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| **Institution: University of Derby** | | |
| **Unit of Assessment: 7** | | |
| **Title of case study: The conservation of coral reefs in the face of climate change** | | |
| **Period when the underpinning research was undertaken: 2014-2020** | | |
| **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:** |
| Environmental Sustainability Research Centre (ESRC) researchers: | | |
| Michael Sweet | Associate Professor | Sept' 2013–present |
| Mark Bulling | Senior Lecturer | August 2010–present |
| David Elliott | Associate Professor | April 2017–present |
| Alfred Burian | Researcher | August 2017–July 2020 |
| Till Röthig | Researcher | Sept' 2018–Sept. 2020 |
| **Period when the claimed impact occurred: 2014–2020** | | |
| **Is this case study continued from a case study submitted in 2014? No** | | |

**1. Summary of the impact** (indicative maximum 100 words)

The ability of reef-forming corals to reproduce naturally has become a challenge worldwide, as the distances between healthy colonies have increased and the environmental conditions for settlement and survival of offspring have deteriorated. Research at the University of Derby has produced, for the first time ever, effective methods to induce in the laboratory the spawning of corals and maximise their early growth, allowing the completion of their entire reproductive cycle in captivity. This has resulted in significant benefits for international coral reef conservation efforts. Institutions are adopting these methods to reproduce successfully endangered corals and to upscale the number of larvae and young corals to be reared and transplanted onto damaged reefs for restoration practices in the field. The research has also triggered additional impacts: shaping United Nations policy, upskilling coral conservation and education practitioners, and engaging non-academics with coral research. The work has escalated from mainland UK to locations such as Florida, Australia, Maldives and Israel.

**2. Underpinning research** (indicative maximum 500 words)

The great majority of the world's coral reefs are in grave danger of suffering severe degradation or even dying out completely by 2100. This is according to the first global examination of the vulnerability of the planet's reef systems undertaken by Heron *et al* for UNESCO in 2017. The continued decline in coral cover is often linked to mass coral bleaching and disease, which in turn appears to be a consequence of increases in sea surface temperatures and other climate related stressors. These processes have resulted in dramatic shifts in the community composition of these valuable and vulnerable ecosystems, causing great concern for economic, social, and ecological scenarios. There is an urgent need to explore options offering effective mitigating solutions to the demise of corals around the world.

Since 2014, Sweet (please see current role and employment dates above) has led an interdisciplinary and collaborative team working on coral research in the Environmental Sustainability Research Centre (ESRC, University of Derby). By integrating organismal and community-level studies, innovative reproduction techniques, and modern statistical methods, a robust and **world-leading research framework for the conservation of coral reefs** has been built in England, thousands of miles away from the source coral reefs that the research aims to protect.

Together with Bulling, Burian, Elliott and Röthig (see current roles and employment dates above), the research has scaled from fundamental experiments on the histopathology of microbially-diseased individuals [3.1], the temporal dynamics of the coral microbiome [3.2] and the microbiome spatial structure under pronounced environmental gradients [3.3], to the ultimate discovery of a new disease infecting corals in Micronesia [3.4].

The core outputs underpinning this case study are:

a) The first ever broadcast spawning of coral species in a controlled mesocosm, accomplished in partnership with a long-term collaboration with Horniman Museum (London) researcher J. Craggs [3.5]. A whole reproductive cycle has been, for the first time, completed *ex situ*.
b) The successful co-culturing of lab-spawned corals and sea urchins [3.6]. Due to the resulting significant increase in survival of the juvenile corals, this methodology promises to overcome the bottle-neck of high mortality of juveniles in *ex situ* systems.

This body of research articulates clear benefits for international coral reef conservation efforts. The research provides methods for the effective spawning of corals and for upscaling the number of larvae and young corals to be reared and transplanted onto damaged reefs for restoration practices in the field.

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

**Publications in peer-reviewed journals** (University of Derby staff researchers are underlined):

**[3.1]** Sweet, M. and Bythell, J. (2015) 'White syndrome in *Acropora muricata*: nonspecific bacterial infection and ciliate histophagy', *Molecular Ecology* 24(5), 1150-1159. DOI:10.1111/mec.13097.
[*Comprehensive description of the pathogenesis of coral white syndrome in a near threatened species, highlighting the complex nature of the polymicrobial populations involved in the disease*.]

**[3.2]** Sweet, M., Brown, B.E., Dunne, R., Singleton, I. and Bulling, M. (2017) 'Evidence for rapid, tide-related shifts in the microbiome of the coral *Coelastrea aspera*', *Coral Reefs* 36(3), 815-828. DOI:10.1007/s00338-017-1572-y.
[*One of the few existing studies that focuses on the transient and core coral microbes and demonstrates the rapid temporal dynamics of the coral microbiome*.]

**[3.3]** Röthig, T., Bravo, H., Corley, A., Prigge, T-L., Chung, A., Yu, V., McIlroy, S.E., Bulling, M., Sweet, M. and Baker, D. M. (2020) 'Environmental flexibility in *Oulastrea crispata* in a highly urbanised environment: a microbial perspective', *Coral Reefs* 39, 649-662. DOI: 10.1007/s00338-020-01938-2.
[*Exhaustive analysis of the changes in the bacterial microbiome in an extreme marine water quality gradient, that adds knowledge to the potential role of the microbiome in coral environmental adaptation and resilience.*]

**[3.4]** Sweet, M., Burian, A., Fifer, J., Bulling, M., Elliott, D. and Raymundo, L. (2019) 'Compositional homogeneity in the pathobiome of a new, slow-spreading coral disease', *Microbiome* 7, 139. DOI:10.1186/s40168-019-0759-6.
[*Detailed characterisation of a new coral disease and of the infection-driven changes in their microbiome*.]

**[3.5]** Craggs, J., Guest, J.R., Davis, M., Simmons, J., Dashti, E. and Sweet, M. (2017) 'Inducing broadcast coral spawning ex situ: Closed system mesocosm design and husbandry protocol', *Ecology and Evolution* 7(24), 11066-11078. DOI:10.1002/ece3.3538.
[*Landmark research that, for the first time, allowed the breaking of the code for coral spawning in laboratory settings.*]

**[3.6]** Craggs, J., Guest, J., Bulling, M. and Sweet, M. (2019) 'Ex situ co-culturing of the sea urchin, *Mespilia globulus* and the coral *Acropora millepora* enhances early post-settlement survivorship', *Scientific Reports* 9, 12984. DOI:10.1038/s41598-019-49447-9.
[*First evidence that juvenile urchins can boost coral survival rate in captivity by 8 times*.]

**Funding:** This research has been supported by funding from the Gordon and Betty Moore Foundation (GBP28.8K), The Waltham Foundation (GBP8K),The University of Reunion (GBP2.6K), together with GBP15K from an EU Consolidator Grant administered by the University of Newcastle. In addition, Sea Life provided approximately GBP26K towards running

costs of the new Aquatic Research Facility at the University of Derby and approximately GBP200K worth of equipment for this facility.

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

The work undertaken by the ESRC team is an evidence-based model for coral studies and backbone for coral conservation. Their research has led to benefits beyond academia and impacts on different strata of society have been triggered: informing international policy, promoting practitioner upskilling, as well as engaging other non-academic audiences with coral research, such as museum visitors and television viewers. Their work has reached from mainland UK to aquaria and marine technology practitioners in Florida, Australia and Maldives.

**Impact on aquaria, marine technology institutes and the aquarium industry**

The novel underpinning research on spawning of corals and co-culturing with sea urchins in laboratory mesocosms, framed in the long-term collaboration with the Horniman Museum and Gardens of London (2013-ongoing), allows the accurate prediction and induction of spawning in captive corals with improved rates of survival. As the Director of Curatorial and Public Engagement at the Horniman Museum states: "*These research milestones are of international significance, enabling large scale efforts for restoration of Coral Reefs, which are under threat from climate change, overfishing and pollution*" [5.1].

The techniques for accomplishing coral spawning have been adopted by different institutions:

-The Florida Aquarium states [5.2]: "…*This is an innovative and impactful new approach to coral reef restoration developed in the laboratory of Dr. Michael Sweet at the University of Derby. The Florida Aquarium (FA) has been actively utilizing the coral reproduction aquarium system design and research protocols developed..." "Prior to this critical work, coral sexual reproduction could only be accomplished in the field, often requiring expensive remote travel and producing highly variable results. The Florida Aquarium quickly recognized the critical importance of this technology …and began construction of four of these aquarium systems at our Center for Conservation in 2017. These aquarium systems gave us the ability to spawn two species of native western Atlantic coral..." "Their work...is truly a game-changer for the future of coral restoration".*

- The Oceanographic Center (Nova Southeastern University Florida) asseverates: "*Your invaluable paper on spawning - it has changed the way we run our systems in the lab, and given us hope that there's a better way to study coral reproduction than capturing gametes in the field!"* [5.3].

- On the other side of the world, the Australian Institute of Marine Science (AIMS), a world leading institution that includes research that focuses on reproduction of broadcast spawning coral species, is using the protocols underpinned by the research**.** As the Manager of the National Sea Simulator at AIMS explicitly credits: *"I fully appreciate the potential applied benefit of the co-culturing principles pioneered by the University of Derby and the Horniman Museum and Gardens, to the research projects carried out in my institution"* [5.4].

The coral techniques developed by the ESRC team have also impacted the Aquarium Industry. The company Aquarium Connections Ltd has turned up over half of the business to the design and building of aquarium mesocosms to induce ex-situ coral spawning. These setups are offered to the market of national and international aquarium specialists (for example, Mote Marine Laboratory, Florida, USA, and ICBO Terramare-Olderburg, Germany). As the Director of the company states: "*Since the adoption of the product, Aquarium Connections has experienced a 23% uplift in its annual turnover. Additionally, we have established relationships with external suppliers of specialist materials required for production which has enhanced their turnover and profit margins*" [5.5].

**Impact on United Nations policy**

The ESRC team's conservation efforts on corals have also informed international policy on coral reef conservation. Sweet is first author of a three co-authored United Nations (UN) report (2019), that provides policy and management recommendations for addressing and reducing the impacts of plastics on shallow water coral reefs [5.6]. The report was launched during the Fourth session of the United Nations Environment Programme (UNEP) Assembly on 15 March 2019. As the

UNEP Programme Officer states: "*The discussion around this report engaged an audience which was made of delegates from governments around the world"*. Since the date of launch until September 2019, the report has been downloaded 2,571 times from the UNEP website, which posits this report among the top quartile most downloaded documents from the website until that date (23 out of 104). As the UNEP Officer acknowledges: "*The report is currently being used as a resource in the ad-hoc open-ended expert group on marine litter and microplastics…. The mandate for their work is to examine the barriers and options to combating marine plastic litter and microplastics from all sources, especially land-based sources, and to provide options for continued work…"* [5.6].

**Upskilling coral reef conservation practitioners and advocates**

The ESRC coral researchers Sweet and Bulling have also generated non-linear impact by enhancing people's capacity and preparedness to promote coral reef conservation at different levels:

a) Local-community orientated: Running of short courses in the Indian Ocean, for example, the "Coral Reef Ecology Field Course", within The University of Derby's Tropical Marine Biology module. This course has been taking place in Maldives from 2014 (9 courses up to date) involving in total 88 attendees, of which 16 have been Maldivian Nationals. As a result of their attendance, the participants have improved their skills, awareness and understanding of why conserving reef ecosystems matters, and progressed in their careers. This is evidenced by their own testimonies. A Maldivian National attendee states: *"…the lecture sessions and research methods taught during the course allowed me to apply for a research grant from Earthwatch Institute UK. M. Sweet guided me during the proposal stage and I am currently conducting a 1 year project named Coral restoration in Kaafu Atoll, Maldives".* And "*I am grateful and appreciate the knowledge shared by M. Sweet and his colleague Mark* (Bulling), *and for letting locals participate in these courses. There are not many such opportunities within the country…"* [5.7]. Another Maldivian National, the current Field Manager of the UK based charity Blue Marine Foundation also claims: *"This exposure was definitely a transformative experience for me…My work entails research, community engagement and education and participatory planning to increase marine protection in the Maldives. The course definitely played a role in increasing my skills and knowledge enabling me to progress this far in my career"* [5.7].

b) Graduate-level orientated: For example, through the "Biology on Corals" course hosted at The Interuniversity Institute for Marine Sciences in Eilat, Israel (November 2019). Evidence of pedagogic impact includes feedback comments by course participants: "*Very interesting and very important views of what can be done*"; "*…Interesting studies and ideas for future coral reefs"* [5.8].

c) PhD-level orientated: A complementary capacity-building impact was generated through the PhD (2016-2018) undertaken by Horniman Museum Curator under the supervision of ESRC researchers (Sweet and Bulling) at The University of Derby. The transfer of knowledge from the ESRC researchers contextualised the significance of the underpinning research and magnified its impact, as the Curator evidences in his own testimonial [5.9]:

*"The supervision articulated into a program of building collaborations and networks across a variety of institutions and countries which extended for me the opportunity to work and share the coral husbandry techniques with colleagues from around the world…My PhD paved the pathway for presenting the latest and most novel coral research not only to the scientific community, but also to the society, as we are doing presently through the bespoke public coral exhibitions at the Horniman Museum".*

**Public engagement impact**

Sweet's ESRC team together with J. Craggs at the Horniman Museum, have engaged museums, the news industry (TV and newspapers) and social/digital media into their coral research. Their work has contributed to raising public awareness about, on the one hand, the imminent environmental threats faced by corals and, on the other, how their research is helping reef conservation. For example:

- A bespoke exhibition was launched in 2016 at the Horniman Museum featuring 'Project Coral', the framework which synthesises the coral research produced by the teams. This exhibit, which is continually on display and acknowledges The University of Derby for the collaborative research,

has reached 143,000 visitors per year (average visitors per year to the Horniman Aquarium for the period between 2016 and 2019) [5.10]. In 2019, Project Coral was chosen as one of the TOP 10 Ocean Influencers of the year by *ECO* magazine, a marine science publication committed to bringing scientists and professionals the latest ground-breaking research, industry news, and job opportunities from around the world [5.10].

- Public displays featuring the coral research have taken place in the Natural History Museum of London (NHM). The events – 'Science Uncovered', from the European Research Nights program (September 2017) and 'Blue Planet II late' (January 2018) – shared the team's coral research with the public (these events had respectively 4,000 and 4,230 visitors per year). General comments from the NHM visitors to these events were*: "A great opportunity to chat to scientists about their work in an informal setting"*, and *"They were incredibly interesting, the projects were incredible to hear about and I learnt so many new jaw dropping things".* Moreover, a NHM video on the coral spawning has so far (August 2020) 2,704 pageviews since it was published in May 2015. On YouTube, this video has 11,552 views to date (August 2020), with comments such as "*masterclass*" in relation to it [5.10].

- The ex-situ coral spawning work has also been presented on the BBC One *Blue Planet UK* series 2019 (Episode 4. 28 March 2019) and was selected as one of the top highlights by the series presenter Gillian Burke. The audience figures for the 28 March episode were: 1.11 million viewers a day for the 16.30 h – 17.15 h slot on BBC One; average share 12.6% of the available audience; audience appreciation (AI) of the series: 85%, with a breakdown of ages, gender and social groups as follows: over 55 years old = 85% AI; Men = 83% AI; Women = 87% AI; ABC1 = 83% AI; C2DE = 87% AI. General audience comments about the episode included: *"Really interesting content*" (Female, aged 77), and "*Informative*" (Male, aged 57) [5.10].

- A video of the spawning shared on Facebook has had, from January 2016 until August 2020, 26,000 views, 504 shares in 34 countries from Brazil, Bahamas, Taiwan, Japan, Australia, Dubai, Singapore, as well as across Europe and USA. Another spawning video shared on EcoTech Marine Facebook site, has had, for the same period mentioned above, 34,000 views, 429 shares in 8 countries [5.10]. All the feedback comments to both videos (n=78) were positive, and 33.3% of the reviews described the research as "*amazing*" "or "*awesome*". Other adjectives used in feedback included "*stunning*", "*brilliant*", "*ground-breaking*" and "*inspiring*".

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

**[5.1]** Testimonial Letter from the Director, Curatorial and Public Engagement at Horniman Museum (London). 12 December 2019.
**[5.2]** Testimonial Letter from Senior Coral Scientist, The Florida Aquarium (US). 3 January 2020.
**[5.3]** E-mail from the Oceanographic Center Nova Southeastern University in Florida (US). 6 March 2020.
**[5.4]** Testimonial Letter from the Manager of the National Sea Simulator at the Australian Institute of Marine Science (AIMS, Australia). 10 December 2019.
**[5.5]** Testimonial Letter from the Director of Aquarium Connections Ltd (London). 13 May 2020.
**[5.6]** Testimonial Letter from Management Officer at United Nations Environment Programme on the use of the 2019 report "Plastics and shallow water coral reefs: Synthesis of the science for policymakers". Authors: M. Sweet, M. Stelfox, J. Lamb. https://www.unenvironment.org/resources/report/plastics-and-shallow-water-coral-reefs-synthesis-science-policy-makers. (Accessed: 14 October 2019).
**[5.7]** Testimonial Letters from attendees at the Maldives Coral Reef Courses (Maldives). November 2019–May 2020.
**[5.8]** Feedback comments from attendees at the 'Biology on Corals' course in Eilat (Israel). 24 November 2019.
**[5.9]** Testimonial letter from Aquarium Curator at Horniman Museum (London). 6 December 2019.
**[5.10] Evidence group demonstrating impact of public and media engagement:** Horniman Museum visitor numbers (2016–2019); *ECO Magazine* 'Top 10 Ocean Influencers' (2019); Natural History Museum visitor numbers (2017–2018); BBC *Blue Planet UK* audience data.