Sustained UK marine observations. Where have we been? Where are we now? Where are we going?

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This introduction traces the earliest interaction of ancient humans with their marine environment, through marine explorations in the Middle Ages and Renaissance, to the development of early marine science in the Enlightenment. This sets the scene for how marine observations developed in the modern era and explains the status of today’s marine observation networks. The paper concludes with an assessment of the future needs and constraints of sustained marine observation networks and suggests the lessons from a long history might be the key to the future.

1. Where have we been: an historical background

It is axiomatic that the historical record, in the sense of the chronology of the sequence of past events, explains how we have arrived at where we are today. There are many wonderful examples of scientific history, each rich in the development of the science described, and some are also illuminating and fascinating in the human dimension; for example, the discovery of the solution for determining longitude [1]. Darwin’s account of the voyage of the Beagle is also a wonderful account of the development of ideas [2]. Appropriately for this Theme Issue, both these examples have observations, primarily at sea, as their principal subject. Many scientists pay little attention to the past (which I believe is a wasted opportunity) preferring perhaps Bacon’s view: ‘that which is past and gone is irrevocable, and wise men have enough to do with the present and things to come’ [3]. I take a different view. I believe there is value in considering the past: because, at
worst, it explains the present state, which is interesting intellectually, but, at best, it can provide us some useful context and insights perhaps to the future. In this sense, I am an advocate of the view, attributed to Aristotle: 'if you would understand anything, observe its beginning and its development' [4]. I am convinced that an appreciation of the examples of the history of marine observations provides a guide, if not a solution, to what is needed for the long-term sustainability of marine observations for the UK.

2. Pre-history and early civilizations

Human societies appear always to have had a well-developed ‘culture’ of the observation of their environments. Some of the earliest artefacts, pre-dating even the advent of writing systems appear to show astronomical images and records inscribed on stones, bones and on the walls of caves (http://www.ancient-wisdom.co.uk/astronomy.htm#Chronology; accessed 21 February 2014). There must also have been a strong oral culture of sharing information based on observations in order to develop proto-agricultural systems and move from hunter–gatherer societies. These early societies were driven by the practical need for survival, thus the primarily astronomical observations they made are assumed to have been the basis of the knowledge needed for, for example, when to plant crop seeds or when to prepare for the hunting of prey animals.

It seems likely, however, that the protoscience observations were not only of practical value or ‘scientific’, because there appears to have been an interesting admixture of the observations with spiritual considerations (http://news.bbc.co.uk/2/hi/science/nature/325290.stm; accessed 21 February 2014). For example, there has been considerable debate for centuries about the purpose of Stonehenge (Salisbury Plain, UK), one of the most striking Neolithic monuments in the world. It seems most likely that Stonehenge served as some form of astronomical observatory. However, there are other features, such as what appear to be ceremonial burials within its boundaries, to suggest that Stonehenge also was of considerable spiritual importance. Göbekli Tepe, a remarkable archaeological site in Turkey, which became known to the general and academic communities only in 1963, seems primarily to have been a religious site, although only a small fraction of the site has been excavated. Aside from its scale, its antiquity challenges the generally held understanding for the timeline for Neolithic developments and one can only speculate whether Göbekli Tepe might reveal similarly intriguing science connections in due course.

Whatever the purpose of Stonehenge, Göbekli Tepe and other similar structures, it is clear that the societies responsible for their construction were sufficiently motivated to invest considerably in their construction. The early developments of science and scientific ideas in all past civilizations, for example those in Egypt, China, Mesopotamia, India and Central America, all appear to have had at their origin, and independently, a strong basis of observation, primarily astronomical. This is not surprising given the obvious nature of the seasons and impact of other astronomical phenomena on individuals and societies; it is difficult not to note a full moon, for example, when one does not have artificial light. It is interesting to speculate how this early protoscience developed to varying degrees over millennia to provide the foundations of modern science. Whatever the developments, it is certain these were only made possible because humankind became less dependent on mere survival. This became possible primarily through the success of the development of agriculture, which enabled individuals to spend time on creative activities rather than spend time only finding food and shelter. Thus, the knowledge gained from the observations made by our forebears, when turned into information of practical value, ‘released’ early societies from their constraints and allowed them to develop. This has modern-day parallels in the pressure to carry out science ‘with impact’.

There are many examples of early civilizations and human activity around the world in coastal regions. In North America, the northwestern Pacific coast is particularly rich in early edifices and artefacts linked to the settlement of the continent from Asia. The Atlantic coast of Europe is also well endowed with prehistoric examples of human settlement. Coastal settlements would
have provided the advantage of a relatively easy-to-find food supply ‘on the doorstep’ and the record from coastal shell-middens suggests that the marine environment was an important food source for these early settlements. These early communities must have had knowledge of the semi-diurnal, spring–neap and annual tidal cycles in order to take advantage of the environment, for example through fishing [5].

Another key interaction between the marine environment and early human societies was the many migrations and colonizations that have occurred, seemingly since humans evolved. Some of these migrations involved significant marine journeys; for example, the colonization of the Pacific, including Australasia, from Asia. The migrations of early hominids, which started initially via land-bridges during periods of lower than current sea-levels, but which ultimately involved challenging sea journeys, must have required an intimate knowledge of the marine environment, acquired from detailed observations. Clearly, any observations made were not carried out in any systematic or planned way, in the sense that observations were made later—hence the term ‘protoscience’ used earlier. However, there is considerable evidence of regular trade occurring in these early societies and it is clear there was a benefit in making these journeys and the albeit perhaps accidental accumulation and use of the knowledge and information required to make them. This thesis is a feature that will run as a common thread throughout this paper. There are fascinating periods of history relevant to this discussion—for example, the Phoenician society [6] and the early Arab societies and their considerable sea journeys and colonizations. The development of mathematics and navigation occurred in parallel with these explorations. A magnificent tour de force about the history of marine exploration from the earliest times to the present day has recently been published [7].

3. Middle Ages and the Renaissance

Leaping forward many millennia (recognizing this introduction is not an inclusive history), any consideration of early marine observations must include the hugely impressive and influential voyages of the Scandinavian peoples during the eighth to eleventh centuries. As well as significant voyages around the entire coast of western Europe, the Mediterranean Sea and the Black Sea, considerable voyages (and in some cases colonizations) were carried out to Iceland, Greenland and North America. These voyages were not ‘one-offs’ in the sense of exploration into the unknown, thus these early navigators must have used effective systems of recording data and observations, if for no other purpose than to return to their places of departure. We should not underestimate our early forebears in their endeavours. However, an interesting question is: why did the individuals responsible for these voyages take the considerable risks of these voyages? They were most certainly not driven by scientific enquiry! Rather, there was benefit for the individuals and society and realized through the accumulation of knowledge.

Approaching more recent times, the fifteenth and sixteenth centuries saw a period of considerable marine activity linked to imperialism, personal gain and national status. There is a huge history of marine voyages and journeys from this period [7] but those of Bartholomew Dias (1487–1488), Christopher Columbus (1492–1500), Vasco da Gama (1497–1499), Ferdinand Magellan (1519–1522) stand out among the most famous and perhaps important. While a discussion about which of the voyages of discovery were the most important is of interest for historians, there is no doubt that careful observations of the marine environment and their recording was a feature of the individuals who made these voyages. Excellent and striking examples of the outputs of these voyages were the maps and charts of the regions explored. Although doubtless intended for navigational purposes, and while sometimes fanciful (e.g. including depictions of sea serpents), these charts were clearly based on first-hand, expert and accurate observations, including oceanographic features. For example, the remarkable 1539 Carta Marina by the Scandinavian Olaus Magnus shows entirely accurately many of the frontal and
eddy features of the northern North Atlantic and Norwegian Sea, only recently revealed by modern-day satellite techniques [8].

4. The Enlightenment

The Renaissance period laid the foundations for modern science, which in turn was developed into what we recognize today during the Enlightenment. The science of the sea and its observation was not restricted as a specialism but rather was as an element of the open and free investigation of the natural world by inventive minds. For example, almost ‘household-name scientists’—Boyle, Halley, Descartes, Galileo, Newton, to name but a few—were involved in the early study of the oceans. Less familiar, perhaps, but of this era, was Luigi Ferdinando Marsili (1658–1730) who arguably could be dubbed the father of oceanography. Marsili published two treatises: on the currents of the Bosphorus (1681) and a general physical oceanography (1725). Marsili’s works could be considered to be the transition between the early era of marine observations and study and the modern day; however, like many chronologies, there is scope for interpretation as to when a particular period ends or starts.

But before moving to the modern era of ocean observations, we need to bring Benjamin Franklin (1706–1790) into the discussion. Franklin, a polymath ‘extraordinaire’, and a statesman and ‘father’ of the USA, was the first Postmaster General of the USA from 1775. During this time, he became aware of the difference in time taken for mail to be delivered between the UK and the then Colonies: mail to the UK typically took two weeks less to be delivered than mail from the UK. Following extensive investigations, including collaborations with mail packet and whaler captains and personal observations made at sea, Franklin consolidated the notion of ocean currents in the Atlantic, hinted at for many years. He eventually published his iconic chart of what he called the Gulf Stream (http://oceanmotion.org/images/franklin-gulf-map.jpg; accessed 14 October 2013). As important as this chart is to the canon of scientific endeavour, one of its significances and benefits, and Franklin’s motivation, was to provide a commercial advantage for trans-Atlantic trade.

Another notable individual who provides a link from the earlier periods to the modern is Maury. Matthew Fontaine Maury (1806–1873) wrote The Physical Geography of the Sea [9], which was a hugely significant contribution at the time and which many consider was the first oceanographic text. However, as already noted, this claim is more accurately attributed to Marsili; indeed, Maury makes reference to Marsili in his introduction. Nevertheless, Maury’s text is excellent and eminently readable (it is available as a new facsimile) and is notable, in my view, for other reasons. First, Maury makes it clear that the data he used were based on observations from volunteer observers and navigators on merchant and warships at sea, pre-empting the notion of using ships of opportunity as platforms for marine observations by many decades. Second, in his introduction Maury writes: ‘... the aim of the author is to present the gleanings from this new field [of research] in a manner that may be interesting and instructive to all, whether old or young, ashore or afloat, who desire a closer look into the “wonders of the great deep” ...’. Whereas in his conclusions he writes: ‘... the great end and aim of all this labor and research are in these, and consist in the shortening of passages [at sea]—[and] the improvement of navigation.’ Thus, Maury encapsulates the two motivations for making marine observations; on the one hand, for ‘research’, that is, for their intrinsic value, while on the other hand for operational/commercial reasons. This tension continues today and is arguably at the root of the difficulties in maintaining sustained observations.

The mid-nineteenth century saw a great flowering in all aspects of science, including marine science. A major driver for increased knowledge of the marine environment was the development of submarine cables for telegraphic communications (more evidence for commercialism being the driver for establishing observations). This resulted in a significant increase in observations of the deep sea, particularly bathymetry. However, this was also a period of the development in biology. There were many great scientists involved in these activities: Edward Forbes, Charles Wyville Thompson, Michael Sars, Albert I of Monaco, to name but a few.
5. The beginning of the modern era

I take as the starting point of the modern era the HMS Challenger expedition (1872–1876). Much has been written about this expedition [10,11] (http://www.challenger-society.org.uk/the_society/history; accessed 24 May 2014), so I will not go into detail. However, it was a remarkable expedition, lasting nearly four years, it covered over 65,000 nautical miles, and studied every ocean apart from the Arctic Ocean; HMS Challenger was the first propeller-driven vessel to cross the Antarctic Circle. Although involving only 360 ‘stations’ many of the findings remain valid today, and the 50 volumes of reports are masterpieces and available online [12] but outstanding in ‘the flesh’. Remarkably, despite the paucity of stations, the bathymetric chart of the World Ocean is surprisingly accurate and the estimated average depth calculated was within 10% of what we estimate today (approx. 4200 m), an amazing achievement given the sounding equipment used weights suspended on piano wire! But more pertinent to the discussion here is the question: what was the motivation behind this major investment of public finances (it was a UK government-funded expedition) into the observation of the ocean, albeit a one-off as opposed to sustained observations? The Challenger expedition is generally considered to be the first expedition funded for the purposes of oceanography and certainly the stated objectives were entirely scientific. However, a case could be made that the principal motivation was one of scientific imperialism. Consider the geopolitics of the time: the British Empire, and its maritime influence, was at its zenith. The growing importance and prominence of the marine environment at that time, linked, for example, to submarine cable laying; the developing prominence of the USA as a world presence in marine science (e.g. Maury’s Physical Geography was a prominent publication); and suspicions that both the USA and Germany were about to mount similar expeditions were strong motivations for the UK to be the first to mount such a voyage. Accordingly, Charles Wyville Thompson, with the support of the Royal Society, appealed to the UK Chancellor of the Exchequer for funding, which was duly granted with the added benefit of the support of the Royal Navy. This was a great success, but one has to speculate whether it was the scientific argument that prevailed or the assurance of the UK as the world’s leading maritime nation.

Whatever the wider motivations of the Challenger expedition, there were considerable developments in marine science throughout the remainder of the nineteenth century, including the establishment of the first dedicated marine science laboratories, for example, in Naples (1872), Roscoff (1872) and Plymouth (1884). Arguably, the establishment of these stations provided the first examples of sustained marine observations, as we shall see later.

No consideration of sustained marine observations would be complete without reference to the International Council for the Exploration of the Sea (ICES). ICES was formed in 1902 and was the first organization in the world with the remit to provide advice on the establishment of marine observations, primarily with a focus on supporting commercial fisheries. ICES has adapted in its 100+ years of existence, but it has largely maintained its ‘core purpose’ [13]. Within its sphere of influence, ICES has been hugely influential, being responsible inter alia for the introduction of standard seawater, the Nansen bottle and the first marine database. According to Hempel, ICES was the ‘midwife’ [14] for the formation of the Scientific Committee for Oceanic Research and the Intergovernmental Oceanographic Commission (IOC). Although ICES was and remains limited in geographical scope to the North Atlantic, it is reasonable to suggest it was the most important oceanographic ‘institution’ in the world up to around the early 1960s, with its influence extending considerably beyond fisheries science. It is also not unreasonable to suggest that ICES is now rather little known (if at all) by many marine scientists outside of fisheries science. It is also worth speculating on the greater role ICES might have played in driving forward a fully comprehensive observing network considerably beyond what we have now.

Now that my rather limited history has ‘arrived’ at the twentieth century it is appropriate to acknowledge Margaret Deacon’s tour de force consideration of the history of marine science to 1900 [15]. My limited account is eclipsed by the considerable and long shadow of Deacon’s never-yet-bettered history, which is an outstanding source of information and erudite interpretation of the development of Western marine science.
Ocean weather ships (OWS) were an interesting, albeit short-lived, chapter in the story of sustained marine observations, a short account of which will provide a ‘bridge’ between the previous historical account and the modern-day position. The motivation for the weather ships (as the name suggests) was to provide consistent, primarily atmospheric data for weather forecasting. As we have seen in connection with Maury, meteorological and other data had long been provided by volunteer merchant ships. However, the inconsistent location and timing of the data collection were not particularly useful for the development of the synoptic data that are fundamental for weather forecasting. Weather ships were first introduced in the Atlantic just before the Second World War but came into their heyday in the late 1940s through to the 1970s. Figure 1 shows the location of the 13 ships in the North Atlantic in the mid-1950s. (OWS were also located in the Pacific Ocean.) As well as a comprehensive set of atmospheric measurements, including upper atmosphere measurements, from radiosonde balloons, oceanographic data were collected, including to deep depths. These measurements were elaborated on as time progressed and by the time of the demise of the ships some of these measurements were very comprehensive [16]. Sverdrup’s classic ‘critical depth’ work [17] was based on data from OWS Mike located between Norway and Iceland. The OWS were gradually withdrawn during the 1970s; however, OWS Mike remained operational until mid-2009, by which time it had provided the platform for the longest running deep-water oceanographic data series in the world.

A consideration of the responsibility for the funding and the stakeholders in the OWS is revealing. While the OWS were clearly initiated for weather forecasting, it was the fledgling airline industry and, for the Atlantic ships, the development of trans-Atlantic flights that provided the motivation for their establishment. This newly emerging industry had a need not only for accurate information about upper atmosphere conditions, for which the OWS were ideally suited, but the OWS were also fitted with radiobeacons, which provided essential navigational information for aircraft. The OWS also provided a valuable and successful search and rescue capability [16]. There was a decreasing need for the OWS as the airline industry developed and navigational and weather forecasting information became more sophisticated, such that in 1975 air-industry funding support was withdrawn. Four OWS were continued for a number of years under the auspices of the World Meteorological Organization (WMO) but ultimately this...
support was removed. Thus, here is a further example of the short-term needs of the commercial market influencing the oceanographic measurement ‘landscape’. The Voluntary Observing Ship (VOS) programme, run under the auspices of the WMO, continues the tradition of worldwide meteorological observations (and some basic ocean observations) and is carried out by over 6000 ships.

7. The present day—a summary of the global position

Globally, there are numerous initiatives currently operating an increasingly sophisticated network of marine observation systems. These are often integrated with meteorological observation systems but to try to understand how all this operates requires ‘navigating’ through a bewildering ‘acronym soup’. The ‘senior’ party with the overall responsibility for the coordination of the global observing system is the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the WMO and IOC. There are of the order of 8000 observation ‘platforms’ comprising: tide gauges; moored and drifting data buoys; Argo profiling floats; gliders; VOS programme; and various ocean carbon programmes. The whole programme is formally integrated through the Global Climate Observing System (GCOS) of the WMO, which also includes terrestrial observation systems and the ‘constellation’ of satellites with Earth observing sensors. There are approximately 70 countries involved in this marine observation network with the USA providing almost half of the platforms.

Summarized in this way, the network seems relatively simple and straightforward, but each of the components has multiple layers of organization and stakeholders. For example, the coordination of the buoys and profiling floats is accomplished through the JCOMM in situ Observations Programme Support Centre; although the drifting buoys are coordinated by the WMO/IOC Data Buoy Cooperation Panel, whereas the IOC-sponsored Global Ocean Observing System has a particular responsibility for the wider coordination of marine observing, which in turn has regional subdivisions; for example, the Southern Ocean Observing System. Organizationally, the system is staggeringly complex if one delves into the details.
one has to be impressed by the emerging success of the endeavour. For example, figure 2 is a snapshot of the global distribution of observations over a 3 day period (29 May–1 June 2014), representing nearly two million observations from almost 3500 individual platforms [18]. This appears to represent significant progress towards a sustained observing system.

8. The present day—a summary of the UK position

What of the UK’s position? The UK is an active player in the global marine observing network, which of course includes UK waters. The UK Met Office has a lead role in GCOS through the international responsibility for the quality of the data obtained by the VOS and buoys. And the UK contributes to the observations directly through the deployment of Argo floats—about 124 UK floats were estimated as operational at the end of May 2014, although none were contributing to data collection in UK geographic waters [19]; however, that is not really their purpose. Similarly, while many of the global VOS, including UK-registered ships, regularly collect data in UK waters, this can only be considered a contribution to a network of sustained observations of UK waters.

I acknowledge being narrow-minded in the remainder of this discussion, because I consider only UK geographic waters. The UK has 14 British overseas territories—for which the UK has various responsibilities—the majority of which have significant marine domains and resources. There are significant and sustained marine observation activities in some of these territories, for example, the Rothera Oceanographic and Biological Time Series at the Rothera research station on the Antarctic Peninsula in the British Antarctic Territory, and around South Georgia; however, I have not considered non-UK geographic waters further.

The UK has one of the longest and sustained networks of observations of its own waters in the world. Tidal measurements were one of the first systematically recorded marine observations. Started in Liverpool in the 1760s, there has been a continuous record of tide measurements since, in a network that now comprises 44 tide gauge stations around the UK. The UK Environment Agency, an agency of the UK Department for Environment, Food and Rural Affairs, currently supports the network. The network was formally established and given long-term support following the serious floods in eastern England (and The Netherlands) following storm surges in January 1953, which resulted in significant loss of life and damage to property. These stations contribute to the global network which ultimately provides the dataset of the Permanent Service for Mean Sea Level [20], which in turn coordinates the JCOMM Global Sea Level Observing System [21]. There is a clear dual motive behind the UK tidal/sea-level measurements: a valuable, long-term, research-led interest in sea-level rise and ocean circulation variability, but also a more potent, short-term need for immediate flood protection for the UK. It is unthinkable now that such measurements would not be sustained. But one might speculate about what the position might be had there not been the floods of 1953. As an aside, the human and economic consequences of the 1953 floods led to the large capital investment of the Thames Barrier to protect the economic interests of London.

Aside from the tidal observations, the first consistent and sustained observations of the UK marine environment were those conducted by the Marine Biological Association of the UK (MBA) off the coast of Plymouth, started towards the end of the nineteenth century. These activities were part of the great ‘flowering’ of interest in marine science touched on earlier. As well as the burgeoning interest in ‘natural history’ that developed in the mid to late Victorian era in the UK, the role of observations in supporting fisheries was an important driver for the MBA. Thus, the connection between science and commercial gain was reinforced.

The long-term observations off Plymouth continue in a series of programmes run by the Plymouth Marine Laboratory, the MBA and the Sir Alister Hardy Foundation for Ocean Science, collectively known as the Western Channel Observatory (WCO) [22]. The WCO has developed over the years and now comprises a comprehensive set of oceanographic measurements collected by remote sensing, data buoys as well as sampling using research vessels. Despite significant difficulties in convincing the funding agencies responsible for funding this activity, the WCO has managed to survive with only the occasional break since the beginning of the twentieth
Figure 3. Sampling effort of the Continuous Plankton Recorder Survey in the North East Atlantic 1949–2012. Warm/hot colours (red/orange) represent more intense sampling than cooler colours (light blue). SAHFOS. Platform provided by Google Earth.

century. A similar series of relatively sustained observations have been made around Scotland, both inshore and offshore through the activities of the Scottish Association for Marine Science [23] and its forerunners, but these also have had challenging funding difficulties from time to time.

Many other similar observation programmes have come and gone and come again over the past decades, including: the Port Erin Marine Time Series (Isle of Man); the Dove Marine Laboratory Time Series (northeast England); the Liverpool Bay Observatory; Menai Straits Time Series and others. Invariably, these programmes require either the support of the host institution, usually a university, or a short-term research grant to a particular individual; this is not a good basis for the establishment of a national sustained observatory.

The Continuous Plankton Recorder Survey (CPR) is one of the longest established series of UK marine observations. The Survey was established in 1931 by Sir Alister Hardy and has been run continuously since then by the Sir Alister Hardy Foundation for Ocean Science and its antecedents, making it one of the longest established marine biological data series in the world [24]. The CPR measures over 500 taxa of phytoplankton and zooplankton from the surface ocean using a standalone plankton recorder towed by volunteer ships. The CPR typically samples on routine ships’ routes at repeat intervals, often monthly, and in 2013 covered over 140,000 nautical miles. The principal area of activity is the North East Atlantic and North Sea, and thus is a comprehensive observatory of UK and closely related waters (figure 3), although CPRs are now deployed in the North Pacific and Southern Ocean.

There also have been consistent, sustained and extensive observations carried out for decades by the UK fishery laboratories: principally (now) the Centre for Environment, Fisheries and Aquaculture Science, in England; the Marine Scotland Marine Laboratory; and the Agri-Food and Biosciences Institute in Northern Ireland. Many of the observations have changed little since their inception, for example the bottom trawl and fish egg surveys, which provide data for the legislative requirements for fisheries management. However, the observations have expanded apace as the remit of the laboratories have changed to take a more ‘ecosystem approach’ and environmental concerns, for example climate change, have grown, together with technology developments. The number and scale of the observatories have also expanded considerably because of the significantly increased involvement of the UK Met Office. Add to all this the substantial monitoring requirements to support European Union environmental protection
Table 1. Needs for marine data and information by broad categories of stakeholders.

<table>
<thead>
<tr>
<th>stakeholder</th>
<th>description</th>
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<tbody>
<tr>
<td>environment</td>
<td>monitoring and protection, e.g. EU Directives</td>
</tr>
<tr>
<td>energy</td>
<td>oil and gas, increasingly renewable, compliance</td>
</tr>
<tr>
<td>military</td>
<td>planning, day-to-day ops, the ‘battle space’</td>
</tr>
<tr>
<td>public safety</td>
<td>flooding, shipping forecasts, search and rescue</td>
</tr>
<tr>
<td>transport</td>
<td>routing and ports and harbours</td>
</tr>
<tr>
<td>leisure</td>
<td>sailing, surfing, diving, angling</td>
</tr>
<tr>
<td>fishing</td>
<td>regulation, ecological forecasts</td>
</tr>
<tr>
<td>academic</td>
<td>quest for knowledge</td>
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<tr>
<td>voluntary</td>
<td>data for campaigns and interest</td>
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legislation, carried out by the UK Environment Agency, and the contributions to the European Space Agency for satellite observations and we have the potential for a very incoherent picture!

The current complexity of all this activity is summarized in figure 4 [25], which is only a partial picture because it does not show the considerable activities carried out in the very near shore waters and estuaries. How can all these multiple activities be brought into some semblance of order? This is the primary purpose of the UK Marine Monitoring and Assessment Strategy (UKMMAS), which was established in 2005 and now falls under the auspices of the UK Marine Science Coordination Committee (MSCC), which was formed in 2008, following a House of Commons inquiry into UK marine science. One of the first tasks of the MSCC was to develop a strategy for UK marine science, which was introduced in 2010 [26]. One of the ambitions articulated in the strategy is to develop a coordinated marine monitoring network, particularly to support UK strategic and marine and maritime commercial interests. The UK Directory of Marine Observing Systems, an output of the UKMMAS, provides a useful portal to the wide range of UK observatories. While the development of a coherent network and provision of data are wholly worthy ambitions, one wonders how achievable they are given the multiplicity of stakeholders and relationships involved (figure 5 [27]). There is surely a need for further rationalization?

9. Where to next?

The considerable challenge the UK faces is to resolve what we have now, that is, the multiplicity of observations, which have essentially evolved over time, with a multiplicity of needs and interests. Table 1 summarizes why broad categories of stakeholders need marine observations, which need to be converted into ‘information’ to be of use and value. There is no doubt that each of the stakeholder groups identified in table 1 would support the notion of a sustained UK marine observation network. So what are the barriers to success? There is certainly no shortage of ideas or technology to develop a sustained network. Marine observation technology is developing at an extraordinary rate, with the advent of increasingly complex autonomous surface and subsurface vehicles from which increasingly complex sensors are being deployed. The technology to deploy cabled observatories is now also very well developed. Nor is there a lack of willingness to deploy this new technology; in fact the rush to deploy all these ‘new toys’ makes the need for a coordinated network all the more urgent.

However, one barrier is the potential for a lack of agreed priorities and responsibility among the multiple stakeholders. Figure 6 [28] attempts to brigade the stakeholders into four broad categories of user: policy, science, voluntary and industry. Each of these users has different motivations and the sources of funding tend to be different. This is clearly a simplification of reality and there is considerable overlap between the four user groups and their interests. For
example, industry frequently has interests in knowledge as a resource to further their business and not just interests in legislation and regulation. Nevertheless, the potential for conflicting priorities is something to be considered. Other barriers to success include the long ‘value chain’: from the collection of the data; the development of useful, quality-controlled products and information; the dissemination of the data; and data archiving. The data themselves may be a barrier, with different users having different data policies and questions over ‘who owns what?’ But by far the biggest barrier to success is the access to funding, especially the mismatch between the long-term need and the invariably short-term nature of the conventional funding models and planning cycles.

But could completely new initiatives emerge to create a different funding model? For example, could volunteer observers provide at least a partial solution? Volunteers are identified in both table 1 and figure 6, and we have already seen the importance of observations made from volunteer ships. However, there is a developing interest in the use of volunteers to make scientific measurements—the so-called citizen science. Tweddle et al. [29] provide a background

Figure 4. The current status of the multiplicity of marine observations (see legend) carried out in UK waters by the wide range of contributors. Not included, for the sake of clarity, are the extensive coastal measurements made by the UK Environment Agency and the UK fisheries laboratories, or the UK tidal stations. Solid continuous lines are the boundaries of national waters [25].
Figure 5. The multiplicity of potential stakeholders, organizations and contributors to the Marine Science Coordination Committee/UK Marine Monitoring and Assessment Strategy sponsored UK sustained marine observation network [27].

Figure 6. Stakeholders with interests in marine observations, grouped into four main categories of policy, science, voluntary and industry. Based on Environment Research Funders Forum [28].

to citizen science (primarily from a biodiversity perspective) and describe the characteristics and requirements for good projects. One of the key requirements for citizen science, and its biggest challenge, is to ensure data quality. This can be achieved as exemplified by an extensive citizen science weather project hosted by the UK Met Office. This project encourages amateur observers to submit their meteorological observations directly to the Weather Observations website (http://www.metoffice.gov.uk). Supported by the Department of Education and the Royal Meteorological Society, several millions of quality-controlled observations have been submitted since 2011. This is an excellent example of what is achievable. Clearly, access to the marine environment is challenging, but there are many thousands of private yachts, which could be deployed in the endeavour of making marine observations. The International SeaKeepers
Society (http://www.seakeepers.org) is a voluntary organization that coordinates simple marine and meteorological data collection from yachts. And recently, the Sir Alister Hardy Foundation for Ocean Science used the French yacht Tara to tow a CPR in a circumnavigation of the high Arctic Ocean, through the North East and North West Passages. It is not possible that an entire sustained network of marine monitoring could be supported by citizen science, but one could envisage significant contributions in the future.

10. Conclusion

So what have we learned by this consideration of the past, present and future of sustained UK marine observations? In some ways, it seems little has changed since the earliest days of human interaction with the marine environment by our forebears, ancient and more modern. Knowledge of the marine environment was, and will remain a central requirement for human survival, society, transport and pleasure. In recent times, scientific endeavour has given us a greater realization of the importance of the marine environment to the working of the planet. Yet a common theme I detect, from the very earliest interaction of humans with the sea to the present day, is the rather depressing realization that it is ‘market forces’ that define our relationship with the sea and how we use and observe it. This is not unique to the marine environment, since the same sentiment defines the entire ‘environment movement’, if I may use such a loose phrase?

What is the size of the ‘market’? A market analysis of the value of the marine and maritime sector to the UK economy was carried out in 2011/2012 [30]. The study concluded that the sector was worth approximately £35bn (approx. 2.5% of the total economy); provided £9bn tax receipts to the Treasury; and provided direct and indirect employment to over 700 000 people—one in 45 of all jobs in the UK. The MSCC [22] estimated that the UK spends approximately £161 million p.a. on all UK marine science. The MSCC acknowledged that its data were somewhat inaccurate; however, if the estimates were two- or even fivefold in error, the discrepancy between the value of the marine sector to the UK economy and the paucity of the investment into the investigation of the marine environment is striking. And this economic evaluation does not consider at all the wider contributions of marine observations to, for example, considerations about climate change and other indirect contributions made by the data. The UK is in a position scientifically to establish a first-class, fit for purpose sustained marine observations network, which could be world-leading. The ‘market’ appears to be more than ‘favourable’; at the very least the UK should exercise some enlightened self-interest and be prepared to invest.

Acknowledgements. In providing this overview, I hope I have provided a suitable introduction to the excellent and interesting detailed science papers that follow. Good and sustained observations are essential for excellent science and we see this in these papers. All the papers that follow have been dependent upon the often painstaking, long-term measurement and research of frequently anonymous and dedicated people—the pathfinders who did not know they were pathfinders at the time, nor are recognized as such—this paper is for them. Many thanks also to Gemma Brice, Pierre Helaouet, Rodney Forster and Dave Mills for help with figures 2, 3, 4 and 5, respectively. And also to the Guest Editors and T. R. P. Owens who reviewed this manuscript and made some very valuable suggestions, which I appreciate; I hope I have gone some way to accommodate at least some of them.

References

Glossary

ABPmer | ABP Marine Environmental Research Ltd
AFBI | Agri-Food and Biosciences Institute (Northern Ireland)
BODC | British Oceanographic Data Centre
Cefas | Centre for Environment, Fisheries and Aquaculture Science
CP2 | Second Commitment Period under Kyoto Protocol
CSSEG | Clean and Safe Seas Evidence Group
EH | English Heritage
EMECO | European Marine Ecosystem Observatory
HBDSEG | Healthy and Biologically Diverse Seas Evidence Group
JNCC | Joint Nature Conservation Committee
Mar Scot | Marine Scotland
MCS | Marine Conservation Society
MECN | Marine Environmental Change Network
MEDIN | Marine Environmental Data and Information Network
Met Office | UK Met Office
MMO | Marine Management Organization
NE | Natural England
NOC | National Oceanography Centre
OPEG | Ocean Processes Evidence Group
OSPAR | Convention for the Protection of the Marine Environment of the North East Atlantic
PML | Plymouth Marine Laboratory
PSEG | Productive Seas Evidence Group
SAHFOS | Sir Alister Hardy Foundation for Ocean Science
SBI | Site of Biological Interest
SEPA | Scottish Environment Protection Agency
UKDMOS | UK Directory of Marine Observing Systems
UKIMON | UK Integrated Marine Observation Network
UKMMAS | UK Marine Monitoring and Assessment Strategy
WG | working group