

Impact case study (REF3b)

Institution: University of Southampton
Unit of Assessment: 07 Earth Systems and Environmental Sciences
Title of case study: 07-05 Managing the seabed through innovative near surface geophysical imaging
<p>1. Summary of the impact</p> <p>Southampton researchers have developed, commercialised and applied an array of new technological methods and interpretative approaches for managing the seabed through novel near surface geophysical imaging. This fundamental research has had demonstrable major impacts on areas as diverse as: improving the preservation and management of underwater cultural heritage (through providing direct UK government guidance and advice); enabling the sustainable use of the marine environment for the largest offshore infrastructure developments (including providers of nuclear power, wind power and trans-national energy connectors); enhanced mineral resource exploitation (for The Crown Estate - owners of the marine estate and regulators of the companies that exploit it); providing object detection service and training for the UK armed forces; assisting national and international law enforcement agencies in underwater search; and finally, disseminating these skills through postgraduate education to the UK and overseas marine survey sector.</p>
<p>2. Underpinning research</p> <p>This research strand started in 1994 with the combining of the University of Southampton (UoS) expertise in high resolution marine geophysics and marine geoarchaeology to develop new acoustic methods to identify and investigate sites of submerged archaeology. Over the last two decades this work has extended to look at multiple aspects of near surface archaeology and geology of the continental shelf for both commercial and scientific purposes:</p> <p>a. RCUK Funded Research: Previous attempts by both the academic and industrial communities to image small buried artefacts in the marine environment met with limited success due to inappropriate equipment, inadequate data collection and processing methods, and a dearth of information on the acoustic properties of common archaeological materials. UoS efforts to address this began with Bull, Dix and Adam's <i>Acoustic Methods in Archaeology</i> project. This project involved pioneering the use of a high-resolution, sub-bottom profiling system, 2D Chirp, to image marine archaeological sites buried in the shallow subsurface. The ability to reconstruct such buried sites enhanced not only their intrinsic archaeological value but also strategies of subsequent heritage management. The results of this work were published in papers that covered: the development of the optimum Chirp processing flow; initial calculations of the acoustic properties of archaeological materials; the extraction of comparable physical properties directly from the acoustic data [3.1]; and the successful testing of these approaches on two historic protected wreck sites, the <i>Mary Rose</i> and the <i>Invincible</i>. Acknowledging the inherent limitations of a 2D survey, which samples data only from seismic waves travelling in one vertical plane, UoS researchers (the original team plus Henstock, Leighton and White) developed a new 3 Dimensional Chirp system [3.2] to facilitate the sampling of the entire wave field in 3D and so provide a more representative visualisation of the subsurface. The crucial developmental break-through that enabled the collection of decimetre scale 3D volumes was solving how to position source and receivers, in x, y and z, at centrimetric accuracy, up to 10 km from a known absolute position. This involved RTK GPS, positioning source and receivers on a rigid array, and very careful design of the system to ensure that all timing was synchronised [3.2]. This project not only included the development of the new system, but also production of new Chirp waveforms to optimise penetration and resolution in a range of substrates and the collection of the first high resolution (decimetre scale) 3D volumes (from both geological and man-made sites). Subsequently, NERC and UoS-supported PhD's extended this work to develop additional methods for the extraction of the physical properties of sediments from acoustic data using attenuation techniques and the collection of the first 3D volume over an historic wreck site (the <i>Grace Dieu</i>) [3.3].</p> <p>b. Government funded Research:</p> <p>Additional funding for the application of both 2D and 3D Chirp to marine archaeology was awarded initially by the Royal Commission for Historical Monuments of England and latterly the English Heritage component of the Aggregates Levy Sustainability Fund (EH-ALSF). This supported both</p>

the early phases of 3D Chirp development [3.2] and further experiments to determine the acoustic properties of a broader range of archaeological materials and how these varied with their state of preservation. Through an additional series of EH-ALSF funded projects the marine geophysical research work was extended (by Dix in collaboration with Sturt, UoS and PhD students) to include new marine geoarchaeological approaches to the investigation, characterisation and interpretation of the wider submerged archaeology (beyond wrecks) of the continental shelf [3.4]. This work includes recent investigations, with the Natural History and British Museums, into the offshore components of the oldest *hominin* occupation sites on the European shelf. Further, Dix also led the development of local and regional hydrodynamic and sediment transport models specifically designed for the management of both wreck and submerged landscape cultural heritage assets. The significance of this work has been recognised by Dix and Sturt being editors of *English Heritage's 2013 Maritime Research Agenda* and authoring a Chapter on Marine Geoarchaeology.

c. Commercially Funded Research:

Technological aspects of 3D Chirp development (including the production of a migration algorithm for optimising the imaging and inversion of the 3D data) and additional case studies on geological targets (lacustrine debris flows) were funded by Kongsberg GeoAcoustics Ltd. The latter work has been extended (through funding of Vardy, UoS, by a Norwegian oil industry consortium) to look at marine slope stability mechanisms for offshore geohazards such as underwater landslides. Further, the MOD have funded a commercial project to use 3D Chirp to identify the presence of unexploded ordnance and other objects within a harbour basin [3.5]. Additionally, based on the reception of the research work funded by the EH-ALSF scheme, the Resource Management Association (a consortium of Cemex UK Marine Ltd, Hanson Aggregates Marine Ltd and Tarmac Marine Dredging Ltd) funded a research project to develop both new techniques of extracting sediment transport data from swath bathymetry [3.6] and the use of this data in hydrodynamic and sediment transport models in the Eastern English Channel and the Severn Estuary.

3. References to the research (the best 3 illustrating quality of work are starred)

*[3.1] Bull, J.M., Quinn, R. and Dix, J.K. Reflection Coefficient Calculation from Marine High Resolution Seismic Reflection (Chirp) Data. *Marine Geophysical Researches*, 20, 1998, 1-11.

[3.2] Bull, J.M., Gutowski, M., Dix, J.K., Henstock, T., Hogarth, P., Leighton, T.J. and White, P.R. Design of a 3D Chirp sub-bottom imaging system. *Marine Geophysical Researches*, 26, (2-4), 2005, 157-169

*[3.3] Plets, R.M.K., Dix, J.K., Adams, J.R., Bull, J.M., Henstock, T.J., Gutowski, M. and Best, A.I. The use of a high-resolution 3D Chirp sub-bottom profiler for the reconstruction of the shallow water archaeological site of the Grace Dieu (1439), River Hamble, UK. *Journal of Archaeological Science*, 36, 2009, 408-418.

[3.4] Westley, K. and Dix, J. Coastal environments and their role in prehistoric migrations. *Journal of Maritime Archaeology*, 1, (1), 2006, 9-28.

*[3.5] Vardy, M. E., Dix, J. K., Henstock, T. J., Bull, J. M. and Gutowski, M. Decimeter-resolution 3D seismic volume in shallow water: a case study in small-object detection. *Geophysics*, 73, (2), 2008, B33-B40.

[3.6] Cazenave, P.W., Dix, J.K., Lambkin, D.O. & McNeill, L.C., 2013. A method for the semi-automated objective quantification of linear bedforms from multi-scale digital elevation models. *Earth Surface and Processes Landforms*, 38 (3), 221-236

Research Funding: SERC: Acoustics Methods in Archaeology (1994-97: £168k)

EPSRC-MOD: A 3D Chirp Sub-bottom profiling System- a new tool for delineating the sub seabed (GR/R12695/01: 2001-04, £303k: www.noc.soton.ac.uk/soes/research/groups/3dchirp/

EH- ALSF Projects (2001-11: £723k): High resolution sonar for the archaeological investigation of marine aggregate deposits [141 downloads since 2011: same dates for download figures below] (archaeologydataservice.ac.uk/archives/view/highsonar_eh_2008/); Re-assessment of the archaeological potential of continental shelves ([~/continentshelves_eh_2008/](http://archaeologydataservice.ac.uk/archives/view/continentshelves_eh_2008/)) [435 downloads]; Modelling Exclusion Zones for Marine Aggregate Dredging ([~/dredging_eh_2008/](http://archaeologydataservice.ac.uk/archives/view/dredging_eh_2008/)) - [172 downloads]; Development of Regional Sediment Mobility Model for Submerged Archaeological Sites ([~/sediment_eh_2010/](http://archaeologydataservice.ac.uk/archives/view/sediment_eh_2010/)) [78 downloads]; and The Relic Palaeo-landscapes of the Thames Estuary (www.cefas.defra.gov.uk/alsf/projects/natural-seabed-resources/09p126.aspx)

EH Funded: People and the Sea: A maritime Research Agenda for England

www.archaeologyuk.org/books/ransley2013

4. Details of the impact

The nature of our work on seabed and near surface imaging and interpretation provides us with wide reaching and significant impact across national and international, commercial and government sectors including: sonar product development; marine cultural heritage management; mineral resource management and assessment; expert analysis to major offshore infrastructure projects; military and law enforcement support; and commercial and military sector training:

a. Commercial: Technological Development 2D & 3D Chirp Systems: The work on 2D and 3D Chirp systems have been subject to a commercialisation agreement [5.1] best summarised by the President of Kongsberg Geoacoustics Ltd. [5.2]: *"The developments in 2D Chirp technology undertaken by UoS and feedback from their research projects using the systems, have been integral to the ongoing development of our leading sub-bottom profiler products (c.£2 million income), whilst our current agreement with them to commercialise their 3D Chirp system is now coming to fruition with the first systems being delivered to clients (first sale to China in 2013). Their academic expertise in sub-bottom data processing and interpretation are world class, helping us to keep our products competitive in a truly global market and our development grounded on cutting edge but solid science"*.

b. Government Statutory Advisors - Heritage: Building on HEFCE, Government and industry funded research, UoS researchers have established an international reputation for setting standards for best practice in marine high-resolution geophysical surveys for the investigation of archaeological sites, with national and international heritage managers. As recognised by the Head of Marine Archaeology at English Heritage [5.3] *"In terms of impact on knowledge and innovation, (the work of UoS) has significantly increased our knowledge and understanding of marine archaeological sites including historic wrecks and prehistoric landscapes which are now submerged. The research has reached many sectors including marine development environmental impact methodologies."* EH have called on this expertise frequently, most recently in the development of their *Marine Geophysical Guidance* [5.4] which *"has been well received by curators and industry"* [5.3] and the inclusion of Dix on both EH's Historic Wreck Panel and the Expert Panel specially convened to advise the MOD on the sensitive site of the *Victory 1744* (2012-present). Dix was also brought in by EH to deliver the UK contribution, of regional and local scale sediment transport models, to an EU web-based heritage management system.

c. The Crown Estate Advisors – Geological: In addition to work on archaeological sites our expertise in near surface imaging and analysis of mineral resources has been strongly endorsed by the Head of Mineral and Infrastructure at The Crown Estate [5.5] who summarised our impact as follows: *"When I took on the role of Head of Minerals and Infrastructure at The Crown Estate they (UoS) were the natural choice to bring into our network of experts to provide rapid and professional advice on all aspects of seabed geology. The recent work they have undertaken on the sand resources of the Thames Estuary [5.6] currently underpins our internal strategy of resource management for this critically important area"*. Marine aggregate resources represent revenue of c. £15-20 million per annum to the Crown Estate.

d. Offshore Marine Infrastructure Development and Resource Assessment: approaches to the acquisition and analysis of geological and geophysical data for cultural heritage management have been adopted by two major environmental and engineering consultancy firms AMEC Ltd. (a FTSE 100 company with offices and projects in 40 countries) and Ramboll Ltd. (190 offices in 21 countries). With AMEC, Dix and Sturt have led the marine archaeological component of two major nuclear power station re-developments (Hinkley Point C and Sizewell, client EDF, 2009-2016), and with Ramboll they are responsible for the entire marine archaeological component of the largest UK offshore windfarm which is currently being built - the London Array (Dong Energy, EoN and Masdar). When fully operational this windfarm will represent 7% of Government's 2015 targets for renewable sources. As stated by an Associate Director of AMEC Environment and Infrastructure UK [5.7] *"The approach to environmental impact assessment for the marine archaeological record developed by the UoS and used in collaboration with AMEC on the Hinkley Nuclear Power Station has been very well received by both the client (EDF) and the regulator (EH). The success has been such that we are spinning out the approach to projects not just in the UK but across our global company."* In addition, Dix and Sturt have also provided expert marine archaeological

support to major submarine pipelines and telecommunication routes (e.g. the GLO-1 Cable route Britain - Nigeria 2007-2008 and the Coots pipeline to the North Sea Carbon Storage facility off Teesside, 2008, both with METOC Ltd) and international power cables (e.g. Britned, 2004-2005: Britain - Netherlands). In 2013, Dix and Sturt established a spin-out group (Coastal and Offshore Archaeological Research - Southampton) with c. £320k of projects already in place.

Dix and Sturt also led the geological and archaeological component of the Outer Thames Regional Characterisation project. This was one of four Regional Environmental Characterisation projects commissioned by DEFRA as part of the Marine Environment Protection strand of the ALSF. These developed understanding of the seabed geology and the biological and historic environment assets of the most intensively used stretches of water on the UK shelf. This work resulted in a publically available report and WebGIS [5.8] which has had 830,750 hits since June 2011. This work also fed into the Marine Aggregate Regional Environmental Assessment initiative, that provided a strategic view of future marine aggregate extraction activities and their potential cumulative and in-combination effects to ensure that individual dredging permissions are suitably informed. This strategy has been endorsed by The Crown Estate and the Marine Management Organisation.

e. Military and Law Enforcement support: following the initial success of the 3D Chirp we were approached by the Ministry of Defence in Salvage & Marine Operations to undertake a buried object detection (including Unexploded Ordnance) survey in 3 Basin, Devonport dockyard, prior to its potential use as the storage site for the UK, decommissioned, nuclear submarine fleet. This was fully accomplished and a pre-use dredging strategy was successfully derived (permission was granted for this data to be used for publication [3.5]). Bull and Dix were commissioned by the Royal Navy (2002-present) to train staff and advise on the operations of the Royal Navy's hydrographic vessels. This included attending sea trials, teaching at *HMS Drake* and onboard the vessels, and the writing of the Standard Operating Procedures for Chirp systems on the RN's fleet.

Dix has also modified the techniques developed at UoS for the investigation of marine archaeological sites for the underwater detection of buried cadavers in response to requests from both UK and international law enforcement agencies. As a consequence he was made an Expert Adviser for Hydro-Forensics for the Serious Organised Crime Agency [5.9] and has, since 2008, provided expert advice on 15 criminal cases both in the UK and abroad. He has been an invited speaker at the Police National Diving and Marine Symposium (2012) and has provided on-going advice on underwater search strategies to the Home Office Science UK's Centre of Applied Science and Technology, the Australian Federal Police and the Netherlands Police Agency.

f. Training and Personal Development: Since 2008 more than 180 people have been trained in high resolution seafloor surveying, many of whom have entered the marine surveying sector and extended the reach of the techniques developed at UoS. As stated by the Managing Director of Fugro-EMU Limited [5.10] "*We have found the skills base in high resolution marine geophysics of the marine science students coming out of Southampton University to be at the very highest level. Consequently, the Fugro EMU Ltd Geosurvey group (as well as the wider Fugro Offshore Survey divisions and many of our competitors) has been, and continues to be, underpinned by Southampton graduates*".

5. Sources to corroborate the impact

[5.1] <http://www.soes.soton.ac.uk/research/groups/3dchirp/index.htm>

[5.2] President, Kongsberg GeoAcoustics Ltd

[5.3] Head of Maritime Archaeology, English Heritage

[5.4] Marine Geophysics Data Acquisition, Processing and Interpretation, Guidance Notes, English Heritage (2013) www.english-heritage.org.uk/publications/marine-geophysics-data-acquisition-processing-interpretation/

[5.5] Head of Minerals and Infrastructure, The Crown Estate

[5.6] Popplestone, C. & Dix, J.K., 2012. Distribution and Resource Assessment of Sand Deposit in the Outer Thames Estuary/Southern North Sea. Publication for The Crown Estate (In repository).

[5.7] Associate Director, AMEC Environment & Infrastructure UK Ltd.

[5.8] Thames REC Interpretation & Analysis WebGIS: <http://www.thamesrecgis.org.uk/>

[5.9] <http://www.soca.gov.uk/about-soca/specialist-operations-centre/crime-team>

[5.10] Fugro-EMU Ltd Managing Director.