Institution: University of Oxford

Unit of Assessment: 7, Earth Systems and Environmental Sciences

Title of case study: First Animals in the 21st Century: Public Engagement with Deep-Time Research

Period when the underpinning research was undertaken: 2003–2020

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:
Derek Siveter	Professor	1988–2014
	Emeritus Fellow	2014–2017
Paul Smith	Director, OUMNH	2012–present
Duncan Murdock	Research Fellow	2017–2020
	Collections Manager	2020–present
Ross Anderson	Research Fellow	2017–present
Nicholas Tosca	Associate Professor	2014–2020
Frances Dunn	Research Fellow	2019–present
Imran Rahman	Research Fellow	2016–present

Period when the claimed impact occurred: 12 July 2019–31 December 2020

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

1. Summary of the impact

World-leading research on the palaeobiology and evolution of animals at the University of Oxford underpinned a landmark exhibition at Oxford University Museum of Natural History (OUMNH). *First Animals* had wider reach than any previous science exhibition at OUMNH, with 219,562 visitors and 5,123 engagements through onsite events. After COVID-19 caused the exhibition to close prematurely, 3,290 people from 61 countries attended an innovative programme of online lectures. More than 13,000 people contributed to the exhibition evaluation, and over 80% of surveyed visitors reported they had learned something new. OUMNH engaged a total of 382 school students and 141 university students through formal sessions, with teachers and lecturers confirming this improved learning and influenced curriculum design and delivery. *First Animals* facilitated collaborations with local artists, resulting in the creation of original artworks that enhanced engagement with diverse audiences. It has also shaped plans for exhibition design internationally, as part of a major new partnership with Yunnan University in China.

2. Underpinning research

First Animals was underpinned by research on the origin and early evolution of animals carried out by staff in UoA7 at the University of Oxford (**Siveter**, **Smith**, **Murdock**, **Anderson**, **Tosca**, **Dunn**, **Rahman**) between 2003 and 2020. Research focussed on the late Ediacaran–Cambrian (~571 to 485 million years ago), a pivotal interval in Earth's history characterised by the initial radiation of large and complex multicellular eukaryotes (the Ediacara biota) and the explosive diversification of animal phyla (Cambrian 'explosion'). This research, which formed the basis of the exhibition and accompanying programme of events, transformed our understanding of:

- The palaeobiology and evolution of invertebrates from the Chengjiang biota in Yunnan province, China. **Siveter's** research on Cambrian arthropods (**G4**), carried out in partnership with the University of Leicester and Yunnan University in China, formed a key part of the first English-language book on the Chengjiang biota, in which the morphology and ecology of these early animals was described in unparalleled detail (**R1**). This research also led to the discovery of the oldest evidence of key biological interactions, such as collective behaviour and host-specific infestation.
- The interactions between Earth systems and organisms during the origin and early evolution of animals. A major collaboration with researchers in Denmark, Sweden and at Durham University revealed close similarities between the Burgess Shale, Chengjiang and Sirius Passet Lagerstätten, informing debate on the environmental setting of the Cambrian 'explosion' (**R2**). **Smith's** work was key for linking sedimentological, geochemical and environmental changes for the Sirius Passet Lagerstätte.
- The origin and early evolution of animal skeletons. Research by **Murdock** (**G3**) compiling and analysing the composition of animal skeletons through time demonstrated that skeletons had evolved independently many times in different groups (**R3**).

- The processes involved in forming exceptionally-preserved fossils. Analyses of clay minerals in rocks from the Burgess Shale undertaken by **Anderson** (**G5**) and **Tosca** at Oxford, in co-operation with researchers at Pomona College and Yale University, informed the mineralogical signature underlying exceptional preservation (**R4**).
- The anatomy, growth and affinities of the Ediacara biota. **Dunn's** research at Oxford (**G2**), part of a collaboration with Bristol and Cambridge, clarified the nature of previously unknown filamentous connections between frondose forms, suggesting a clonal or colonial life history for some groups (**R5**).
- The utility of 3D modelling for reconstructing the form and function of extinct organisms. **Rahman** (**G1**) carried out computer simulations of fluid flow for digital models of Ediacaran organisms and, in collaboration with researchers in the USA and Canada, uncovered the oldest evidence of commensalism by large multicellular lifeforms (**R6**).

3. References to the research: The references below are a selection of those on which the impact is based. All are journal articles with the exception of **R1**, which is a published book.

R1. Hou, X-G, Aldridge, R.J., Bergström, J., Siveter, David J., **Siveter, Derek J.** & Feng, X-H. 2003. *The Cambrian fossils of Chengjiang, China. The flowering of early animal life*. 233 pp, Blackwell, Oxford. *(448 citations; Google Scholar, 07/12/2020)*. Supplied on request.

R2. Hammarlund, E. U., **Smith, M. P.**, Rasmussen, J. A., Nielsen, A. T. & Harper, D. A. T. 2019. The Sirius Passet Lagerstätte of North Greenland—A geochemical window on early Cambrian low-oxygen environments and ecosystems. *Geobiology*, **17**, 12–26. DOI: 10.1111/gbi.12315. *(9 citations; Google Scholar, 07/12/2020)*.

R3. **Murdock, D. J. E**. 2020. The 'biomineralization toolkit' and the origin of animal skeletons. *Biological Reviews*, **95**, 1372–1392. DOI: 10.1111/brv.12614. *(6 citations; Google Scholar, 07/12/2020)*.

R4. **Anderson, R. P.**, **Tosca, N. J.**, Gaines, R. R., Mongiardino Koch, N. & Briggs, D. E. G. 2018. A mineralogical signature for Burgess Shale-type fossilization. *Geology*, 46, 347–350. DOI: 10.1130/G39941.1. *(37 citations; Google Scholar, 07/12/2020)*.

R5. Liu, A. & **Dunn, F.** 2020. Filamentous connections between Ediacaran fronds. *Current Biology*, **30**, 1322–1328. DOI: 10.1016/j.cub.2020.01.052. *(6 citations; Google Scholar, 07/12/2020)*.

R6. Gibson, B. M., **Rahman, I. A.**, Maloney, K. M., Racicot, R. A., Mocke, H., Laflamme, M. & Darroch, S. A. F. 2019. Gregarious suspension feeding in a modular Ediacaran organism. *Science Advances*, **5**, eaaw0260. DOI: 10.1126/sciadv.aaw0260. *(9 citations; Google Scholar, 07/12/2020)*.

The research at Oxford was funded by:

G1. **Rahman**, "Echinoderms: A model system for investigating the origin of animals", Royal Commission for the Exhibition of 1851 Research Fellowship, 2016, GBP31,500.

G2. **Dunn**, "The rise of animals: challenging Darwin's dilemma", Royal Commission for the Exhibition of 1851 Research Fellowship, 2019–present, GBP144,000.

G3. **Murdock**, "The hard parts of the Cambrian explosion", Leverhulme Trust Early Career Fellowship, 2016–2019, GBP89,000.

G4. **Siveter**, "Fossils of the Herefordshire and Chengjiang Lagerstätten", Leverhulme Trust Emeritus Fellowship, 2014–2017, GBP21,846.

G5. **Anderson**, "Fossil evidence for the evolution of complex life", All Souls College Post-Doctoral Research Fellowship, 2017–present, GBP214,225.

4. Details of the impact

Pathways to impact. The aim of *First Animals* was to engage a broad range and diversity of audiences with the latest research on animal origins, providing opportunities to develop their interest in and knowledge of this and related topics. Research in University of Oxford UoA7 provided new information about the biology, ecology and evolution of early animals (**R1, R3, R5, R6**) and the taphonomy of exceptionally-preserved fossils (**R2, R4**), and this was the foundation on which the exhibition was built. The exhibition displayed 52 specimens from OUMNH's collections and 67 fossils on loan from partner organizations, including key objects that had never been seen by the public. For the first time ever, fossils from three globally significant sites of exceptionally-preserved fossils, Chengjiang, Burgess Shale and Sirius Passet – the focus of the underpinning research – were exhibited together. New discoveries on the form and function of early animals (**R1, R5, R6**) were crucial for reconstructing them as 3D models, allowing these

long-extinct organisms to be brought to life in an interactive digital experience (*Cambrian Diver*). University of Oxford researchers collaborated with local artists, who produced a series of artworks that were displayed as part of the *First Animals* exhibition (and in a complementary exhibition at the North Wall Arts Centre in Oxford). The accompanying programme of events, which included accessible talks, family friendly activities, late night events and workshops, provided diverse opportunities for attendees to learn about the work from the researchers.

Reach. *First Animals* attracted record numbers of visitors for an exhibition at OUMNH. Between July 2019 and March 2020, 219,562 people visited *First Animals*, which represents an average of 882 per day (**E1**); this is the best-attended research exhibition ever hosted at OUMNH, and compares very well to temporary exhibitions at the UK's national museums (e.g. the Natural History Museum, London attracted approximately 130,000 visitors to its *Wildlife Photographer of the Year* exhibition between October 2019 and March 2020). 42% of all visitors to the Museum visited *First Animals* during the period it was open, higher than all previous science exhibitions at OUMNH. This included large numbers of first-time visitors and young people; 44% of exhibition visitors had never visited the Museum before and 56% were under 16 years old (**E1**).

The exhibition was accompanied by English- and Chinese-language websites (**E2**), which were available throughout the exhibition and afterwards as legacy sites. Unique pageviews for the English site totalled 18,535 (July 2019–September 2020), and the average dwell time of 8 minutes 21 seconds (**E2**) is double previous exhibition pages hosted by OUMNH. 3D models from the exhibition on Sketchfab, based on University of Oxford research (**R1, R5, R6**), were viewed 127,692 times and downloaded 1,694 times (July 2019–December 2020). *First Animals* was also very popular on social media; a Facebook post on the Cambrian seafloor had approximately 64,000 views, quadrupling the Museum's previous high (**E1**).

Reach was extended by positive press coverage (**E3**). A review in *New Scientist* highlighted: "*For a glimpse of life right at the start of the age of animals, you can't ask for anything better than this*". Moreover, pieces in *The Guardian*, *CBC News* and elsewhere emphasised *First Animals* as a tourist destination, helping to attract record numbers of visitors to the exhibition. 60% of surveyed exhibition visitors were from beyond Oxfordshire and the surrounding region, and some visitors travelled specifically to see *First Animals*; one talk attendee stated: "*I live in the USA* [and] *came for this exhibit*" (**E1**).

The onsite events programme reached a total of 5,123 people, including 768 talk attendees, 1,504 participants in the November 2019 late night event, and 2,467 engagements through family activities and volunteer-led object handling (**E1**). Following the closure of the Museum due to COVID-19 in March 2020, OUMNH moved engagement online, developing a series of online lectures delivered by University of Oxford researchers and their collaborators (**E4**). This further enhanced the reach of the research, with 3,290 people attending 11 one-hour lectures (average attendance of 59 minutes per lecture), more than three times the number of people who would have attended in-house talks, and much wider international participation (attendees from 61 countries). The talks generated very positive comments on social media, for example: "*Thank you so much for making these wonderful talks available to the public, @morethanadodo. The strange summer of 2020 was so much better with this series*" (**E1**). Recordings of the talks on YouTube had 4,710 views (May–December 2020) (**E4**).

Impact on individual knowledge. Over 13,000 people contributed to the evaluation of the exhibition, with more than 500 people providing feedback on events. This demonstrated that *First Animals* had a strong impact on public understanding of research on animal origins. 80% of 5,357 surveyed visitors indicated they had learned something new, including 72% of those who identified with the statement 'science is not for me' (**E1**). This is supported by feedback from visitors and attendees, which shows they gained new knowledge of animal origins, for example: "[I learned about what] *the seabed looked like 500m years ago*"; and "*Animals emerged so much earlier than I thought*" (**E1**). There is also evidence of in-depth learning in specific topics related to the underpinning research, for example: "[I learned about] *how energetic synthesis mechanisms drive evolutionary diversification in low O2 waters*" [**R2**]; and "[I learned that] *Ediacaran animals existed before the Cambrian Explosion*" [**R5**] (**E1**).

Individuals engaging with *First Animals* noted the key role research played in the exhibition, with 79% of respondents recognising OUMNH as a place where they were exposed to current science and research (**E1**). They also had a new-found appreciation for the work involved in

scientific research, for example: "*The dedication and teamwork of these scientists convinces me that they have truly figured out details explained*"; and "*I have great respect for the patience and determination of the researchers, and really appreciated the time spent with us*".

The programme stimulated the intention to engage with the content further, with 88% of those who attended the onsite talks stating they would likely return for future events (**E1**). Significantly, visitors and attendees were inspired to learn more about the subject, for example: "***A great series of rare fossils. I must read more about them***"; "***I have little knowledge of fossils, so I learnt a lot and will pursue my newfound interest in this subject matter***"; and "***I feel more comfortable now with this topic and in the future, I'll read more books about it because I'm now asking more and more questions about this period***".

Impact on school education. OUMNH hosted school visits to the exhibition and programme, with qualitative feedback (e.g. **E5**) demonstrating that these visits enhanced science education. In November 2019, the Museum ran an A-level study day on the *First Animals* research (**R2, R3, R5**) for 51 people (students from five schools). Oxford Spires Academy also visited the exhibition with 21 people (students), and *First Animals* research was a key part of the Cells study day at the Museum (298 people, A-level students from 17 schools). The impact of these visits on the delivery of the school curriculum is highlighted in **E5**: "*In Year 13 Geology we teach case studies of exceptional preservation of fossils and on our visit to the museum we listened to several lectures on early life including the Sirius Passet Lagerstätte of North Greenland* [**R2**] *- a case study that we have not covered and provided fresh insight into the concepts of exceptional preservation…**The students have benefitted by gaining a more complex understanding of the early development of multicellular life on Earth. The extent of the impact has been measured subjectively via discussions in class and a perceived improvement in understanding**...* [The visits] *serve to inspire students to study at a higher level*".

Impact on teaching in higher education. OUMNH facilitated visits by 7 universities (Bristol, Cardiff, Imperial, Nottingham, Oxford, Southampton and Warwick), during which 153 people (91 undergraduates, 50 postgraduates and 12 staff) were able to learn about the underpinning research, including work on the Ediacara Biota (**R5, R6**) and the Chengjiang (**R1**), Sirius Passet (**R2**) and Burgess Shale (**R4**) Lagerstätten, through direct interactions with the researchers themselves (Smith, Murdock, Dunn and Rahman all led tours), as well as via the exhibition. The effect of this deeper engagement is clear from **E6**, with the programme director of the University of Bristol MSc in Palaeobiology (the longest-established and most successful Masters programme of its kind in the world) highlighting the role of the exhibition in stimulating interest in the underpinning research: "*…the exhibition had a strong impact on many of the students, five of whom have chosen to carry out research projects on early animal evolution. These include two who have selected projects on Sirius Passet, one of the fossil sites that the exhibition focussed on* [**R2**]. ***I have no doubt that visiting the exhibition played a part in influencing their decision***". This influence is confirmed by the testimonial from one of the students, **E6**: "*The exhibition reinforced my passion for early animal evolution and definitely motivated me in completing my MSc thesis work... It showed me that the public are interested in other aspects of palaeontology aside from the big beasties and that scientific communication regarding early animal evolution is an avenue I can pursue as part of my career…The exhibition also influenced me in deciding to apply for a PhD at Oxford and carry out research on early animal evolution at this institution, hopefully in 2022*". The impact on teaching in higher education also extended to potentially influencing curriculum design, **E6**: "*The innovative methods used to illustrate the organisms and their environment were spectacular: in particular the use of the interactive screens showing the Cambrian sea floor and the use of virtual reality headsets to show the way these animals lived. **This has been inspiring for me and I hope to be able to obtain some similar headsets to use in my regular teaching sessions in the future***".

Impacts on creativity, culture and society. University of Oxford researchers worked closely with a local group of artists (Oxford Printmakers Co-operative, OPC) to create original artworks. During workshops in March and April 2019, the exhibition and underpinning research were introduced to the artists, who responded by creating pieces that explored and celebrated this work. These new artworks were exhibited in the Museum as part of a trail and were available for purchase in the shop (18 artworks sold for a total of GBP1,848). This collaboration resulted in a ripple-effect of additional impact: the artworks were also displayed in a separate exhibition at the

North Wall Arts Centre in Oxford; the artists ran a public workshop at OUMNH in September 2019, which enabled 7 participants to learn about the research linked to *First Animals* while making artworks of their own; and the same art–science workshop model was later used by OPC to engage schools with both the art and the research that had inspired them (**E1**). The impact of this collaboration is detailed by the artists in **E7**: "*We couldn't have worked without the patient explanations and "Show and tell" sessions with the three main researchers - Dr Jack Matthews, Dr Imran Rahman and Dr Duncan Murdock. They were just excellent and their dedication to their work was an inspiration to all of us printmakers. Personally, I found the whole collaboration absolutely brilliant and* ***understanding more of the whole evolution of life gave me a whole new respect for our amazing planet and our origins and have a desire to make even more prints of a 'geological" nature***".

Impact on wider engagement. The exhibition provided positive experiences for visitors without high levels of engagement in science. 66% of visitors who identified with the statement 'science is not for me' rated the experience as 'excellent' (**E1**). *First Animals* also provided new opportunities for engagement with underserved audiences; touch tours were developed for blind and partially sighted visitors (12 people), and object handling was offered as part of autism friendly openings (55 people). In late 2019, Museum researchers worked with Crisis, the national charity for homeless people, to help a client create and deliver a public tour of *First Animals*. The impact of this is evidenced by **E8**: "*Delivering the tour helped me improve my confidence. When I researched information myself, and then when I spoke it in front of the experts it made me very happy. I taught 2 people from Crisis* [who hadn't been involved in the training] *the facts on the tour which was great… I would love to volunteer at the museum in the future*".

International impacts. The research underpinning *First Animals* (**R1**) was the stimulus for a major new partnership between OUMNH and Yunnan University (**E9**), which enabled the loan of 55 Chinese fossils that were integral to the exhibition. The design of planned exhibitions at Yunnan (delayed due to COVID-19, see mitigation statement) has been strongly influenced by *First Animals*, as highlighted in **E10**: "…*we have begun plans to tour the First Animals exhibition at Yunnan University in 2021–2022. We will collaborate closely with colleagues at Oxford University Museum of Natural History as we design this exhibition, working to ensure the fossils are displayed together with details of the collaborative research undertaken at Yunnan and Oxford.* ***This represents a major change from previous exhibitions at Yunnan University***".

5. Sources to corroborate the impact

E1. First Animals exhibition and programme evaluation report by OUMNH. Corroborates data on visitors to the exhibition, reach on social media, significance of impacts on individual knowledge, creativity, culture and society, and quotes from visitors. Public document.
E2. First Animals exhibition website statistics (Google Analytics for OUMNH website). Corroborates data on pageviews and dwell time of website visits. Confidential document.
E3. Portfolio of media coverage of exhibition, accompanied by statistics on reach. From Oxford Printmakers Co-operative website, CBC News, New Scientist, Daily Info (locally-run guide to Oxford). Corroborates the positive press coverage of the exhibition. Public documents.
E4. First Animals online lectures analysis report by OUMNH. Corroborates audience data for the online lectures. Public document.
E5. Testimonial from Geology teacher, Poole Grammar School. Corroborates significance of impact on school education. Confidential document.
E6. Portfolio of testimonials from visiting groups from Universities of Bristol, Cardiff, Nottingham, Southampton, Warwick and Imperial College London. Corroborates significance of impact on higher education. Confidential document.
E7. Testimonial from the Oxford Printmakers Co-operative. Corroborates significance of impact on creativity, culture and society. Confidential document
E8. Testimonial from the Arts Coordinator, Crisis Skylight Oxford. Corroborates significance of impact on wider engagement. Confidential document.
E9. Formal partnership agreement between OUMNH and Yunnan University. Corroborates the agreement to loan fossils for the exhibition. Confidential document.
E10. Testimonial from Deputy Director of Yunnan Key Laboratory for Palaeobiology, Yunnan University. Corroborates plans for the exhibition tour. Confidential document.