

Development of a Benthic Imagery Action Plan for the United Kingdom

van Rein, H.^{*a}, Hinchin, H.^a, Hawes, J.^b, Durden, J.^c, Benson, A.^d, Lindenbaum, C.^e, Boulcott, P.^f, Webb, K.^a

a Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PE1 1JY, UK.

b Centre for Environment, Fisheries and Aquaculture Science, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK.

c National Oceanography Centre, European Way, Southampton, SO14 3ZH, UK.

d Envision Mapping Ltd, Mallan House, Bridge End, Hexham, NE46 4DQ, UK.

e Natural Resources Wales, Maes y Ffynnon, Penrhosgarnedd, Bangor, Gwynedd, LL57 2DW

f Marine Scotland Science, Scottish Government Marine Laboratory, PO Box 101 375, Victoria Road, Aberdeen, AB11 9DB, UK.

* Lead author contact: Henk van Rein (marinemonitoring@jncc.gov.uk)

1. Summary - context

The collection and analysis of benthic imagery is an efficient and non-invasive method of acquiring evidence from the seabed (van Rein *et al.*, 2009). In the UK, the marine biodiversity conservation community use this evidence for many purposes, including habitat mapping (Populus *et al.*, 2017; EUSeaMap¹), species distribution modelling (NBN Atlas²), condition assessment of designated marine conservation features (Mercer *et al.*, 2007; Goodwin *et al.*, 2011a, b, c, d; Curtis, 2012; Field, 2012; Goodwin *et al.*, 2012; Irving and Northen, 2012; Ware and Meadows, 2012; Eggleton and Meadows, 2013; Axelsson *et al.*, 2014; Hawes *et al.*, 2014; Bunker, 2015; Moore *et al.*, 2015; Sheehan *et al.*, 2015; Mercer, 2016; Sheehan *et al.*, 2016; O'Dell *et al.*, 2016; NRW, 2018; Moore, 2019; Noble-James *et al.*, 2019), monitoring change in condition of those features over time (Mercer *et al.*, 2007; Bunker, 2015; Moore *et al.*, 2015; Mercer, 2016; Vance and Ellis, 2016; Newman *et al.*, 2017; Newman *et al.*, 2018), and assessing effectiveness of fisheries management measures (Goodwin *et al.*, 2011c; Vance and Ellis, 2016; European Maritime and Fisheries Fund Marine Scotland newsletter³). Outside of the marine biodiversity conservation community the range of uses increases further, to include scientific research, underwater exploration, management and mitigation of marine infrastructure, to name but a few (see Durden *et al.* 2016 and Schoening *et al.*, 2017 for reviews).

Perhaps owing to the wide range of uses of benthic imagery, there is also a wide range of data collection platforms and methods, survey standards and design, processing and analysis protocols that are routinely used in the UK. The North-East Atlantic Marine Biological Analytical Quality Control Scheme (NMBAQC⁴) and Marine Environmental Data and Information Network (MEDIN⁵) work to address issues of standardising benthic imagery data quality across these numerous approaches. Despite these efforts, however, there is still a lack of widely-accepted standards currently in use, resulting in variable levels of imagery data and derived product quality across the UK. This limits the potential for dissemination of high-quality imagery data between organisations, reducing potential cost and efficiency

¹ EMODnet Seabed Habitats: <https://www.emodnet-seabedhabitats.eu/>

² NBN Atlas: <https://nbnatlas.org/>

³ EMFF Scotland: <https://www2.gov.scot/Resource/0054/00542176.pdf>

⁴ NMBAQC: <http://www.nmbaqcs.org/scheme-components/epibiota/>

⁵ MEDIN: <https://www.oceannet.org/>

savings. Furthermore, these issues may also affect the extent to which imagery may be best utilised by emerging new technologies, such as computer vision and machine-learning.

A UK benthic imagery workshop, ‘The Big Picture’⁶, was held in March 2019 to bring together key stakeholders from different organisations and disciplines across the UK, with a view to solving the key issues around benthic imagery data (3KQ, 2019). Fifty participants shared knowledge and experience during the three-day workshop, building a common picture of the issues, opportunities, ideas and possible actions to better harness the potential of benthic imagery by improving analysis techniques, data use and method standardisation. Workshop participants agreed to appoint a cross-organisation task and finish group, the Plan Development Group (PDG), to develop a *Benthic Imagery Action Plan* for the UK, based on the recommendations from the workshop.

The Benthic Imagery Action Plan (this document), hereafter referred to as the *Action Plan*, collates and streamlines the recommendations from The Big Picture Workshop into 87 tasks, organised into seven coherent workflows. This framework is focused on maximising the potential of benthic imagery within the marine biodiversity conservation community of the UK, although improvements may be equally applicable to other users of benthic imagery. The PDG suggest a collaborative working approach be adopted to maximise the use of available knowledge, resources and technology across organisations. Under the governance of the NMBAQC, which is in turn governed under the UK’s Healthy and Biologically Diverse Seas Evidence Group (HBDSEG), the Action Plan will lay out a ‘road map’ for organisations to follow for the next five years, encompassing the immediate needs for method improvement and standardisation. However, this Action Plan should also be considered as a ‘live’ and developing process, rather than a static document. It is envisaged that the development and incorporation of emergent technologies may be introduced to the benthic imagery workflows in future.

2. Background

2.1. Scope of Action Plan

There are a wide range of users and potential uses for benthic imagery in the UK. Attempting to coordinate improvements in image and data quality, analytical approaches, data-sharing and upgrades in technology for all these uses is a colossal task. To make the task more realistic and achievable, the first version of this Action Plan focuses on those benthic imagery workflows used by the community of users who collect benthic imagery to report on the status and condition of benthic marine biodiversity, or the **marine biodiversity conservation community of the UK**.

The marine biodiversity conservation community of the UK are mostly represented by arm’s length government bodies and agencies, although there are research institutes and environmental consultancies who also work in this area. The marine biodiversity conservation community of the UK is focused on collecting the highest quality evidence to report on the status and condition of a wide range of seabed habitats across the UK. They collect, analyse and interpret this evidence following a wide variety of guidelines, including those written by the Joint Nature Conservation Committee (JNCC)⁷, Mapping European

⁶ Big Picture Workshop report: <http://www.nmbaqcs.org/media/1765/the-big-picture-workshop-2019.pdf>

⁷ JNCC: <https://jncc.gov.uk/our-work/marine-monitoring-resources/>

Seabed Habitats project (MESH)⁸ and the NMBAQC, to name a few (see Marine Monitoring Method Finder⁹ for a wider selection).

It is anticipated that this Action Plan will be active for many years, perhaps with research and development elements still active in ten years' time. However, the majority of the work is expected to fall within the next five years (2020-2025). This medium-term timeframe balances the immediate needs expressed by the Big Picture Workshop participants, with the anticipated time required to carry out improvements to current benthic imagery working practices and data flows. It is expected that the biggest changes to benthic imagery data quality, procedure and standards will occur over this medium-term time frame. It is acknowledged that the Action Plan will need to be reviewed by the wider group at regular intervals within these time frames to incorporate advances in technology and amend the work flows to reflect any changes in the target community for the Action Plan, or approaches to benthic imagery data as a whole.

2.2. Aims of Action Plan

The three core aims of the Action Plan are to:

- 1. *Improve quality and comparability of benthic imagery data across UK;***
- 2. *Incorporate advances in benthic imaging technology into existing work flows;***
- 3. *Improve collaboration opportunities for organisations working with benthic imagery.***

These aims must be considered within the scope of the work, i.e. be directly applicable to the marine biodiversity conservation community of the UK and largely be achievable within a five-year timeframe.

There are recommended ways of working that will support the success of this Action Plan. Chief among these is that work is carried out by all involved with a spirit of cooperation in mind. This means that organisations would be willing to communicate with one another, to work together to deliver common goals and, when they produce useful outputs, to share those with the wider benthic imagery community of the UK. It is with this cooperative attitude that the Big Picture Workshop was carried out. It allowed many, diverse organisations to outline what they perceive as the most pressing impediments in using benthic imagery, thereby bringing into focus a wide range of issues. By working together and drawing on a wide experience base, the Big Picture Workshop participants proposed many solutions to these issues, which are now collated in this Action Plan. The result is an ambitious and far reaching Action Plan

2.3. Guiding principles of Action Plan

To ensure the effective delivery of core aims to the widest range of end users, workshop participants of the Big Picture proposed seven guiding principles that were designed to shape the delivery of the Action Plan. These are:

- 1. *To develop best practice methods that reflect a trade-off in cost, time, effort, quality, consistency, level of detail, transparency and confidence;***

⁸ MESH: <https://www.emodnet-seabedhabitats.eu/resources/recommended-operating-guidelines/>

⁹ Marine Monitoring Method Finder: <http://archive.jncc.gov.uk/default.aspx?page=7171>

- 2. To future-proof imagery analysis approaches so that they will incorporate technological improvements over time;**
- 3. To develop methods that are not overly-prescriptive (as this can be counter-productive);**
- 4. To increase the sharing of benthic imagery resources and data;**
- 5. To achieve more consistency of benthic imagery data standards between organisations;**
- 6. To streamline improvements in benthic imagery quality into coherent work-flows;**
- 7. To publish all benthic imagery procedures, guidance and advice online, made available on the NMBAQC website.**

2.4. Production of the Action Plan

The Action Plan is made up of tasks that each aim to address an imagery-related issue, or requirement, that was raised by participants during workshop sessions of the Big Picture Workshop. These tasks differ in the type of action they require to order to address them. For example, some tasks are best accomplished as a standard project, with distinct aims and objectives, timelines with resource requirements, ending with a distinct product. Other tasks may be best carried out by a literature review and a publication. Others will require only stakeholder engagement, discussion in a workshop and perhaps agreement on working principles to take forward. However the task is carried out, each has a suggested deliverable or set of deliverables. Once a deliverable is produced for a task, that task may be considered complete and the original issues tackled, or at very least, significant progress made towards reducing the negative effects of the issue. Some tasks are more complex, however, and will require sustained efforts that are likely to be ongoing in nature. Rather than actions per say, such tasks consist more of processes that may involve periodically reviewing guidelines or updating techniques as new ones emerge.

The PDG have carefully considered each tasks' requirements, deliverables and dependencies and suggested a framework that groups the tasks into seven themes:

1. Governance and co-ordination;
2. Overarching guidelines and purposes for imagery;
3. Acquisition of imagery;
4. Imagery annotation approach;
5. Image annotation software and machine learning;
6. Data flow;
7. Training and Quality Assurance.

Within each theme the dependencies and connections between the tasks are visualised using flowcharts (Figures 2-8). These show how tasks can be related to each other and suggest a logical order in which tasks should be carried out to maximise resource use and efficiency. As previously mentioned, this suggested framework is proposed by the PDG as a sensible way to tackle the large and complex range of benthic imagery issues raised in the Big Picture Workshop. However, there will inevitably be other ways to approach these tasks and this will require flexibility. Organisations interested in this Action Plan should approach tasks with this in mind: that this is a suggested framework only and other approaches / methods may be equally suitable. The one caveat is that such approaches should be reported to the Action Plan Coordinator so that they can be considered within the wider Action Plan.

Finally, all tasks have been prioritised into three categories (High, Medium and Low priority) to indicate their relative importance. This prioritisation is based on three factors: 1. how many linkages the task has to other tasks (i.e. dependencies); 2. the chronological order in which the task must be completed relative to other tasks; and 3. the urgency of the task as recommended by the PDG and participants of the Big Picture Workshop. These priorities have been added to an Action Plan Tracker spreadsheet, along with task names, descriptions and expected deliverables. This is available on the Big Picture Group communications platform (currently on the BIG PICTURE Microsoft Teams site, managed by JNCC).

2.5. How to use this Action Plan

This Action Plan relies on interested organisations working together, sharing resources and opportunities in a spirit of cooperation. This inclusive approach aims to benefit all who work with benthic imagery in the UK and aims to work through the community of organisations referred to as the Big Picture Group. Additionally, the Action Plan may act as a framework to drive and justify the commission of work or research that will contribute to the improvement of benthic imagery data. This approach was proposed by the PDG as a collaborative, coherent way to drive the work forward with minimal duplication of effort. Nevertheless, organisations are not bound in any way to follow these principles.

The Action Plan is freely available to all, but the live Action Plan Tracker, updated by the Action Plan Coordinator, is only available on the Big Picture Group communications platform. If an organisation wishes to work with the Big Picture Group they will have access to this Platform and all its resources. They may also be able to contact and be contacted by all others in the Group. To register, contact the Action Plan Coordinator (currently JNCC).

The PDG have outlined an eleven-step process for the Big Picture Group to complete the 87 tasks in this Action Plan (Figure 1). Overall, this Action Plan aims to operate in a 'task and finish' capacity. As such, when all these tasks have been completed, the Action Plan will be complete and considered finished. In practice, however, the Action Plan will operate as a 'live' document that can be updated as new tasks arise or issues become redundant due to technological advances.

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

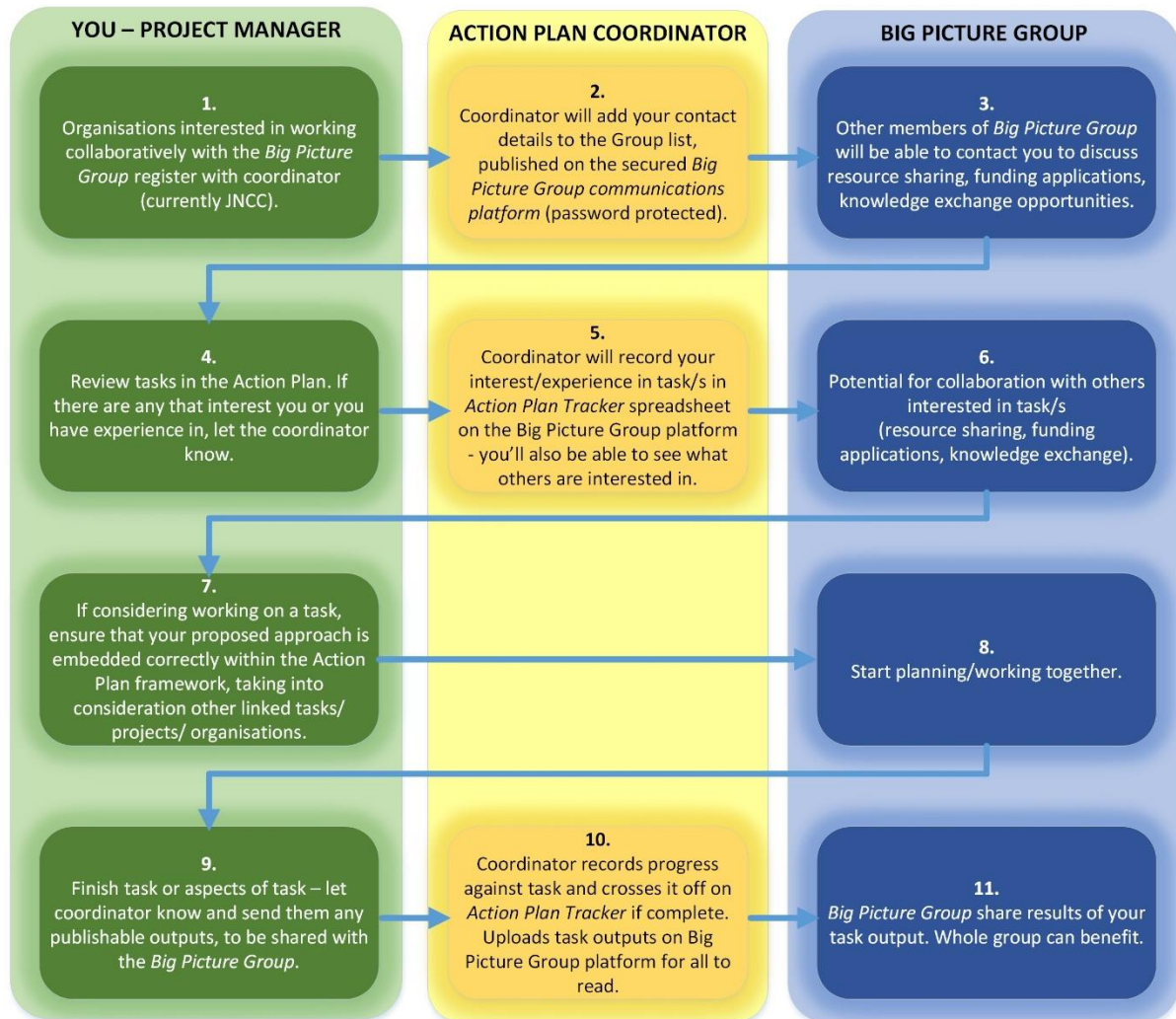


Figure 1. Proposed stages of carrying out a task from the Action Plan, including roles and requirements for each role at each stage. Note description of tasks in section 2.4.

3. Themes and Action Plan tasks

3.1. Governance and coordination tasks

The tasks of this theme aim to set up the governance and management framework necessary for coordination of the Action Plan (Table 1; Figure 2). High priority tasks involve creating a central coordinator to manage activities under the Action Plan. This coordinator will be appointed by the NMBAQC, under HBDSEG, and made responsible for recording and reporting progress of Action Plan tasks, whilst also driving communication across the Big Picture Group.

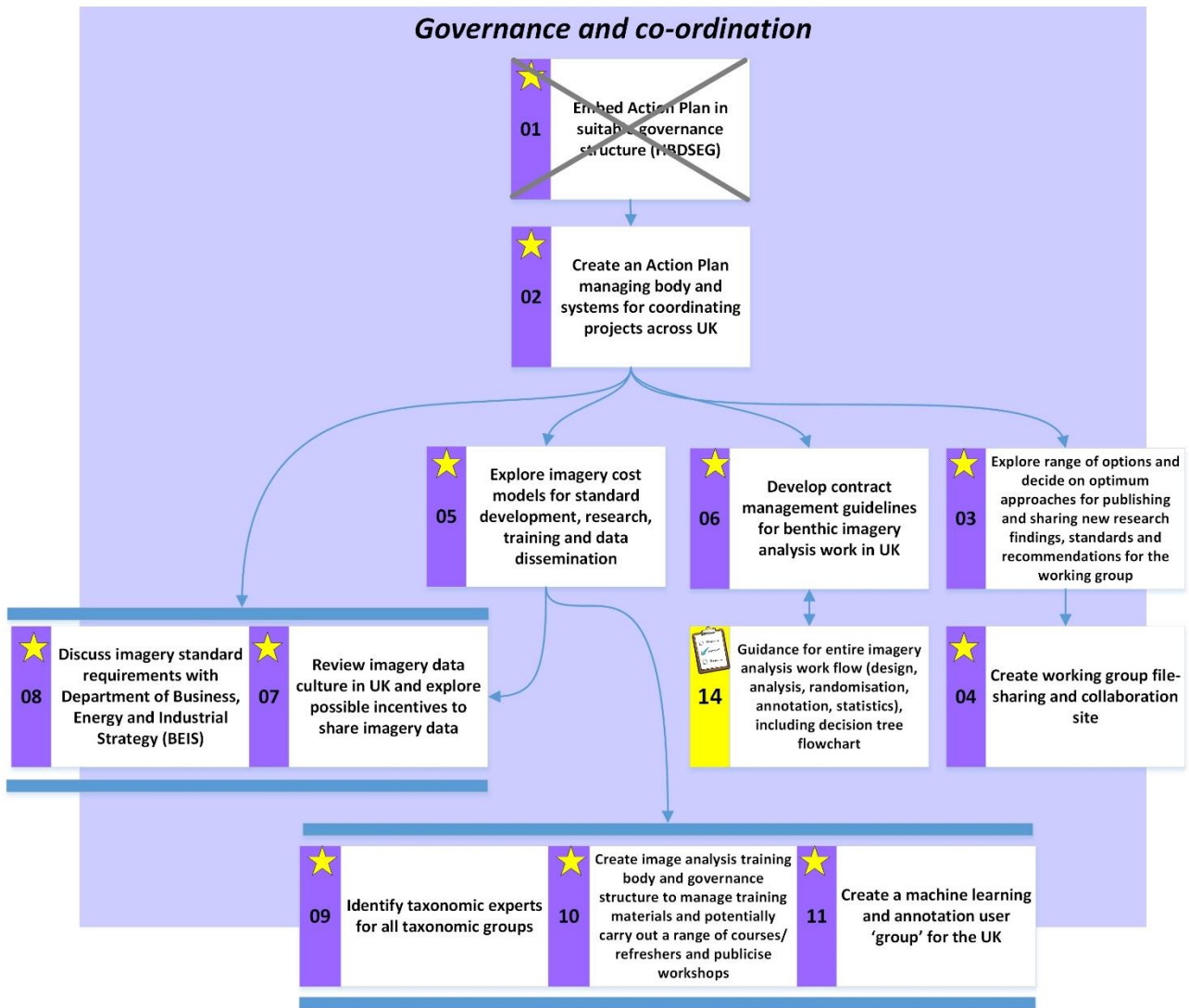


Figure 2. Workflow of key tasks to progress governance and co-ordination aspects of the Benthic Imagery Action Plan. Purple-edged tasks are from the ‘Governance and co-ordination’ theme (‘star’ icon) and yellow-edged tasks are from the ‘Overarching guidelines and purposes’ theme (‘notes’ icon). Note that tasks that are crossed out have already been completed.

Table 1. Description of key tasks to progress governance and co-ordination aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
1	Embed Action Plan in suitable governance structure (HBDSEG) HBDSEG or one of its sub-groups, e.g. NMBAQC, are an ideal group to champion and report progress of the Action Plan to. They represent all the marine biodiversity conservation interests for the UK Marine Monitoring and Assessment Strategy (UKMMAS).	H	HBDSEG Benthic Imagery Action Plan (Note this task is now complete)
2	Create an Action Plan managing body and systems for coordinating projects across UK A central managing body/coordinator to record and report progress of Action Plan tasks, and to liaise with users of the Action Plan.	H	Benthic Imagery Action Plan Coordinator
3	Explore range of options and decide on optimum approaches for publishing and sharing new research findings, standards and recommendations for the working group	L	Recommended information sharing routes for imagery work
4	Create working group file-sharing and collaboration site File sharing site and communications platform already set up for Big Picture Group using Microsoft Teams could be good start point to develop this task. Site must develop according to the needs of the Action Plan and Big Picture Group.	M	File-sharing and collaboration site for Big Picture Group
5	Explore imagery cost models for standard development, research, training and data dissemination Understanding of current imagery related costs needed, as well as potential funding sources. Development of potential cost models to fund all stages of benthic imagery workflows in future, e.g. centrally funded by Competent Monitoring Authorities (CMAs) and government or funded by commissioning organisation? Exploration of suitability and viability of different costs models, as well as group wide consideration of modes for implementation.	M	Options for imagery cost models for standards development

Task no.	Task name and description	Priority	Suggested deliverable/s
6	<p>Develop contract management guidelines for benthic imagery analysis work in UK</p> <p>The quality of benthic imagery products, as well as the relationship between contractors and clients, can be improved by general contract management guidance for benthic imagery analysis work carried out in the UK. The guidance could include as a check lists for all parties to follow. Must include work in the following areas:</p> <ul style="list-style-type: none"> • Improve clarity of specification in image analysis contracts to improve quality of products, efficiency and promote realistic tenders; • Include aspects of conflict of interest and issues of timing guidelines (for analysis) in specifications; • Consider how to improve two-way communication throughout image analysis contracts, as well as embedding formal feedback sessions (review of initial subset of data, or a 'wash up'), at regular intervals throughout contracts; • Provide more information to contractors on purposes/objectives of survey and sampling design to improve understanding and accuracy of tendering; • Consider how to improve the quality of imagery and metadata let out in image analysis contracts, including removal of poor-quality imagery beforehand; • Add an initial familiarisation phase to each image analysis contract to review data and improve learning opportunities pre-annotation; • Add options to share all data after a contract or not: 'opt in or opt out' clause; • Implement recording of annotation metadata, i.e. analysis methods, annotation approach, analysts, training level, accreditation, analyst variability. 	M	Improved imagery analysis contract specifications
7	<p>Review imagery data culture in UK and explore possible incentives to share imagery data</p> <p>Literature reviews, questionnaires and interviews to understand data sharing culture of different organisations in UK. Explore barriers to data sharing, e.g. industry/academia/government could be credited (good publicity rewards) or free advertising opportunities created to raise positive profile of organisations or organisations could pay reduced subscription fees to save costs.</p>	L	Range of options for incentives for sharing of imagery data across UK
8	<p>Discuss imagery standard requirements with Department of Business, Energy and Industrial Strategy (BEIS)</p> <p>This task aims to improve communication and to build a positive relationship between the regulators of offshore industry activities (BEIS) and the marine biodiversity conservation community of the UK. Develop mutually beneficial targets for the future.</p>	L	BEIS collaboration for standard setting
9	<p>Identify taxonomic experts for all taxonomic groups</p> <p>This group likely exists in different forms so may simply involve contacting existing groups. Important to determine which of the experts would be willing to be contacted for identification queries, training and other Action Plan work.</p>	M	List of benthic taxonomic experts

Task no.	Task name and description	Priority	Suggested deliverable/s
10	<p>Create image analysis training body and governance structure to manage training materials and potentially carry out a range of courses/refreshers and publicise workshops</p> <p>The NMBAQC are a logical starting point for this group. The future group must have sustainable cost model for operation as a training body, including consideration of training funds/subsidies for participants. Must engage with universities, museums, consultancies, international taxonomists.</p>	L	Imagery training body
11	<p>Create a machine learning and annotation user 'group' for the UK</p> <p>This group likely exists in different groups so task would need to connect with those groups initially. Additional call of interest for organisations interested in image annotation and machine learning to identify a pool of experts to build supportive, collaborative community across stakeholders. Consider expanding groups membership to international organisations would have additional benefits of expertise and access to new resources.</p>	M	Machine learning and imagery annotation user group

3.2. Overarching guidelines and purposes for imagery tasks

The tasks of this theme aim to create overarching guidelines for benthic imagery workflows, estimating sampling units and a framework for developing standards for a range of purposes behind the use of benthic imagery (Table 2; Figure 3). There is a lack of understanding of the driving purposes behind the use benthic imagery in the UK and a need to develop common purposes and requirements is essential in creating future benthic imagery standards. High priority tasks will, therefore, aim to deliver a list of core purposes for benthic imagery use and recommend minimum standards for imagery acquisition, analysis and data formats for each core purpose.

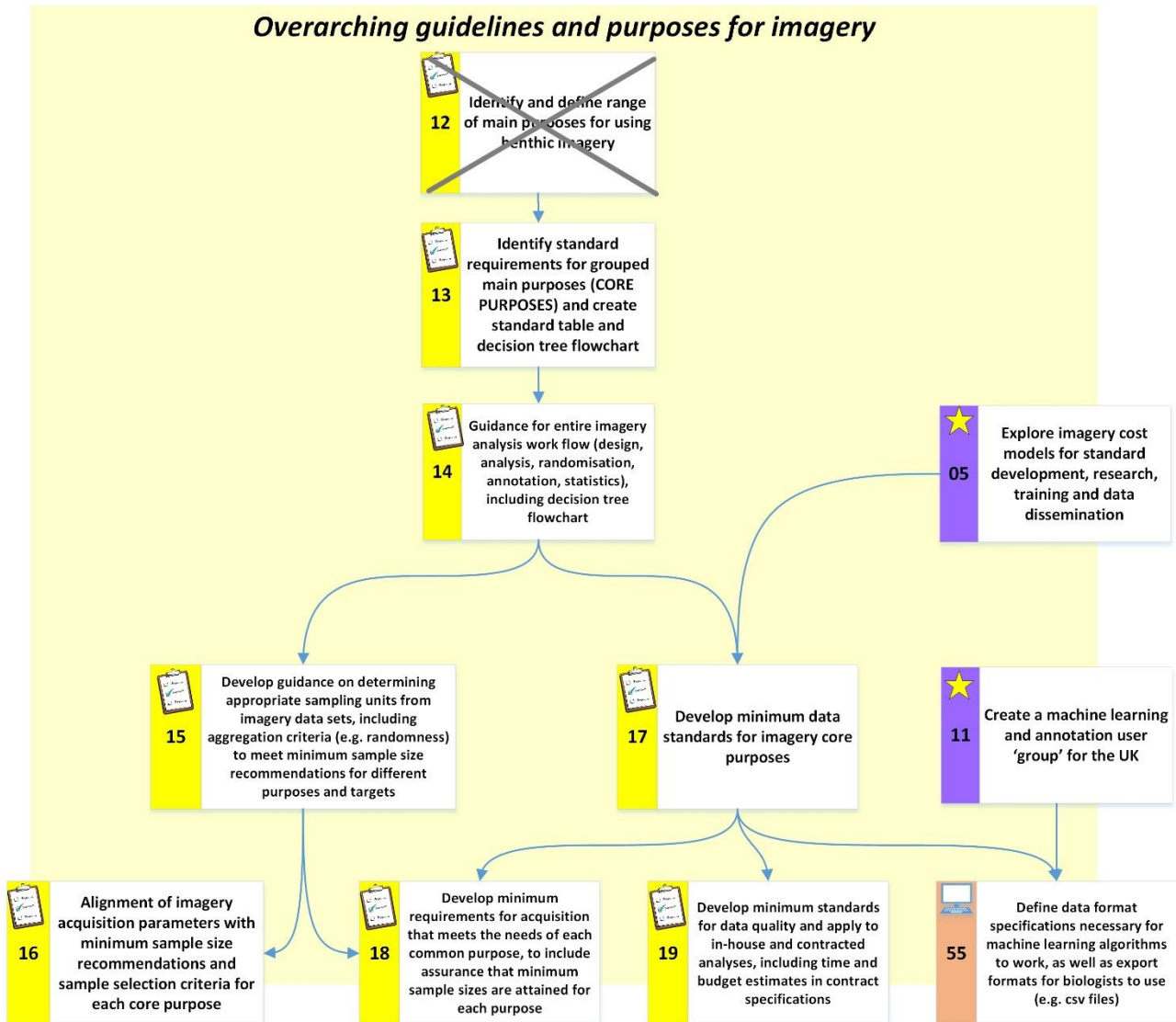


Figure 3. Workflow of key tasks to progress the aspects of the Benthic Imagery Action Plan relating to the purposes of using benthic imagery and overarching guidelines. Yellow-edged tasks ('notes' icon) are from this theme, purple-edged tasks are from the 'Governance and co-ordination' theme ('star' icon) and peach-edged tasks are from the 'Image annotation software and machine learning' theme ('computer' icon). Note that tasks that are crossed out have already been completed.

Table 2. Description of key tasks to progress the aspects of the Benthic Imagery Action Plan relating to the purposes of using benthic imagery and overarching guidelines.

Task no.	Task name and description	Priority	Suggested deliverable/s
12	Identify and define range of main purposes for using benthic imagery JNCC started work on this task – questionnaire sent out to Big Picture Group to determine uses/purposes of benthic imagery, how it is acquired, why it used, how it is processed and what products are produced.	H	Defined range of standard purposes for using benthic imagery (Note this task is now complete)
13	Identify standard requirements for grouped main purposes (CORE PURPOSES) and create standard table and decision tree flowchart Purposes grouped by similarity to represent core purposes - imagery products/outputs must form the basis of each core purpose. Core purposes structured into hierarchy of minimum standard for all imagery, general level (mapping) and then specific level (monitoring). Decision-tree flowchart produced to help users identify their purposes. Cost of implementing each purpose must be considered. Core purposes will be used to develop basic minimum standards for data outputs and working practices in future.	H	Core purposes for using benthic imagery and minimum requirements for each purpose Decision-tree flowchart to identify user purposes (Note work on this task is ongoing)
14	Guidance for entire imagery analysis work flow (design, analysis, randomisation, annotation, statistics), including decision tree flowchart Guidance for entire work flow, including design, analysis/annotation design (preparation to extract/annotate), statistical tests, implementation of standards to randomise the order of all imagery to be analysed to reduce learning effects on data. Guidance must convey importance of each stage in entire work flow being connected and interdependent (from acquisition to annotation/analysis to reporting).	H	Decision tree flowchart for imagery analysis workflow Annotation order of imagery randomised in procedures
15	Develop guidance on determining appropriate sampling units from imagery data sets, including aggregation criteria (e.g. randomness) to meet minimum sample size recommendations for different purposes and targets Assignment of standard, minimum, sample sizes for different purposes and targets based on defining the sampling population under investigation and determining the number of individuals needed within each sampling unit. Guidance must also include table for recording aims of each study and what the sampling population (spatial scale/size) is. Summary flow chart to cover steps needed to define sampling units, aggregate data and determine correct number of replicates needed. Provide numerous examples of different survey scenarios for context. Provide clear terminology.	M	Sampling unit guidance
16	Alignment of imagery acquisition parameters with minimum sample size recommendations and sample selection criteria for each core purpose Recommendations produced for each core purpose. Task targeted at improving technical aspects of imagery acquisition by better aligning image resolution constraints, ground resolution specification, image size/video length considerations, quality constraints, random selection criteria (e.g. randomness of samples for data aggregation) during sampling.	H	Acquisition practices aligned with sample size and selection recommendations

Task no.	Task name and description	Priority	Suggested deliverable/s
17	<p>Develop minimum data standards for imagery core purposes</p> <p>Consider the most appropriate levels that an analysis needs to reach for each purpose. Could use MEDIN data ingestion standards to develop standards for each core purpose (this would make all data collected under each purpose compliant with MEDIN). However, data standards must be cost effective and sustainable to be implemented so task will need to consider this aspect too.</p>	H	Imagery data output standards for standard purposes
18	<p>Develop minimum requirements for acquisition that meets the needs of each common purpose, to include assurance that minimum sample sizes are attained for each purpose</p> <p>Requirements produced for each purpose. Task targeted at developing guidelines for minimum imagery acquisition requirements for each purpose, that meet the data output requirements, with incorporated quality assurance measures.</p>	M	Minimum acquisition standards for standard purposes
19	<p>Develop minimum standards for data quality and apply to in-house and contracted analyses, including time and budget estimates in contract specifications</p> <p>Task involves developing data quality standards that can be quickly applied to raw imagery data sets to ensure they are fit for purpose, i.e. they are fit for annotation, further analysis and data storage later on.</p>	M	Data quality standards for in-house and contractual analyses

3.3. Acquisition of imagery tasks

The tasks of this theme include numerous reviews of current benthic imagery acquisition systems and approaches, as well as new technology, to provide best practice recommendations for the future (Table 3; Figure 4). The Big Picture Workshop conveys a sense that image acquisition is too difficult to standardise across platforms, gear, depths and habitats and that efforts are better focused on standardising outputs from surveys. If survey products can be standardised across purposes then this will allow flexibility in operational budgets, organisation-specific gear and platform choices. The high priority task is represented in two other themes of this Action Plan and aims to periodically update guidance on the acquisition and analysis of benthic imagery data to ensure that optimum approaches are being used and new technologies are incorporated when fit for purpose.

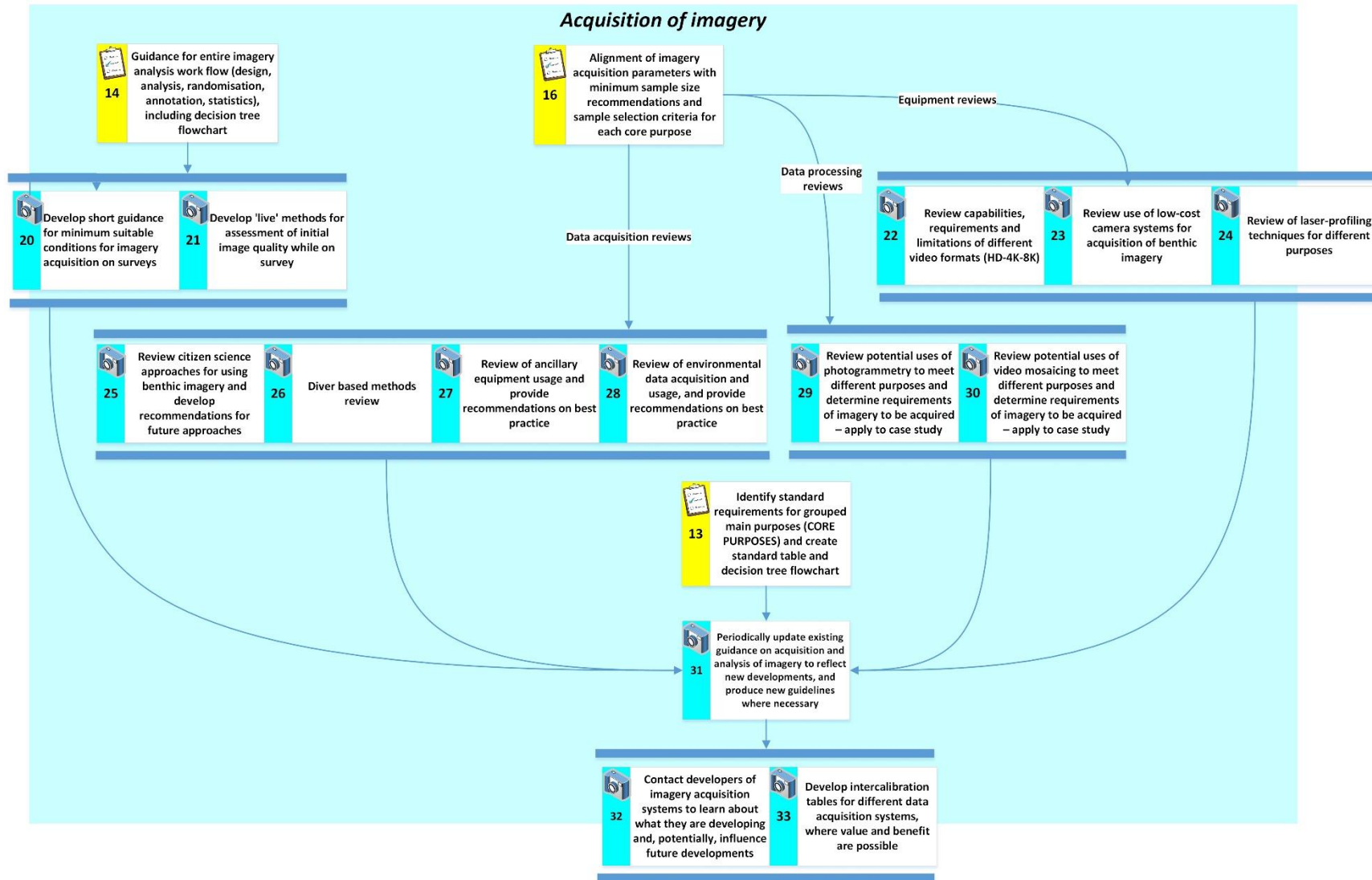


Figure 4. Workflow of key tasks to progress imagery acquisition aspects of the Benthic Imagery Action Plan. Turquoise-edged tasks are from this theme ('camera' icon) and yellow-edged tasks are from the 'Overarching guidelines and purposes' theme ('notes' icon).

Table 3. Description of key tasks to progress imagery acquisition aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
20	<p>Develop short guidance for minimum suitable conditions for imagery acquisition on surveys</p> <p>This task provides guidance on suitability of survey conditions during the acquisition of the imagery. It should cover what conditions are optimum for imagery acquisition, i.e. to improve quality of data and what limits could be placed on suitability of conditions at sea as well as water clarity issues. Guidance must consider inshore/offshore survey differences.</p>	M	Guidance to ensure imagery of good enough quality for analysis
21	<p>Develop 'live' methods for assessment of initial image quality while on survey</p> <p>A 'live' assessment of the quality of raw imagery on survey could reduce cost and efforts later on by enabling users to filter out poor quality imagery early on in data flows. This can have implications for image analysis contracts, especially if poor quality imagery can be removed early on.</p>	M	Enhanced on-survey QA and QC of imagery
22	<p>Review capabilities, requirements and limitations of different video formats (HD-4K-8K)</p> <p>This much needed review should aim to forecast future scenarios where still imagery is extracted from frame grabs taken from video. The review must weigh up costs, benefits and limitations of different video formats and make recommendations regarding suitability of video format for extracting still images.</p>	L	Future capabilities of video
23	<p>Review use of low-cost camera systems for acquisition of benthic imagery</p> <p>Low-cost camera systems are widely used in shallower water (e.g. Go-Pro). Aspects of their usage, costs, benefits and limitations should be reviewed to produce recommendations for their optimum use.</p>	M	Low-cost camera system recommendations
24	<p>Review of laser-profiling techniques for different purposes</p> <p>This review should explore practical applications and uses for this technology and develop recommendations accordingly.</p>	L	Laser-profiling recommendations
25	<p>Review citizen science approaches for using benthic imagery and develop recommendations for future approaches</p> <p>There is massive potential in the use of citizen science approaches for benthic imagery work, especially with the collection of recreational diver imagery or crowd-sourced image annotation of large data sets. This important review must collate examples of existing approaches, evaluate their effectiveness and consider where these existing approaches, or new ones, may be suitable for future benthic imagery work.</p>	M	Citizen science recommendations
26	<p>Diver-based methods review</p> <p>A long overdue review of the range of diver-based imagery acquisition approaches, their costs, benefits and limitations. Review has potential to recommend the optimum approaches for using diver-based imagery for the future.</p>	M	Guidelines for diver imagery acquisition with recommendations

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
27	<p>Review of ancillary equipment usage and provide recommendations on best practice</p> <p>This review is more relevant to large camera systems that increasingly have ancillary equipment (lasers, sensors for pressure, temperature, conductivity, turbidity, chlorophyll, light) attached to the camera frame. This review should identify the uses of this equipment and the range of situations in which it is useful. It would be useful to consider the implications of use of this equipment on smaller camera systems too.</p>	M	Best-practice recommendations on use of ancillary equipment
28	<p>Review of environmental data acquisition and usage, and provide recommendations on best practice</p> <p>A review of different environmental parameters determined directly from imagery, e.g. sediment composition, habitat, and indirectly by ancillary equipment attached to the camera frame, e.g. temperature, salinity, turbidity, chlorophyll. Recommend best-practice for the acquisition of this data, to also include some analysis recommendations.</p>	M	Best-practice recommendations on environmental data acquisition
29	<p>Review potential uses of photogrammetry to meet different purposes and determine requirements of imagery to be acquired – apply to case study</p> <p>Review of the technology, current and potential applications, costs, benefits and limitations, to provide recommendations for future application for different purposes. Consider carrying out a case study.</p>	L	Photogrammetry recommendations
30	<p>Review potential uses of video mosaicing to meet different purposes and determine requirements of imagery to be acquired – apply to case study</p> <p>Review of the technology, current and potential applications, costs, benefits and limitations, to provide recommendations for future application for different purposes. Consider carrying out a case study.</p>	L	Video mosaicing recommendations
31	<p>Periodically update existing guidance on acquisition and analysis of imagery to reflect new developments, and produce new guidelines where necessary</p> <p>This general task is represented in three themes and related to the need to update guidance on benthic imagery acquisition and analysis periodically so that the most up-to-date approaches are being used. Guidance should include specific quality assurance measures, such as training, as well as quality control checks for data, and perhaps also variability assessments (habitats and analysts).</p> <p>It is anticipated the exact focus of guidance from this task will be informed by user needs. Current interests expressed around Drop Down Video and SCUBA diver guidance suggest updates in these areas are a high priority. Furthermore</p>	H	Periodic reviews of procedures

Task no.	Task name and description	Priority	Suggested deliverable/s
32	<p>Contact developers of imagery acquisition systems to learn about what they are developing and, potentially, influence future developments</p> <p>Develop communications and build relationships with developers of imagery acquisition systems to influence future developments.</p>	L	Developer involvement in benthic imagery work
33	<p>Develop intercalibration tables for different data acquisition systems, where value and benefit are possible</p> <p>Assessment of data acquisition systems and potential for intercalibration of data outputs. This task aims to enhance the accessibility of imagery data sets where value and benefit of using intercalibration tables can be demonstrated.</p>	L	Intercalibration tables for acquisition equipment

3.4. Imagery annotation approach tasks

The tasks of this theme aim to develop optimum approaches for annotation (data extraction) of benthic imagery. Numerous reviews and research studies will explore the trade-offs between cost, efficiency, quality, volume, consistency and confidence of identification and enumeration of taxa to meet a range of purposes (Table 4; Figure 5). Many of these tasks are considered high priority as they relate to day-to-day activities of many organisations, in which cost, efficiency and data quality are key considerations when annotating benthic imagery.

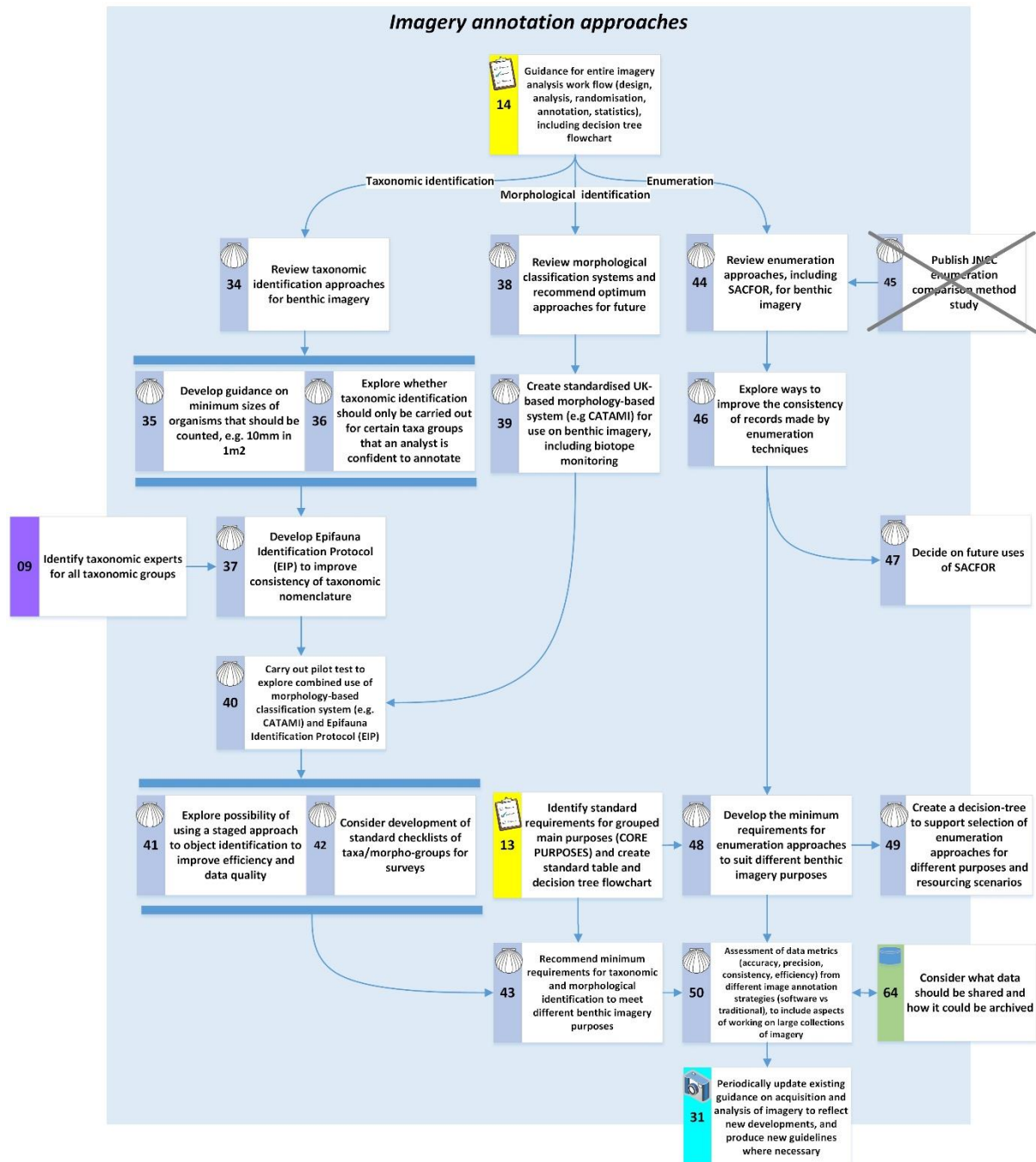


Figure 5. Work flow of key tasks to progress the imagery annotation aspects of the Benthic Imagery Action Plan. Blue-edged tasks are from this theme ('shell' icon), yellow-edged tasks are from the 'Overarching guidelines and purposes' theme ('notes' icon), purple-edged tasks are from the 'Governance and co-ordination' theme ('star' icon), green-edged tasks are from the 'Data flows' theme ('database' icon) and turquoise-edged tasks are from the 'Acquisition of imagery' theme ('camera' icon). Note that tasks that are crossed out have already been completed.

Table 4. Description of key tasks to progress the imagery annotation aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
34	Review taxonomic identification approaches for benthic imagery This task may be best carried out with the assistance of a questionnaire sent out to the Big Picture group.	H	Review of identification approaches
35	Develop guidance on minimum sizes of organisms that should be counted, e.g. 10mm in 1m² Guidelines on the minimum size of taxa that can be accurately identified from different types of benthic imagery, including different levels of image resolution, ground resolution, image quality, stills vs video.	M	Minimum taxa size guidelines for enumeration
36	Explore whether taxonomic identification should only be carried out for certain taxa groups that an analyst is confident to annotate Comparison of different taxonomic identification scenarios in which all taxa in an image are identified by every analyst and where a limited list of taxa are analysed by each analyst. Each analyst must demonstrate expertise in identification of the taxa on their limited list. Guidelines could be produced from the results to promote taxonomic identification strategies that maximise efficiency and data quality.	M	Taxonomic identification guidelines
37	Develop Epifauna Identification Protocol (EIP) to improve consistency of taxonomic nomenclature The NMBAQC have started work on this with the support of the JNCC. This existing work must provide a starting point for this task. Urgent need for more consistency in taxonomic identification standards for imagery annotation. List of expert taxonomists expected to be consulted to develop the EIP.	H	Epifauna Identification Protocol
38	Review morphological classification systems and recommend optimum approaches for future Review existing of morphological systems to include advantages and disadvantages of systems such as CATAMI ¹⁰ , Morphological Taxonomic Unit (MTU) catalogue, deep-sea morphologies ¹¹ and Sponge Morphologies (Bell and Barnes, 2001).	H	Review of morphological classification systems
39	Create standardised UK-based morphology-based system (e.g. CATAMI) for use on benthic imagery, including biotope monitoring Work has started on this task between Cefas and JNCC but will require significant additional input from datasets across the UK to develop a CATAMI-style morphological classification system.	H	Morphology-based classification system for epifauna in UK

¹⁰ CATAMI classification system: <http://catami.github.io/>

¹¹ Deep sea morphologies: <http://www.deepseacatalogue.fr/>

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
40	<p>Carry out pilot test to explore combined use of morphology-based classification system (e.g. CATAMI) and Epifauna Identification Protocol (EIP)</p> <p>Application of UK morphological classification system alongside EIP should first be trialled to assess efficiency and quality of this combined approach. It could also be trialled using image annotation software for additional benefits. This pilot test aims to produce guidelines to recommend next steps.</p>	M	Taxonomic and morphological identification guidelines
41	<p>Explore possibility of using a staged approach to object identification</p> <p>Using existing guidance, trial different annotation approaches to optimise efficiency and data quality, e.g. identify physical features first, then morphological (e.g. CATAMI), then genus and species (if possible).</p>	M	Taxonomic and morphological identification guidelines
42	<p>Consider development of standard checklists of taxa/morpho-groups for surveys</p> <p>Using existing guidance, trial the effect of having standards list with a reduced number of taxa/morpho-groups for annotators to use on survey to improve efficiency and data quality. If successful, trial use of develop a standard approach for making and using the taxa/morpho-group checklists</p>	M	Reduced taxa/morpho-groups lists for surveys
43	<p>Recommend minimum requirements for taxonomic and morphological identification to meet different benthic imagery purposes</p> <p>Review and evaluate existing approaches to taxonomic and morphological feature identification, and develop guidelines for minimum requirements for what taxa and morpho-groups must be identifiable from imagery for different benthic imagery purposes.</p>	M	Minimum identification guidelines for standard purposes
44	<p>Review enumeration approaches, including SACFOR, for benthic imagery</p> <p>Review of enumeration approaches to evaluate their costs, benefits and limitations. Range of approaches could be better understood using a questionnaire to Big Picture Group.</p>	H	Enumeration method review
45	<p>Publish JNCC enumeration comparison method study</p> <p>This study has been completed and will be published by JNCC by end of December 2019.</p>	H	Enumeration method comparison report (Note this task is now complete)
46	<p>Explore ways to improve the consistency of records made by enumeration techniques</p> <p>Test and trial different enumeration approaches to maximise consistency of data recorded by different human analysts. Computer annotation may also be explored in this task as algorithms may yield more consistent results by annotating benthic imagery data sets.</p>	H	Consistency recommendations
47	<p>Decide on future uses of SACFOR</p> <p>Review uses of SACFOR and results from method comparison studies to understand best use of SACFOR in future. Perhaps retained as intercalibration or mapping tool for next 5 years?</p>	M	SACFOR recommendations

Task no.	Task name and description	Priority	Suggested deliverable/s
48	Develop the minimum requirements for enumeration approaches to suit different benthic imagery purposes Optimum enumeration approaches can be developed for taxa and morph-groups to suit each benthic imagery purpose, to benefit data quality, improve efficiency and enhance data sharing opportunities across UK. Approaches should align to different resourcing scenarios and needs of the purpose.	M	Minimum enumeration guidelines for standard purposes
49	Create a decision-tree to support selection of enumeration approaches for different purposes and resourcing scenarios Create flowchart to help users select the ideal enumeration approach for their resources and purposes.	L	Minimum enumeration guidelines flowchart for standard purposes
50	Assessment of data metrics (accuracy, precision, consistency, efficiency) from different image annotation strategies (software vs traditional), to include aspects of working on large collections of imagery Comparison studies of different annotation strategies exploring the costs and benefits of using traditional human-based data recording vs annotation software used by humans. Study could also explore use of annotation software used by machines (machine-learning). Important to use large data sets for comparisons to highlight current and future needs.	M	Optimisation of annotation software approaches vs traditional approaches

3.5. Image annotation software and machine learning tasks

Initially, the tasks of this theme focus on the uptake and application of image annotation software by human analysts. This is expected to have benefits in efficiency and quality. Then the focus expands to utilise and develop current machine learning approaches, which often rely on human-annotated imagery for training, to achieve reliable automated annotation of benthic imagery (Table 5; Figure 6). Many of the tasks in this theme are understandably high priority and focused on directing the development of automated approaches to improve efficiency, quality of data and reduce costs of imagery annotation. One of the key tasks is to create pathways for existing imagery data sets to be made available for machine learning development.

The tasks in this theme are considered critical to the longer-term usage of benthic imagery for seabed evidence purposes in the UK. Sampling platforms and equipment, such as Autonomous Underwater Vehicles, are capable of collecting large datasets consisting of 100,000s of images. There is no current provision to annotate datasets this large so they are usually subsampled. This loss of potential evidence will be further compounded as increasingly large datasets are collected in future. Coupled with this data volume problem are data quality concerns associated with human annotators, as raised at the Big Picture Workshop. Although this Action Plan aims to address many of this concerns, it will be advantageous to develop machine-based annotation to reduce the burden on human annotators and cope with the volumes of new imagery data coming in.

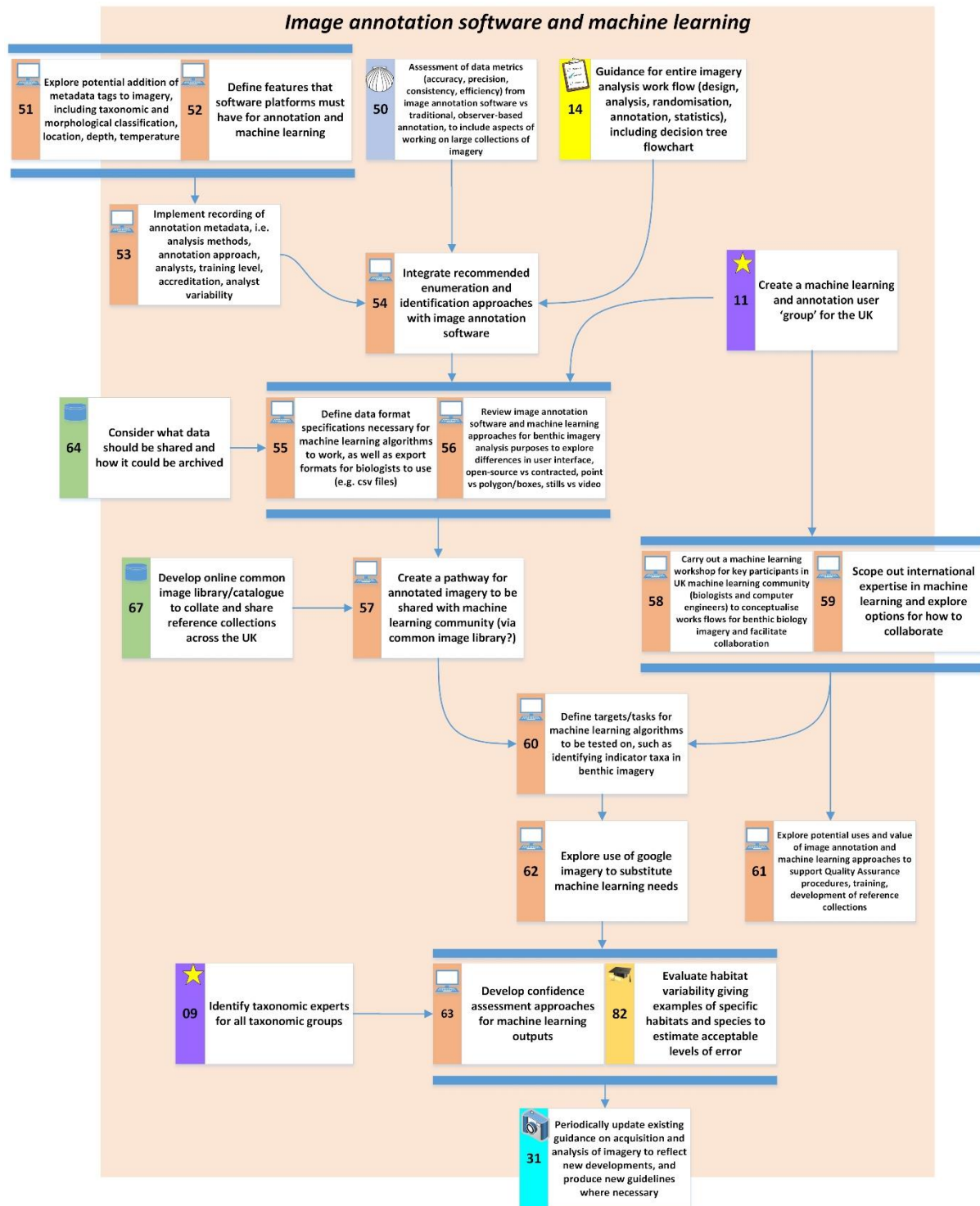


Figure 6. Workflow of key tasks to progress the application of imagery annotation software and machine learning aspects of the Benthic Imagery Action Plan. Peach-edged tasks are from this theme ('computer' icon), blue-edged tasks are from the 'Imagery annotation approaches' theme ('shell' icon), yellow-edged tasks are from the 'Overarching guidelines and purposes' theme ('notes' icon), purple-edged tasks are from the 'Governance and co-ordination' theme ('star' icon), green-edged tasks are from the 'Data flows' theme ('database' icon), orange-edged tasks are from the 'Training and Quality Assurance' theme ('mortarboard' icon) and turquoise-edged tasks are from the 'Acquisition of imagery' theme ('camera' icon).

Table 5. Description of key tasks to progress the application of imagery annotation software and machine learning aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
51	<p>Explore potential addition of metadata tags to imagery, including taxonomic and morphological classification, location, depth, temperature</p> <p>Trial application and develop use of various metadata tags/labels for benthic imagery. Should include location tags of taxa/morpho-groups (to create location-based taxa lists in future) and ancillary sensor data if possible: depth, temperature, turbidity etc.</p>	H	Addition of metadata tags to imagery
52	<p>Define features that software platforms must have for annotation and machine learning</p> <p>Software features of importance to machine learning applications.</p>	H	Requirements of annotation and machine learning platforms
53	<p>Implement recording of annotation metadata, i.e. analysis methods, annotation approach, analysts, training level, accreditation, analyst variability</p> <p>Trial application and develop use of annotation metadata tags/labels for benthic imagery. Should include tags/labels of analysis methods, annotation approach, analysts, training level, accreditation, analyst variability, all of use for data sharing.</p>	H	Annotation metadata recorded in procedures
54	<p>Integrate recommended enumeration and identification approaches with image annotation software</p> <p>This milestone task combines the optimum annotation theory and approaches with annotation software to produce high-quality digitally annotated imagery and data.</p>	H	Optimum identification and enumeration approaches used with annotation software
55	<p>Define data format specifications necessary for machine learning algorithms to work, as well as export formats for biologists to use (e.g. csv files)</p> <p>Consult with leading developers to determine their data format specifications (import/export) of machine learning algorithms.</p>	H	Data format requirements for machine learning algorithms
56	<p>Review image annotation software and machine learning approaches for benthic imagery analysis purposes to explore differences in user interface, open-source vs contracted, point vs polygon/boxes, stills vs video</p> <p>Numerous review likely exist to provide this task with a head-start. Search AUV community research for current software. Explore all ensemble approaches (multiple models can learn from each other).</p>	H	Review of current annotation and machine learning approaches
57	<p>Create a pathway for annotated imagery to be shared with machine learning community (via common image library?)</p> <p>Data flows need to be understood and sources of annotated imagery discovered. Pathways to machine learning community must be able to cope with hundreds of thousands of images for train algorithms (estimated 100K images needed of different taxa and morpho-groups).</p>	H	Open access to imagery library (for machine learning algorithms)

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
58	Carry out a machine learning workshop for key participants in UK machine learning community (biologists and computer engineers) to conceptualise works flows for benthic biology imagery and facilitate collaboration	M	Machine learning workshop for benthic ecologists
59	Scope out international expertise in machine learning and explore options for how to collaborate Seek our expertise in machine learning to collaborate in UK projects where possible.	M	List of international contacts with expertise in machine learning using benthic imagery
60	Define targets/tasks for machine learning algorithms to be tested on, such as identifying indicator taxa in benthic imagery Targets may be specific taxa, morph-groups, communities, biotopes, habitats or substrata. Must be relevant to scope of Action Plan. May consider open competitions within machine learning community to stimulate development of specific tools to detect targets (requires funding/rewards for prizes).	H	List of targets/tasks for machine learning algorithms
61	Explore potential uses and value of image annotation and machine learning approaches to support Quality Assurance procedures, training, development of reference collections	M	Role of annotation and machine learning approaches in QA
62	Explore use of google imagery to substitute machine learning needs	M	Use of google images for machine learning applications
63	Develop confidence assessment approaches for machine learning outputs Confidence assessment will likely be verified by human annotators, perhaps expert taxonomists in the target taxa/group. These assessments should become standard for all machine learning outputs in the scope of this Action Plan.	L	Machine learning confidence assessments

3.6. Data flow tasks

The tasks of this theme relate to benthic imagery data flows. Data sharing flows, gaps in flows and solutions to gaps are investigated by the tasks (Table 6; Figure 7). The high priority task involves the creation of a central imagery library or catalogue to store reference collection imagery, at first, but to eventually grow and serve training and testing needs as well as machine learning training needs. This key task of the Action Plan will have long-term benefits for the all benthic imagery users but will have numerous challenges to overcome, such as management of the library and costs of maintenance.

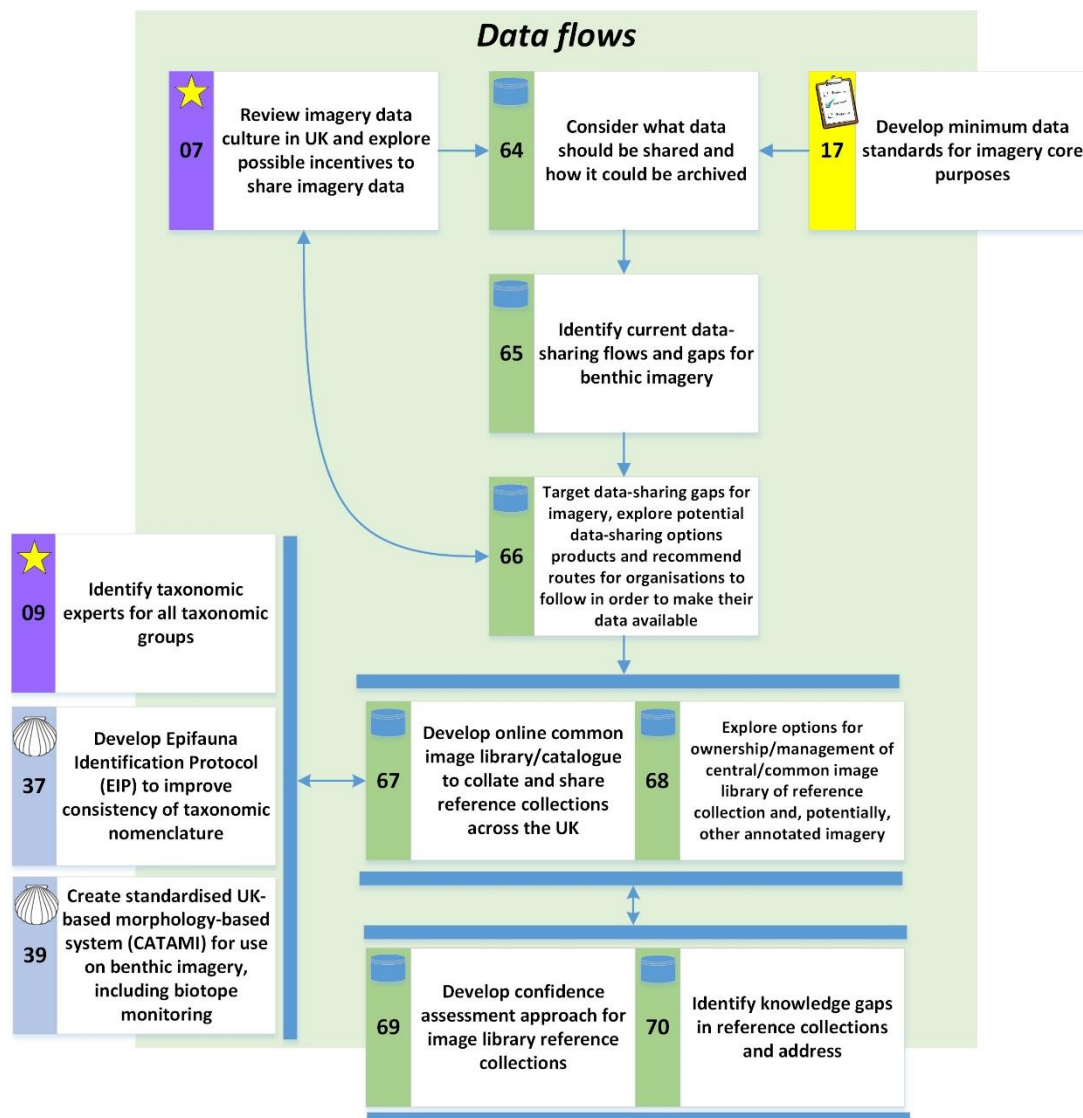


Figure 7. Workflow of key tasks to progress data flow aspects of the Benthic Imagery Action Plan. Green-edged tasks are from this theme ('database' icon), purple-edged tasks are from the 'Governance and co-ordination' theme ('star' icon) and yellow-edged tasks are from the 'Overarching guidelines and purposes' theme ('notes' icon).

Table 7. Description of key tasks to progress the application of imagery annotation software and machine learning aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
64	<p>Consider what data should be shared and how it could be archived</p> <p>Consider full range of data generated from benthic imagery and the potential value and benefits of sharing that data. Important to understand data culture of different organisations and incentives for sharing data.</p>	M	Data archive flows
65	<p>Identify current data-sharing flows and gaps for benthic imagery</p> <p>Flows should be mapped out and costs/benefits/limitations evaluated. JNCC Marine Monitoring Platform Guidelines data flow diagram could be a good start point for this task. May also require a questionnaire to Big Picture Group to understand every organisations unique data flows.</p>	M	Understanding current data-sharing flows and gaps
66	<p>Target data-sharing gaps for imagery, explore potential data-sharing options products and recommend routes for organisations to follow in order to make their data available</p> <p>This task relates to the potential of re-purposing imagery, i.e. adding value to imagery that has already been collected and used once before. Likely sharing-routes between WoRMS, OBIS, Pangea, Marine Recorder, DASSH, MEDIN. Important to understand data culture of different organisations and incentives for sharing data.</p>	M	Options and recommendations to address data sharing gaps

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
67	<p>Develop online common image library/catalogue to collate and share reference collections across the UK Reference collections generated following NMBAQC guidelines can be used as a feedback mechanism to improve consistency of future identification. Imagery library could collate existing reference collection imagery from organisations and be expanded to include other potential libraries and existing resources including MEDIN, DASSH, Habitas, NOAA, FathomNet¹² (MBARI), JNCC imagery library; National Oceanography Centre (NOC), Cefas, Marine Scotland Science). Can draw on experiences of sharing reference collections from ICES Working Group on Nephrops norvegicus (Nephrops) Surveys (WGNEPS). Set up quality assurance and quality control processes for incoming imagery using experts, including assignment of confidence scores. Library could link to WoRMS database via API. Must be available offline too with live link to WoRMS when online. Can provide guidance to levels of appropriate levels of taxonomic identification (link to EIP). Methods for querying catalogue using metadata tags (e.g. taxa, location, depth). Expand image library into a catalogue, to include imagery of a range of conditions (image quality, resolution), morphological classifications (CATAMI?), Vulnerable Marine Ecosystems (VMEs), references of abundance, video and stills. Must include metadata for all above and, eventually, multiple examples of each item (under different conditions, camera systems, camera angles).</p>	H	Benthic imagery library
68	<p>Explore options for ownership/management of central/common image library of reference collection and, potentially, other annotated imagery Ideally should be publicly funded and free (HBDSEG/NMBAQC?) but could have subscription costs if needs be. Must have a sustainable cost model. Need to send out data call for available imagery, offer incentives, assess imagery quality (validation by experts), tag imagery and existing catalogue imagery. Need to identify what's required/scope of a common image library, then identify priorities and trial it on a data set – test a beta version.</p>	M	Range of options for implementation of Benthic imagery library
69	<p>Develop confidence assessment approach for image library reference collections This task ensures the quality of reference imagery is maintained as it is used by the benthic imagery library.</p>	L	Image library confidence assessments
70	<p>Identify knowledge gaps in reference collections and address Address gaps by feeding them back into imagery acquisition/survey stages of work flows.</p>	L	Complete reference collections

¹² FathomNet: <https://www.mbari.org/wp-content/uploads/2019/11/Barnard.pdf>

3.7. Training and Quality Assurance tasks

The tasks of this theme focus on the training of imagery analysts and assessing their work to ensure standards are met. Training methods are reviewed, gaps and targets identified and a large range of new courses, workshop and resources are proposed, including developing a Centre of Excellence for Benthic Taxonomy in the UK (Table 7; Figure 6). There are numerous linkages with tasks in different themes of this Action Plan, reflecting the nature of training and testing work: that it is essential in all areas of work and necessary for continued quality and efficiency of imagery acquisition, annotation and production of imagery related products.

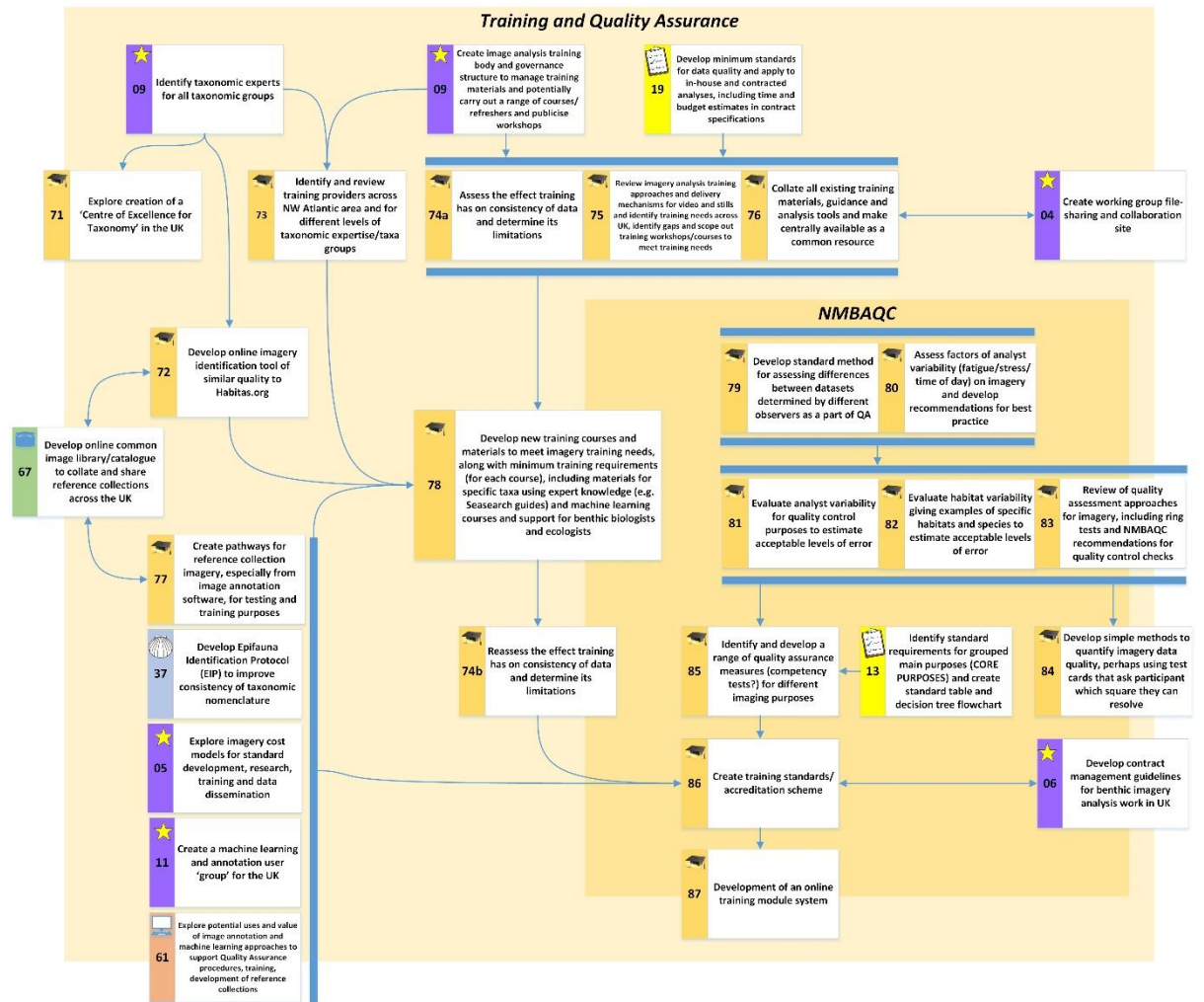


Figure 6. Workflow of key tasks to progress the application of training and Quality Assurance aspects of the Benthic Imagery Action Plan. Orange-edged tasks are from this theme ('mortarboard' icon), yellow-edged tasks are from the 'Overarching guidelines and purposes' theme ('notes' icon), purple-edged tasks are from the 'Governance and co-ordination' theme ('star' icon), blue-edged tasks are from the 'Imagery annotation approaches' theme ('shell' icon), green-edged tasks are from the 'Data flows' theme ('database' icon) and peach-edged tasks are from the 'Image annotation software and machine learning' theme ('computer' icon).

Table 7. Description of key tasks to progress the application of training and Quality Assurance aspects of the Benthic Imagery Action Plan.

Task no.	Task name and description	Priority	Suggested deliverable/s
71	Explore creation of a 'Centre of Excellence for Taxonomy' in the UK Develop strategies to maintain experience and skill of human observers as machine learning algorithms and annotation software are used more frequently, to include definition of future role of human observers.	M	UK Centre of Excellence for Benthic Taxonomy
72	Develop online imagery identification tool of similar quality to Habitas.org Tool should be an online resource that contains links to all resources, book references, upcoming training courses, online catalogues. A range of imagery must be used for examples of taxa and morphotaxa, e.g. from drop camera video and stills, diver stills, AUV video.	M	Online identification tool
73	Identify and review training providers across North-West Atlantic area and for different levels of taxonomic expertise/taxa groups	L	List of training providers
74	Assess the effect training has on consistency of data and determine its limitations Important to determine the value of training in this task. Assessment of this value should be determined before training improvements have been made and afterwards to evaluate effectiveness of training and this part of the Action Plan.	M	Training benefits and limitations report
75	Review imagery analysis training approaches for video and stills and identify training needs across UK, identify gaps and scope out training workshops/courses to meet training needs Training needs could be identified by questionnaire across Big Picture group. Workshops may be proposed for annotation tools, taxonomy, enumeration methods, video identification, automated annotation, machine learning, different biomes, SACFOR, NMBAQC, generic taxonomy and local/regional taxonomy, emerging taxonomic techniques (i.e. molecular). Evaluate delivery mechanisms for training resources and introductions of new techniques, including for maintenance of training standards over time (i.e. refresher tests), and recommend most appropriate routes. Explore options for central resources: completely public repository in NMBAQC, Conservation Agency, Natural History Museum, MarLIN, Universities) vs restricted access (but no costs) vs licensed access (costs for access). Explore delivery of training via online route vs workshop route (e.g. Field Studies Council, Dale Fort), inhouse vs external training and the levels required of each.	H	Imagery analysis training needs Training workshops and courses proposals

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
76	<p>Collate all existing training materials, guidance and analysis tools and make centrally available as a common resource</p> <p>Review to discover training tools and resources, followed by collation and then summarise and make available, perhaps via a table of weblinks (similar to the JNCC Marine Monitoring Method Finder¹³). Must include Habitas.org, Marine Biologists Forum (Facebook).</p>	H	Imagery training resource hub
77	<p>Create pathways for reference collection imagery, especially from image annotation software, for testing and training purposes</p> <p>This task will be facilitated by creating a central imagery library of reference collection, from which software can be developed to extract test and training imagery. Note there is another task to create pathways for annotated imagery into machine-learning workflows (Task 57).</p>	M	Recommendations for best flows of reference collection imagery for use in testing and training
78	<p>Develop new training courses and materials to meet imagery training needs, along with minimum training requirements (for each course), including materials for specific taxa using expert knowledge (e.g. Seasearch guides) and machine learning courses and support for benthic biologists and ecologists</p> <p>This task aims to develop multiple courses and training materials to meet benthic imagery analysis needs and purposes. Courses could be aimed at beginner (introductory), intermediate and expert levels. Could have different training requirements for different purposes (levels of training). Could have basic inductions with set pass/fail limits to achieve accreditation. Tests could be designed for different levels of skill and taxonomic expertise – generic entry level requirements vs detailed taxa-specific requirements (carried out by experts). Explore delivery options such as webinars and online courses to reduce costs. Strategies to improve general knowledge and understanding of data handling skills, annotation software and machine learning algorithms</p>	H	Courses and materials bespoke to training needs identified in the review
79	<p>Develop standard method for assessing differences between datasets determined by different observers as a part of QA</p> <p>There are statistical approaches useful for assessing the difference between data annotated by different analysts, including exploration of Lin's Concordance Correlation Coefficient, or Largo function in BIIGLE¹⁴ software. Different approaches should be compared and most reliable, optimum method should be standardised by the NMBAQC.</p>	H	Observer data assessment tool for QA
80	<p>Assess factors of analyst variability (fatigue/stress/time of day) on imagery and develop recommendations for best practice</p> <p>A study to investigate factors that contribute to variability of data determined by analysts. Should incorporate existing knowledge on the subject to make recommendations for best practice.</p>	M	Guidelines for annotation best practice

¹³ Marine Monitoring Method Finder: <http://archive.jncc.gov.uk/default.aspx?page=7171>

¹⁴ BIIGLE: <https://www.biigle.de/>

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Task no.	Task name and description	Priority	Suggested deliverable/s
81	<p>Evaluate analyst variability for quality control purposes to estimate acceptable levels of error</p> <p>Develop methods to determine the variability of individual analysts and determine acceptable levels of error for imagery annotation purposes.</p>	M	Analyst variability assessment tool for quality/ring tests
82	<p>Evaluate habitat variability giving examples of specific habitats and species to estimate acceptable levels of error</p> <p>Determine the variability of habitats and species in benthic habitats and determine acceptable levels of error for imagery annotation purposes. The Marine Biological Association (MBA) have work in this area to follow up on for this task.</p>	M	Guidelines on acceptable levels of habitat and species variability
83	<p>Review of quality assessment approaches for imagery, including ring tests and NMBAQC recommendations for quality control checks</p> <p>Review current Quality Assurance measures for benthic imagery in the UK to determine successes, overlap and redundancy, include assessment of which organisations follow NMBAQC recommendations. Organisations to update internal and external Quality Control guidelines.</p>	M	Updated NMBAQC quality control checking guidelines for internal and contracted work
84	<p>Develop simple methods to quantify imagery data quality, perhaps using test cards that ask participant which square they can resolve</p> <p>Explore existing methods for this task, including Nephrops TV survey quality checks. Adopt useful methods for rapid assessment of quality of imagery before annotation.</p>	M	Image quality assessment tool
85	<p>Identify and develop a range of quality assurance measures (competency tests?) for different imaging purposes</p> <p>May involve development of competency tests for certain groups of taxa, morpho-groups, indicators, biotopes, enumeration methods and regions to ensure appropriate standards are met for each imagery purpose. Methods may be developed to evaluate observer variability. Consider frequency of tests (annual) and potential for 'accreditation' – minimum competency for different standards.</p>	M	Quality assurance measures/competency tests required to meet all standard purposes
86	<p>Create training standards/accreditation scheme</p> <p>This task brings together many other tasks as it requires an understanding of financial incentives for accreditation, possible endorsement funding models, standard setting and numerous training resources. Could link this scheme to the Field Studies Council (FSC) or NMBAQC. Could be endorsed by Chartered Institute of Ecology and Environmental Management (CIEEM) or Institute of Environmental Sciences (IES). Useful to review Marine Stewardship Council (MSC) accreditation schemes for this task.</p>	M	Training standards/accreditation scheme
87	<p>Development of an online training module system</p> <p>System must be accessible and easy to use/good interface. For example, Marine Stewardship Council audit training systems. System could also have online practice tests for refreshers.</p>	L	Imagery training resource hub: live training module system

4. References

3KQ, 2019. The Big Picture Benthic Imagery Analysis Workshop. Workshop report for JNCC, 151pp.

Axelsson, M., Dewey, S. and Wilson, J. 2014. Isles of Scilly Complex SAC: Reef Feature Condition Assessment - Kelp forest communities and vertical rock: 2013 baseline dive survey. Natural England Commissioned Reports, Number 160.

Bell, J.J. and Barnes, D.K.A. 2001. Sponge morphological diversity: a qualitative predictor of species diversity? *Aquatic Conservation: Marine and Freshwater Ecosystems* 11: 109 – 121.

Bunker, F. St. P. D. 2015. Intertidal Monitoring of rocky reefs, Pembrokeshire Marine SAC. Population trends for selected species 2005 to 2014. NRW Evidence Report No: 59, 64pp, Natural Resources Wales, Bangor.

Curtis, L.A. 2012. Plymouth Sound and Estuaries SAC Seagrass Condition Assessment 2012. Report Number: ER12-185 for Natural England. 78p.

Durden, J.M., Schoening, T., Althaus, F., Friedman, A., Garcia, R., Glover, A.G., Greinert, J., Stout, N. Jacobsen, N., Jones, D.O.B, Jordt, A., Kaeli, J.W., Koser, K., Kuhnz, L.A., Lindsay, D., Morris, K.J., Nattkemper, T.W., Osterloff, J., Ruhl, H.A., Singh, H., Tran, M. and Bett, B.J. 2016. Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding. *Oceanography and Marine Biology: An Annual Review*, 54, 1S72.

Eggleton, J.D. and Meadows, W. 2013. Offshore monitoring of Annex 1 reef habitat present within the Isles of Scilly Special Area of Conservation. Natural England Commissioned Reports, Number 125. 74p.

Field, M.D.R. 2012. Plymouth Sound and Estuaries SAC: Kelp Forest Condition Assessment 2012. Final report. Report Number: ER12-184 for Natural England. 46p.

Goodwin, C., Picton, B., Breen, J., Edwards H. and Nunn, J. 2011a. Sublittoral Survey Northern Ireland (2006 – 2008). Northern Ireland Environment Agency Research and Development Series No. 11/01.

Goodwin, C., Picton, B., Breen, J. and Edwards H. 2011b. The Maidens — Report from the Sublittoral Survey Northern Ireland project. Northern Ireland Environment Agency Research and Development Series No. 11/02

Goodwin, C., Edwards H., Breen, J. and Picton, B. 2011c. Rathlin Island - A Survey Report from the Nationally Important Marine Features Project 2009-2011. Northern Ireland Environment Agency Research and Development Series No. 11/03.

Goodwin, C., Edwards H., Breen, J. and Picton, B. 2011d. Shamrock Pinnacle - A Survey Report from the Nationally Important Marine Features Project 2009-2011. Northern Ireland Environment Agency Research and Development Series No. 11/04.

Goodwin, C., Breen, J., Edwards, H., Bennett, S., Burrows, G., and Picton, B. 2012. Skerries and Causeway Survey - A Survey Report from the Nationally Important Marine Features

Development of a Benthic Imagery Action Plan for the UK

Version: 1.1

Lead author: *Henk van Rein*

Release date: 08/04/20

Project 2006-2009. Northern Ireland Environment Agency Research and Development Series No. 12/01.

Hawes, W., O'Dell, J., Axelsson, M., Dewey, S. & Allen, C. 2014. St Austell Bay Maerl Survey - Acoustic and Video Analysis. A report to Natural England by Seastar Survey Ltd., 41 pages.

Irving, R.A. and Northen, K.O. 2012. Condition Assessment Monitoring for Reefs, Isles of Scilly European Marine Site - Diving Survey June 2011. 2011. Natural England Commissioned Reports, Number 104. 138p.

Newman, P., Lock, K., Burton, M. and Jones, J. 2017. Skomer Marine Conservation Zone Annual Report 2016. NRW Evidence Report No: 198, 67pp.

Newman, P., Lock, K., Burton, M. and Jones, J. 2018. Skomer Marine Conservation Zone Annual Report 2017. NRW Evidence Report No: 250, 80pp.

Noble-James, T., Jesus, A. & McBreen, F. 2017. Monitoring guidance for marine benthic habitats. JNCC Report No. 598. JNCC, Peterborough. URL: http://archive.jncc.gov.uk/pdf/report_598_final_web.pdf

Noble-James, T., Judd, A., Clare, D., Diesing, M., Eggett, A., Kröger, K. & Silburn, B. 2017 (Revised 2019). Croker Carbonate Slabs cSAC/SCI Initial monitoring report. JNCC/Cefas Partnership Report No. 17. JNCC, Peterborough.

NRW, 2018. Pembrokeshire Marine / Sir Benfro Forol Special Area of Conservation: Indicative site level feature condition assessments 2018. NRW Evidence Report Series, Report No: 233, 67pp, NRW, Bangor.

Mercer, T., Howson, C. M., and Moore, J. J. 2007. Site Condition Monitoring: Loch Sunart marine SAC and SSSI. Scottish Natural Heritage Commissioned Report No. 286 (ROAME No. R06AC701).

Mercer, T. S. 2016. Across-Wales intertidal SAC monitoring, Pen Llyn a'r Sarnau SAC August 2014. NRW Evidence Report No: 75, pp 95 + vii, Aquatic Survey & Monitoring Ltd. Harehope Quarry, Co. Durham.

Moore, C.G., Cook, R.L., Porter, J.S., Sanderson, W.G., Want, A., Ware, F.J., Howson, C., Kamphausen, L. & Harries, D.B. 2017. 2015 site condition monitoring of marine sedimentary and reef habitats in Loch Laxford SAC. Scottish Natural Heritage Commissioned Report No. 943.

Moore, C.G. 2019. Biological analyses of underwater video from monitoring and research cruises in Lochs Ailort and Fyne, the Sounds of Barra and Mull, inner Moray Firth, off Wester Ross, Noss Head and Rattray Head, and around the Southern Trench in outer Moray Firth. Scottish Natural Heritage Research Report No. 1085.

O'Dell, J., Shakspeare, A., Axelsson, M. and Dewey, S. 2016. Shell Flat and Lune Deep Drop-Down Video Survey. A report to Natural England by Seastar Survey Ltd., 76 pages.

Populus J., Vasquez M., Albrecht J., Manca E., Agnesi S., Al Hamdani Z., Andersen J., Annunziatellis A., Bekkby T., Bruschi A., Doncheva V., Drakopoulou V., Duncan G., Inghilesi R., Kyriakidou C., Lalli F., Lillis H., Mo G., Muresan M., Salomidi M., Sakellariou D., Simboura M., Teaca A., Tezcan D., Todorova V. and Tunesi L., 2017. EUSeaMap, a European broad-scale seabed habitat map. 174p.

Sheehan, E.V., Cousens, S.L., Holmes, L.A., Nancollas, S., Hooper, E. and Attrill, M.J. 2015. Condition assessment of Thanet Coast Special Area of Conservation. Natural England Commissioned Report NECR165. 51p.

Sheehan, E.V., Cousens, S.L., Gall, S.C. and Attrill, M.J. 2016. Condition assessment of the Lyme Bay Annex I reef habitats in the Lyme Bay and Torbay cSAC. Natural England Commissioned Report RP1605. 46p.

Schoening, T., Durden, J., Preuss, I., Branzan Albu, A., Purser, A., De Smet, B., Dominguez-Carrió, C., Yesson, C., de Jonge, D., Lindsay, D., Schulz, J., Möller, K., Beisiegel, K., Kuhn, L., Hoeberechts, M., Piechaud, N., Sharuga, S. and Treibitz, T. 2017. Report on the Marine Imaging Workshop 2017. Research Ideas and Outcomes 3: e13820. <https://doi.org/10.3897/rio.3.e13820>.

Vance, T. and Ellis, R. 2016. Lundy SAC: Subtidal Reef Condition Assessment and No Take Zone Benthic Monitoring Survey 2014/15. Report 2178 for Natural England. 63p.

Ware, S. and Meadows, B. 2012. Monitoring of Plymouth Sound and Estuaries SAC 2011. Final Report (C5521) for Natural England. 48p.

5. Annexes

5.1. Annex I: Version Control

Build status:

Version	Date	Lead author	Reason/Comments
0.1	13/09/19	HVR	First draft – rough outline
0.2	22/11/19	HVR	Second draft – full draft of Action Plan
0.3	20/12/19	HVR	Third draft - full draft of Action Plan
1.0	24/03/20	HVR	Final draft – now considered a ‘live’ Action Plan
1.1	08/04/20	HVR	Revised authorship

Distribution:

Copy	Version	Issue Date	Issued To
Electronic	0.1	13/09/19	Plan Development Group
Electronic	0.2	22/11/19	Plan Development Group
Electronic	0.3	20/12/19	Big Picture Group and HBDSEG members
Electronic	1.0	27/03/20	Published on NMBAQC website
Electronic	1.1	08/04/20	Published on NMBAQC website