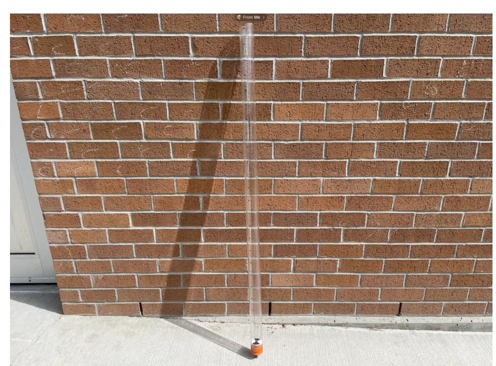


Figure 4: Turbidity Tube

**Stream flow:** Materials: Rubber duck, timer and tape measure.

To start, measure the length of ten metres upstream of the egg box sample site, then drop the rubber duck one metre upstream from the starting point to allow the duck's velocity to match the stream velocity. Start the timer as it reaches the starting line and stop the timer as the duck reaches the final line. Repeat this procedure five times and determine the average of the values recorded [16].

## 2.2 Advanced Stream Habitat Survey

The Advanced Streamkeeping Habitat Survey was used during our data collection to gather further information about Bowker Creek's conditions and its suitability for a future Chum salmon egg box [16]. This module provided us with a list of six steps which allowed for smooth sampling.

### Step 1 – Choose a reference site and benchmark:

To establish a reference site within an area with suitable stream conditions, measure the stream's bankfull channel. This is the area of the creek up to the vegetation line (see Figure 5). Multiply this number by at least twelve and place a marker at the upstream and downstream boundaries. Choose a benchmark between these two boundaries (see Figure 5a). This will be the site used in steps 2–4 [16].

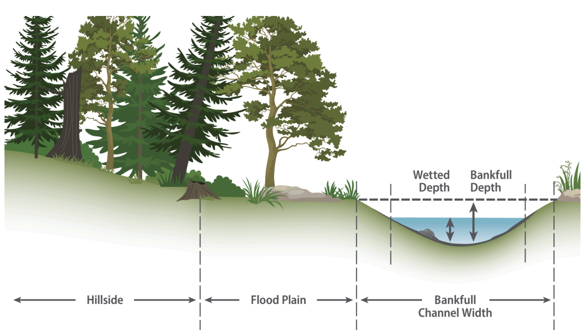



Figure 5: Cross Section of a Stream

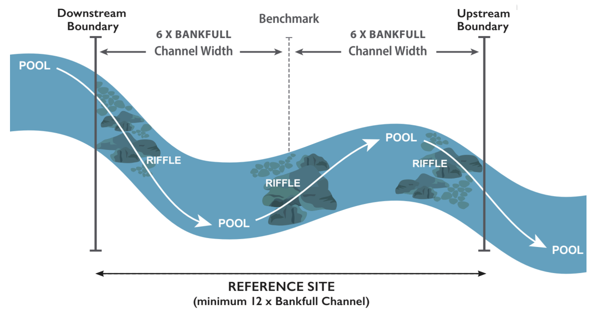



Figure 5a: Natural Meander Pattern of a Stream

### Step 2 – Conducting a cross sectional survey:

This step will consist of four measurements: the width of the wetted channel and bankfull channels, and the depth of the wetted channel and bankfull channels. Complete each of these measurements at the downstream boundary, your benchmark, and the upstream boundary [16].

*Width of wetted channel:* Stretch a measuring tape perpendicular to water flow across the wetted area of the stream. This measurement will be used in step 3.

*Width of bankfull channel:* Stretch a measuring tape between the bankfull markers.

*Wetted depth:* Measure the wetted depth periodically along the stream, depending on stream width. Start 0.1 metre away from the left bank and measure from the bottom of the water to the surface.

*Bankfull depth:* Stretch a measuring tape across the stream at the bankfull indicators and measure from the bottom of the creek to the tape every half metre, as done with the wetted depth (see Figure 4) [16]

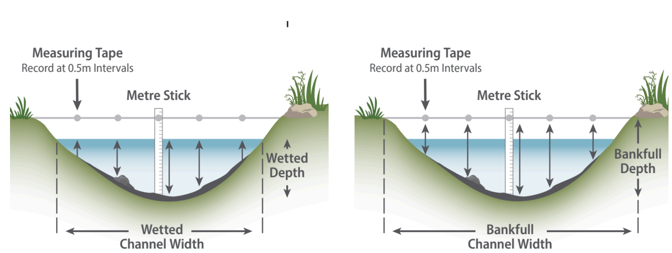



Figure 6: Wetted and Bankfull Channel Measurements.

## Step 3 – Calculating stream discharge:

Using measurements from step two, multiply the wetted width by wetted depth to obtain the cross-sectional area in metres (see Figure 5).

| | | | | |
|---|---|---|---|---|
| Cross-sectional area of Wetted stream ($m^2$) | ________ wetted width | x ________ average wetted depth | = ________ | ($m^2$) |

Figure 7: Calculating the Cross-Sectional Area in Metres

Drop a tennis ball one metre upstream of the benchmark and time how long it takes to travel ten metres. Repeat five times and calculate the average velocity (m/sec) by dividing ten metres by the average time. Determine total stream discharge ($m^3$/sec) by multiplying the cross-sectional area by the average water velocity and then by 0.8 as a correctional factor (see Figure 6) [1].

| | |
|---|---|
| Average Time (sec) | ( ______ + ______ + ______ + ______ + ______ ) = ______ ÷ 5 = ____________<br>trial 1, trial 2, trial 3, trial 4, trial 5, total trials, Average Time (sec) |
| Average Velocity (m/sec) | ________ ÷ ______ = ______________<br>length (m), average time (sec), Average Velocity (m/sec) |
| Average Stream Discharge (m3 /sec) | __________ x ___________ x 0.8 = _________<br>cross sectional area ($m^2$), average velocity (m/sec), correction factor, Discharge ($m^3$ /sec) |

Figure 8: Calculating the Average Stream Discharge in Cubic Metres

## Step 4 – How to Conduct a Longitudinal Survey:

Use a hip chain starting from the benchmark, walk upstream and mark with flag tape the upstream end of every habitat unit (pool or riffle) until reaching six times the bankfull channel width. Return to the benchmark and repeat downstream. For each habitat unit, identify whether it is a pool or riffle, measure its length, calculate the percent slope, measure continuous length with the hip chain, and conduct a cross sectional survey [16].

## Step 5 – Habitat Characteristics:

Different sizes and types of streambed material influence plant and animal life in a stream. Substrate sizes range from fines, such as sand and clay, to large boulders and bedrock (see Table 1). Although a variety is ideal, a streambed consisting of gravel, boulders, and pebbles is more stable than one made up of fine sediment (see Figure 9) [16].

Table 1: Size categories of streambed material

| | |
|---|---|
| fines | smaller than a ladybug |
| gravel | ladybug to tennis ball |
| cobble | tennis ball to basketball |
| boulder | larger than a basketball with definable edges |
| bedrock | solid slab of rock |

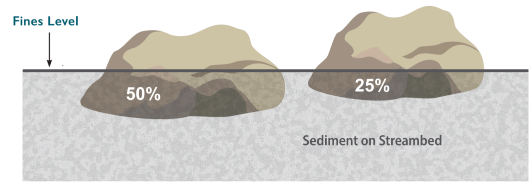



Figure 9: Estimating the Embeddedness of Gravel and Cobble

## Step 6 – Collecting, reporting, evaluating information:

Rate the habitat quality of the reference site using the recorded measurements and observations from Step five. Transfer the measurements to the RESULTS column in Data Sheet: STEP 6. The scores of each of the nine habitat characteristics are weighted to reflect their importance to biological productivity of the stream. Add the values to get the total score for the reference site [16].

# 3. Results

When looking at the data gathered for the upstream and downstream sites in Bowker Creek, several trends can be seen. The pH values were relatively consistent at the upstream location, as the majority of samples were between 7.4 to 7.6 (see Table 2). There was one day in January with a discrepancy in this pattern when the pH was higher than average, with a result of 7.8. The pH of the downstream location were found to be fairly consistent, with an average result of 7.4, and some variance during the weeks of November 19, 2025 and February 26, 2026 (see Table 3). These results from both locations are acceptable for salmon, as they can survive in streams with an average pH of anywhere between 6.0 to 8.5 [17]. Being an urban waterway, Bowker Creek is prone to alteration as a range of inputs, such as stormwater runoff which may include fertilizers, oils, or gasoline, are continuously occurring. It is suspected that this was the case with any major pH differences, especially considering that they occurred during months of high rainfall, and therefore more water runoff from roads and other impervious surfaces.

## 3.1 Turbidity

When looking at the turbidity results, it is seen that this test had the highest fluctuation when comparing sampling days. At the upstream site, there was variation of between 49cm to 120cm throughout the first half of testing. From January onwards, when the eggs would be introduced to Bowker Creek, the turbidity became higher and the data was more consistent, ranging from 95cm to 120cm. The eggs would have been hatching into the alevin stage relatively soon after we concluded our testing, so seeing that the data was improving at this point was a very promising result. A high turbidity reading means that the water is clear and free of excess sediment, so these are ideal conditions for young fish. Had the turbidity been low in these months, the eggs, and then later their gills and fins, could get smothered by the debris, making this site potentially hazardous [17].

The turbidity in the downstream site was consistently worse than the upstream site throughout testing, ranging from 22cm to 120cm. This is likely due to this downstream location being a restored wetland that stretches over a wide bank with areas of low water flow. This can cause sediment to build up in the creek and lead to low turbidity readings. The turbidity was ideal at the start of testing, with a result of 120cm, but rapidly fell between November 22 and December 3, 2025. It rose again in the following weeks before dropping to its lowest level at the beginning of January. From here onwards, it slowly rose before getting back to clear conditions as we concluded our sampling.

## 3.2 Temperature Differences

Water and air temperatures are directly related because as the air heats or cools, so will the water. Salmon generally thrive in water temperatures between 5°C to 20°C. A lower water temperature leads to a decrease in the risk of fish disease occurring. As the water and air temperatures rise, more plants will grow, which will increase oxygen levels. Once they start to decompose, they will use up the oxygen in the water, which will place stress on aquatic life [17]. The upstream site had a consistent difference in air and water temperatures of 0°C to 1°C throughout testing, with only a couple outliers in December (3°C) and February (1.5°C and 6°C). The data taken from the downstream site showed similar findings, with results of 0°C to 1°C, and anomalies of 1.5°C in November, 2°C in December, and 3°C in February. On February 5, 2026 both sites had their highest temperature difference. This was due to a short term spike in air temperature where temperatures reached a record breaking 14°C [20]. Days like these are common in Victoria as spring appears, and therefore this result is not concerning.

## 3.3 Oxygen Saturation

Ideal oxygen saturation levels for healthy salmon-bearing streams are anywhere between 90% to 110% [17]. Having a high oxygen content is crucial for young salmon in a stream as they grow into adulthood. This is because having access to oxygen will help them maintain enough energy to survive and grow [19]. The results at the upstream site were relatively consistent, seeing results between 75% and 90%. Oxygen levels were lower throughout the winter but once it hit January, the data increased to more ideal numbers, ranging from 79% to 99%. This location had promising results because as it neared that time that the eggs would hatch, the oxygen levels were increasing. When looking at the downstream site, however, we found alarming results. The data from the second half of sampling were considerably lower than the other location, with some days seeing results as low as 60% oxygen saturation. It is suspected that this is caused by an input feeding into the wetland that did not affect the upstream site. Furthermore, there was high rainfall during the months of January and February which would have caused faster travelling water and therefore an increase in aquatic oxygen levels at the narrower upstream site. This excess water could have spread out across the open wetland, which may have been why there was less of an increase at the downstream site.

## 3.4 Stream Flow

Significant variation between days could be seen in the stream flow velocity data. The upstream site showed a range between 12m/s to 35 m/s throughout testing, while the downstream site had results between 10m/s to 36 m/s. These large ranges may be due to a number of factors. Sampling was executed during the winter when heavy rainfalls sporadically occur in Victoria, which was a contributing factor to any variation during the sampling period.

Table 2: Results of Water Quality Tests From the Upstream Location Throughout Testing

| | 11/20/25 | 11/27/25 | 12/03/25 | 12/09/25 | 12/19/25 | 01/08/26 | 01/14/26 | 01/22/26 | 02/05/26 | 02/24/26 |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.4 | 7.4 | 7.6 | 7.4 | 7.4 | 7.8 | 7.4 | 7.4 | 7.4 | 7.4 |
| Turbidity (cm) | 120 | 53 | 33 | 45 | 49 | 95 | 108 | 110 | 120 | 120 |
| Temperature Difference (water/air) (°C) | 0.0 | 1.0 | 1.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 6.0 | 1.5 |
| Oxygen Saturation (%) | 75 | 90 | 75 | 75 | 90 | 93 | 99 | 80 | 98 | 79 |
| Stream flow (m/s) | 0.282 | 0.673 | 0.382 | 0.781 | 0.781 | 0.605 | 0.776 | 0.389 | 0.503 | 0.340 |

Table 3: Results of Water Quality Tests From the Downstream Location Throughout Testing

| | 11/19/25 | 11/22/25 | 12/03/25 | 12/11/25 | 12/19/25 | 01/9/26 | 01/15/26 | 01/22/26 | 02/05/26 | 02/26/26 |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.6 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.0 |
| Turbidity (cm) | 120 | 35 | 29.6 | 75.2 | 68.9 | 22 | 66 | 83 | 77 | 110 |
| Temperature Difference (water/air) (°C) | 1.5 | 1 | 2 | 0.5 | 1 | 1 | 0 | 0.1 | 3 | 0.1 |
| Oxygen Saturation (%) | 88 | 90 | 74 | 85 | 80 | 63 | 82 | 65 | 88 | 60 |
| Stream flow (m/s) | 0.278 | 0.806 | 0.479 | 0.961 | 0.853 | 0.387 | 0.543 | 0.403 | 0.466 | 0.329 |

## 3.5 Water Quality Index

Throughout testing, both sites consistently had either acceptable (30-40) or good (40-45) ratings on the water quality index. Chum salmon spawning occurs around November, during the beginning of testing. During this time, the water quality at the upstream site was found to be highly acceptable (see Table 4). The downstream site showed greater variation in the early winter months, but ultimately was found to have generally acceptable conditions. The second half of testing was when the egg box would have been implemented into Bowker Creek. During this time, the upstream site followed similar trends to the first months of testing, with all data showing that the water quality was acceptable to good. The downstream site, however, showed a decline in water quality when compared to previous months. Quality varied from the low end of acceptable to good. Despite this, it was found that the results from both locations are still suitable for young salmon.

Table 4: Overall Water Quality Results for Each Test Day From Both Sampling Focations

| | 11/19/25 | 11/22/25 | 12/03/25 | 12/11/25 | 12/19/25 | 01/9/26 | 01/15/26 | 01/22/26 | 02/05/26 | 02/26/26 |
|---|---|---|---|---|---|---|---|---|---|---|
| Upstream Site | 40.16 | 38.51 | 37.33 | 38.10 | 40.89 | 36.16 | 43.15 | 36.63 | 40.48 | 37.21 |
| Downstream Site | 42.44 | 40.45 | 38.53 | 37.04 | 34.92 | 33.04 | 40.64 | 36.39 | 37.28 | 35.51 |

## 3.6 Results Of Advanced Stream Assessment

Table 5: Advanced Stream Assessment Results for the Downstream Site

| Characteristic | Results | Good | Acceptable | Marginal | Poor | Score |
|---|---|---|---|---|---|---|
| 1: Streambed material: % boulder and cobble | 28% | 15 - 20<br>50% | 10 - 15<br>30 - 50% | 5 - 10<br>10 - 30% | 0 - 5<br>< 10% | 8.5 |
| 2: Embeddedness | 60% | 15 - 20<br>25 - 0% | 10 - 15<br>15 - 25% | 5 - 10<br>75 - 50% | 0 - 5<br>> 75% | 6.5 |
| 3: Instream cover | 0 | 15 - 20<br>> 3 | 10 - 15<br>2 - 3 | 5 - 10<br>1 - 2 | 0 - 5<br>< 1 | 0 |
| 4: % Pool habitat<br><2% stream slope<br>2-5% stream slope<br>>5% stream slope | 2 <<br>% slope<br><br>26%<br>% pool | 11 - 15<br>> 60% pool<br>> 50% pool<br>> 40% pool | 7 - 11<br>50 - 60%<br>40 - 50%<br>30 - 40% | 3 - 7<br>40 - 50%<br>30 - 40%<br>20 - 30% | 0 - 3<br><40%<br><30%<br><20% | 2 |
| 5: Off-channel habitat: ponds, side channels with protection from flood flows | 0 (none) | 11 - 15<br>Year round, good protection | 7 - 11<br>Seasonal, good protection | 3 - 7<br>Seasonal, minimal protection | 0 - 3<br>Little or none, no protection | 0 |
| 6: Bank stability: evidence of erosion or bank failure | 16.5 | 11 - 15<br>Stable none | 7 - 11<br>Moderately Stable some | 3 - 7<br>Moderately unstable some | 0 - 3<br>Unstable lots | 14 |
| 7: Bank vegetation: % stream bank covered by vegetation | 64% | 8 - 10<br>> 90% | 5 - 8<br>70 - 90% | 2 - 5<br>50 - 70% | 0 - 2<br>< 50% | 4 |
| 8: Overhead canopy: % bankfull channel overhung by trees and shrubs | 26% | 8 - 10<br>> 30% | 5 - 8<br>20 - 30% | 2 - 5<br>10 - 20% | 0 - 2<br>0 - 10% | 5 |
| 9: Riparian zone: # bankful channels | 42 | 8 - 10<br>2 or more<br>Abundant on whole floodplain | 5 - 8<br>1 - 2<br>Good species mix | 2 - 5<br>< 1<br>Common, few species | 0 - 2<br>0<br>Sparse or absent | 5 |
| Total Score | 43 | 102 - 135 | 66 - 102 | 30 - 66 | 0 - 30 | Marginal |

Table 6 - Advanced Stream Assessment Results for the Upstream Site

| Characteristic | Results | Good | Acceptable | Marginal | Poor | Score |
|---|---|---|---|---|---|---|
| 1: Streambed material: % boulder and cobble | 60% | 15 - 20<br>50% | 10 - 15<br>30 - 50% | 5 - 10<br>10 - 30% | 0 - 5<br>< 10% | 16 |
| 2: Embeddedness | 11% | 15 - 20<br>25 - 0% | 10 - 15<br>15 - 25% | 5 - 10<br>75 - 50% | 0 - 5<br>> 75% | 17 |
| 3: Instream cover | 0 | 15 - 20<br>> 3 | 10 - 15<br>2 - 3 | 5 - 10<br>1 - 2 | 0 - 5<br>< 1 | 0 |
| 4: % Pool habitat<br><2% stream slope<br>2-5% stream slope<br>>5% stream slope | <2<br>% slope<br><br>0%<br>% pool | 11 - 15<br>> 60% pool<br>> 50% pool<br>> 40% pool | 7 - 11<br>50 - 60%<br>40 - 50%<br>30 - 40% | 3 - 7<br>40 - 50%<br>30 - 40%<br>20 - 30% | 0 - 3<br><40%<br><30%<br><20% | 1 |
| 5: Off-channel habitat: ponds, side channels with protection from flood flows | 0 (none) | 11 - 15<br>Year round, good protection | 7 - 11<br>Seasonal, good protection | 3 - 7<br>Seasonal, minimal protection | 0 - 3<br>Little or none, no protection | 0 |
| 6: Bank stability: evidence of erosion or bank failure | 7 | 11 - 15<br>Stable<br>none | 7 - 11<br>Moderately Stable<br>some | 3 - 7<br>Moderately unstable<br>some | 0 - 3<br>Unstable<br>lots | 7 |
| 7: Bank vegetation: % stream bank covered by vegetation | 87.5% | 8 - 10<br>> 90% | 5 - 8<br>70 - 90% | 2 - 5<br>50 - 70% | 0 - 2<br>< 50% | 7 |
| 8: Overhead canopy: % bankfull channel overhung by trees and shrubs | 75% | 8 - 10<br>> 30% | 5 - 8<br>20 - 30% | 2 - 5<br>10 - 20% | 0 - 2<br>0 - 10% | 9 |
| 9: Riparian zone: # bankful channels | | 8 - 10<br>2 or more<br>Abundant on whole floodplain | 5 - 8<br>1 - 2<br>Good species mix | 2 - 5<br>< 1<br>Common, few species | 0 - 2<br>0<br>Sparse or absent | 3 |
| Total Score | Marginal | 102 - 135 | 66 - 102 | 30 - 66 | 0 - 30 | 60 |

## 3.7 Streambed Material Results

The purpose of measuring the sizes of streambed material is to make sure that the ground is suitable for salmon to spawn. Salmon make a nest in the sand to lay their eggs in, so the sediment must be fine enough to allow this. If it is too fine, the nest will collapse on top of the eggs, smothering them. Therefore, there must be enough boulder and cobble in the streambed to prevent this. Enough gravel is also important because an abundance of fine sediment could cause a large amount of turbidity, which is harmful to fish. This was measured by reaching into the sediment and picking up a small handful of rocks and sand. Each particle was then measured according to Table 1. Additionally, a low recording of embeddedness is important since it means that the sediment will be free and loose, which will prevent excess silt. Embeddedness was recorded by estimating the depth in which the larger pieces were stuck into the finer ones. For the upstream site, there was a recorded amount of 60% boulder and cobble. This is ideal for salmon because it means that eggs will not be smothered by an excess of fine sediment. Meanwhile, the downstream site recorded only 28% of boulder and cobble. This is marginal, as it remains possible that the sediment could still collapse on the eggs. Additionally, there is a low amount of embeddedness (11%) in the upstream site, which is beneficial, but there is a higher amount (60%) in the downstream site.

## 3.8 Instream Cover Data

Instream cover includes large rocks or woody debris that lies in the water. This is vital to the growth of salmon because it protects the eggs and the fry from predators such as ducks, and it helps to keep the water temperature stable by providing shade. It is also important because it gives the newly hatched fish a place to live and hide until they are strong enough to emerge. For both sites, there was no visible evidence of instream cover, which is inadequate for the growth of salmon.

## 3.9 Pool Habitat Percentage

Pools are calm segments of a stream, and these locations are typically where returning salmon would lay their eggs. Pools are important because they provide a safe place for the eggs to grow and hatch. They form in areas of low water movement, so the water is typically cleaner because sediment stays at the bottom, instead of being pushed along by heavier flow. Ideally, around 50% pool habitat or more is good for salmon. There was not a large difference between sites, but downstream showed more evidence of pools. There were two pools recorded downstream, in comparison to one in the upstream section. Although, the upstream section is typically slower and calmer, even though the pool habitat is sparse.

## 3.10 Overhead Cover Results

Salmon eggs are very sensitive, so the temperature of the water is very important. Overhead cover provides shade in the form of trees or bushes, which keep the conditions stable and cool. In order for salmon eggs to survive, the water must stay consistent in terms of temperature, and shade is the ideal way to do this. The upstream site has numerous trees on both sides of the stream. The banks are healthy in this sense, and there is approximately 75% cover in this area. This is very satisfactory because it provides shade over a lot of the water, giving it constant temperature stability year-round. On the other hand, the downstream site only grants 26% cover. The only thing providing this is a large tree overhanging the creek, while there are many trees on the banks of the other site.

## 3.11 Bank Stability

It is important for the health of the stream and everything that lives in it for the banks to be stable. This way, they will not easily erode and the water will stay clear and healthy. If the banks are not stable enough, they will fall apart and the sediment will taint the water. This is not acceptable for salmon as they need non-turbid water to survive. For this to happen, there needs to be plenty of plants growing in the riparian zone. The plant's roots help to keep the banks together, and therefore prevent erosion from occurring. The stability was measured by counting the places on the banks with evidence of active erosion. The upstream site had an acceptable amount of stability with seven places with active erosion. On the other hand, the downstream site was better, with 14 places with evidence of erosion. Vegetation is measured by recording the lengths of banks without vegetation within ten metres up and downstream from the site. There was a visible difference between sites. The upstream site recorded a good figure of 87% of the bank covered by vegetation. The downstream site, on the other hand, only recorded 64% vegetation, mostly due to the left bank being a large concrete wall.

## 3.12 Riparian Zone

The riparian zone is the area between the stream and the uplands, and its health is vital to the well-being of the stream. A large biodiversity in the riparian zone is important because of the benefits from all plant species. Trees help provide shade, which controls the temperature of the water, while large groups of plants filter pollutants and help keep the banks stable. The riparian zone is measured by width; it is recorded as the amount of bankfull channel widths could fit into it, extending outwards. For example, if the riparian zone is double the width of the bankfull channel, this is recorded as two. Both sites were similar as they each promoted moderately healthy banks, with one bank being considerably larger and more biodiverse than the other. The upstream site's riparian zone was documented as three, while the downstream site was recorded as five. According to Table 4, the downstream location is on the brink between 'acceptable' and 'marginal', while the recordings for the upstream site are strictly 'marginal'.

# 4. Discussion

## 4.1 Test Relevance For Salmon Growth

The pH level impacts a salmon's ability to breathe, keep a proper salt balance, and reproduce successfully. Optimal pH levels for salmon growth in freshwater is between 6.0 and 8.5. Extremely acidic or too basic pH levels can damage the fish's gills and skin causing excessive mucus production that make breathing difficult, or kill them directly. Acidic water disrupts the balance of sodium and chloride ions in the fish blood, potentially leading to circulatory failure and eventual death. High pH levels convert ammonium into highly toxic ammonia, which can damage their gills and reduce their ability to absorb oxygen. Consistently high or low pH levels inhibit fish growth development and negatively impact reproduction rates [20].

Turbidity is the measure of the cloudiness, caused by suspended silt, clay particles, or organic matter in a body of water. This is a critical water quality parameter for salmon, since high turbidity levels negatively damage their physical health, impede feeding, destroy habitats, and reduce their overall survival rates. High levels of suspended particles can physically hurt or clog delicate salmon gills. If the gills are sufficiently damaged or clogged the salmon is unable to obtain sufficient oxygen, which can cause stress or death. Rough sediments can result in infections of injured gill tissues. Salmon rely on their sight to catch their food. Dirty water makes it more challenging for fish to locate their prey, causing them to expend more energy to find sufficient food, resulting in reduced growth rates and poor overall health. When particles that are suspended in the water eventually settle, then can smother a streambed resulting in eggs not receiving enough oxygen and salmon fry being trapped under the layer of sediment leading to high mortality rates. Silt can also fill in deep pools of water that salmon use to rest and obstruct their migration path. Another complication is that particles suspended in water absorb sunlight, which increases water temperature, which in turn decreases oxygen solubility. Higher turbidity levels also reduce light penetration in water, which also decreases the amount of photosynthesis, which results in reduced dissolved oxygen levels in the water. The ideal water turbidity levels range from 100cm to 120cm [21].

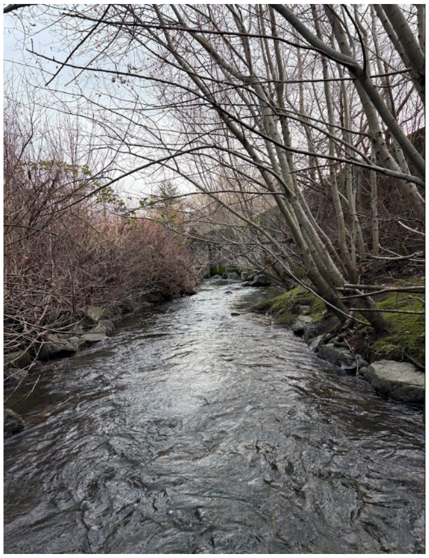
Water and air temperatures are directly related because as the air heats or cools, so will the water temperature. A lower water temperature leads to a decrease in the risk of fish diseases occurring. As the water and air temperatures rise, the amount of dissolved oxygen found in the water decreases. Cold water holds more oxygen than warm water. Warmer temperatures can result in increased algae growth, which can stress aquatic life [21].

Dissolved Oxygen or oxygen saturation is a critical factor for salmon development as they rely on it to support their high metabolic demands for oxygen, especially for egg development and fry growth. Low levels of oxygen can lead to reduced swimming and feeding which increases stress and mortality levels. Salmon gills extract dissolved oxygen from the water. Eggs need adequate oxygen flow through the stream bed to prevent premature hatching and smaller fry sizes. Low oxygen levels affect juvenile and adult salmon as well. This is because they may experience extreme stress and reduced growth and development, which will limit their ability to swim and hunt for food. The more oxygen that is present, the less pressure is placed on the salmon's immune system, which makes the fish more disease resistant. There is less oxygen in warm water, which means that during droughts and summer months, the salmon can die. Additionally, the warm water also increases their metabolic rate and need for oxygen to survive [22].

Stream flow velocity is an important measurement to determine how favorable one location might be over another. The flow of water is critical for keeping spawning salmon beds well oxygenated. Low velocity or stagnant water can lead to deficient oxygen levels which results in salmon eggs and alevins suffocating. Salmon use water velocities as a clue on how to navigate their stream. For example, high-velocity spring runoff flows may signal to juvenile salmon that it is time to move to the sea. These high flow events also assist young salmon in avoiding predators and passing hazardous areas, which increases their survival rates. Faster moving water allows young fish to conserve energy by "drift feeding," where fish wait for food to be carried past their location. Returning adult salmon may use water flow as a "scent marker" to find their home stream. Moderate water velocities result in better growth rates for salmon. Steady flow rates also help to beneficially redesign rivers by moving sediments off of gravel beds. These beds are used for spawning and creating deep water pools where fish can rest. Flooding can wash away the gravel beds used for laying eggs. Reduced water flow or drought conditions also negatively impact juvenile fish survival rates. Lastly, higher water flows helps to keep water temperatures lower, which prevents overheating during hot summer months and keeps the water sufficiently oxygenated [23].

## 4.2 Upstream Site Description

Figure 9: Photo of the Upstream Site,
Taken By Luc Hodkinson



The upstream site is located near the outdoor athletic track at Oak Bay High School. This narrow stretch of water, as wide as 1.8 metres in certain locations, is surrounded by growing trees. The water mostly flows freely downstream, with very few slower moving pools or other side channels. One side of this stream comes up against a concrete wall that supports the track. The other side is covered in shrubs and trees and is close to an urban path which runs along Bowker Creek.

## 4.3 Downstream Site Description

Figure 10: Photo of the Downstream Site
Taken By Luc Hodkinson

The downstream site is approximately 200 meters away from the upstream location. The water quickly flows by a narrow rock wall along this site before opening up to a fast channel. It continues along the solid rock wall on one side, but the other streambank contains reeds and wetland side eddies, where slower water pools. Overall, this section of the stream is more like an open wetlands portion of a river where ducks congregate. However, there are fewer trees covering this stretch of the stream.

## 4.4 Stream Evaluation

The group used the periodic testing results to compare the upstream and downstream sites at Bowker Creek. The upstream site had fairly steady pH readings throughout the testing period from November 2025 to February 2026. The turbidity levels showed strong seasonal variation in levels. Other than two testing dates, the temperature difference between air and water was fairly minimal. Dissolved oxygen levels were never lower than seventy-five percent; and, half of the testing results showed levels at ninety percent or higher.

In comparison, the downstream site also has consistent pH readings, but its turbidity readings showed even greater variation than the upstream site. The temperature difference readings were steadier than the upstream site. The downstream site temperature difference range was 0.1°C to 3°C. However, the downstream site had lower oxygen saturation levels than the upstream site. It only had one reading at ninety percent and several low readings of the mid-sixties. Stream flow results were generally better for the downstream site in 2025 and better for the upstream site in 2026. This shows the seasonal variation in water flows through differently structured stretches of Bowker Creek.

For the purpose of this study, an Advanced Stream Assessment was completed on December 23, 2025 at both sites. This assessment evaluated various indicators of creek habitat quality, including stream bed materials, embeddedness of the rocks, instream cover, pool habitat stream slope, off-channel habitat, bank stability, bank vegetation, overhead canopy cover, and riparian zone condition. Collectively, these characteristics were assessed to provide insight into the stream's channel stability, habitat suitability, complexity and the overall ecological health of the stream system.

The analysis of the Bowker Creek upstream site revealed acceptable scores for most of the criteria used in the Advanced Stream Assessment, but comparatively low scores for the categories of instream cover, pool habitat percentages, and off-channel habitat availability. Instream cover refers to the structural elements immediately above and within a water channel, including such features as wood debris of various sizes, undercut banks, boulders, rocks, instream vegetation, plants hanging over the water surface that provide shade and hiding places, and deep pools of slow moving water. Upon closer observation, there is limited evidence of side channels, backwater areas or slower flowing eddies for the upstream site. These characteristics might make it a challenge for fish to locate possible areas of low velocity refuge in the stream, especially during periods of high creek flow such as during high volume winter rains. The pool percentage habitat analysis measures the width of a stream covered in water during low-flow conditions. An optimal stream location provides young salmon with a broad mix of habitat types, including a high proportion of deep pools, gliding water zones, and riffle areas, which provide varied water flow regimes. Within the various types of pools, woody debris, boulders, undercut banks, and or instream vegetation provide cover for developing fish.

In contrast, the Bowker Creek downstream site showed mostly marginal to poor outcomes for most of the Advanced Stream Assessment criteria. The downstream site only showed promise for good bank stability and because of the reed covered areas, there were some seasonal areas of slower moving water. The downstream location also has fewer trees shading its water, which means that this portion of the creek would be subject to greater temperature fluctuations, especially during the hot summer months. Increased water temperature negatively impacts the dissolved oxygen levels.

Consequently, it is evident that the better potential location for the second salmon egg releasing station is the upstream site, as it scored slightly better on the ten overall test samples for pH, turbidity, temperature differential, saturated oxygen levels, and stream flow. Additionally, it showed more promise as a hatching site using the Advanced Stream Assessment criteria. Even though the upstream site should be the preferred location, it has some shortcomings for three of the Advanced Stream Assessment characteristics, namely: instream cover, percentage pool habitat, and reduced off-channel habitat.

Despite the aforementioned structural challenges at the upstream site, the three observed limitations could potentially be mitigated through targeted creek habitat restoration and enhancement measures similar to those implemented in Goldstream Provincial Park and Colquitz Creek Park. These comparable stream restoration projects have demonstrated that restructuring initiatives, such as developing side channels and expanding the types of water pools available and intentionally placing a mix of large and small woody debris can significantly enhance the survival rates for salmon eggs released into a stream. Similar restoration strategies could be applied to Bowker Creek. For example, the Friends of Bowker Creek could increase habitat and pool type diversity, provide greater shade and temperature stability, improve overall stream health and create more sustainable conditions capable of supporting salmon populations over the long term.

## 4.5 Comparable Local Salmon Rivers

**Colquitz River:**

Since 2019, volunteers and community partners have successfully restored over 300 metres of the Colquitz River, which resulted in 465 salmon returning to spawn in 2022. This restoration work has included the construction of manmade riffles, which provide protection from predators, an increase in dissolved oxygen levels through stream flow disturbance and sheltering pools of slower moving water, and improving the upstream spawning gravel beds to ensure the proper sized rocks are situated there. In addition, three Newbury weirs have been installed, which are low, v-shaped rock structures built across the stream to control water flow, while still allowing salmon to swim upstream. They help stabilize stream banks, create deeper water in the center of the channel, and make upstream passage easier for migrating salmon. These structures are particularly necessary to foster the Chum salmon, which do not have the same ability to jump as other salmon species and are particularly sensitive to migration barriers and altered channel gradients [24].

The restoration project also selectively added woody debris to enhance the fish habitat and large boulders to stabilize the riverbank during seasonal high water flows and prevent soil erosion. In addition, the volunteers monitor the river flow, plant native vegetation along riverbanks to provide shade, organic material and improve riverbank stability. They also remove invasive species, like Himalayan blackberry and common ivy, to ensure the native plants grow. The continuous monitoring of all these enhancements has led to the return of spawning Coho and Chum salmon in the park [24].

The local municipality built split-rail fencing to prevent dogs and humans from contaminating the restored river portions. Improved signage was erected so the public understands the important restoration work being conducted and instructs park goers to stay on designated paths. They also built viewing platforms overlooking the river so citizens can safely watch the spawning salmon without disturbing their reproductive efforts [24].

**Goldstream River Park:**

One natural characteristic which makes Goldsteam Park waters ideal for the Chum salmon, is the coarse gravel bed that lies beneath the stream. Another characteristic of note is the cool water, which holds more dissolved oxygen. The pebbles allow water to flow in between rocks and increase the amount of oxygen reaching salmon nests, called "redds". The gravel also protects the newly hatched alevins from being washed away during winter storms or being eaten by predators like birds. For the Coho and Chum salmon, the gravel must be the right size of between one to fifteen centimeters. This will allow the female to make an indentation in the stream floor and bury her eggs, with just the use of her tail [25].

Another example of these restoration efforts include the removal of large boulders that have fallen into the river beds, which would otherwise block salmon movement, installing spawning gravel beds, and relocating large pieces of wood downstream to support side pools or eddies. In addition, more native plants were planted close to the stream beds to increase biodiversity and stream cover. There is also a volunteer-led local hatchery, which incubates, monitors, and raises salmon eggs to increase the salmon frys' survival rates. As recently as last September 2025, efforts were made to fence off certain areas of the streams to lower the impact of human footprints in or near the stream shoreline. This was also to prevent the dogs from eating salmon carcasses. This is crucial for the salmon life-cycle because as the fish decompose, they provide nutrient rich waters, which help salmon fry to thrive. These fences also prevent the dogs from urinating or defecating into the streams, which indirectly releases unwanted pathogens and negatively affects the overall water quality of the streams. All of these combined efforts have contributed to turning Goldstream Park into a much more productive salmon spawning body of water [25].

## 5. Conclusion

In efforts to restore Bowker Creek to a functioning watershed, the Capital Regional District implemented a 100-year action plan as part of the Bowker Creek Blueprint. This plan supported the efforts of Friends of Bowker Creek to add an initial salmon egg box. They did this after conducting environmental testing under the supervision of the Department of Fisheries and Oceans. Oak Bay High School was approached by Friends of Bowker Creek in Fall 2025, as they were interested in looking at a location near the school for a second Chum salmon egg box in the creek. The goal of our project was to determine the best location to place this additional box, which could also function in a public education capacity. There was a focus on returning Bowker Creek to being a salmon-bearing stream in the future and raising public awareness about how to protect this waterway. Following the completion of our project, a copy of the project paper will be provided to the Friends of Bowker Creek organization, which they will use to determine the most suitable location for the second salmon egg box in Bowker Creek. Friends of Bowker Creek will collaborate with the hatchery at Goldstream Provincial Park to provide Chum salmon eggs for this initiative.

The Advanced Stream Habitat Survey focused on collecting detailed quantitative data to assess the physical health, structural complexity, and long-term changes of a creek's habitat. In comparison, the Water Quality Survey is dedicated to determining general stream flow health. Tests were conducted at two potential locations. The downstream site was located in an open wetland, while the upstream site was in a sheltered environment, making the upstream site a more suitable location for the implementation of a second box. Additionally, this site was seen to be a constant and stable location, showing better results from the Stream Bed, Overhead cover, and Water Quality Surveys. The downstream site showed stable and acceptable conditions with minimal evidence of bank erosion, but a decline in the water quality appeared during the late winter months. This, along with the lack of overhead cover and the stream bed results, would make it less suitable as a habitat for the Chum salmon egg box.

## 6. Acknowledgements

We acknowledge that the land on which Bowker Creek runs is part of the traditional territory of the Coast Salish Peoples, specifically the Lək̓ʷəŋən people, the Songhees and Esquimalt Nations, and we thank them for their stewardship.

We are also incredibly grateful for those who have made this project possible. We would like to thank our teachers for their help throughout the entirety of this process and to our parents their continued support. We would like to extend our deepest gratitude to Mr. Shrubsole for his guidance and dedication, and without whom we would not have been able to do this project. We would like to acknowledge Friends of Bowker Creek for inspiring this project and for providing us with the opportunity to make meaningful change in our community.

## References

[1] Bowker Creek Initiative. (n.d.). *Bowker Creek blueprint*. https://bowkercreek.org/

[2] Capital Regional District. (n.d.). *About the Bowker watershed*. https://getinvolved.crd.bc.ca/bowker-creek-initiative/news_feed/about-the-bowker-watershed-2

[3] Capital Regional District. (n.d.). *Bowker Creek information resources*. https://www.crd.ca/environment/stormwater-watersheds-harbours/local-stewardship-groups/bowker-creek-initiative/bowker-creek-information-resources

[4] District of Saanich. (n.d.). *Bowker Creek initiative*. https://www.saanich.ca/EN/main/community/natural-environment/watersheds/bowker-creek-initiative.html

[5] Fisheries and Oceans Canada. (n.d.). *Pacific salmon*. Fisheries and Oceans Canada. https://www.pac.dfo-mpo.gc.ca

[6] Fisheries and Oceans Canada. (n.d.). *Salmonid life cycle*. https://www.pac.dfo-mpo.gc.ca/education/docs/salmonid-cycle-salmonide-eng.html

[7] Fisheries and Oceans Canada. (2025). *Goldstream River restoration story*. https://www.dfo-mpo.gc.ca/campaign-campagne/pss-ssp/stories-articles/2025-goldstream-eng.html

[8] First Nations Health Authority. (n.d.). *Traditional food fact sheets*. https://www.fnha.ca/Documents/Traditional_Food_Fact_Sheets.pdf

[9] Fondriest Environmental. (n.d.). *Dissolved oxygen*. https://www.fondriest.com/environmental-measurements/parametres/water-quality/dissolved-oxygen/

[10] Friends of Bowker Creek Society. (n.d.). *Chum salmon recovery*. https://bowkercreek.org/Chum-salmon-recovery/

[11] Friends of Bowker Creek Society. (2021, July 15). *Getting ready to place 30,000 salmon eggs in Bowker Creek*. https://bowkercreek.org/2021/07/15/getting-ready-to-place-30000-salmon-eggs-in-bowker-creek/

[12] Hunt, B. P. V., & Johnson, B. T. (n.d.). *The Hakai juvenile salmon program: Early life history drivers of marine survival in sockeye, pink, and Chum salmon in British Columbia, Canada.*

[13] Peninsula Streams Society. (n.d.). *Colquitz River restoration projects*. https://peninsulastreams.ca/our-work/restoration-projects/colquitz-river/

[14] TranBC. (2020, November 25). *Getting Goldstream River going in the right direction*. https://www.tranbc.ca/2020/11/25/getting-goldstream-river-going-in-the-right-direction/

[15] Victoria World Heritage Society. (2025). *Brief: Bowker Creek watershed (May 2025).* https://victoriaworldheritage.org/wp-content/uploads/2025/05/Brief_BowkerCreekWatershed_202505217.pdf

[16] Fisheries and Oceans Canada. (2023). *Streamkeepers module 2: Advanced stream habitat survey* (Revised ed.). Department of Fisheries and Oceans Canada.

[17] Fisheries and Oceans Canada. (2024). *Streamkeepers module 3: Water quality survey* (Revised ed.). Department of Fisheries and Oceans Canada.

[18] van Reeuwyk, C. (2026, February 6). *Snow still a possibility for Victoria despite record-breaking temperatures. Saanich News.* https://saanichnews.com/2026/02/06/snow-still-a-possibility-for-victoria-despite-record-breaking-temperatures/

[19] National Oceanic and Atmospheric Administration. (2005). *The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage*. NOAA. https://www.noaa.gov/sites/default/files/legacy/document/2020/Oct/0.7.115.29756-000004.pdf

[20] Fondriest Environmental, Inc. (2013, November 19). *pH of water*. Fondriest Environmental. https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

[21] Atlas Scientific. (n.d.). *How does temperature affect dissolved oxygen?* Atlas Scientific Blog. https://atlas-scientific.com/blog/how-does-temperature-affect-dissolved-oxygen/

[22] National Oceanic and Atmospheric Administration. (2020). *[PDF report]*. NOAA. https://www.noaa.gov/sites/default/files/legacy/document/2020/Oct/0.7.115.29756-000004.pdf

[23] University of California, Santa Cruz. (2021, May). *Salmon streamflows*. UC Santa Cruz News. https://news.ucsc.edu/2021/05/salmon-streamflows/

[24] Peninsula Streams Society. (n.d.). *Colquitz River restoration projects*. https://peninsulastreams.ca/our-work/restoration-projects/colquitz-river

[25] TranBC. (2020, November 25). *Getting Goldstream River going in the right direction*. https://www.tranbc.ca/2020/11/25/getting-goldstream-river-going-in-the-right-direction/

# Chemical analyses of Gulbene city ponds

Madara Daugerte, Kristiāna Kokoreviča, Sintija Šīve, Olita Priede, Sabīne Mičule, Roberts Kondričs

*Gulbene County Secondary School , Latvia, anda@gnvsk.lv*

## *Abstract*

Water is a very important resource in our city - Gulbene, because it plays a big role for our environment, wildlife and humans. There are many ponds here, but no swimming places, so it is important to examine some of the ponds in our area. It will be interesting to find out if the chemical quality of the water meets bathing water standards and if there are any signs of pollution or imbalance. The ponds we will be researching are Dzirnavu pond, Emzes pond, pond in Sparites park, Asaru pond, pond in Skolas street courtyard. To know the pollution intensity and chemical factors, the methods we will be using are oxygen concentration determination with sensor and indicator, spectrophotometry as well as qualitative ion determination. We predict that after this research we will get to know that the ponds are polluted and not suitable for usage according to the visual condition that they are overgrown. In the end we will be able to determine the causes of pollution, suggest practical solutions and raise awareness of the problem

## *Keywords*

*Water pollution; Chemical pollution; Water quality; Surrounding environment*

## Introduction

This experiment was conducted to understand how polluted our ponds are and how safe it is to use them. Water samples were collected from 5 different ponds and one of the methods that we used was titration, to find out how dirty is water in our local area. After experiment we learned that absorption[3] in every pond is zero, that means that water didn't absorb any dirt or pollution. The other method was qualitative analysis of ions[1], where we tried to determine whether there were any excess ions present, but we did not find any, which means that the water is of good quality, but we can't be one hundred percent sure, because we could have made some mistakes during the experiment. At the same time, we found out that normal amount of oxygen, that should be in water is 6-10 mg/L[2] and all 5 ponds had right amount of oxygen. After experiment we can say that our local ponds are safe to use for ourselves.

## About city – Gulbene

Gulbene is a city in the northeastern part of the Vidzeme region of Latvia located 186 km from Riga, the capital city. The name "Gulbene" originates from the Latvian word "gulbis", which means "swan", because swan is the main symbol of Gulbene, and legends say that the place where the city now stands was once a paradise for swans. The town is well-known for its rich history, cultural and historical heritage - its surrounding area offer attractions such as Vecgulbene Manor, Stāmeriena Palace, and the Gulbene District History and Art Museum, where visitors can explore the region's cultural history. What is more, it is the only place in the Baltics where a narrow-gauge railway train regularly operates. About the nature - more than 200 hectares of the city's territory are covered by magnificent parks, as well as Latvia's longest river, the Gauja River, winds through the district. The city has SIA "ZAAO" as the new waste management company of Gulbene which helps to reduce pollution and protect nature.

## Primary reason of our research

Very sole and important motive of the conducted research was to examine, gather and test water samples from city’s 5 main ponds to ascertain if the bodies of water have optimal, safe environment which would indicate their compatibility with the city itself. The experiment not only reassured and confirmed water quality of city’s ponds, but it also as well provided an insight to the surrounding environment – what makes it a threat or problem for water reservoir? Is it compatible with living organisms? What could be done to resolve the problem? With that in mind this examination may also raise awareness of water quality and aquatic lifeform conservation where it would benefit investigation even more.

## Description about the ponds

- ### Dzirnavu pond:

It is in populated area. Next to it there is a workshop, LPG station, manor, garages, former brewery and private houses. One of the sources of pollution could be human – caused pollution and industrial waste from the workshop and chemical substances from the LPG station. However, it does not have pronounced smell and is transparent, the visual condition is bad - the water colour is greenish brown with aquatic plant sediments and foam. The environment in this place is overgrown with algae and grass. In the water can be seen small grass insects and worm – like creatures. Some waterfowl tend to inhabit this area.

- ### Asaru pond:

Located in the park. Next to the pond is forest, school and sports stadium. The environment around is slightly polluted most likely from people and students who tend to visit the park - next to the shore there are some litters. The bottom of the pond is overgrown and covered with brown tree leaves. The water colour is mostly transparent with a slight brown tint and there is no pronounced smell. There are little signs of life in the water – small number of insects like ants. Animals visible in the area are small birds.

- ### Emzes pond:

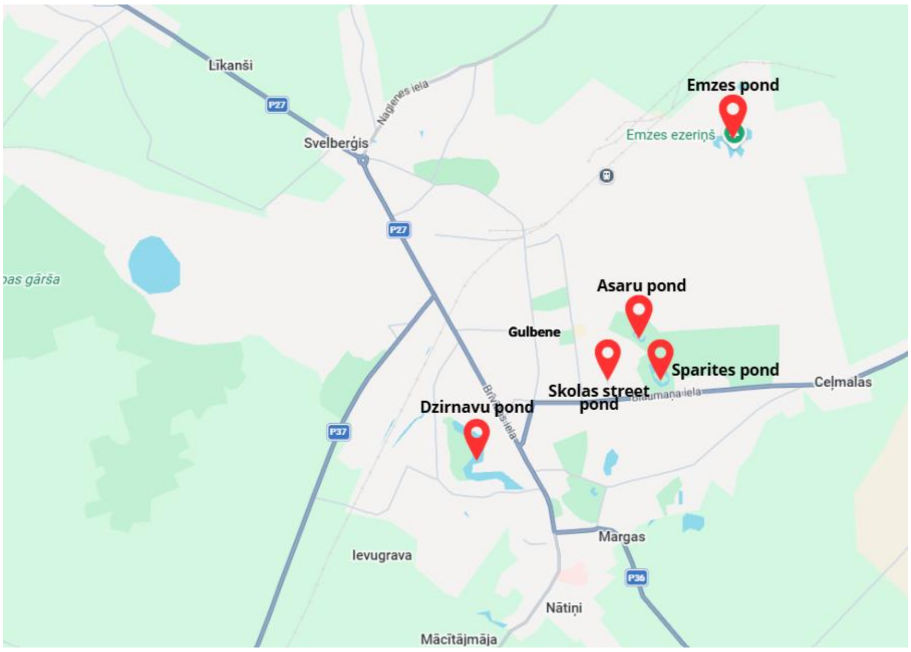
Located in Emzes park. Next to it there is only car service, mostly – forest around. The pollution may be little due to water transparency, colourlessness and no specific smell - very few people visit the area because it is far away from the city centre. The bottom of the pond and the shore is overgrown and with brown tree leaves and algae. Mostly found animals in the area are small insects, ducks and birds.

- ### Skolas street pond:

Located in a highly populated area. There are private houses, a parking lot around it. The water sample is transparent with no smell, however the colour in the pond seems to be polluted due to its green colour, muddiness, the number of algae and substances on the pond’s surface. Main pollutants might be litter and exhaust fumes from cars. Sometimes ducks and frogs can be found in this area.

- ### Sparites pond:

Located in Sparites park near school, highway, forest and Asaru pond. People regularly visit this park. It is tidy, not overgrown with green shore. Might be polluted from litter and human activity. The water sample is transparent with a little brown tint and no specific smell. Small insects can be found, but mostly animals like ducks and birds (There used to be swans there), sometimes – forest animals.




Map of the researched ponds

## Pollution

There are many different types of water pollution like ground water pollution, urban storm water runoff, agricultural, atmospheric and chemical pollutants, pathogens, pesticides and herbicides, sediment pollution and saltwater intrusion. For the selected ponds these types of pollution are relevant: urban storm water runoff mostly due to snow melting, pesticides and herbicides might have an effect depending on park maintenance, chemical pollutants because some of the ponds are near roads where vehicle related pollutants can affect the water[4].

## Method of the investigation

For our investigation we chose 5 ponds: Dzirnavu, Emzes, Sparites, Asaru and Skolas street pond. In 16th and 17th of April we collected water samples from the shore of each pond, however, from Dzirnavu pond we collected 2 samples from 2 different shores because of its large area. In 17th of April, we determined the oxygen concentration[2], used the spectrophotometry[3] method and performed qualitative ion determination[1] in all the samples and recorded the results obtained to get to know about pollution and overall water composition.

## Summary and conclusion

### Process and results

In this year's 16th and 17th of April all samples were collected from the 5 main city's ponds. For every pond there were two water selections from different locations in the reservoir (mostly shoreline). All samples were amassed in laboratory and tested in following morning. Here are the results:

- Using qualitative analysis of ions[1], it was determined that mainly there was no unnecessary excess or oversaturation of ions, such as $Fe^{2+}$; $Fe^{3+}$; $Cu^{2+}$; $CO_3^{2-}$; $S^{2-}$ and $SO_4^{2-}$ ones.
- By also looking at pH[5] level with the help of universal indicator it was found to be on average ≈7 - 6 (mainly neutral).
- With the help of electrochemical probe (sensor) results showed that on average oxygen concentration in water samples were 7,5% or 75000ppm, which is quite suitable for environment considering the optimal range is 6-10% [1].
- After reviewing experiment results, it was discovered that all water sample's absorption[3] was 0, which meant that none of the ponds soaked up any harmful chemicals or substances.

Water sample quantitative analysis

| | Emzes pond | Asaru pond | Spārītes pond | Skolas street pond | Dzirnavu pond (first end) | Dzirnavu pond (second end) |
|---|---|---|---|---|---|---|
| pH | 6 | 7 | 6 | 6 | 6 | 7 |
| Oxygen level | 7,6% | 7,8% | 7,7% | 7,3% | 7,7% | 7,4% |
| Ions | No excess ions | No excess ions | No excess ions | No excess ions | No excess ions | No excess ions |
| Spectrum analysis | 0 | 0 | 0 | 0 | 0 | 0 |

## Conclusion

Overall, the investigation about water quality in the city's main ponds, considering the expected outcomes, has turned out successful enough. Starting with research proposal – for years Gulbene's residents, including us, has been questioning the state of city's main ponds since they aren't always in the municipality's focus. We finally decided to put end to this question by conducting the research and getting the necessary answer.

After conducting several methods to each water sample and then analysing the results it was deduced that every pond's water quality is as following: the environment is mainly neutral, there isn't any excess or oversaturation of ions, pH concentration is entirely appropriate, and water absorption is 0, meaning minimal pollution whatsoever.

Given that the results are superb it can be reasoned that the water quality and environment in all the city's main ponds is compatible not only with the city itself, but also with the wildlife as well. However, our research process and situation isn't ideal for few reasons:

- This year the winter season was very rich in snow, and when the spring came by all accumulated snow melted away. This meant that the ponds water chemical composition was cleansed, therefore making sample results seem positive.
- Our school does not have more specific tools and devices to analyse an additional data of water's chemical composition, for instance water's biological pollution, thus limiting this research's range.
- Human error is also likely to have had influenced the results, since nearly every measurement was conducted and confirmed by a person.
- Since this research – it's measurements - was based only on one period the results can't be fully interpreted, therefore it would be logical if examination was conducted again in other seasons, such as summer.

If these doubts are taken in, it means that our research is not completely and thoroughly conducted, leaving some parts uncertain. Despite having few uncertainties, these results could also encourage others to focus more on conserving water reservoirs by regularly checking water quality, removing possible pollution sources from surrounding environment and managing life form balance in body of water, therefore keeping the nature prosperous and preserved[6].

## References


1. EBSCO. Elizabeth Mohn (2023) Qualitative chemical analysis.
2. EPA. Dissolved Oxygen (2021) pp. 1.
3. Ajay Kumar Goswami (2024) Spectrophotometric Determination of Vanadium, Chromium and Manganese pp. 9. – 15.
4. Chaundhry FN', Malik MF (2017) Factors Affecting Water Pollution: A Review pp. 1.-2.
5. Colin J.P. McKean. Brent W. Huggins (1989) pH Determination And Measurement pp. 10.-15.
6. IGI Global (2024) Sensors for Environmental Monitoring, Identification, and Assessment pp. 88. – 90.