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Report on the UK-IMON International Workshop on New Monitoring Technologies, September 2013

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Executive Summary

Background

The annual cost of UK marine monitoring has been estimated to be of the order of £80 million. Future funding for sustained observing and monitoring of the marine environment is uncertain, despite an increase in the demand for marine data by a broad range of end-users. Business as usual is not an option. To meet the challenge the UK community needs to find new ways of working together to increase effectiveness by reducing the overall cost and/or increasing the efficiency of current observing programmes. This can be done through, for example, better coordination of marine observing programmes, sharing resources and making best use of all data regardless of the original purpose for which it was collected. Another way to increase efficiency is to make best use of new monitoring technology that can reduce cost in future programmes. These drivers were the inspiration for a workshop bringing together international experts to discuss future monitoring technologies.

Aims and Objectives

The brief for the workshop was to review future observing technologies and how they could be used to deliver some of the UK's monitoring needs differently, at less cost and to consider possible efficiencies that might be gained.

The aim of the UK-IMON workshop was to determine how best to increase efficiency, effectiveness and cost reduction through the use of new monitoring technologies. The main objectives were to:

1. Hold an international workshop to review and evaluate, against agreed criteria, new observing technologies in order to identify future approaches that could reduce cost and increase efficiency and effectiveness of UK marine monitoring,
2. Prioritise up to 10 of the most promising observing technologies, based on predetermined and agreed criteria and to develop a detailed plan to 'roll out' the three highest rated monitoring technologies in to the UK marine monitoring network.

Outcomes of the workshop

The organisation of the workshop was supported by IMarEST and was sponsored by learned societies and industry. It attracted more than 100 participants with half of the attendees from UK Government research centres and agencies, a third came from industry, and the remainder came from UK higher education institutes and overseas – further details in the full report.

From the outset it was recognised that the workshop would be the beginning of a process and not an end in itself. By looking across the needs of different sectors it has become possible to identify, for the first time, where there are common needs and so provide a potential starting point for future investment of benefit to all. Recommendations have been developed to address these common needs in order to promote the widest possible support and buy-in.

Recommendations

In devising recommendations it has become clear that an underlying core infrastructure is required to fully benefit from future investment. Such a capacity will provide a reliable, consistent and persistent framework for marine observing where the full value of current and future investments can be realised.

A fundamental requirement for any integrated marine observing network is that an effective data management system is in place. This is a prerequisite and the full benefits of any investments cannot be realised without the appropriate level of investment in this key component of an integrated monitoring system.

The specific recommendations are put forward as a series of options that are not mutually exclusive and could all be adopted or in any combination.

Option 1 – Towards a UK Integrated Marine Observing Network

In 5 years we aim to have in place the first sustainable building blocks for an integrated and interoperable UK marine observing network based on a cross-sector (industry, government, research) partnership that provides data that are timely, quality assured and easy to use for multiple purposes and delivering clear societal benefit. The network would be composed of a backbone of sentinel fixed in-situ observing sites, augmented by HF radar stations on offshore oil and gas platforms and shore stations, and emerging mobile autonomous robotic vehicles. As a coherent and collaborative network we would anticipate the need to interoperate with current and future regional, national, European and global scale observing systems including European and international data management infrastructures based around common standards. There are many anticipated benefits that include improved collaboration and an increase in the efficiency and reliability of data collection in terms of the quality and quantity of data available and its readiness for re-use for multiple purposes.

Option 2 – Better integration/use of existing and future infrastructure for observations

In order to create a UK wide network of marine monitoring systems the main task is to improve interoperability between the different components of the UK monitoring network that is comprised of different data collection systems. The outcome will be an interoperable network with common standards for the acquisition, processing, dissemination and management of data where data sharing and collaboration is the norm. This is a key step towards achieving an Integrated Marine Observing Network. The actions to achieve this include:

- Identification and adoption of common marine communication standards (e.g. data formats),
- Agreeing common procedures for data quality assurance and workflows,
- Commitment to implementation of a UK data management strategy,
- Work to identify the investment required to achieve the agreed level of interoperability.

The full costs of this option are dependent on the final scope but would require work to bring together appropriate experts and representatives of the key UK monitoring networks through UK-IMON building on prior work. Involvement of the operational and commercial sector is regarded as essential. An initial investment of £50k would provide the resource to hold two workshops and inter-sessional work to develop a costed plan for presentation to funders. The benefits of this option are primarily in terms of increased efficiency in the methods of data collection and in the work-flow that generates useable information from marine observations.

Option 3 – Supporting UK development and wider uptake of marine autonomous and robotic systems

It is clear that there is significant investment in these technologies by a number of UK marine science organisations as well as government. Most of the platforms considered under this heading were rated at high technology readiness levels. Consequently, the recommendations we make are primarily concerned with increasing the utility of such systems for specific purposes and in this case primarily to meet policy requirements. The following actions are recommended:

- Build on current knowledge base, identify common gaps in the information required to improve uptake for future applications,
- Collate information on the running costs of autonomous mobile platforms,
- Identifying opportunities future collaboration between UK-IMON partners for trials and pilot studies,
- Common communication standards to ensure interoperability with marine monitoring network.

The benefits accruing from further investment in this area include significantly reduced risk to personnel, major cost savings where vessels or other platforms may be replaced and the potential to make observations in locations and during periods where other platforms are inoperable.

Option 4 – Addressing gaps in current monitoring

A number of gaps were identified in current capability and the following two options are proposed for investment in order to move these to an operational capability.

(i) Optical imagery for plankton identification (< 2 yr)
(ii) Molecular biological techniques (sequencing and probe based) for monitoring microbial diversity, contaminant impact and non indigenous species (5 – 10 yr)

<u>Justification</u>

All recommendations are based on clearly identified user needs across more than 1 sector. Option 1 provides an over arching vision of what UK-IMON can achieve and is entirely consistent with the cross sector view of the need for an integrated observing network. The ambition is to provide the backbone of an integrated network based on established and novel autonomous technologies incorporating fixed and mobile systems. As a starting point such a system provides key information to meet the meet needs of multiple sectors and is of clear societal value, for example, search and rescue, safety at sea, surface physics (waves, tides) with real-time data delivery for assimilation into forecast models. Such an approach will make substantial use of existing and future autonomous monitoring technologies with the promise of reducing cost and increasing effectiveness.

Fully realising the benefit of current and future investment in monitoring technologies not only requires effective data management but adoption of standards and protocol to ensure the different component can inter-operate (Option 2). This recommendation also benefits all sectors and is entirely in alignment with user requirement to improve integration of UK monitoring.

Option 3 takes into account both cross sector user needs identified at the workshop and the UK investment already taking place in these monitoring technologies. A fit-for-purpose integrated observing network will require both fixed and mobile platforms.

While many potential gaps were identified in understanding ecosystem functioning and structure there was wide agreement on the paucity of information on planktonic abundance, distribution and species composition. Option 4 proposes to address this shortfall through medium and longer term investment in optical and molecular techniques for quantification of plankton across a potentially wide size range (mm to < 2µm).

1. Introduction

The annual cost of UK marine monitoring has been estimated to be of the order of £80 million. Future funding for sustained observing and monitoring of the marine environment is uncertain, despite an increase in the demand for marine data by a broad range of end-users. Business as usual is not an option. To meet the challenge the UK community needs to find new ways of working together to increase effectiveness by reducing the overall cost and/or increasing the efficiency of current observing programmes. This can be done through, for example, better coordination of marine observing programmes, sharing resources and making best use of all data regardless of the original purpose of its collection. Another way to increase efficiency is to make best use of new monitoring technology that can reduce cost in future programmes.

The brief for the workshop was to review future observing technologies and how they could be used to deliver some of the UK's monitoring needs differently, at less cost and to consider possible efficiencies that might be gained. The intention was for the workshop to be an opportunity to horizon-scan the observing technologies that might be available in the next 5–10 years looking within the UK and internationally and to consider how these may be of benefit to the monitoring of the seas around the UK seas. The workshop was international in scope aiming to bring some of the world leaders in ocean observing technologies to the UK.

2. Aims and objectives

The aim of the UK-IMON workshop was to determine how best to increase efficiency, effectiveness and cost reduction through the use of new monitoring technologies:

1. To hold an international workshop on future marine monitoring technologies, by the end of September 2013,
2. To review and evaluate, against agreed criteria, new observing technologies in order to identify future approaches that could reduce cost and increase efficiency and effectiveness of UK marine monitoring,
3. To prioritise up to 10 of the most promising observing technologies, based on predetermined and agreed criteria,
4. To develop a detailed project plan to 'roll out' the three highest rated monitoring technologies in to the UK marine monitoring network,
5. To develop a longer term plan for other promising technologies,
6. To report to the MSCC by the end of March 2014.

3. Approach and findings

An organising committee was formed that comprised of UK-IMON partner organisations. The organising committee was chaired by David Mills (Cefas). NOC Southampton hosted the workshop and provided logistical support while IMarEST provide all the necessary support for registration including a website. A registration fee was charged to support the cost of the facilities provided by NOC and sundry expenses. IMarEST also provided general publicity and organised sponsorship from learned societies and from commercial organisations. Facilities were provided for exhibition space for commercial and other participants and for a poster session. The participants list is in **Appendix A** and the agenda is provided in **Appendix B**.

The programme had three main components: identification of user needs across the societal benefit areas, thematic reviews of the monitoring technologies from an international and a UK perspective and an evaluation conducted by theme and in plenary session. The technologies subjected to thematic review were conducted under four themes (conventional platforms, autonomous platforms, sensors and additional data acquisition systems).

To maximise the opportunities for exchange of information amongst the workshop participants a range of communication strategies were adopted that included novel and traditional, formal and informal. These included:

- Formal presentations - the presentation sessions were predominantly a forum for disseminating knowledge about technologies, followed by question and answer sessions.
- Breakout groups – for each of the four themes enabling participants to gain more information about technologies and applications, to discuss and evaluate the technologies.
- Plenary session - provided an opportunity for all participants to engage in debate about the relative merits of different technologies and approaches and to seek consensus.
- Poster session – promoted dialogue between scientists, practitioner and technology developers.
- Frequent breaks in the proceedings – refreshment breaks, lunches and the ice-breaker provided opportunities for participants for a range of interactions including the opportunity browse the stands and displays of industry representatives.

A very wide range of technologies were presented and some overarching themes of core development needs emerged clearly and almost independently of the technologies considered:

- The need for standardisation (in data capture, storage, QA/QC etc)
- The need to better interface observations and models to ensure the data collected is of the correct nature to support model developments and that the models are used to identify the areas as well as temporal and spatial scales at which future observations are required
- The need for sensors to become compatible with the widest possible range of platforms through reduction in size, cost, power consumption and increases in longevity, robustness and stability
- The desire to develop a coherent framework into which all UK marine monitoring efforts can be embedded, regardless of platforms used, who funds or conducts the observations and for what need, thus enabling greater complementarities and efficiencies.

A clear measure of success of the workshop was evident in the number and nature of participants. Half of the attendees came from UK Government research centres and agencies, a third came from industry, and the remainder came from UK HEIs and overseas (Figure 1). Further details are shown below (**Figure 1**) and the full list of participants is given in the **Appendix A**.

- Public sector (research) representatives (27) included 15 staff from NOC
- Public sector (policy/ops) representatives (20) included 14 staff from Defra/Cefas
- Industry representatives (33) included BP and several SMEs
- UK HEI representatives (10) included UEA, NUI, Exeter, Plymouth, Southampton, Heriot-Watt
- International representatives (10) came from France, Italy, Norway, US and Australia

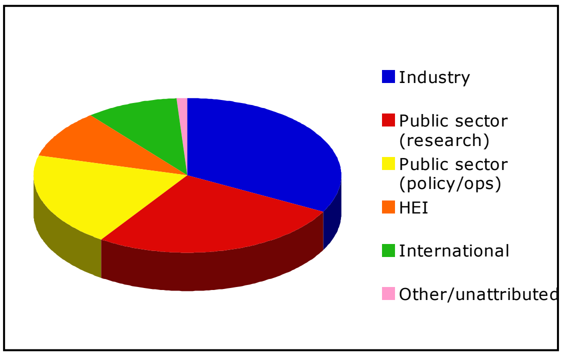

Figure 1: A breakdown of the different sectors represented at the workshop.

3.1 User Needs

The needs of users from five different sectors including, policy, oil and gas, renewables, marine operations and research were described through formal presentations. Each speaker was asked to summarise future requirements in the short, medium and long term timescales (**Table 1**).

Table 1a: Compilation of user needs for Research, Policy, Operational (Met Office) and Oil and Gas industry over short (0-2 years), medium (2-5 years) and long (5-10 years) timescales

User community	Time	Requirement
Research	0-2 years	1. More gliders and AUV vehicles
		2. Develop unmanned surface vehicles for data transmission
		3. Use glider as virtual moorings
	2-5 years	4. Add biogeochemical sensors to Argo floats and increase depth capability
		5. Under sea-ice glider/long-range AUV observing
		6. Full ocean depth/1 year deployable gliders
	5-10 years	7. Develop integrated pan-Atlantic chemical and physical observing systems
		8. Instrument active slope sediment pathways
		9. Surface air-sea flux at high latitude
Operational service provider (Met Office)	No specific timescales	10. Maintain current sparse buoy network for forecast model validation, calibration and assimilation
		11. Consider replacement of buoys with wave gliders if more cost effective
		12. Constellation of cheap altimeters (or swath altimeter)
		13. Robust biogeochemical sensors for profiling platforms (gliders, floats etc) and buoys
		14. I investment in monitoring technologies guided by outputs from models with more mature assimilation systems
Policy	0-2 years	15. Cost-effectiveness of monitoring increased
		16. Smarter use of existing platforms
		17. Improved data on impacts of key infrastructures
		18. Evidence to influence European developments on monitoring tools
	2-5 years	19. As above
		20. Improved monitoring data on species, habitats and ecological processes
	5-10 years	21. As above
		22. Better understanding of environmental change
Industry needs – oil and gas	0-2 years	23. Maintain existing North Sea MetReach network
		24. HF radar systems; gliders, assimilate data into numerical models
		25. Improved collaboration and data sharing
		26. MEDIN standards to be adopted and supported
	2-5 years	27. Extend HF radar network; potential for expansion to include offshore sites (bi-static technology)
		28. Increase autonomous in situ monitoring of multiple parameters with data transmission via existing/new fibre optic networks
		29. Improved numerical models especially 3D currents to the west of Shetland
		30. Routine AUV/glider missions – data assimilation into operational models
		31. Climate modelling and the potential for changes in the criteria for the next 50 years due to changes in storm severity, tracks, increases in sea level
	5-10 years	32. UK wide network of marine monitoring systems
		33. Data sharing and collaboration is the norm
		34. All data freely available through MEDIN and the DACS

Table 1b: Compilation of user needs for renewables industry over short (0-2 years), medium (2-5 years) and long (5-10 years) timescales. This table reflects the greater level of detail provided by this sector.

Time	Category	Requirement
0-2 years	Marine Mammals	35. Refine use of hydrophones for long term monitoring
		36. Evaluate utility of active sonar systems
	Birds	37. Effective data sharing (MEDIN) – EIA to monitoring
		38. Improve science and data on offshore windfarm effects on birds
	Benthos/fish	39. Better integration of monitoring across different sectors
		40. Co-design of monitoring programmes
	Physical environment and processes	41. Automated techniques for scour monitoring
2-5 year	Marine Mammals	42. Collision risk models for tidal devices
		43. Active sonar system development
		44. Automated analysis for passive and active acoustic systems
		45. Understanding responses to noise, disturbance, wave and tidal devices
	Birds	46. Better species recognition
		47. Remote sensing technique development – operationalise active radar
		48. Understanding behaviour in response to single and multiple stressors
		49. Untangling natural and anthropogenic impacts
	Benthos and Fish	50. Improve remote sensing and imaging of benthic communities
		51. Fish response to noise
		52. Improved information on scale and resolution of impacts – more data
		53. Untangling natural and anthropogenic impacts
	Physical environment and processes	54. Stability of seabed features
		55. Predictive modelling of sand wave movement
		56. Surveys to re-focussed monitoring
5-10 years	Marine Mammals	57. Understanding of population status in lager management units with many wide ranging species
		58. Exploring connectivity between populations/groups
	Birds	59. Cumulative impact assessment of multiple windfarms
		60. Connectivity issues of wide ranging species
	Benthos and Fish	61. Improved definition of spawning areas for noise sensitive fish
		62. Connectivity of wide ranging fish species

User requirements fell mainly into one of two categories:

- Shortfalls in knowledge and understanding, for example,
  - connectivity of wide ranging species,
  - distinguishing between natural and anthropogenic impacts,
  - understanding the interaction between multiple stressors
- Technology development of for existing platforms, for example,
  - Adding biogeochemical sensors to Argo and other platforms
  - Making better use of existing platforms
  - Developing software to make better use of measurements currently carried out

Gliders and other autonomous mobile platforms were identified by several users either directly or indirectly (**Table 1**: 1-3, 4, 5, 11, 28, 30) and primarily in the research and operational user requirements. Several users also identified the need for data sharing and compliance with data management (**Table 1**: 25, 26, 33, 34, 37) infrastructures (e.g. MEDIN). Similarly, a number of users identified the requirement for an integrated and smarter approach to monitoring where a common infrastructure can meet multiple purposes based on collaboration (**Table 1**: 7, 16, 25, 32, 39, 40). The Oil and Gas user requirements presentation strongly emphasised the infrastructure needs both in the short and long term. The generic requirements for further development of biogeochemical sensors was identified specifically (**Table 1**: 4, 13) and more generically through making better use of existing platforms (**Table 1**: 15, 16, 20, 28) by adding new sensors.

The largest number of gaps in our understanding was identified in the Renewables user needs presentation (**Table 1b**) alongside challenges for further technology development and in particular of passive and acoustic sensors.

3.2 Technology Review

In this part of the workshop two keynote presentations were given at the beginning of each of the 4 sessions providing an overview from an international and UK perspective. Each session then incorporated a number of 5 min flash-talks. In addition, posters and trade stalls provided further relevant information (see **Appendix B** for programme and abstract book). All Presentations given at the workshop have been published on the UK-IMON website at http://www.uk-imon.info/Workshop%20Presentations.html. A significant part of the workshop was set aside to network, to discuss technologies in detail and exchange views on needs and priorities amongst the participants. The effectiveness of this approach was evident in the very high level of engagement between the participants during these periods. Further details of the strategies to promote active communication were given earlier.

It is worth noting the effectiveness of flash talks in covering a lot of material in a short space of time. They provided a welcome contrast to the longer more traditional presentations and injected a considerable dynamic element to the workshop.

3.3 Evaluation of technologies by theme

Criteria for evaluation of the technologies and guidance were developed by the committee in conjunction with Defra and these were published via the IMarEST website in advance of the event (see **Appendix C** for guidance published at http://www.imarest.org/Portals/0/IMarEST/Events/UK-IMONNewMonitoringTechnologies/2013/UKIMON2013TechnologyEvaluation.pdf).

Following the programme of keynote talks and flash presentations, specific breakout groups dedicated to the four themes were formed to review technologies in detail and the resulting information was tabulated in spreadsheets against agreed ranking criteria. The criteria and scoring system used were:

- Policy, science and operational oceanography/industry relevance (high, medium, low)
- Technology readiness level (1–5 as per Appendix C)
- Payload capacity (for platforms) or number of platforms compatible with (for sensor)
- Application area (coastal zones, shelf sea, open ocean, all)
- Data quality/confidence (high, medium, low)
- Cost to become operational (with confidence level)

- Running cost (approximate annual)
- Other considerations;
  - Could the technology be developed to do measure other variables?
  - Could the platforms or measurement system (e.g. sensors, sampler) be miniaturised?
  - Could we reduce hardware cost?
  - How adaptable is the technology to meet future needs.

A cumulative assessment was then to be made using the evaluations of individual criteria resulting in an overall assessment score (1 to 5, with 5 being highest). An expert panel was convened for further discussion of the material presented. The excel spreadsheets collated by topic to rank technology are attached as **Appendix D** and a summary is given below.

3.3.1 Conventional platforms (topic 1)

A total of 12 different types of platform were reviewed: three vessel types (large research vessels, small research vessels and ships of opportunity), the continuous plankton recorder (CPR), three types of moorings (sub-surface moorings anchored on seabed, surface moorings and profiling moorings), three types of landers/sub-surface observatories (stand-alone instrumented caged with no data transmission, non-cabled communicates with surface and cabled to the land or offshore-rig) and two types of drifters (Core Argo and other drifters). All of these platforms play an important and established role in marine monitoring and are at a high technology readiness level (all at TLR 5 apart from the sub-surface observatories with data transmission which were rated as TLR 4). In the overall assessment, research vessels (RV's) and surface moorings ranked particularly high, as their size and large payload capacity makes them most versatile. RVs were considered to be essential due to unique capabilities (e.g. trawling) and to their key role in the deployment and recovery of other platforms (e.g. gliders, moorings) or as basis for the deployment of new technology.

3.3.2 Autonomous platforms (topic 2)

A total of 13 different types of platform were reviewed: four classes of autonomous underwater vehicle (AUV class #1 small/coastal/shore based, class #2 medium/shelf, hybrid/long-range and class #3 large/deep), bio-mimetic fish, Crawlers/rovers /benthic, two classes of buoyancy gliders (deep and shallow), remotely piloted aircraft / underwater autonomous vehicles / underwater autonomous systems, two classes of unmanned survey vehicles (short and long duration), profiling floats and surface drifters. Mammals were also considered but were covered in more detail under topic 4. The group derived cumulative scores as a sum of scores given to relevance, readiness level and cost, which resulted in buoyancy floats, drifter and long-endurance unmanned surface vehicles being rated most highly.

3.3.3 Sensors (topic 3)

The sensors theme considered a wide range of instruments and types of sensors, but even so the list cannot be seen as fully comprehensive, due to the very large number of sensors currently available and known to be in development. Passive samplers were specifically identified as a gap in the review process. A total of 11 different lab-on-chip devices for different analytes were identified that ranged from physical parameters (e.g. conductivity and temperature), chemical parameters (e.g. pH, oxygen and nutrients) and biological entities based on flow-cytometry or nucleic acid probing. For lab-on-chip technology the readiness levels varied from the very early stages (TLR 1) for the biological determinants through to the more advanced (TLR 3-4) for chemical and physical parameters. A total of 19 other sensor technologies were discussed, ranging from acoustic recorders (active and passive) to optode technology, mass spectroscopy to Raman spectroscopy , field effect transistors to “Sniffer” (infrared spectroscopy) technology and variable fluorescence techniques. A wide range of optical imaging technologies for whole organisms were reviewed including flow-cytometry, video microscopy and holographic imaging, as well as molecular biological techniques such as nucleic acid and protein sensing and organism based sensing (such as mussels in “biotaguard”). A large number of these techniques are at high technology readiness levels and some are widely used already. Some of the sensors or instruments evaluated have relatively high costs and power needs or are large, limiting their applicability to a smaller sub-set of available sampling platforms, while other smaller devices, such as the lab-on-chip devices are compatible with a very wide range of platforms. Sensors can be classified in various different ways, though their detection technology (optical, acoustic, electrochemical etc), their target analyte (physical parameter, chemical or biological target) or their complexity (true sensor with direct signal generation or analytical instrument of varying degree of complexity such as build in liquid-handling and sample preparation capability). For this theme no attempt was made to rank the reviewed technology, as the selection of the most appropriate sensor really is entirely mission driven and platform dependent, but key information that could inform future investments were recorded against the criteria.

3.3.4 Other data acquisition systems (topic 4)

This theme considered the other data acquisition systems in four categories: earth observation satellites, vessels of opportunity (includes ferries, fishing and yachts), static platforms of opportunity (shore based radar, lobster pots, oil rigs) and vertebrates of opportunity (marine mammals, fish, people). During the evaluation the advantages of augmenting established monitoring with these additional novel techniques were highlighted. A particular challenge for the evaluation process in this theme was the need to consider technology readiness level (TRL) for both platforms and the combination of platform with sensor/data acquisition system. In general, platforms were ranked at a higher TRL that for the sensors/data acquisition system.

3.4 Outcome to the evaluation procedure

Evaluation was carried out by workshop participants working in four breakout groups one for each theme lead by the two theme session Chairpersons. Each group were provided with a set of criteria and a scoring system as identified earlier. The results of the evaluation procedure discussion were compiled in a spreadsheet. While significant progress was made in evaluation within themes it proved difficult to reach consensus on a final rank for the technologies across themes. Considerable discussion took place to try to reach consensus and indeed discussion on the reasons for the difficulty in reaching consensus. The barriers to reaching consensus included:

- The difficulty inherent in ranking across different themes that include such diverse platforms and sensors/instruments,
- The multi-dimensional nature of any proposed ranking exercise, with mixed criteria such as: availability in time; technology readiness level; cost (broken down in developing, establishing and operationally running the technology); number of core variables covered through the use of any particular technology; and, number of stakeholders interested in outputs,
- The dependence of the rank on perceived priority need that varies by user sector.

To illustrate the nature of the problem some simple scenarios are described below. Consider the possibility of replacing an established method of measuring a single parameter such as salinity. A straightforward exercise could be carried out with a quantifiable outcome that would enable a decision to be reached relatively easily. The criteria could be: is the new approach able to measure salinity to the same levels of accuracy and precision, will the new approach reduce cost, is it robust enough to meet operational demands and so on. In contrast, consider the challenge of determining the relative importance of different technologies that measure different parameters. For example, comparing a new technology to measure water current speed and direction compared to new technology to measure particle size or genomics based measures of biodiversity is a completely different problem and cannot be achieved by simple comparison of capability. In this latter case the decision about what to measure is likely to precede a decision about what technologies to develop. These contrasting examples illustrate the difficulty of evaluating both within and across themes. Furthermore, the challenge of achieving consensus across a broad range of end users encompassing policy, research and operational requirements at the workshop proved far more difficult than anticipated.

4. Conclusions

The collected outputs from the workshop including abstracts, presentations, records of the evaluations by theme and the synthesis provide an important resource for the community. They provide an up to date and comprehensive overview of current and future technologies available to meet a variety of end-user needs. The end-user requirements captured at the beginning of the workshop also provide a valuable insight into future needs.

It was apparent from the workshop proceedings that there is a broad range of sensors of marine physical properties currently available and fully operational. In contrast, the range of chemical and biological sensors regarded as fully operational is more limited but there are many sensors at a lower technology readiness level. Many of these pre-operational sensors have the potential to measure variables needed for calculation of the indicators required for assessment of good environmental status for the MSFD.

In order to realise the vision of reducing cost and increasing coverage by using new technologies, integrating monitoring schemes across different sectors (policy, science and industry) and working to agreed protocols plus a significant increase in coordination of efforts will need to be facilitated.

Ideas for further consideration and follow-up actions were identified by the Expert Panel and in subsequent discussions and can be grouped into three main themes:

4.1 Monitoring technologies directed at gaps (variables or coverage)

4.1.1. Optical imagery for plankton identification (for example a combination of Zooscan, flow cytometry, optical particle counter and the LiZa particle size analyser for zooplankton to cover the size spectrum)

- Relates to policy requirements for species level information and the need to improve understanding of ecosystem structure and function

4.1.2. Transition molecular biological techniques (sequencing and probe based) from research tools to an operational capability for monitoring microbial diversity, contaminant impact and non indigenous species

- Relates to identified policy requirements for chemical and biological core variables

4.1.3. Addition of noise to core variables (see talk on ambient noise monitoring by Wildlife Acoustics and on-going Defra project on noise monitoring using AUV)

- An agreed gap

4.2 Better integration/use of existing infrastructure for observations

4.2.1. Better use of RV cruises for collaborative and integrated ecosystem assessments

- Leads to a more efficient approach to collecting marine data for multiple purposes

4.2.2. "Vertebrates of opportunity", i.e. the suggestion to make more extensive use of techniques such as crowd sourcing of information (example bathymetry data from fishing and leisure vessels – see TEAMSURV presentation, bottom temperature records from loggers attached to lobster pods- see talk on crowd-sourcing of oceanographic data), and using animals, such as fish or mammals to carry sensor packages to collate information of biological as well as environmental relevance

- Holds the potential to reduce cost but may also fill gaps in spatial and temporal coverage

4.2.3. Expansion of the "black box" system (Olex for bathymetry) used on fishing vessels to increase the range of parameters recorded

- A potentially cost effective approach through the use of fishing fleet or inshore fisheries and conservation authority (IFCA) vessels in the acquisition of data of scientific and/or policy relevance. The approach could be extended to other ships of opportunity such as sailing boats.

4.2.4. Expansion of Bio-Argo

- Addition of biogeochemical sensor to Argo floats is a recognised future development need

4.3 Changing observational strategies to make better use of emerging technology

4.3.1. Installation of a High Frequency (HF) radar network (see Brahan project) to provide wave and current data (a shared need across all user communities) and thus potentially act as a major component of an integrated monitoring system

- Identified as the potential basis of a cross sector initiative that could be extended geographically using Oil and Gas platforms infrastructure that could form the basis of a shared regional monitoring network

4.3.2. Further development of lab-on-chip based technology to achieve widest sensor/platform compatibility

- Clearly identified as an important technology with the potential to significantly increase the effectiveness of robotic and autonomous platforms. The relative importance of the target measurement (nutrients, contaminants) depends on the requirements

4.3.3. The use of unmanned aerial vehicles for monitoring fishing fleet compliance

- Regarded a potential cost saving measure

5. Recommendations

In this section some first steps are proposed to build on the outcome of the workshop and identify what we need to do next. In making recommendations it is not our intention that these are the only ideas for future investment, and indeed investment is already taking place in some of the areas identified, but they do provide a meaningful starting place. Inevitably there will be alternative view points. The recommendations are presented as options and may be seen as standalone or part of a series of potential linked investments.

Option 1 – Towards a UK Integrated Marine Observing Network

In 5 years we aim to have in place the first sustainable building blocks for an integrated and interoperable UK marine observing network based on a cross sector (industry, government, research) partnership that provides data that is timely, quality assured and easy to use for multiple purposes and delivering clear societal benefit. The network would be composed of a backbone of sentinel fixed in-situ observing sites, augmented by HF radar stations on offshore oil and gas platforms and shore stations, and emerging mobile autonomous robotic vehicles. As a coherent and collaborative network it would anticipate the need to interoperate with current and future regional, national, European and global scale observing systems including European and International data management infrastructures based around common standards. There are many anticipated benefits that include improved collaboration and an increase in the efficiency and reliability of data collection in terms of the quality and quantity of data available and its readiness for re-use for multiple purposes.

Pros: Defining an end-point for development enables us to measure progress and provide a vision to gather round and work towards. Working towards a shared vision that has meaning and value to all partners provides the best chance of changing what we do now in order to meet the challenges of the future. There is the potential for EU funding to support capacity building and sustained operation.

Cons: Gaining wider buy-in to an ambitious vision may prove difficult to achieve in practice. Agreeing common standards with an ever widening group may also be difficult to achieve.

Option 2 - Better integration and use of existing and future infrastructure for observations

In order to create a UK wide network of marine monitoring systems the main task is to improve interoperability between the different components of the UK monitoring network that is comprised of different data collection systems. The outcome will be an interoperable network with common standards for the acquisition, processing, dissemination and management of data where data sharing and collaboration is the norm. This is a key step towards achieving an Integrated Marine Observing Network. The actions to achieve this include:

- Identification and adoption of common marine communication standards (e.g. data formats),
- Agreeing common procedures for data quality assurance and workflows,

- Commitment to implementation of a UK data management strategy,
- Work to identify the investment required to achieve the agreed level of interoperability.

The full costs of this option are dependent on the final scope but would require work to bring together appropriate experts and representatives of the key UK monitoring networks through UK-IMON building on prior work. Involvement of the operational and commercial sector is regarded as essential. An initial investment of £50k would provide the resource to hold two workshop and inter-sessional work to develop a costed plan for presentation to funders. The benefits of this option are primarily in terms of increased efficiency in the methods of data collection and in the work-flow that generates useable information from marine observations.

Pros: Without this investment we retain a patchwork of monitoring programmes with the value of current and future investment not being fully realised. Benefit would accrue to all marine monitoring programmes.

Cons: A fundamental assumption is that funding for UK marine monitoring will continue at a level to retain viable monitoring programmes that warrant further investment for the next 5-10 years otherwise any investment of this type is not justified.

Option 3 – Supporting UK development and wider uptake of marine autonomous and robotic systems

It is clear that there is significant investment in these technologies by a number of UK marine science organisations as well as government. Most of the monitoring platforms considered were rated at high technology readiness levels. Consequently, the recommendations we make are primarily concerned with increasing the utility of such systems for specific purposes and in this case primarily to meet policy requirements. The following actions are recommended:

- Build on current knowledge base, identify common gaps in the information required to improve uptake for future applications,
- Collate information on the running costs of autonomous mobile platforms,
- Identifying opportunities future collaboration between UK-IMON partners for trials and pilot studies,
- Common communication standards to ensure interoperability with marine monitoring network.

The benefits accruing from further investment in this area include significantly reduced risk to personnel, major cost savings where vessels or other platforms may be replaced and the potential to make observations in locations and during periods where other platforms are inoperable.

Pros: Builds on a current capability and investment that has a significant potential to change how we undertake marine monitoring.

Cons: Not all marine monitoring commitments (e.g. fisheries surveys) can currently be met by these systems. Cost savings may only result if UK research vessel capacity can be reduced.

Option 4 – Addressing gaps in current monitoring

A number of gaps were identified in current capability and the following two options are proposed for investment in order to move these to an operational capability.

(i) Optical imagery for plankton identification (< 2 yr)

(ii) Molecular biological techniques (sequencing and probe based) for monitoring microbial diversity, contaminant impact and non indigenous species (5-10 yr)

Pros: All have the potential for an automated and cost effective method of making measurements required to meet policy and science requirements. Deployed on a range of platform these approaches can provide high-frequency spatial and temporal coverage.

Cons: For policy purposes agreement will be required on the acceptability of novel and indirect methods for measuring variables potentially used in environmental assessments where established techniques may be replaced. These methods generate large data sets that need appropriate curation and processing to be of value.

Justification

All recommendations are based on clearly identified user needs across more than 1 sector. Option 1 provides an over arching vision of what UK-IMON can achieve and is entirely consistent with the cross sector view of the need for an integrated observing network. The ambition is to provide the backbone of an integrated network based on established and novel autonomous technologies incorporating fixed and mobile systems. As a starting point such a system provides key information to meet the meet needs of multiple sectors and is of clear societal value, for example, search and rescue, safety at sea, surface physics (waves, tides) with real-time data delivery for assimilation into forecast models. Such an approach will make substantial use of existing and future autonomous monitoring technologies with the promise of reducing cost and increasing effectiveness.

Fully realising the benefit of current and future investment in monitoring technologies not only requires effective data management but adoption of standards and protocol to ensure the different component can inter-operate (Option 2). This recommendation also benefits all sectors and is entirely in alignment with user requirement to improve integration of UK monitoring.

Option 3 takes into account both cross sector user needs identified at the workshop and the UK investment already taking place in these monitoring technologies. A fit-for-purpose integrated observing network will require both fixed and mobile platforms.

While many potential gaps were identified in understanding ecosystem functioning and structure there was wide agreement on the paucity of information on planktonic abundance, distribution and species composition. Option 4 proposes to address this shortfall through medium and longer term investment in optical and molecular techniques for quantification of plankton across a potentially wide size range (mm to < 2μm).

Pros: Defining an end-point for development enables us to measure progress and provide a vision to gather round and work towards. Working towards a shared vision that has meaning and value to all partners provides the best chance of changing what we do now in order to meet the challenges of the future. There is potential for EU funding to support capacity building and sustained operation.

Cons: Gaining wider buy-in to an ambitious vision may prove difficult to achieve in practice. Agreeing common standards with an ever widening group may also be difficult to achieve.

6. Appendices

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Appendix B: Programme and abstract book

See separately attached pdf or http://www.imarest.org/Portals/0/IMarEST/Events/UK-IMONNewMonitoringTechnologies/2013/UKIMON2013Programme.pdf

Appendix C: Technology evaluation guidance

Workshop on New Monitoring Technologies – Evaluation Procedure Overview

1. Introduction

This document provides an overview of the approach to evaluating the technologies that will be reviewed at the workshop. A ranking procedure will be developed in advance of the workshop. The purpose of this document is to alert workshop participants to the criteria that will be used for evaluation and for presenters to take these into account in the preparation of material for the workshop.

2. Aim and objectives

The aim of this UK-IMON workshop is to determine how best to increase capability and efficiency and to achieve a cost reduction in measuring a range of physical, chemical and biological marine data (UK-IMON core variables) through the potential use of new technologies:

1. To review and evaluate, against agreed criteria, the new technologies in order to identify those that are most likely to increase capability and efficiency and reduce the cost of UK marine monitoring/observation;
2. To prioritise for future investment up to 10 of the most promising technologies.

3. Ranking criteria

The actions proposed as a result of the workshop are likely to be taken over 3 different time scales: short term (6–18 months), medium term (2–5 years) and long term (5–10 years). The evaluation procedure should take into account these time-scales. The proposed main criteria are:

- Technology readiness level (TRL Table 2);
- Cost – will the new technologies save money? This criterion needs to take into account:
    - Cost of transitioning to operational status (i.e. TRL5 in Table 2), relative cost of new versus current technologies;
    - Potential for reducing operation costs both human (increased autonomy) and hardware related (e.g. running costs);

- Relevance to requirements of policy, operational and research end-users:
    - Consider capability in relation to the list of UK-IMON core variables (Appendix 1) taking into account temporal and spatial sampling requirements;
    - Take into account the relative importance of user requirements;

- Multi-purpose (technologies that may be able to meet multiple requirements)

4. Other considerations

The workshop will provide an opportunity to consider what new technologies could be introduced to operational monitoring programmes over a range of different timescales. While the ranking criteria given above are important there are other issues to take into account in evaluating potential future monitoring technologies. These include:

- What is their capacity, i.e. what can they measure now and in future?
- What is the quality of those measurements – are they better, the same or worse than current technologies?
- Are they accepted internationally? This is particularly relevant for measurements required to demonstrate policy compliance;
- How adaptable are the potential new technologies – could they adapt to different requirements in the future?

Table 2: OOI = Ocean Observing Initiative (US), TRL – technology readiness level

OOI TRL	Description
1. Proof of Concept / Development	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. The application is speculative and there is no proof or detailed analysis to support the assumption. Includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.
2. Research: Prototype	The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated or relevant environment. Prototype instrument packages have been used to collect data in research studies of technology or environmental parameter.
3. Research: Proven	Technology has not been commercialised but is clearly beyond prototype stage. Multiple instrument packages have been fabricated and deployed for extended periods under expected environmental conditions. Publications exist which demonstrate scientific utility of data.
4. Commercial	Technology has been proven to work in its final form and under expected environmental conditions. Instruments are in commercial production with appropriate supporting materials (replacement parts, operations manual, etc.)
5. Operational	Actual application of commercial or research-proven technology in its final form and under sustained operational conditions. Independent, third-party evaluation or application that demonstrates reliable long-term field operations.

Appendix D: Ranking spreadsheets by topic

See separately attached Excel spreadsheets.

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