Institution:
Bangor University, 1007857

Unit of Assessment:
UoA 7 – Earth Systems and Environmental Sciences

Title of case study:
Adoption of viral environmental surveillance tools to protect public health during the COVID-19 pandemic.

Period when the underpinning research was undertaken:
2013 – 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
1. Professor Davey Jones	1. Professor of Soil and Environmental Science	1. 1996 – present
2. Professor James McDonald	2. Professor in Biology (Biotechnology)	2. 2010 – present
3. Dr Kata Farkas	3. Shellfish Centre Research Officer	3. 2015 – present
4. Dr Shelagh Malham	4. Reader in Marine Biology	4. 2001 – present
5. Professor Lewis Le Vay	5. Professor and Director of CAMS	5. 1997 – present
6. Professor Colin Jago	6. Professor in Ocean Sciences	6. 1989 – 2018
7. Dr Peter Robins	7. Snr Lecturer in Physical Oceanography	7. 2004 – present
8. Professor Julia Jones	8. Professor in Conservation Science	8. 2005 – present

Period when the claimed impact occurred:
2013 – 31st December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

As evidenced by the SARS-CoV-2 pandemic, pathogenic viruses represent a major global threat to human health and wellbeing. Over the last decade, Bangor research has developed a range of analytical tools, technologies and models for the effective surveillance of harmful viruses in the wider environment, leading to risk-based industry standards. Working in partnership with UK and devolved governments, our wastewater-based surveillance tools have been adopted, piloted and rolled out at the national scale: (a) for whole-community monitoring of COVID-19 incidence, (b) to provide an early warning system to protect critical national infrastructure from SARS-CoV-2 outbreaks, (c) as a decision support tool to show which city areas should be targeted for mass testing, and (d) to evaluate the success of COVID-19 mitigation measures.

2. Underpinning research

The COVID-19 pandemic will shape this generation. It has highlighted how viruses can severely disrupt society, community wellbeing and at the time of writing is responsible for the loss of 121,000 lives in the UK. Over the last decade, research at Bangor has developed a range of quantitative analytical and modelling tools to enable the tracking of human pathogenic viruses for public health surveillance and risk assessment purposes. This is exemplified by Bangor's work on the identification of novel betacoronaviruses in animal reservoirs **[3.1]**, the metaviromic characterisation of viral communities in the environment **[3.2, 3.a]**, and quantitative determination of viruses in a range of environmental matrices, including human sewage, river water, sediments, estuaries, coastal waters and food **[3.3, 3.4, 3.5, 3.a-3.l]**. Meeting this research need has been strongly driven and financially supported by industry (e.g. water companies, food producers, shellfisheries), local authorities and government agencies (e.g. Food Standards Agency, Department for Environment, Food & Rural Affairs, Public Health Wales, Department of Health and Social Care) as well as by a wide range of large UKRI and EU grants **[3.a-3.l]**.

The UK produces 10,000,000,000 litres of sewage each day. This wastewater represents one of the main routes by which harmful viruses can enter the environment. Bangor University work has revealed that many harmful viruses of national importance (e.g. Norovirus, Rotavirus, Hepatitis A/E) are present in very high abundance in both untreated and treated sewage (10^6-10^9 viral particles per litre), particularly during localized disease outbreaks **[3.3, 3.5, 3.d, 3.e, 3.j]**. Human contact with sewage therefore poses a major risk to public health. Bangor's research provided early evidence that viral monitoring of wastewater may provide a cheap, unbiased and effective tool to monitor levels of infection in a whole community. This approach proved particularly suitable for viral diseases which frequently don't result in hospitalization (i.e. not reported), but which Public Health England estimate cost the UK economy GBP200,000,000 per year in terms of loss of working days and health care (e.g. Norovirus) **[3.3]**.

Bangor University's research has also shown that, in contrast to faecal bacteria, many pathogenic viruses are not effectively removed by conventional sewage treatment, inevitably leading to their release and accumulation in important environmental reservoirs where human contact can occur (e.g. sediments, bathing waters, beaches, shellfish) **[3.2, 3.5, 3.6, 3.a, 3.e]**. Working directly with water companies, the research showed that Norovirus release in both untreated and treated sewage can lead to a rapid accumulation of Norovirus in shellfish, and that the virus can remain infectious even after light cooking **[3.5, 3.a, 3.b, 3.c]**. This led to work with EU agencies to alter legislation designed to protect bathing and shellfish waters, so that it also captured the risk posed by enteric viruses. Support for this came from an industry-funded critical review of the risk of Norovirus infection from the consumption of shellfish using epidemiological data **[3.f]**: our analysis revealed that 16% (11,800 cases/year) of food-borne Norovirus outbreaks were attributed to the consumption of oysters between 1992 and 2014. Critical to the introduction of viral standards, however, are the validation of methods that enable accurate quantification of infectious viral particles in environmental matrices. A range of methods to distinguish between infective and non-infective (damaged) Norovirus particles were therefore developed **[3.3]** and in collaboration with the EU, water companies and industry bodies (e.g. Shellfish Association of Great Britain, Seafish, Food Standards Agency) to ensure that proposed changes to the legislation were robust **[3.e, 3.f]**.

Most recently, partnering with the Food Standards Agency (FSA), a hydrodynamically-driven risk modelling tool was developed which takes key information (including sewage discharge, river flow, weather and tidal patterns) to predict, in real-time, the likelihood of viral contamination in the coastal zone **[3.g]**. This *active management* tool is now under testing by the FSA as a mechanism to reduce the risk of shellfish contamination, reduce food-borne outbreaks and subsequent community transmission, and protect the livelihoods of UK shellfisheries valued at GBP20,000,000 per annum.

At the start of the COVID-19 pandemic Bangor researchers, led by Professor D. Jones, identified that faecal shedding of SARS-CoV-2 into wastewater could be used to provide an unbiased estimate of the prevalence of COVID-19 within an entire community **[3.6]**. Building on the novel methodologies developed for quantifying and sequencing (by metaviromics) human pathogenic viruses in water and shellfish **[3.2, 3.3]**, viral surveillance approaches to track SARS-CoV-2 in major UK cities (e.g. Manchester, Liverpool, Cardiff) was rapidly adapted and deployed. In the first COVID-19 wave Bangor research showed that viral levels in sewage accurately reflected cases in the wider community, validating the approach. In addition, the Bangor team developed novel human faecal markers (e.g. CrAssphage) to allow for normalisation for external factors such as wastewater flow and dilution **[3.4]**. Further, through quantitative risk assessment and infectivity screening together with Welsh Water and United Utilities we showed that the risk of contracting SARS-CoV-2 through environmental routes involving wastewater and biosolids contamination was extremely low **[3.l]**. The Bangor team also worked with the NERC Biomolecular Analysis Facility to develop new sequencing methods for SARS-CoV-2 in wastewater allowing the Department of Health and Social Care (DHSC) to identify and quantify the abundance of SARS-CoV-2 variants circulating in the population. After the first COVID-19 wave Bangor developed enhanced high-throughput methods for viral extraction from wastewater allowing rapid scaling up of the technology. This led to the establishment of the national wastewater-based surveillance programme run by the DHSC. Our COVID-19 work was supported by 3 UKRI grants and 3 grants from government agencies (DHSC, Defra and Welsh Government) totalling GPB2,800,000 **[3.i, 3.j]**. Bangor's research provided key evidence to SAGE and Welsh Government's Technical Advisory Group of COVID-19.

3. References to the research

Research Outputs

3.1 Razanajatovo, N. H., **Jones, J. P. G.** et al. (2015) Detection of new genetic variants of Betacoronaviruses in endemic frugivorous Bats of Madagascar. *Virology Journal,* **12**, 42. DOI (Peer-reviewed journal article).
3.2 Adriaenssens, E. M., **Farkas, K., Jones, D. L., McDonald, J. E.** et al. (2018) Viromic analysis of wastewater input to a river catchment reveals a diverse assemblage of RNA viruses. *mSystems,* **3**(3), e00025-18. DOI (Peer-reviewed journal article).
3.3 **Malham S.K., Farkas, K., McDonald, J. E., Jones, D. L.** et al. (2018) Seasonal and spatial dynamics of enteric viruses in wastewater and in riverine and estuarine receiving waters. *Science of the Total Environment,* **634,** 1174-1183. DOI (Peer-reviewed journal article).
3.4 **Farkas, K., McDonald, J. E., Malham, S. K.,** and **Jones, D. L.** et al. (2020) Viral indicators for tracking domestic wastewater contamination in the aquatic environment. *Water Research,* **181,** 115926. DOI (Peer-reviewed journal article).
3.5 **Malham, S.K., McDonald, J.E.,** and **Jones, D.L.** et al. (2016) The Use of *Mytilus edulis* bio-sentinels to investigate spatial patterns of Norovirus and faecal indicator organisms contamination around coastal sewage discharges. *Water Research,* **105**, 241-250. DOI (Peer-reviewed journal article).
3.6 **Jones, D.L.**, Baluja, M.Q., Graham, D.W. et al. (2020) Shedding of SARS-CoV-2 in feces and urine and its potential role in person-to-person transmission and the environment-based spread of COVID-19. *Science of the Total Environment,* **749,** 141364. DOI (Peer-reviewed journal article).

Grants

3.a **Jones, D.L.** (2014-2019) VIRAQUA: New approaches for the quantitative detection of human pathogenic viruses within the freshwater-marine continuum. *NERC EMHH Programme*: NE/M010996/1. GBP1,182,476 Bangor lead partner (GBP524,664).
3.b **Jago, C.** (2012-2015) The multi-scale response of water quality, biodiversity and C sequestration to coupled macronutrient cycling from source to sea. *NERC Macronutrients Programme:* NE/J011908/1. GBP830,320.
3.c **Jones, D.L.** (2020) National COVID-19 Wastewater Epidemiology Surveillance Programme. *UKRI COVID-19 Response Programme:* NE/V010441/1, GBP90,952.
3.d **Malham, S.K.** (2017) Review of current evidence to inform selection of environmental predictors for Active Management Systems in classified shellfish harvesting areas. *Food Standards Agency*: FSA Project FS103001. GBP27,965.
3.e **Malham, S.K.** (2012-2014) Bacterial and viral dynamics in wastewater, estuarine and coastal water. *Welsh Water*: C000728 DCWW0702011. GBP228,332.
3.f **Malham, S.K.** (2012-2016) Shellpath: Human pathogens (bacteria and viruses) in shellfish. *European Fisheries Fund, Bangor Mussel Producers, Welsh Water*: 910007. GBP552,577.
3.g **Malham, S.K.** (2018-2021) DASSHH. Developing an Assurance Scheme for Shellfish and Human Health. Seafish, *Food Standards Agency, EA:* C003750, C004051. GBP429,546.
3.h **Jones, D.L.** (2020) Use of wastewater analysis to evaluate the incidence of coronavirus (SARS-CoV-2) in the UK population. *NERC Urgency programme:* NE/V004883/1. GBP197,108.
3.i **Jones, D.L.** (2020) Wastewater-based community-level surveillance of COVID-19 in Wales: Phase I. *Welsh Government:* C064/2020/2021. GBP743,265.
3.j **Jones, D.L.** (2020) UK-wide wastewater-based epidemiology as an early warning system. *Department for Environment, Food and Rural Affairs:* C29950. GBP1,407,483.
3.k **Malham, S.K.** (2020) Co-surveillance of wastewater and environmental water samples for SARS-CoV-2 and pathogenic viruses in South Africa and Nigeria: Incidence and risks. *GCRF-UKRI COVID-19 Response Programme*: EP/V044613/1, GBP324,336.
3.l **Farkas, K.** (2020) Environmental stability of SARS-CoV-2: Establishing health risks. Welsh Government – *Ser Cymru fund:* Project 92. GBP87,236.

4. Details of the impact

a) Industry standards for shellfish in relation to Norovirus

Bangor's research into microbial pathogen transport in catchments and estuaries has stimulated initiation, and informed direction of, regulatory development work undertaken by regulators (Food Standards Agency [FSA], Environment Agency [EA]) and industry (Seafish, Shellfish Association of Great Britain [SAGB]), on potential for risk-based assurance schemes for shellfish, linking environmental risk predictors (e.g. rainfall) to temporal controls of shellfish harvesting.

Accumulation of human enteric pathogens in filter-feeding shellfish is a potential human health risk that is regulated through monitoring of *E. coli* as an indicator of faecal contamination. This is a significant regulatory burden for industry, with periods of poor water quality leading to restrictions on harvesting or closure of production areas. In 2016, Professor Le Vay chaired a large stakeholder meeting (industry, FSA, EA, Public Health England, Centre for Environment, Fisheries and Aquaculture Science) investigating industry concerns about the regulatory system, following an unprecedented and unexplained high *E. coli* event and closure of shellfish production across SW England. Bangor's fundamental research into the processes governing the transport and fate of viruses and bacteria in coastal waters and shellfish receptors **[3.d-3.f]** was then used by the FSA to devise a policy roadmap and new active management systems for minimising shellfish contamination and public health risk. The Director of Operations at Seafish reported *"without doubt the underpinning research and support provided by Bangor University has been... instrumental in driving change and improvements across the shellfish regulatory and production landscape"* **[5.1]**.

Professor Le Vay provided science advice to the UK Shellfish Stakeholders Working Group (SSWG), a UK-wide body formed to address industry concerns about impacts of frequent closures and public-health downgrades of shellfish production areas. This led to Bangor being commissioned to undertake a full-scale proof of concept of adaptive management of shellfish waters (Developing an Assurance Scheme for Shellfish and Human Health – DASSHH **[3.g]**) and advising Seafish (Le Vay, Seafish Expert Panel) and FSA, in review of potential for changes to regulation of shellfish waters. Based on this work, the development of a risk-based approach to the classification of shellfish production waters via DASSHH was identified as a critical action in the English Aquaculture Strategy 2020 (Le Vay is member of Seafood 2040, Aquaculture Leaders Group) **[5.1, 5.2]**.

Half of EU aquaculture production comes from live bivalve shellfish, with a value of over €1200,000,000 (01-2016), supporting over 8000 companies and over 60,000 jobs. Bangor research focused on detecting and quantifying pathogenic viruses in various environmental and animal matrices including wastewater and shellfish. It also highlighted the inability of the approved Norovirus testing method to discriminate between active and inactive virus leading to inaccurate quantification of Norovirus in environmental samples. This work informed effective industry rebuttal of amendments to Regulation (EC) 854/2004 to include statutory limits for Norovirus in shellfish harvested for human consumption (tabled in 2015). This helped secure thousands of jobs and live shellfish to continue to be sold safely to the market by avoiding a projected 50% reduction in sales during winter months over 5 years **[5.3]**.

b) National scale surveillance of SARS-CoV-2: informing government and agency planning to protect public health

Bangor's research directly led to the creation and implementation of the national wastewater surveillance programme for tracing COVID-19 in the UK **[5.4, 5.5, 5.6]**. This programme is run by UK Government via the Joint Biosecurity Centre, Department of Health and Social Care and Department for Environment, Food and Rural Affairs. UK Government has invested over GBP40,000,000 into the programme. It directly supports decision making (e.g. success of non-pharmaceutical interventions; NPIs) and the targeting of resources in the *Test and Trace* programme (e.g. where to deploy surge testing). Bangor provided the proof-of-concept and validated viral analysis methods which were subsequently adopted by the national programme **[5.4]**. Defra's Project Manager reported that '*Bangor University's work has significantly impacted our work as part of the national response to COVID-19',* adding that the '*Pioneering research of Bangor University early in the pandemic formed the basis of the establishment of the English national COVID-19 Wastewater Monitoring Programme'* and that the Programme's success has depended on the *'early engagement with the* [Defra] *Programme team to understand and embed policy response needs into Bangor's research service at the outset, coupled with clear communication of progress and codesign of solutions to complex or sensitive issues surrounding handling of the pandemic response'* **[5.4]**.

In the period Aug-Dec 2020, the national programme has provided near real-time information on levels of SARS-CoV-2 circulating in all the major towns and cities in the UK (4 samples/week at 44 core sites) **[5.4]**. This is used to evaluate the success of NPIs and also to track the spread of newly emerged variants of concern in the UK (e.g. Lineage B.1.1.7., Kent variant). Viral analysis was undertaken jointly by the Environment Agency and Bangor University laboratories. The Director General for the Joint Biosecurity Centre, UK reported that Bangor's Wastewater programme enabled them *"to respond to sometimes rapidly emerging situations as part of our national Test & Trace Efforts"* confirming that the Bangor team made *"a very critical difference at this time of national crisis"* **[5.6]**.

In addition, wastewater testing in the suburbs of 20 UK cities (in-sewer monitoring) has been used to directly inform decision making on a local scale. Together with United Utilities and the Department of Health and Social Care, Bangor undertook the pilot programme in Liverpool where data was collected from 8 suburbs and the information used to geographically target surge testing and introduce non-pharmaceutical interventions. Following the pilot, it was subsequently rolled out to all major UK cities **[5.4]**.

Bangor is the central analysis laboratory for the Department of Health and Social Care's critical infrastructure COVID-19 prevention programme which aims to protect national supply chains. This programme collects wastewater from 25 key industrial facilities (e.g. meat processing plants, distribution depots) daily and reports within 24 hours on levels of COVID-19 incidence within the workforce. This has successfully identified COVID-19 outbreaks within the workforce, followed by surge testing to identify infected individuals and the introduction of effective control measures.

In addition to SARS-CoV-2 the Welsh Government and Public Health Wales have used the Bangor laboratories to monitor other infectious diseases of public health concern (e.g. influenza A/B, Respiratory syncytial virus, Enterovirus D68) to inform planning **[5.5]**. Professor D. Jones chairs the Welsh Government COVID technical advice group and sits on the UK Parliament SAGE sub-committee, Transmission in the Wider Environment which has produced many guidance documents to UK and Welsh Government on COVID-19 related environment issues and its mitigation, including those associated with wastewater. The Chief Scientific Advisor for Health in Wales reported that Bangor's research *"has had a major impact on Welsh Government's response to Covid-19"*, and added that *"the epidemiological analysis enabled by this work has provided vital insights to Welsh Government…..Ministers to inform the response to Covid-19"* **[5.5]**.

5. Sources to corroborate the impact

5.1 **Testimonial from the Director of Operations at Seafish** (participant in the impact process) confirming the central role of **Le Vay, Malham** and Bangor's research in determining new regulatory approaches to active management and shellfish hygiene.
5.2 **The English Aquaculture Strategy, SEAFOOD 2040** which identifies the development of a risk-based approach to the classification of shellfish production waters as a critical action that is already underway as a result of the Bangor-led DASSHH project.
https://www.seafish.org/document/?id=5817e990-b59f-4c60-9d99-11d1ea19b24c
5.3 **Testimonial from the CEO of the Shellfish Association of Great Britain** (participant in the impact process) highlighting Bangor's work in respect to microbial pollution associated with shellfish, including Bangor's central role in the arguments placed before the European Commission (DG Sanco).
5.4 **Testimonial from the Project Manager (Joint Head of Science and Research, Environmental Monitoring for Health Protection, Defra)** (participant in the impact process) corroborating Bangor's key role in providing the methods and rationale that led to the establishment of the English COVID-19 wastewater surveillance programme.
5.5 **Testimonial from the Chief Scientific Advisor for Health in Wales / Welsh Government** (participant in the impact process) corroborating Bangor's fundamental role in initiating the Welsh COVID-19 wastewater surveillance programme and the provision of information which has guided national policy during the COVID-19 pandemic.
5.6 **Testimonial from the Director General, Joint Biosecurity Centre** (participant in the impact process) corroborating Bangor's key role in the COVID-19 wastewater surveillance programme.