Report Card 3. Low dissolved oxygen levels recorded in seawater and some associated physiochemical readings between the 28th to 31st of July 2023 and the 4th to the 10th of August 2023.

Low oxygen levels in seawater, or hypoxia, can significantly affect marine ecosystems, particularly in estuarine environments where sessile organisms occur, or activities such as mariculture are practised. For example, oysters can be sensitive to changes in water quality, and low oxygen levels may adversely affect their growth, survival, and overall health. Monitoring and understanding the interactions between oxygen levels and various environmental factors are desirable for a more holistic and effective oyster cultivation management strategy going forward with multiple projections associated with climate change.

This report examines STREAM sensor (InSitu AquaTRoll 500) readings in Bannow Bay when some atypically low oxygen readings were recorded (28th to 31st of July 2023 and some less significant readings between the 4th to the 10th of August 2023).

The mariculture industry is reliant on the marine environment for favourable biophysical conditions, and for this reason, a changing climate can lead to various impacts. For example, alterations in the frequency and intensity of storms can threaten infrastructure such as salmon cages. The rise in sea levels can alter the shoreline morphology, which can reduce the area that is suitable for certain habitats utilised by the industry. Changes in rainfall patterns can increase the turbidity and nutrient levels in estuaries and coastal waters, which may trigger harmful algal blooms, thereby negatively impacting bivalve farming. Moreover, ocean acidification has the potential to disrupt the early developmental stages of shellfish. Rising seawater temperatures may impact an organism's growth and survival. Also, a changing marine environment may result in an increased virulence of disease, parasites and pathogens.

Towards the end of July 2023, it was noted that the dissolved oxygen levels being recorded in Bannow showed several drops to relatively low levels (as an alarm) and, on one occasion, to less than 30%. This may be due to the drift of the oxygen sensor being used or a build-up of anoxic material around the sensor. Still, as a precaution, it was recorded and reported to BIM and the oyster farmers in the area. In August, there were also several low but less significant oxygen readings. This report provides an overview of the data recorded at Bannow Bay, Wexford, and Wellington Bridge for comparison purposes. Also included in this report are recommended oxygen levels at WFD sites.

The STREAM project is part funded through the ERDF Ireland Wales Programme

STREAM Strategy

As the Earth's climate continues to change and evolve, the health of our oceans and marine ecosystems is under increasing pressure. Monitoring seawater quality parameters such as temperature, salinity (conductivity), pH, dissolved oxygen, chlorophyll, ORP (oxidation-reduction potential), and nutrients such as fDOM (fluorescent dissolved organic matter) is important for a variety of reasons:

1. Early Detection of Changes: Live telemetry broadcasting of seawater quality data allows local authorities, mariculturists, scientists and researchers to detect changes in local seawater conditions in real-time. This early detection is vital for understanding how climate change affects marine ecosystems and identifying potential issues before they become problematic.
2. Climate Change Impact Assessment: By continuously collecting and analysing data on temperature, salinity, and other parameters, stakeholders and researchers can better assess the impact of climate change on oceanic systems. Rising temperatures, altered salinity levels, and changing pH can profoundly affect marine life, including species migrations and shifts in food webs.
3. Ecosystem Health Monitoring: Seawater quality data provides insights into the overall health of marine ecosystems. Dissolved oxygen levels, for instance, are essential for the survival of marine organisms. Insufficient oxygen can lead to "dead zones" where aquatic life might struggle to survive. Regular monitoring helps pinpoint these areas and aids in developing strategies for their mitigation.
4. Nutrient Management: Nutrients like nitrogen and phosphorus are essential for marine productivity. However, excessive nutrient inputs from human activities can lead to harmful algal blooms and oxygen depletion. Continuous monitoring helps in understanding nutrient dynamics and implementing effective management strategies.
5. Data-Driven Policy Decisions: Live and recorded telemetry data permits policymakers and resource managers to make more informed decisions. With accurate and up-to-date information, regulatory measures might be developed to mitigate the impacts of climate change on marine environments and promote sustainable practices.
6. Public Awareness and Education: Broadcasting live seawater quality data can engage the public in understanding the dynamic nature of ocean systems and the urgency of addressing climate change. This awareness can help increase support for conservation efforts and policies protecting marine ecosystems.

Therefore the ongoing collection and broadcasting of seawater quality data, encompassing parameters like temperature, salinity, pH, dissolved oxygen, chlorophyll, ORP, and nutrients (nitrates) such as fDOM, play a pivotal role in understanding and mitigating the effects of climate change on our oceans. The insights gained from this data contribute to scientific research and guide management strategies and policy decisions that are essential for marine ecosystems' long-term health and sustainability.

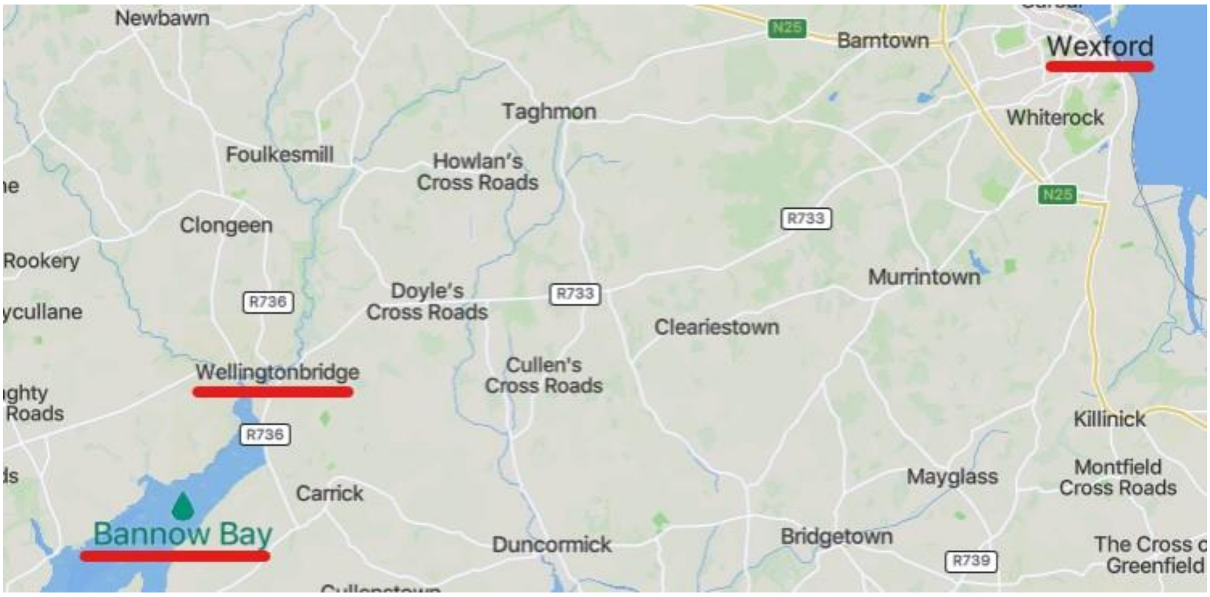
The STREAM project is part funded through the ERDF Ireland Wales Programme

Methodology used in this report

In February 2023, a STREAM Aqua TROLL 500 was deployed in an intertidal area in Bannow Bay. This sonde can hold up to four interchangeable sensors and also has an antifouling wiper (five ports). The data from the Sonde can be accessed through a smartphone interface, which also allows for calibration of the device and the creation of reports. The sensors employed, included temperature, conductivity (salinity), pH/ORP, Dissolved Oxygen and chlorophyll a.

To the AquaTroll 500 a VuLink data logger and global cellular telemetry device was attached by cable to the AquaTroll 500 sonde. The VuLink completes the monitoring instrumentation, telemetry, and software that work together within In-Situ's shared ecosystem to collect, access, and manage data. The Vu Link also provides air temperature and pressure readings. STREAM sensors (Exo2 and Trios Opus) had previously been deployed in Wellington Bridge and Wexford and the data from these sites is compared with those recorded at Bannow bay (Figure 1).

Figure 1. The locations of STREAM sensors of interest for this report (Bannow, Wellington Bridge and Wexford).



STREAM Bannow physiochemical readings 28th to 31st of July 2023

Below are the physicochemical readings recorded by the STREAM sonde from the 28th of July to the 31st of that month. Included are Depth (m), Dissolved Oxygen %, pH, Salinity (PSU) and Temperature (°C) for Wexford, Wellington Bridge and Bannow as means of comparison. The Corock river flows through Wellington Bridge and into Bannow Bay.

Also as means of comparison the relationship between physiochemical readings was also undertaken in August between the three sites, in particular to better assess the relationship between the Wellington Bridge and Bannow monitoring sites.

The tidal cycle (Figure 2) plays a crucial role in shaping the physicochemical properties of coastal and marine environments. These fluctuations influence salinity, temperature, dissolved oxygen, nutrient availability, and chemical composition, all of which profoundly affect the ecology and biology of these dynamic ecosystems. Understanding these tidal influences is essential for conserving and managing coastal and marine habitats. Figure 1 shows the tidal cycle at Wexford, Wellington Bridge and Bannow during the period of interest for this report (28th to 31st of July 2023).

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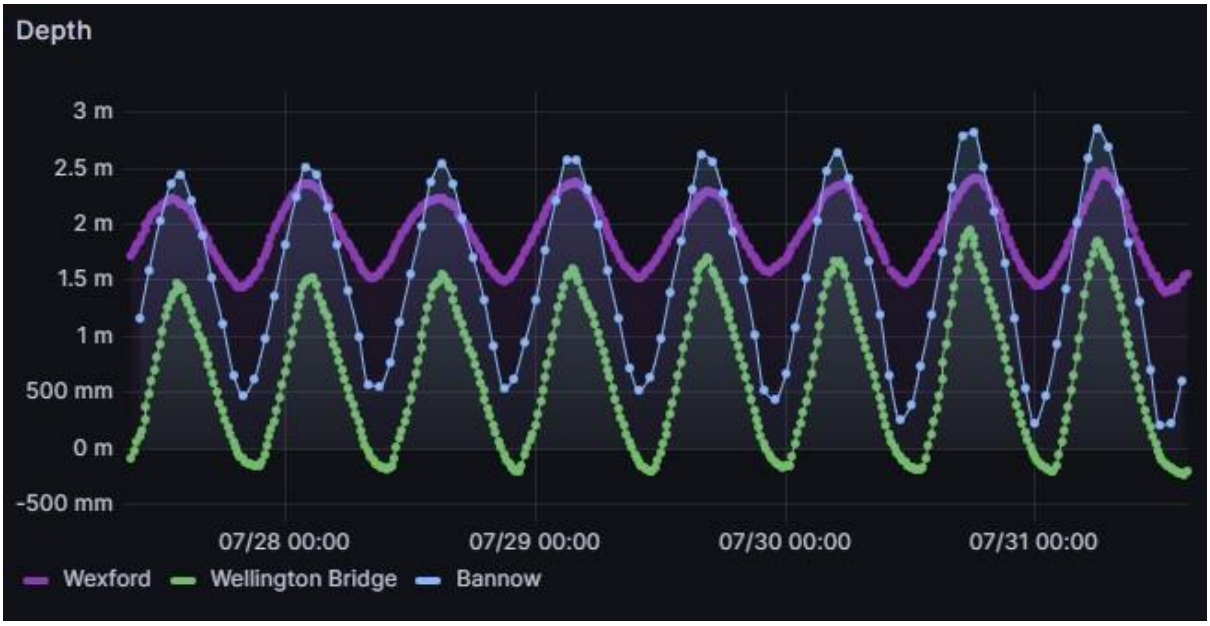
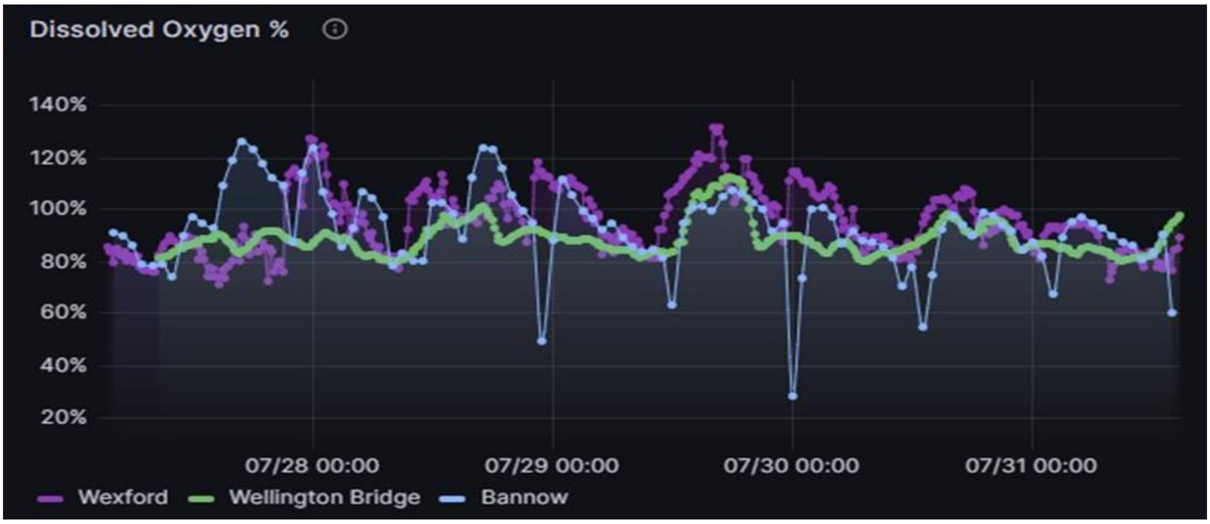
Figure 2. Tidal Cycle - Depth (m) at Wexford, Wellington Bridge and Bannow Bay (28th to 31st July 2023).



Tidal movements play a role in regulating dissolved oxygen concentrations in aquatic environments. As the tide bring in seawater, it may carry a higher dissolved oxygen content. This oxygen-rich water can then replenish coastal areas during high tide, benefiting marine life. During low tide, when water may become stagnant in some areas, dissolved oxygen levels may sometimes decrease, potentially stressing aquatic organisms. But, these types of influences are very seasonal and geographically dependent.

Figure 3 shows dissolved oxygen (%) at Wexford, Wellington Bridge and Bannow Bay. As can be seen at the Bannow Bay site there were six pronounced declines in oxygen level between the 28th and 31st of July 2023.

Figure 3. Dissolved oxygen (%) at Wexford, Wellington Bridge and Bannow (28th to 31st July 2023).



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Tidal variations influence the pH and chemical composition of coastal waters. For example, mixing seawater and freshwater during tidal changes can affect pH levels, affecting the acid-base balance in these ecosystems. Additionally, tides can affect the distribution and concentration of various ions and chemicals, affecting the chemistry of marine habitats. When pH levels are lower (more acidic) in estuarine waters, they could reduce the solubility of oxygen, potentially leading to lower dissolved oxygen levels (Below are some of the key factors that influence pH).

Freshwater Inputs: The pH of estuarine water can be significantly affected by the pH of incoming freshwater from rivers and streams.
Tidal Movements: Mixing seawater and freshwater during tidal changes can alter pH levels.
Biological Activity: Biological processes, such as photosynthesis and respiration by aquatic plants and animals, can influence pH by affecting carbon dioxide levels.
Anthropogenic Activities: Pollution and runoff from human activities can introduce chemicals that alter estuarine pH.
Climate Change: Ocean acidification driven by increased atmospheric carbon dioxide can affect estuarine pH.

Figure 4 shows the pH readings recorded at Wexford, Wellington Bridge, and Bannow Bay. Still, no clear association exists between the recorded pH levels and low oxygen levels in Bannow.

Figure 4. pH readings at Wexford, Wellington Bridge and Bannow Bay (28th to 31st July 2023).

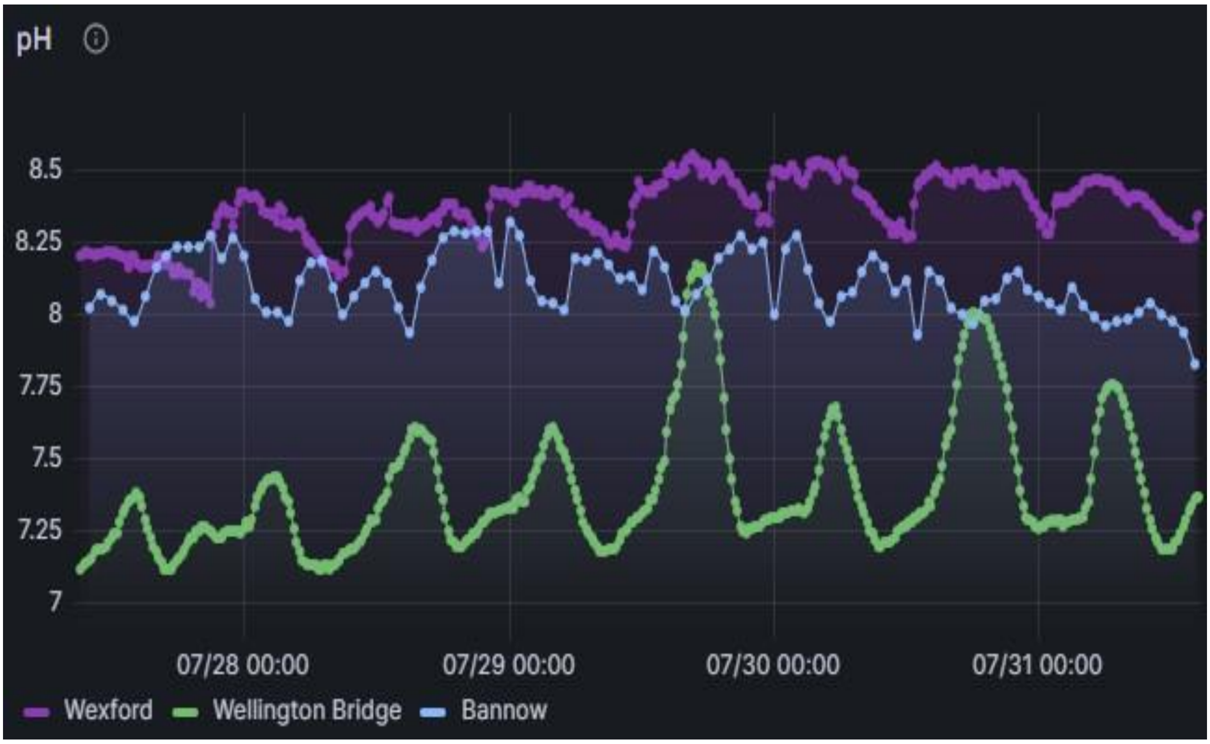

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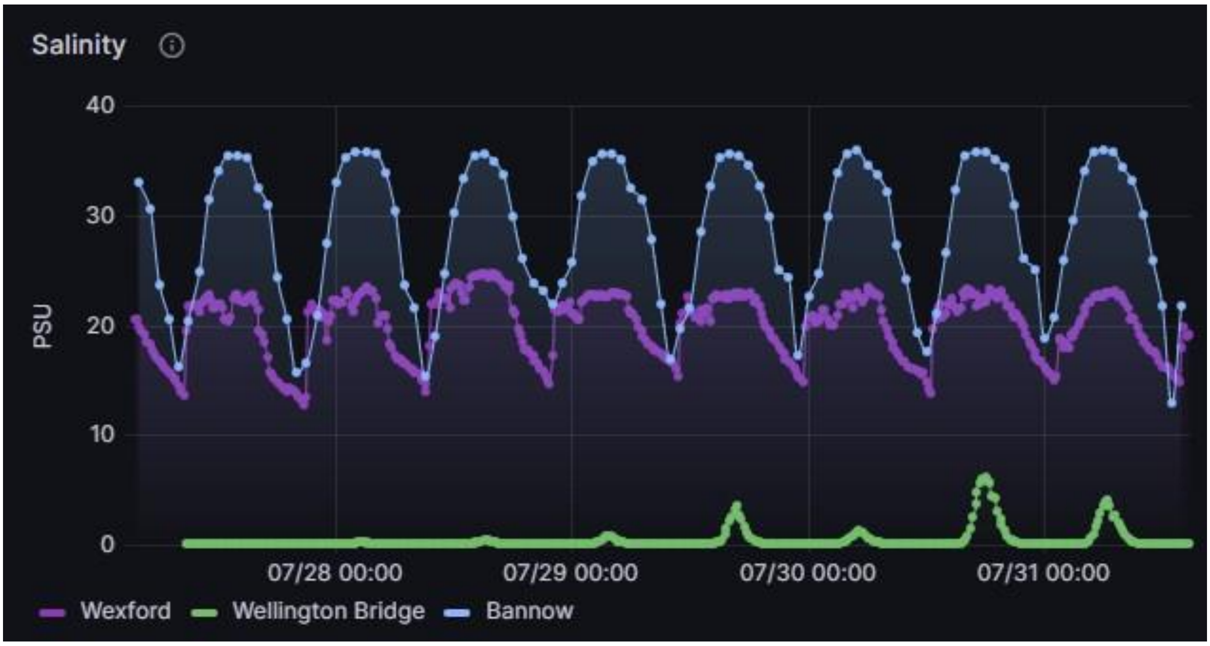
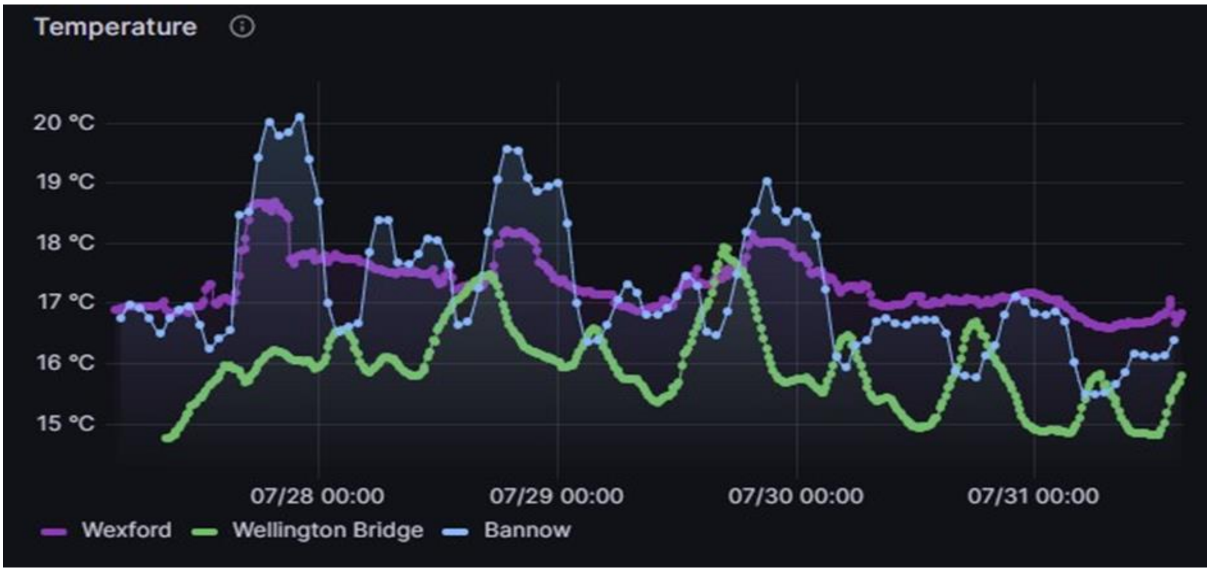
Figure 5 depicts the salinity readings (PSU) recorded at Wexford, Wellington Bridge, and Bannow Bay.

Figure 5. Salinity (PSU) readings at Wexford, Wellington Bridge and Bannow Bay (28th to 31st July 2023).



The tidal cycle and freshwater inputs are crucial in shaping an estuary's temperature dynamics. Freshwater inputs from rivers and streams can also influence temperature by introducing cooler or warmer waters, depending on their source and seasonal variations. These combined factors create a dynamic thermal environment vital to estuarine ecosystems (Figure 6).

Figure 6. Temperature C readings at Wexford, Wellington Bridge and Bannow Bay (28th to 31st July 2023).



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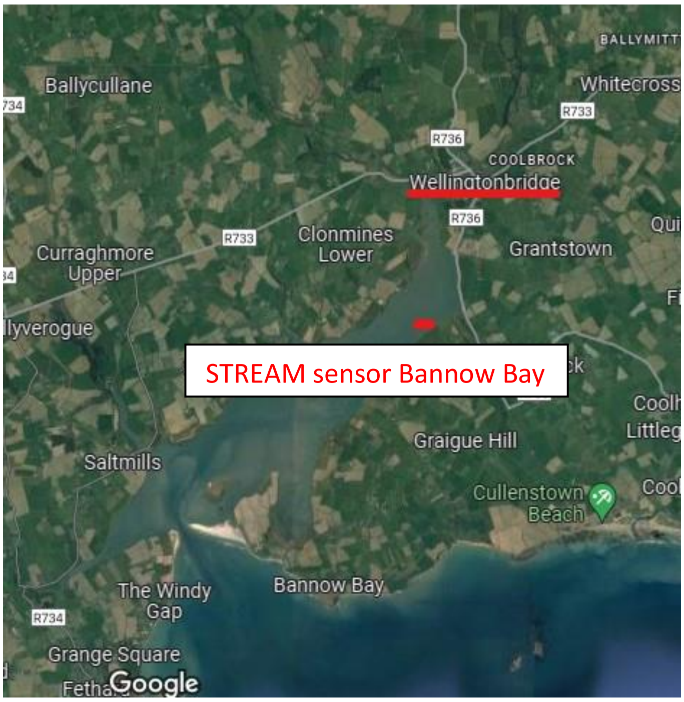
Wellington Bridge and Bannow Report 10th August 2023

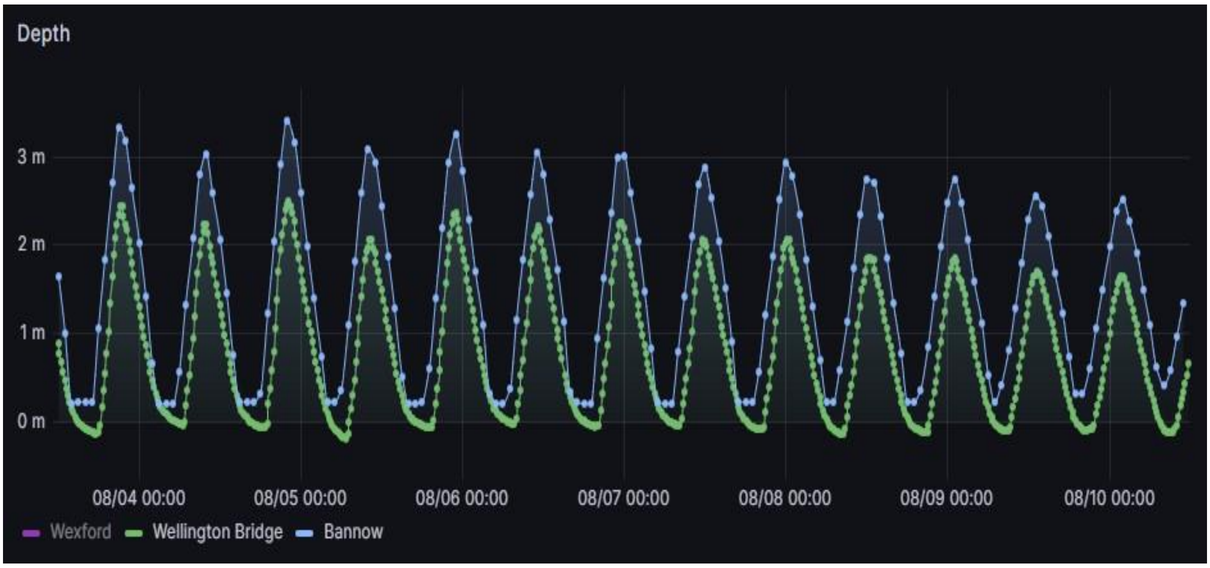
Figure 7. Shows the location of Wellingtonbridge and STREAM sensor in Bannow Bay.



The physiochemical readings at Wellington Bridge and Bannow (Figure 7) were also examined as part of this report card for some less pronounced drops in oxygen levels (%) between the 4th and 10th of August, a 2023nd the following figures show the readings for these two locations.

Figure 8 demonstrates the tidal cycle for the report period between the 4th to 10th August 2023 at Wellington Bridge and Bannow.

Figure 8. Tide Depth (m) between the 4th to 10th August 2023 at Wellington Bridge and Bannow



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As recounted earlier in this report, oxygen levels in saline waters of a tidal estuary are influenced by several factors. Tidal movements play a significant role. Organic matter decomposition, affected by temperature and biological activity, can consume oxygen. Nutrient levels, phytoplankton, pollution, and salinity variations also affect oxygen concentrations, making estuarine oxygen levels dynamic and sensitive to environmental changes. Figure 9 shows the dissolved oxygen (%) levels at Wellington Bridge and Bannow and five abrupt declines in the readings that may be associated with the sensors operation or a localised environmental event.

Figure 9. A comparison of percentage oxygen levels recorded at Wellington Bridge and Bannow – showing five declines in readings at Bannow Bay (4th to 10th August 2023).

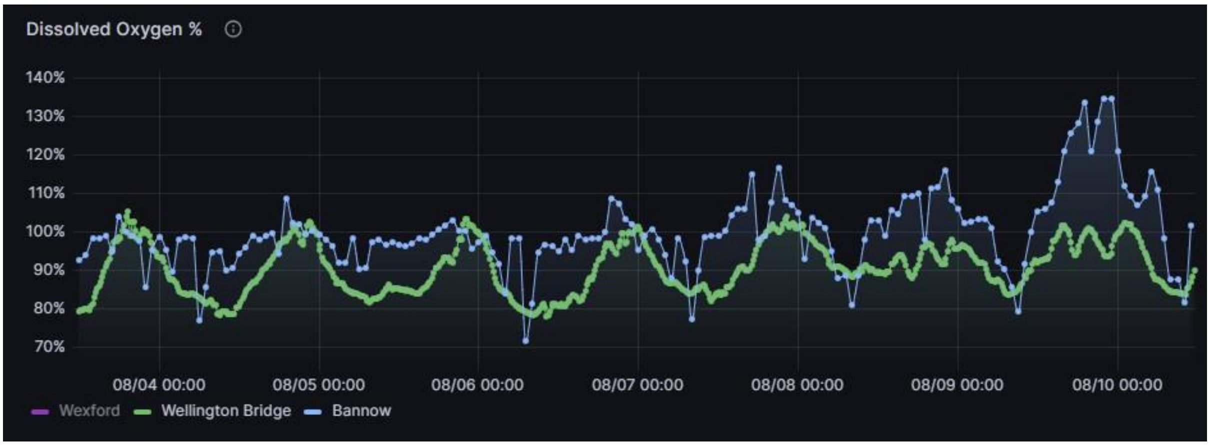

Table 1 sets out the approximate time at which the low oxygen was recorded in Bannow Bay, the dissolved oxygen percentage and the approximate time at which the sensor was recovered by water as the time came back in. From this information, it appears that shortly after low tide the dissolved oxygen levels were also low.

Table 1. Lower dissolved oxygen levels in Bannow recorded at Bannow Bay and the time at which the sensors were being recovered (4th to 10th August 2023):

Date	Time	Lower Oxygen %	Sensor recovered by water at: (after low tide)
4th August 2023	6:00	79%	5:00
6th August 2023	7:00	71.8%	6:00
7th August 2023	8:00	77.4%	7:00
8th August 2023	8:00	80.9%	7:00
9th August 2023	9:00	79.5%	7:00

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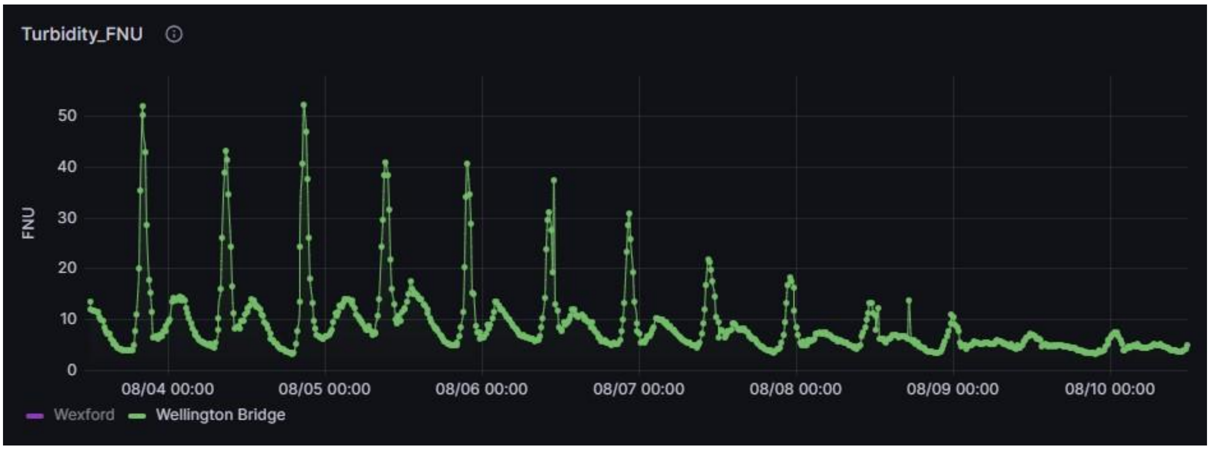
As the Corock river flows through Wellington Bridge and into Bannow Bay it was decided investigate the data in Wellington Bridge for turbidity (Figure 10) to see if any relationship between the two sites could be ascertained.

Figure 10. Turbidity (FNU) at Wellington Bridge (4th to 10th August 2023).



It was noted that the highest turbidity levels in Wellington Bridge (4th to 10th August 2023) appeared to occur approximately one hour before high tide (Figure 11).

Figure 11 the times at which the highest turbidity readings (FNU) occurred at Wellington Bridge and the time of high tide that day.

Date	Time	Highest Turbidity	High Tide Time
3rd August 23	20:10	51.86	21:10
4th August 23	8:30	43.11	10:00
4th August 23	20:40	52.35	22:30
5th August 23	9:00	38.41	10:40
5th August 23	21:40	40.6	23:00
6th August 23	11:00	37.46	11:30
6th August 23	22:10	28.71	23:40

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The importance of Oxygen

Unlike land animals, marine organisms encounter a significantly more formidable task when extracting oxygen from their environment to sustain their metabolism. As depending on its temperature and salinity, seawater can contain 20-40 times less oxygen by volume than air (with saltwater holding slightly less oxygen than freshwater). Moreover, the oxygen diffusion rate through water is approximately 10,000 times slower than in air. Consequently, even minor reductions in dissolved oxygen levels can substantially impact marine animals.

The concentration of dissolved oxygen in ocean water typically ranges from 7 to 8 milligrams per litre (mg/L). When the concentration drops below 4 mg/L, organisms start to react, and mobile species either migrate out of or avoid the area. Water with less than 0.2 mg/L of dissolved oxygen is anoxic and cannot sustain most life forms. Hypoxic water is water that has little detectable dissolved oxygen.

Dissolved oxygen concentration in surface water is essential for chemical reactions and the survival of aquatic organisms. Low dissolved oxygen levels can cause stress or even the death of fish and other organisms. Oxygen concentration is reported in milligrams per litre or as a percentage. Anthropogenic nutrient enrichment and increased water temperatures may lead to reduced oxygen concentrations. In Table 1 below the WFD stipulates that in shellfish waters the standard value for dissolved oxygen should be equal to or greater than 70% as an average value which the site usually is.

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Table 1. Dissolved oxygen %, European Communities (quality of shellfish waters) regulations 2006 S.I. no 268 of 2006

Parameter No.	Parameter	Unit of Measurement	Standard/Value	Reference Method of analysis or inspection	Frequency of sampling
6	Dissolved oxygen	Saturation per cent	(a) Equal to or greater than 70 per cent (average value)	Winkler's method or electrochemical method	Monthly, with a minimum of one sample representative of low oxygen conditions on the day of sampling.
			(b) No individual measurement to indicate a value less than 60 per cent unless it can be established that there are no harmful consequences for the development of shellfish colonies.		However, where major daily variations are suspected, a minimum of two samples in one day must be taken.

Table 2. Dissolved oxygen mg/L (approx... quality of shellfish waters)

Status	Marine 5% percentile
Good	⩾4.0<5.7 mg/L
Moderate	⩾2.4<4.0 mg/L
Poor	⩾1.6<2.4 mg/L
Bad	<1.6 mg/L

Monitoring Oxygen Levels

1. Regular calibration and cleaning of sensors: Implement a systematic management program to measure dissolved oxygen levels and deploy sensors at different geographic locations within the estuary. This will help identify areas prone to low oxygen conditions and track seasonal changes.

2. Integrated Approach: Combine analysis of oxygen monitoring with measurements of temperature, pH, salinity, and chlorophyll levels to gain a comprehensive understanding of the factors influencing oxygen concentrations.

Impacts and Interactions

1. Elevated Temperature: Seasonally warmer temperatures can reduce the solubility of oxygen in water, potentially exacerbating hypoxic conditions. Additionally, high temperatures can increase metabolic rates in oysters and other organisms in an area, leading to higher oxygen demand.

2. pH fluctuations: Extreme pH levels, may impact oxygen solubility and disrupt the balance of chemical reactions that influence oxygen availability.

3. Low/High Salinity: Both low and high salinity levels can contribute to oxygen stress on organisms within a bay. Also low salinity may create stratification, limiting oxygen mixing, while high salinity can impact oxygen solubility.

4. Chlorophyll Levels: Elevated chlorophyll levels, often indicative of algal blooms, can lead to oxygen depletion during their decomposition after their population collapse or at night when the phytoplankton respire. Algal blooms may also shade out underwater vegetation, further reducing oxygen production.

Potential Impacts on Oyster Cultivation

1. Growth: Low oxygen levels can lead to reduced oyster feeding efficiency and metabolic stress.

2. Survival: Prolonged exposure could in an extreme case lead to mass mortality event.

3. Quality and Marketability: Potentially study the impacts of various conditions on the oysters.

Mitigation and Management

1. Site Selection: Choose oyster cultivation sites strategically, and identify optimum location for oyster maintenance. i.e. for discussion only only - consider lowering the density (number of bags per trestle), relocating oyster bags, remove bags from being submerged (when oxygen is removed from the water) and spray seawater onto the bags to reduce the oyster temperature (evaporation) but allow them to respire in saturated air.

Water Quality Regulation

1. Collaborate with regulatory agencies (e.g. County Council, Uisce Eireann, SFPA, BIM, EPA, Marine Institute) to ensure water quality standards are upheld and measures implemented to reduce nutrient pollution.

2. Restoration Efforts: Implement habitat restoration projects to enhance natural oxygen production and reduce the impacts of adverse environmental conditions.

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Summary

In summary, low oxygen levels in seawater in an extreme event could significantly threaten oyster cultivation in estuarine environments. Monitoring oxygen levels and understanding their interactions with temperature, pH, salinity, and chlorophyll levels are essential for effective oyster cultivation management. By implementing appropriate monitoring strategies and mitigation measures, oyster farmers can ensure the health and sustainability of their operations while safeguarding the estuarine ecosystem.

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Appendix 1. Conversion of dissolved oxygen % to mg/L taking into account salinity and temperature.

Fondriest Environmental, Inc. “Dissolved Oxygen.” Fundamentals of Environmental Measurements. 19 Nov. 2013. Web. < https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ >.

O2 mg/L = (Measured % DO)*(DO value from chart at temperature and salinity)

Example if 70% Dissolved oxygen is measured in seawater that is 35 ppt and at a temperature of 15 C then multiply 0.70 * (Table figure) 8.135 = 5.69 mg/ L DO

TEMPERATURE (°C)	SALINITY (g/kg)								
	0	5	10	15	20	25	30	35	40
0	14.621	14.120	13.636	13.167	12.714	12.277	11.854	11.445	11.051
1	14.216	13.733	13.266	12.815	12.378	11.956	11.548	11.154	10.773
2	13.829	13.364	12.914	12.478	12.057	11.650	11.256	10.875	10.507
3	13.460	13.011	12.577	12.156	11.750	11.356	10.976	10.608	10.252
4	13.107	12.674	12.255	11.849	11.456	11.076	10.708	10.352	10.008
5	12.770	12.352	11.947	11.554	11.175	10.807	10.451	10.107	9.774
6	12.447	12.043	11.652	11.272	10.905	10.550	10.206	9.872	9.550
7	12.139	11.748	11.369	11.002	10.647	10.303	9.970	9.647	9.335
8	11.843	11.465	11.098	10.743	10.399	10.066	9.744	9.431	9.128
9	11.559	11.194	10.839	10.495	10.162	9.839	9.526	9.223	8.930
10	11.288	10.933	10.590	10.257	9.934	9.621	9.318	9.024	8.739
11	11.027	10.684	10.351	10.028	9.715	9.412	9.117	8.832	8.556
12	10.777	10.444	10.121	9.808	9.505	9.210	8.925	8.645	8.379
13	10.537	10.214	9.901	9.597	9.302	9.017	8.739	8.470	8.210
14	10.306	9.993	9.689	9.394	9.108	8.830	8.561	8.300	8.046
15	10.084	9.780	9.485	9.198	8.921	8.651	8.389	8.135	7.888
16	9.870	9.575	9.289	9.010	8.740	8.478	8.223	7.976	7.737
17	9.665	9.378	9.099	8.829	8.566	8.311	8.064	7.823	7.390
18	9.467	9.188	8.917	8.654	8.399	8.151	7.910	7.676	7.449
19	9.276	9.005	8.742	8.486	8.237	7.995	7.761	7.533	7.312
20	9.092	8.828	8.572	8.323	8.081	7.846	7.617	7.395	7.180
21	8.914	8.658	8.408	8.166	7.930	7.701	7.479	7.262	7.052
22	8.743	8.493	8.250	8.014	7.785	7.785	7.561	7.344	6.929
23	8.578	8.334	8.098	7.867	7.644	7.426	7.214	7.009	6.809
24	8.418	8.181	7.950	7.725	7.507	7.295	7.089	6.888	6.693
25	8.263	8.032	7.807	7.588	7.375	7.168	6.967	6.771	6.581
26	8.113	7.888	7.668	7.455	7.247	7.045	6.849	6.658	6.472
27	7.968	7.748	7.534	7.326	7.123	6.926	6.734	6.548	6.366
28	7.827	7.613	7.404	7.201	7.003	6.810	6.623	6.441	6.263
29	7.691	7.482	7.278	7.079	6.886	6.698	6.515	6.337	6.164
30	7.558	7.354	7.155	6.961	6.772	6.589	6.410	6.236	6.066
31	7.430	7.230	7.036	6.846	6.662	6.483	6.308	6.137	5.972
32	7.305	7.110	6.920	6.735	6.555	6.379	6.208	6.042	5.880
33	7.183	6.993	6.807	6.626	6.450	6.278	6.111	5.948	5.790
34	7.065	6.879	6.697	6.520	6.348	6.180	6.017	5.857	5.702
35	6.949	6.767	6.590	6.417	6.248	6.084	5.924	5.768	5.617
36	6.837	6.659	6.485	6.316	6.151	5.991	5.834	5.681	5.533
37	6.727	6.553	6.383	6.218	6.056	5.899	5.746	5.597	5.451
38	6.619	6.449	6.283	6.121	5.963	5.810	5.660	5.513	5.371
39	6.514	6.348	6.186	6.027	5.783	5.722	5.575	5.432	5.292
40	6.412	6.249	6.090	5.935	5.783	5.636	5.492	5.352	5.215

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STREAM

Sensor Technologies for Remote Environmental Aquatic Monitoring

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Report

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