

Institution: University of Cambridge		
Unit of Assessment: UoA5		
Title of case study: Biobullets for the control of commercially important pests in the water supply industry		
Period when the underpinning research was undertaken: 2000 to present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr David Aldridge	Role(s) (e.g. job title): Affiliated Lecturer Senior Lecturer	Period(s) employed by submitting HEI: 1997 – 2004 2004 - present
Period when the claimed impact occurred: 2014 to present		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact (indicative maximum 100 words)		
<p>Invasive non-native mussels and clams are some of the world's most economically and ecologically important pests, costing the UK water supply industry GBP8M each year and driving dramatic ecosystem shifts and declines in native biodiversity. Existing control approaches, such as the use of chlorine, cause significant deleterious environmental effects themselves. Researchers at the University of Cambridge have developed a 'BioBullet' against these mussels and clams, which encapsulates toxins in a harmless edible coat, enabling efficient, targeted product delivery and dramatically reducing environmental pollution. The BioBullet is now in widespread use by seven UK water companies and at one waterworks and has been identified as 69% cheaper (saving GBP188,000 per year) than the alternative, more hazardous control methods. The commercial company delivering this technology has generated [text removed for publication].</p>		
2. Underpinning research (indicative maximum 500 words)		
<p>Invasive species are one of the top five threats to the natural environment, costing the UK economy GBP1.8 billion per year (House of Commons Environmental Audit Select Committee, 2019). Within the UK, some of the largest threats include the zebra mussel, <i>Dreissena polymorpha</i>, quagga mussel, <i>Dreissena rostriformis bugensis</i>, and the gulf wedge clam, <i>Rangia cuneata</i>. Unlike native freshwater mussels, many invasive mussels attach to hard surfaces leading to biofouling: the accumulation of mussels in water pipes cause major problems for water companies including blocking raw water supply mains and raw water monitoring lines, affecting the quality of supply to customers. The UK water industry spends approximately GBP8M annually to control invasive species (Water UK, <i>Water companies playing leading role in the battle against invasive species</i>, 25 Oct 2019).</p> <p>In 2000, Dr David Aldridge and Prof. Geoff Moggridge of the University of Cambridge founded the company BioBullets Ltd, based on the idea that a control agent could be delivered to zebra mussels in an edible coating, overcoming the animal's valve closure response to toxins and allowing the use of small doses of agent in an environmentally friendly way. In 2003, Dr Aldridge co-authored a European umbrella patent for the encapsulation of any material for delivery to filter feeders (such as mussels) [R1]. Bringing the patent into the company, the founders were able to show that mussels filter and concentrate the coated control agents ('BioBullets') without detecting that they have consumed a toxin, and that any uneaten product dissolved to harmless concentrations within hours, preventing any impact on recipient waters. In a laboratory setting, BioBullets were found to have no mortality on native mussels at the dose levels used to control</p>		

invasive mussels [R2]. Patent protection for the US and Canada was granted in 2008 and 2013, respectively [R1]. Dr Aldridge, as part of the Aquatic Ecology Group (AEG) at the University of Cambridge, has continued to investigate the biology, spread and management of invasive mussels [R3].

Water pipe maintenance has traditionally been by pre-chlorination, however this is toxic to humans and other animals. Chlorine causes mussels to close their valves for up to three weeks, requiring continuous pumping into waterways, and is expensive and hazardous to store. There has, therefore, been continued tightening of regulatory controls on the discharge of chlorine into the environment (e.g. the European Water Framework Directive 2000/60/EC). This, together with recent EU Regulation on Invasive Species (1143/2014) that requires stakeholders to take direct measures to contain invasive species on their landholding, presents a need for alternative solutions, which BioBullets offer.

The AEG contributed to a 2014 risk assessment funded by the UK Government Department for Environment, Food and Rural Affairs (DEFRA) to identify the highest risk future invaders [R4] and subsequently detected the quagga mussel in the UK for the first time [R5]. In 2018, they demonstrated that the newly established non-native wedge clam, *Rangia cuneata*, posed a significant threat to biodiversity and water provision in Lincolnshire [R6]. In 2018 BioBullets created two revised and improved formulations that enable use in longer pipelines and have elevated toxicity with smaller particles. In 2019 the team demonstrated that these new formulations were effective in controlling gulf wedge clams [R7].

This innovative approach to tackling invasive species has led to a new approach for UK water companies to overcome a significant problem.

3. References to the research (indicative maximum of six references)

R1. Aldridge, DC, Moggridge, GD. European patent EP1251741B1 (24 September 2003), US patent US7378104B2 (27 May 2008), Canadian patent 2396938 (21 March 2013)

R2. Aldridge, DC, Elliott, P, Moggridge, GD. Microencapsulated BioBullets for the control of biofouling zebra mussels. *Environmental Science and Technology* 2006. **40**: 975-979. DOI: 10.1021/es050614+

R3. Aldridge, DC, Elliott, P. & Moggridge, GD. The recent and rapid spread of the zebra mussel (*Dreissena polymorpha*) in Great Britain. *Biological Conservation*. 2004. 119: 253- 261. DOI: 10.1016/j.biocon.2003.11.008

R4. Roy, HE, Peyton, J, **Aldridge, DC** et al. Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Global Change Biology*. 2014. doi: 10.1111/gcb.12603

R5. Aldridge, DC, Ho, S, Froufe E. The Ponto-Caspian quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897), invades Great Britain. *Aquatic Invasions*. 2014. 9, 529-535 doi:10.3391/ai.2014.9.4.11

R6. Kemp JS, Tang F, **Aldridge DC**. Quantifying invader impact: applying functional response metrics to a rapidly spreading non-native species. *Freshwater Biology*. 2018. 63, 1514-1522. DOI: 10.1111/fwb.13180

R7. Tang F, **Aldridge DC**. Microencapsulated biocides for the targeted control of invasive species. *Scientific Reports*. 2019. 9:18787 doi.org/10.1038/s41598-019-55392-4

All research outputs have been published in peer-review journals.

Competitive funding received

2001 – 2004 Silver bullets for zebra mussels (GR/R27723/01) - EPSRC (Anglian Water Services as Project Partner), GBP238,100

2003 Department for Trade and Industry SMART Award in collaboration with Thames Water Utilities, Ltd. GBP10,000

Mar 2000 BioScience Business Plan Competition (sponsored by BBSRC, MRC, GlaxoWellcome and the Gatsby Foundation) – GBP25,000

2009-2012 GBP1,120,000 Technology Strategy Board (now InnovateUK) and UK water industry - BioBullets for the control of zebra mussels

4. Details of the impact (indicative maximum 750 words)

The accumulation of mussels and clams in waterways has become a key issue for water companies in the UK; the blockage that accumulation of zebra mussels can cause in waterways is shown in Figure 1, an image of a raw water pipe, half-filled with the animals. The adoption of BioBullets by UK water companies has changed how this industry approaches the control of existing zebra and quagga mussel infestations, leading to a reduction in the use of chlorine in water supplies and so reducing a major human and animal aquatic toxin. Further, BioBullets are being used as the first approach to addressing new challenges as the mussels spread and invade previously unaffected systems. .



Figure 1. Blockage of a raw water pipe in southern England showing an accumulation of zebra mussels that have half-blocked the pipe.

Guidance and approvals

In 2018, based on underpinning University of Cambridge research, BioBullets created two revised formulations that showed substantial improvements over previous products:

- i. the new products have a longer dissolution time (3 hours compared with 1-2 hours), enabling use in longer pipelines;
- ii. one of the products has elevated toxicity to mussels, requiring lower doses (5 mg/l compared with 25 mg/l) and shorter dosing times (3 days compared with 10 days) resulting in a 16x reduction in product application;
- iii. the particles are significantly smaller (7-25 μm) than previous formulations (101-105 μm) [R4] and more closely mimic natural food particles in size, enabling a much more targeted and efficient delivery to mussels, which prefer particles of 10-20 μm .

Product improvement was achieved by three key production innovations: (i) faster peripheral velocity using a rotary atomiser; (ii) refined machining, surface finish and profiling of the atomisation disc imparted more energy into the liquid film; (iii) improved rheological properties of the premix slurry created a lower viscosity premix [R6].

The two new formulations (Silver Bullets 1000 and Silver Bullets 2000) were approved by the UK Drinking Water Inspectorate in the same year under Regulation 31 of the Water Supply (Water Quality) Regulations [E1, page 18]; within this regulation, the BioBullet is the only mussel control solution that has been approved for use. At the same time, the products were assigned a new category, moving from Section A.4, which only allowed use while the waterworks is off-line, into Section A.9, which allows for use while the waterworks is online under standard operational conditions. This new listing dramatically enhances the commercial viability of the products as they can be used without having to temporarily stop the waterworks from supplying drinking water during treatment. As such, this new approval enables mussel control with minimal impact on standard operational procedures.

Impact on water supply companies

To date, BioBullets products have been used by seven UK water companies (Anglian Water, Bristol Water, Northern Ireland Water, Severn Trent Water, South Staffs Water, Thames Water, Welsh Water) which collectively supply 52% of the UK population (34.7 million people) with drinking water. [Text removed for publication], serving a population of 1.1 million people and all the associated businesses in an area of 2,400 square kilometres around [text removed for publication], has estimated BioBullets to be 69% cheaper than the pre-chlorination approach they previously used, saving them GBP188,000 per year [E2].

Bristol Waters' first trial of BioBullets took place in early September 2019 at Purton Treatment Works in Gloucestershire, which supplies over 400,000 people in the City of Bristol and surrounding areas. A survey undertaken at the canal abstraction point six weeks after dosing recorded a mussel mortality rate of 44% despite the trial taking place outside the optimum seasonal window. Encouraged by these results Bristol Water ran a further trial in October 2020, and data indicate that mussel mortality will exceed the desired target of 60%.

In addition to the commercial product itself, Bristol Water's Quality Scientist and Sampling Technician Manager states that they have "received sound technical guidance from Dr David Aldridge at every stage and site support was provided prior to the trial to ensure correct application of the product and to confirm an appropriate, repeatable method for accurately quantifying mussel mortality." [E3]

Thames Water is the UK's largest water and wastewater services provider, supplying 2.6 billion litres of water a day to 15 million people within a 13,000 square km area, from parts of Gloucestershire in the west, to areas of Kent and Essex in the east (Thames Water, About Us). They outline that mussels growing in stored water tunnels present a double risk to the water supply by blocking flow and requiring tunnels to be taken out of service for cleaning, at a cost of around GBP1M per annum. Their lead research scientist says, "Following a review of possible control methods BioBullets were selected as the most attractive solution for mussels in our 96km of vulnerable tunnels. [They have] demonstrated that mussels can be controlled in stored water tunnels and pipes in a way that does not add risk to the water quality or downstream treatment process." They describe it as an affordable solution that has the benefit of being deployed as a portable treatment plant for a limited number of weeks, in contrast to longer term storage of hazardous chemicals. The SB2000 product helped them clear an operationally critical supply pipe, which had become blocked with zebra and quagga mussels [E4].

[Text removed for publication] provides water and sewerage in [text removed for publication]; daily, they supply 560 million litres of clean water for almost 1.8 million people and treat 320 million litres of wastewater ([text removed for publication] About Us). In their report on the use of BioBullets from July 2020, they state that dosing with BioBullets removed [text removed for publication]

Impacts on commerce

The formation of BioBullets has led to employment within Biobullets Ltd [text removed for publication] [E6], pages 56 and 59. There have also been commercial benefits for the product manufacturer, TasteTech Ltd, as follows. Since 2014, TasteTech Ltd, has successfully increased their annual turnover from GBP4.9M to GBP7.1M and increased their staff from 55 to 67. The Managing Director of the company says that their collaboration with BioBullets "has helped the company develop and grow in several ways". These include: increasing their knowledge of microencapsulation particle construction, which has helped them improve products for the food industry; purchase of new equipment that would otherwise have not been acquired, and which has "proved invaluable" enabling them to predict and optimise performance; and development of their internal strategy to establish new alliances with several large companies and institutions [E7].

Research at the University of Cambridge, which generated the product of BioBullets, has enabled a novel approach to tackle a significant issue for the UK water supply industry, offering a cost-effective solution that avoids use of chlorine, a compound that can be harmful to animals

and humans. As a commercial entity, BioBullets now provides employment and is a profitable company contributing to the UK economy.

5. Sources to corroborate the impact (indicative maximum of 10 references)

E1. Drinking Water Inspectorate list of approved products for use in potable water supplies and separate approvals for SB1000 and SB2000 combined; relevant approvals on page 18.

E2. Internal report from [text removed for publication]

E3. Testimonial from [text removed for publication]

E4. Testimonial from [text removed for publication]

E5. Report from [text removed for publication] on BioBullet dosing

E6. Consolidated company accounts, BioBullets Ltd, 2013-2019; key data on pages 56 and 59E7.

E7. Testimonial from TasteTech Ltd