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Image Processing and Statistical Analysis for MPA Monitoring
Workshop Report

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Summary

This report summarises and shares the outputs from the ‘Image Processing and Statistical Analysis for MPA Monitoring Workshop’, which took place on 24 and 25 October 2023. The workshop was hosted by JNCC to review the processes used by the arm’s length bodies (ALBs) of the UK Government to process and analyse still imagery of the marine benthic environment for the monitoring of Marine Protected Areas (MPAs). The workshop aimed to present the work of the ALBs and drive forward discussions on the analytical processes used to monitor benthic habitats through imagery.

Five areas of imagery processing and analysis were discussed in depth: monitoring purposes/objectives, data collection, statistical analysis, pre-survey planning and image processing. Current methods across the ALBs were reviewed and best practice was debated. The conclusions that have been made are:

- a call for consistency through the creation of shared tools and guidelines,
- early consultation with statisticians, and
- for clear, realistic, and specific research questions.

The workshop brought together people from across the UK who work to monitor and protect our inshore and offshore MPAs. A process was agreed which will guide ongoing monitoring projects and tie together work between ALBs, improving efficiency and consistency.

Text version of all the flowcharts in this report are available within Appendix 2.

Contents

1 Background

1.1 Purpose

The ‘Image Processing and Statistical Analysis for MPA Monitoring Workshop’ came about to coordinate the approach of government agencies’ methods of processing and analysing still imagery for marine conservation purposes. Imagery is often used as a tool to monitor marine ecosystems, particularly within the UK MPA network. This workshop was to focus on the use of drop-down camera stills, which is one of the methods most often used to monitor the benthic ecosystem around the UK coastline by numerous government agencies.

Government agencies both inshore and offshore make use of drop frame cameras to monitor the health of the benthic ecosystem, however there is a lack of coordination which means that resource is being lost by “re-inventing the wheel” or tendering expensive external contracts to complete the processing and analysis of the imagery once it is collected. Discussion and consolidation of best practise guidelines would streamline the process and improve efficiency at a time when workload across the arms-length bodies (ALBs) is only increasing.

1.2 Aim

The stated aim of the workshop is written up in Figure 1 below.

Our aim: to review current drop camera still image processing and statistical analysis methods used by UK Government agencies to agree recommended guidelines that can be used for monitoring of the UKs MPA network

Figure 1. The stated aim of the workshop.

The workshop would draw together government agencies from across the UK who monitor benthic systems, including: JNCC, the Centre for Environment, Fisheries and Aquaculture Science (Cefas), the Scottish Government’s Marine Directorate, the Department of Agriculture, Environment and Rural Affairs (DAERA), Natural Resources Wales (NRW), and the regional Inshore Fisheries and Conservation Authorities (IFCAs).

This workshop was carried out with the goal to agree on best practise guidelines for drop camera still image processing and statistical analysis, then presenting these through one or more flowcharts.

2 Methods

2.1 Use of Conceptboard

As the workshop was a hybrid event with about half of attendees attending online, Conceptboard, a web-based application, was used as a visual mind-mapping platform which would allow sharing and generation of ideas within the room, online and between the two. Users were able to create sticky notes with their thoughts and ideas and move them around wherever necessary. The Conceptboard for the workshop is viewable in Appendix 3.

2.2 Case Study Presentations

The workshop was opened with a session in which each organisation had the opportunity to present a case study to the group. This gave everyone an opportunity to describe the challenges that they often face in the environments they work in, the research questions that are being asked and the reasons for the chosen methodology. A question and answer session (Q & A) after each presentation sparked discussion points that would be revisited later. See section 3.1 for more information on the case study presentations.

2.3 Looking Forward Presentations

Presentations on novel techniques and potential improvements to existing techniques were given by colleagues from JNCC and Cefas on topics which described methods for the following topics: implementing AI for imagery analysis, quantification approaches for taxa in still imagery and sample unit selection for survey planning. These presentations were put in place to get workshop attendees thinking about new and improved ways of working which may not yet been a part of their imagery collection and processing workflow. See section 3.2 for more information on the looking forward presentations. Slides from the presentations can be found on the Conceptboard in Appendix 3.

2.4 Brainstorming Stations

2.4.1 Stations

A mind-map was prepared on Conceptboard with a visible “station” workspace for each of five areas of imagery processing and analysis:

- monitoring purposes/objectives,
- data collection,
- statistical analysis,
- pre-survey planning and,
- image processing.

Groups of two to three workshop attendees started at each station and were given 10 minutes to note down ideas relevant to the topic on sticky notes. When the allotted time had elapsed, each group moved clockwise to the next station, repeating the process until every station had been visited.

2.4.2 Now. How? Wow! Categorisation

Each station area was further split into three sections: 'Now.' 'How?' and 'Wow!'. Attendees were given another 10 minutes at each station to sort all the present sticky note ideas into one of those three categories, defined as in Figure 2 below.

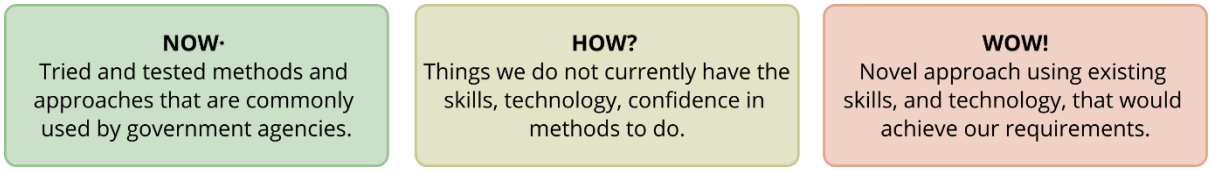

Figure 2. Definitions of the 'Now, How, Wow' terms in the brainstorming session

After completing the first station in this second cycle, if a group disagreed with any of the categorisations of the previous group, this was noted as a comment containing a suggestion as to where it may be better placed, and why.

2.5 Flowchart Creation

Originally, attendees were to create flowcharts based on an exercise in which sticky notes in the monitoring purposes/objectives section would be ranked according to perceived importance and priority. However, it was decided during the workshop that a more specific example was needed for this exercise. Instead, a case study was drawn up from the JNCC Pobie Bank survey in 2020. This survey was chosen as it was a recent imagery-based survey which had a clear monitoring objective which attendees would be able to build a process around. The hypothesis in Figure 3 was the basis of this activity.

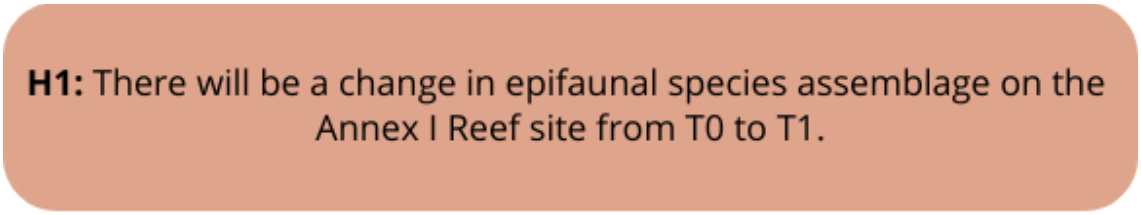

Figure 3. Hypothesis used as the basis of the flowchart task.

The workshop attendees were split into four groups: three in the room and one online. Each group was given 30 minutes to create a flowchart on Conceptboard to illustrate the method they would use to test the above hypothesis. After this, a nominated person from each group presented their creation to the rest of the attendees. Discussions were held, highlighting the features from each flowchart that were liked most and those that could be improved. Attendees were able to vote on the flowchart that they liked the best. Later, the flowcharts were combined, and the attendees were given the opportunity to comment on the final combined copy.

3 Discussion

3.1 Presentations 1: Case Studies

3.1.1 Cefas MPA Imagery Analysis (Hayden Close, Cefas)

Hayden Close presented on the method that Cefas generally use to analysis and process imagery on their offshore surveys. He described how images are taken with an STR SeaSpyder camera, approximately every 10 seconds. Checks on image quality (white balance, Field of View (FOV), flash) are being automated by an R-Shiny app which is currently in development. Imagery analysis is done through the Bio-Image Indexing and Graphical Labelling Environment (BIIGLE) annotation platform. Data is truncated to remove mobile fish and reduce the level of taxonomic precision where the quality of the imagery makes it necessary. Point counts, percentage cover and relative abundance are all enumeration methods that are used, and multivariate analysis is run after data transformation including the Hellinger transformation and k-means clustering to produce a Non-metric Multi-dimensional Scaling (nMDS) plot.

Discussion after this presentation focussed on why different methodological decisions had been made. No specific research questions are in place to narrow down which statistical methods should be used during the analysis phase. There are pushes from Cefas for a shift to monitoring single indicator species, as community analysis has high variability, difficulties in species identification (ID) and large expense.

3.1.2 MPA Monitoring Using Still Imagery (Sajan Sebastian, Natural England)

Sajan Sebastian presented on the imagery-based survey processes used by Natural England in its inshore marine protected areas. Natural England works with other organisations including academic institutions to conduct its monitoring and relies on outsourcing any analysis completely. There is a recognised need to standardise methods used by sub-contractors during this analysis. Both baseline and ongoing monitoring are being conducted, including direct groundtruthing by dive team and field unit. Image quality is mentioned as a big challenge in the inshore, where surveys are conducted to monitor seagrass coverage, for fisheries management and to research ecosystem delivery and functions for the marine Nature Conservation and Ecosystem Assessment (mNCEA) project.

3.1.3 The Canyons MCZ Still Imagery Analysis (Jonny Savage, JNCC)

Jonny Savage outlined the method used by JNCC for the still imagery data collection and analysis at The Canyons MCZ. Still images collected are analysed in BIIGLE, where each image is annotated for count and cover of present taxa, substrate type, imagery quality and FOV. Northeast Atlantic Marine Biological Analytical Quality Control (NMBAQC) Scheme guidelines are followed where possible. Video collected concurrently with the still images is used to assign biotopes to each image. R scripts are used to select images for analysis by filtering for complete metadata, good image quality and the chosen limits of FOV, then making a random selection of images until a minimum cumulative ‘total viewable area’ threshold is reached. The same statistical analysis process is followed as Cefas.

Discussion again focusses on where the analysis steps have come from and why they are being used. It is highlighted that the protocol currently used by JNCC and Cefas originally stems from the Mapping European Seabed Habitats (MESH) project in 2007 (Coggan *et al.* 2007) and this has been gradually adapted by trial and error, for example deciding to no longer use the SACFOR scale. Quantification approaches are questioned and covered later

in the day by James in his presentation. Again, the need for a specific research question is raised, to establish the best indicators of change and most appropriate analysis methods.

3.1.4 Thoughts on MPA Monitoring (Jon Barry, Cefas)

Jon Barry gave his thoughts on statistical methods used for MPA Monitoring in general from the perspective of in-house statistician at Cefas. He described the main survey questions as: have the extents of any of the designated features changed over time, and have the assemblages/species compositions of those features changed over time? He emphasised that survey design is crucial, as there is a need to make temporal comparisons that are unbiased. Statistics should be used as an indicator, but the main driver of decisions should be ecological. He also underlined the use of univariate statistics as having potential which should not be ignored in favour of only using multivariate statistics.

Discussion after this presentation highlighted the need for both statistical and ecological expertise to be input during the survey planning process, particularly if the survey is likely to be repeated and conclusions drawn about temporal variation. Opinions on what is practical and realistic to achieve while at sea also need to be heard. There is importance in methodological consistency, which can produce datasets which are comparable over time. It was requested to have a shared toolkit for what works best in each scenario, so that expertise can be shared between government agencies.

3.2 Presentations 2: Looking Forward

3.2.1 Potential for Artificial Intelligence (AI) in Monitoring Seabed Habitats Using Imagery (Anna Downie, Cefas)

Anna Downie presented a project which had been created to test the use of AI in analysing marine imagery by using sea pens. Sea pens are easy to distinguish from their habitat in imagery and are therefore a simple case study through which to test AI taxa enumeration. Imagery from 15 years of nephrops stock survey in Farnes East MCZ provided the volume of data necessary to train the model. This survey will allow the study of natural variation in sea pen abundance and distribution, as well its response to environmental gradients such as PSA, suspended matter and fishing intensity. It was noted in the Q & A that this would be easy to adapt and would be applicable to multiple purposes.

3.2.2 Quantification Approaches (James Albrecht, JNCC)

James Albrecht presented a literature review, which was subcontracted to Galathea Marine Consultants, on different approaches to quantification in marine imagery. This included an explanation of each method and what it has previously been used for, including: abundance count, percentage cover, point count, presence/absence and frequency of occurrence. The main recommendations from this report were: to always consider the purpose of your study, to standardise the terminology used for each enumeration approach, and to first validate the use of your chosen approach in the survey habitat to ensure pertinence of statistical assumptions.

Conversation post-presentation pointed to a need for consistent rules that are followed for the enumeration of each taxon, for example sponges, which are often counted through both the point count and percentage cover methods depending on their size. It was noted that there is no perfect quantification method; the most crucial thing is remaining consistent in the methodology to ensure comparability of the results.

3.2.3 Statistical Basis for Estimating Volume of Imagery Required in a Marine Survey (Rob Harbour, JNCC)

Rob Harbour presented on a statistical method for estimating the volume of imagery required for marine surveys, to prevent both over and under-sampling. This method works based on the assumption that the exact research question is known, for example whether change in species richness or abundance is being tested for. The exact amount of change and confidence expected determines the level of statistical power that will be required. An R-package called iNEXT (Hsieh *et al.* 2016) was presented as a way to calculate the necessary sample coverage for your survey site (number of images in one sample unit). An equation (Sokal & Rohlf 1995) for calculating sample size (number of sample units) was presented, and an R script which was written for working through the equation.

Questions focussed on how this would change current methods. Traditionally within JNCC and Cefas, stations have been used as sample units, and power analysis has been used to calculate the number of images needed. It was pointed out that this power analysis method is designed for grab sampling and should not be applied to imagery. Applying this method to *video* imagery would also be possible, but the number output from the equation would be equal to the area coverage required, rather than the number of videos. This method is best based on data from a groundtruthing visit to the site in question, or one similar. It should be repeated each time there is a return visit to the site.

3.3 Brainstorming Stations

3.3.1 Monitoring Purposes/Objectives

The discussion around monitoring purposes and objectives (Figure 4) illustrated how broad a range of objectives exists within the government agencies, however everyone agreed that the monitoring objectives currently in use were not specific enough to properly serve their purpose, and this may have caused many of the other difficulties encountered further on in the process.

There was a request for analyses and results to be purposefully tied into specific questions which address not just whether there is ecological change over time, but what causes they are likely to be resulting from.

The use of time series as a monitoring method was talked about because of the high resource intensity of visiting offshore sites. There are three types of monitoring used by JNCC and Cefas (Type 1 - sentinel/surveillance; Type 2 – operational; Type 3 - investigative) (Noble-James *et al.* 2017). These originate from the Water Framework Directive, where water is tested around every two weeks for abnormalities (*Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy*, 2000). It was questioned if this was applicable in its current form to offshore monitoring, where the frequency of monitoring is around every three to five years. Other options were considered, such as using a pass/fail system to assess whether the ecosystem is healthy, though this relies on already having the knowledge of what a healthy ecosystem looks like for that site.

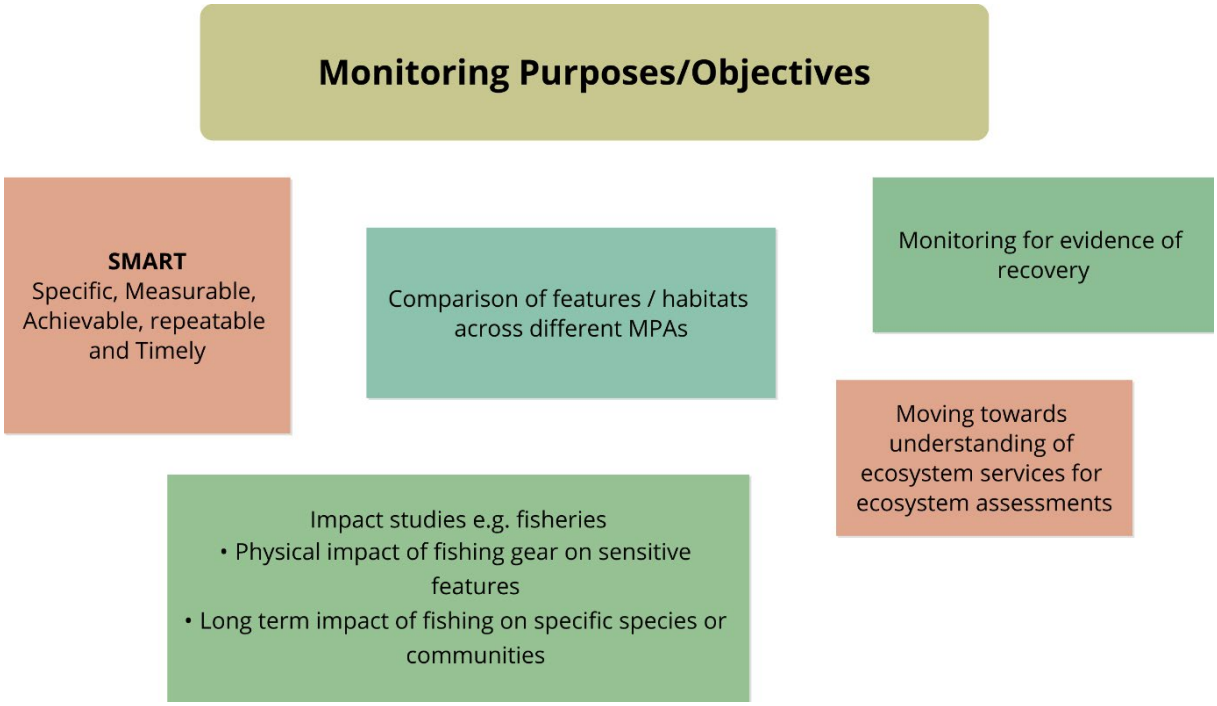

Figure 4. Selection of sticky notes created for the Monitoring Purposes/Objectives station on Conceptboard during the workshop. To see all the ideas generated during the workshop, you can view a PDF of the Conceptboard in Appendix 3.

3.3.2 Data Collection

Consistency appeared to be a key point in data collection discussions. The importance of following existing guidelines that have been put in place to help (e.g. NMBAQC), having knowledgeable staff on every survey and maintaining a consistent sampling effort were all mentioned as way in which consistency can be kept. Looking to the future of marine imagery, attendees pointed to technology to shorten time scales and improve accuracy, including the use of Autonomous Underwater Vehicles (AUVs) with real-time processing and analysis, and photogrammetry of protected features.

A selection of ideas from the 'Data Collection' station from Conceptboard is viewable in Figure 5.

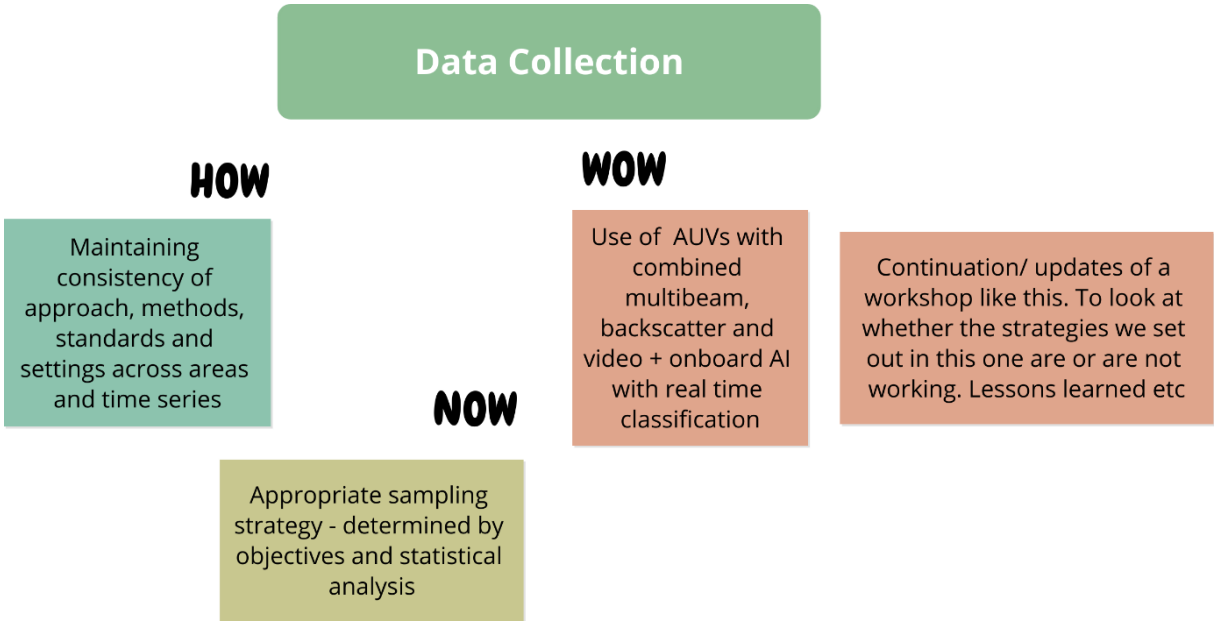

Figure 5. Selection of sticky notes created for the Data Collection station on Conceptboard during the workshop. To see all the ideas generated during the workshop, you can view a PDF of the Conceptboard in Appendix 3.

3.3.3 Statistical Analysis

An important point in discussions about statistical analysis was the incorporation of a feedback loop in survey design: data gathered from one survey should be incorporated into the next year's power analysis and sampling design. Some points were repeated from the Q & As of the presentations made earlier in the workshop, for example the need to consider consulting a statistician during in the planning stage. There was much debate over the use of univariate vs multivariate statistics to monitor a site, this perhaps indicates a need for clear guidance on the costs and benefits to both approaches, and which research questions each approach would be appropriate for. The statistical choices made should be decided by the objectives of the survey and the research questions being asked, but most importantly, should make ecological sense. Statistics should not dictate the decisions being made but provide guidance. In the future, statistics could be used in conjunction with new technology to assess changes to habitat over time, for example from photogrammetry data.

The 'Statistical Analysis' station from Conceptboard is viewable in Figure 6.

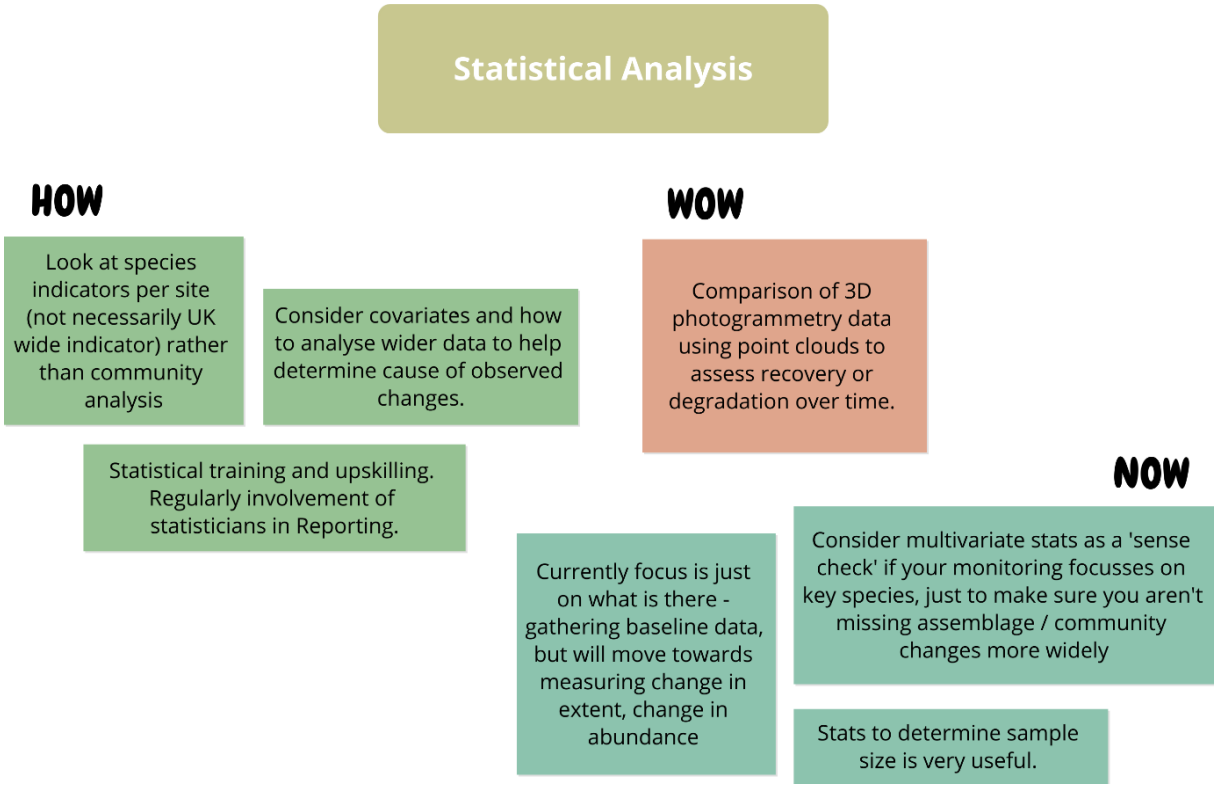

Figure 6. Selection of sticky notes created for the Statistical Analysis station on Conceptboard during the workshop. To see all the ideas generated during the workshop, you can view a PDF of the Conceptboard in Appendix 3.

3.3.4 Pre-Survey Planning

Discussion on pre-survey planning ranged from objectives to practical considerations. Attendees agreed that survey objectives should be realistic and flexibly achieved through statistically robust back-up plans. The existence of pre-existing data should be investigated whether it is from previous surveys, other agencies, or even industry, as any data will help to give a rough idea of the realities of the site. Contingency planning should be made for equipment, weather and extra time so that the team can remain agile and adaptable throughout the survey, regardless of any problems that may arise.

Ideally, a pilot study would be carried out for each site before any monitoring begins to assess the practicalities of using different types of equipment or enumeration techniques.

The ‘Pre-Survey Planning’ station from Conceptboard is viewable in Figure 7.

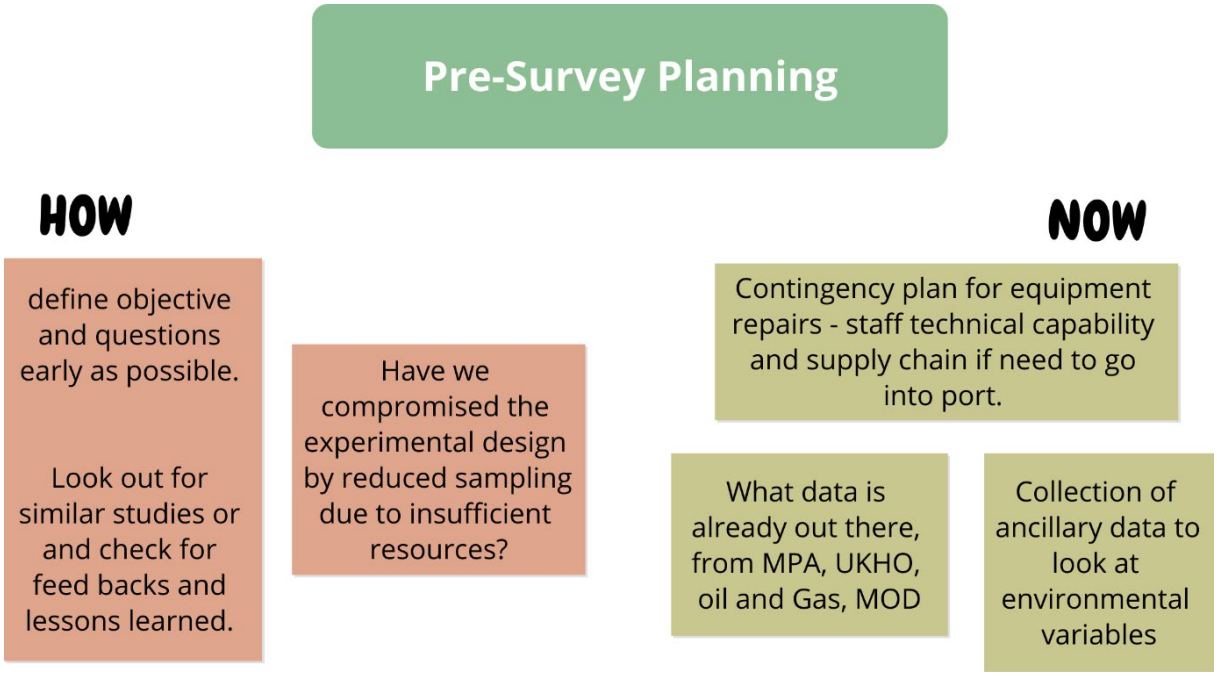

Figure 7. Selection of sticky notes created for the Pre-Survey Planning station on Conceptboard during the workshop. To see all the ideas generated during the workshop, you can view a PDF of the Conceptboard in Appendix 3.

3.3.5 Image Processing

The idea that came up most often during the image processing discussion was the need for consistency and standardisation of processing methods. This may include the software used, label trees, enumeration tactics, image colour correction, acceptability standards of images in terms of quality, FOV, etc. and the quality control process. This would allow for more sharing of tools, training and comparability of data across the ALBs. Attendees were keen for as much of the imagery processing method to be automated as possible, and for the eventual inclusion of machine learning and AI to further improve the process.

The ‘Image Processing’ station from Conceptboard is viewable in Figure 8.

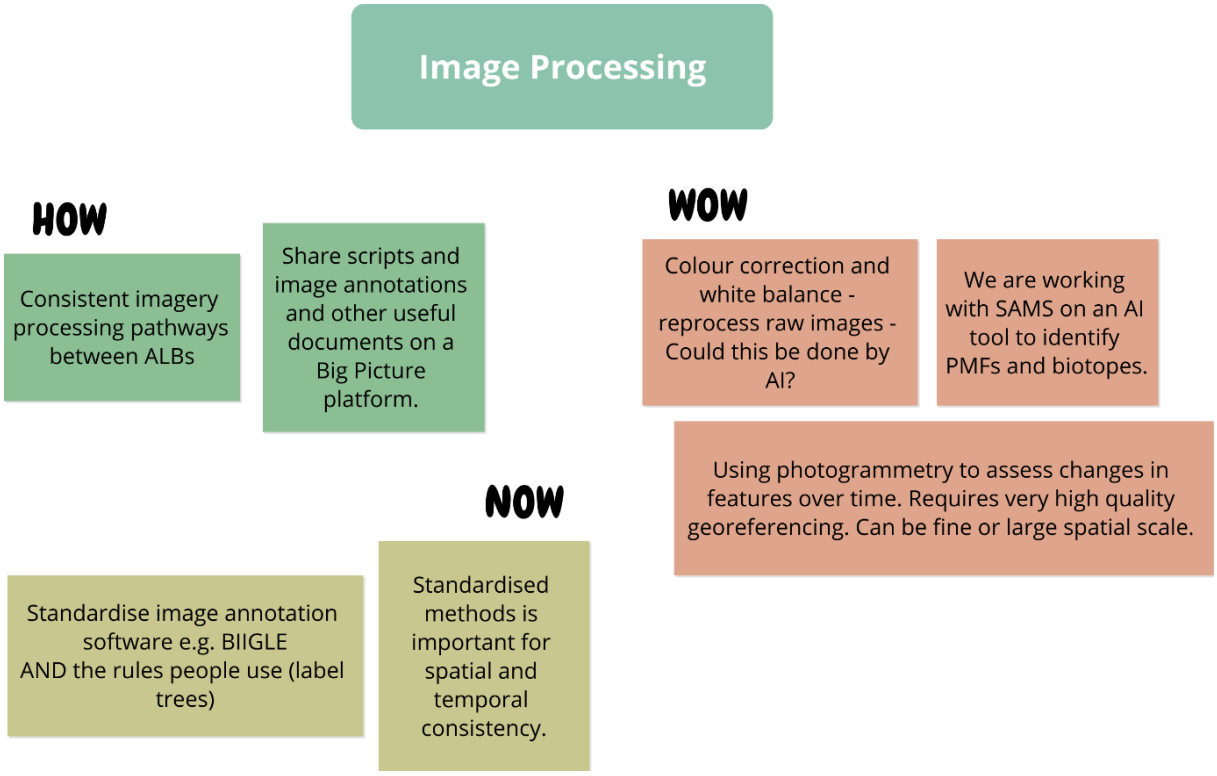

Figure 8. Selection of sticky notes created for the Image Processing station on Conceptboard during the workshop. To see all the ideas generated during the workshop, you can view a PDF of the Conceptboard in Appendix 3.

3.4 Flowchart Creation

Three flowcharts were made, illustrating the different approaches each group would have to achieve the sub-objective of the Pobie Bank Reef survey in 2020 and test this hypothesis (Figure 9).

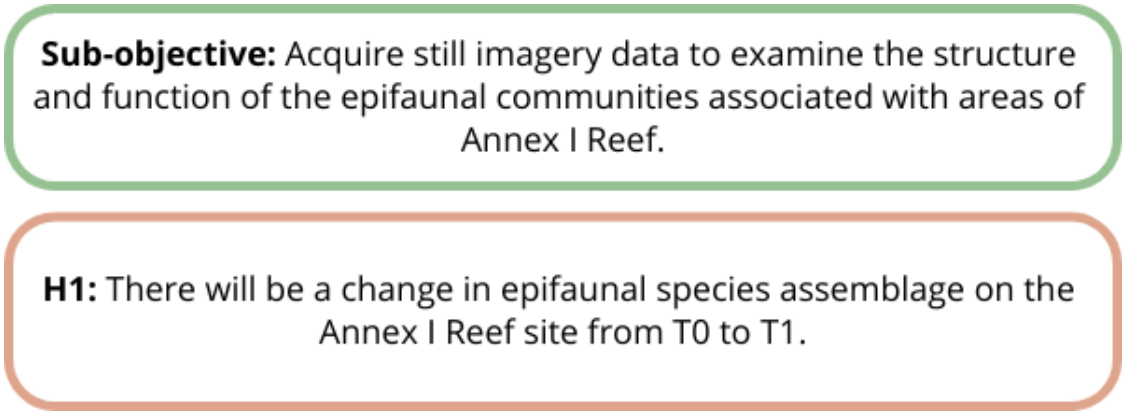

Figure 9. Sub-objective and hypothesis (H_1) which formed the basis for the flowchart activity.

Each flowchart was then reviewed by the group and anything particularly helpful or insightful was highlighted with a sticky note. This feedback is summarised below.

3.4.1 Group 1

Group 1 produced the flowchart visible in Figure 10. This was appreciated for its level of detail in the pre-survey planning and emphasis on creating standards and guidelines for

consistency. Creating an image reference collection to be adapted at each time point for example, using BIIGLE for image annotation and having clearly defined rules which determine taxa ID and enumeration methodologies.

3.4.2 Group 2

Group 2 produced the flowchart visible in Figure 11. This flowchart was chosen as the best out of three at the end of the session, largely due to its high level of detail and explanation, which captures the complexity of decision-making, as well as the inclusion of a feedback loop from the concluding stages of one survey to the planning stages of the next.

3.4.3 Group 3

Group 3 produced the flowchart visible in Figure 12. This flowchart was appreciated for its step-by-step methodology and checks taken throughout the process. This conveys the importance of considering what has been done at T_0 before and while carrying out the T_1 survey.

3.4.4 Blended Flowchart

A flowchart has been put together (Figure 13) which attempts to draw together the best qualities of each of the flowcharts created during the session and incorporate some of the recommendations made throughout the report. This flowchart is a high-level guidance tool for those working with marine imagery for the monitoring of MPAs.

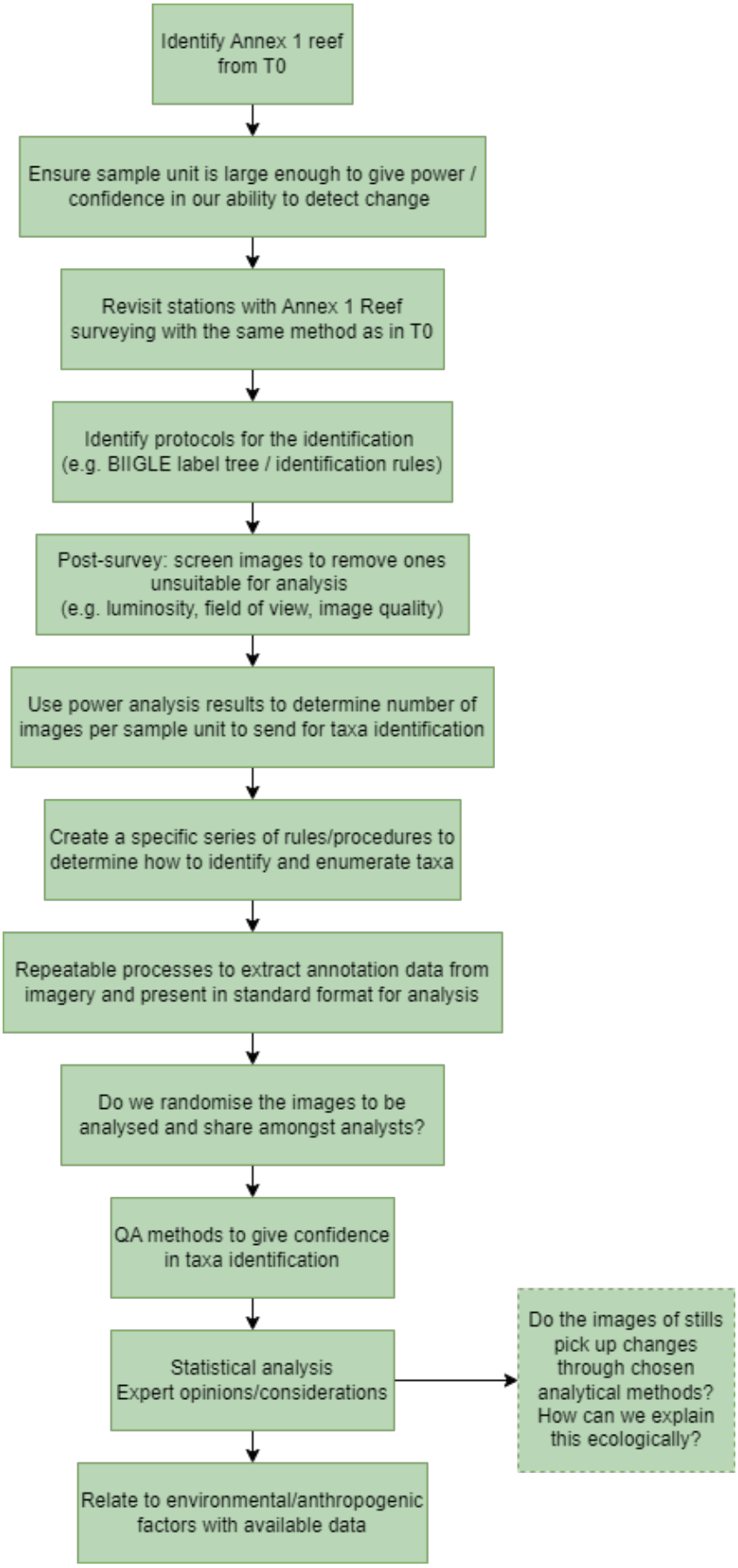

Figure 10. Flowchart produced by Group 1, edited for clarity.

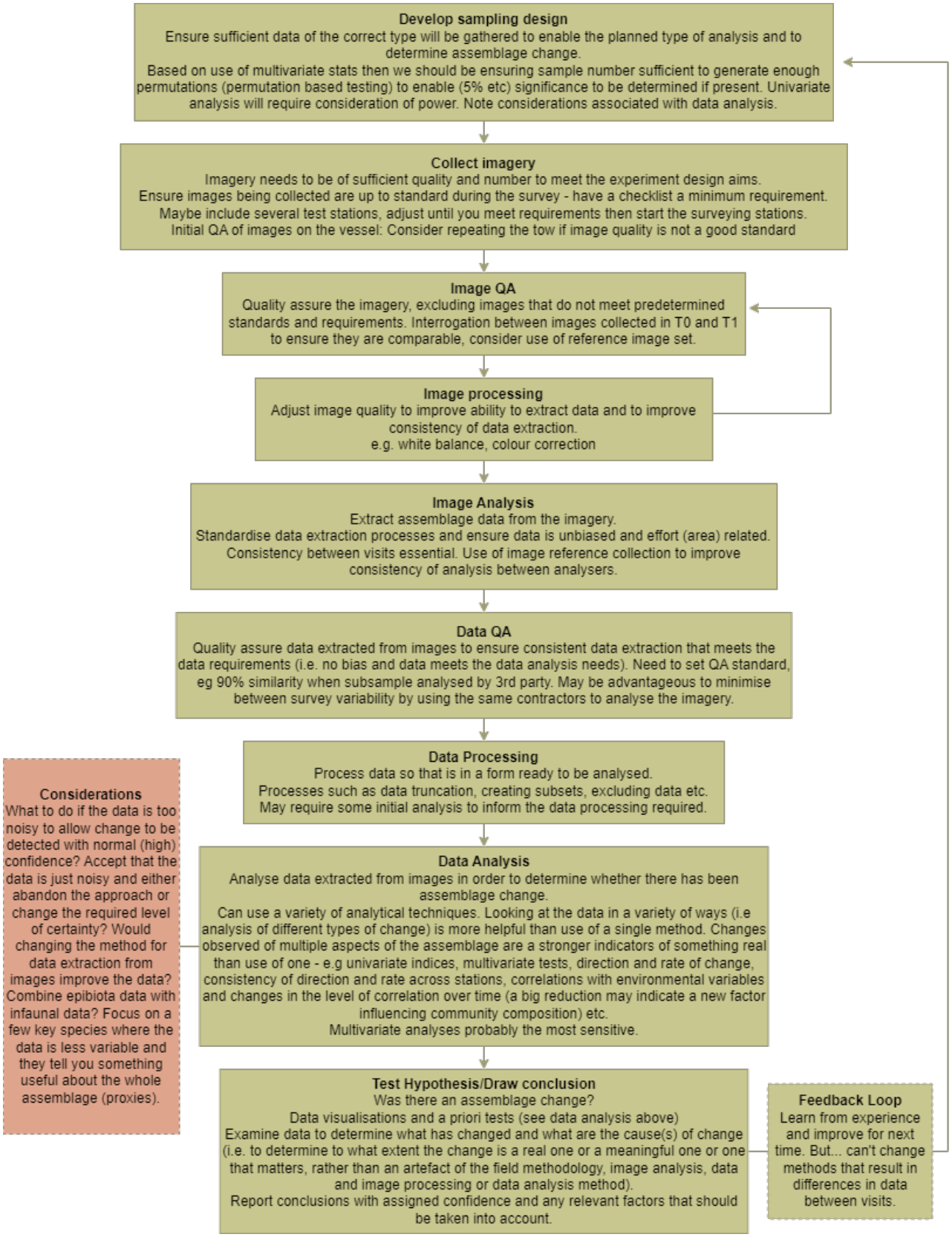

Figure 11. Flowchart produced by Group 2, edited for clarity.

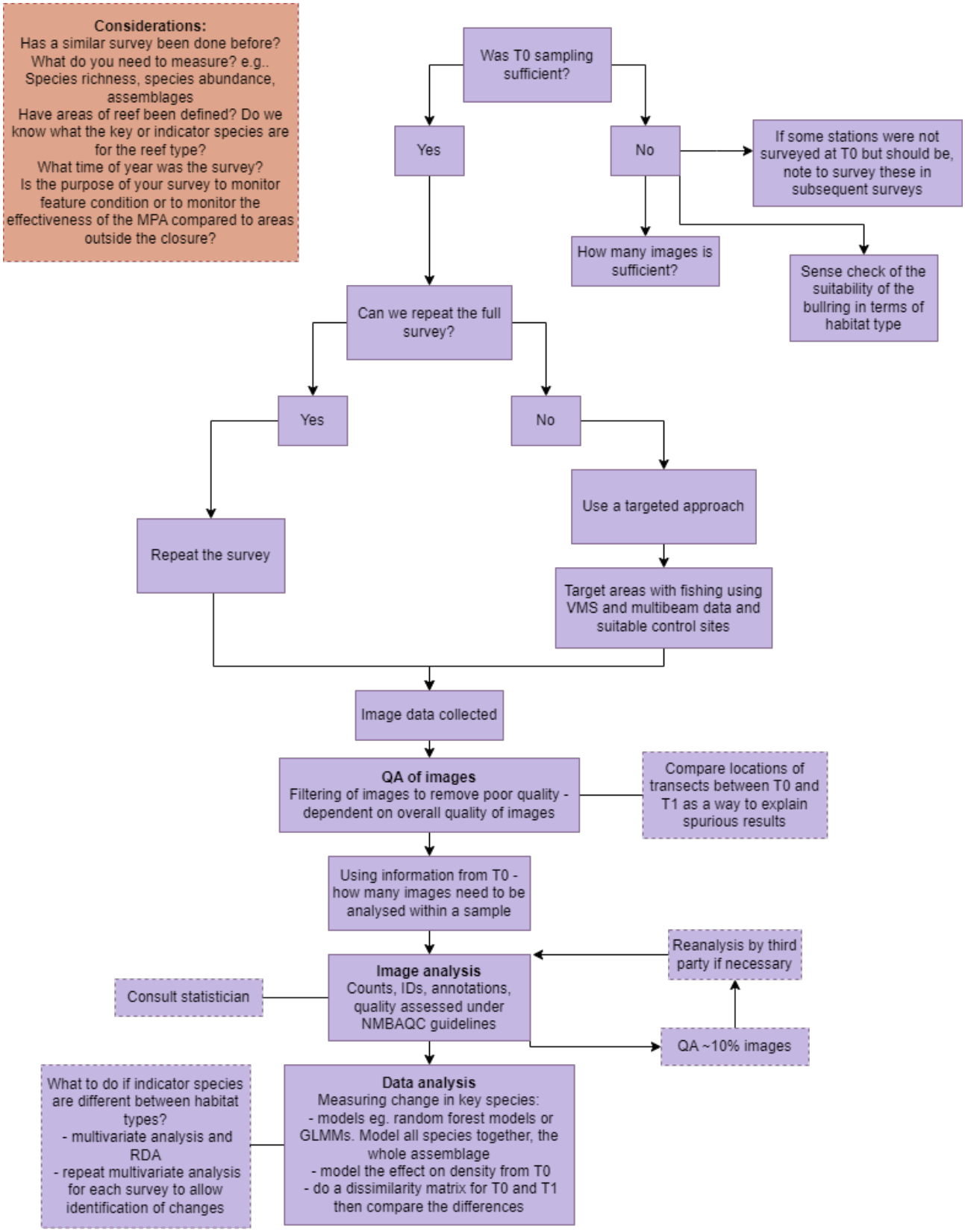

Figure 12. Flowchart produced by Group 3, edited for clarity.

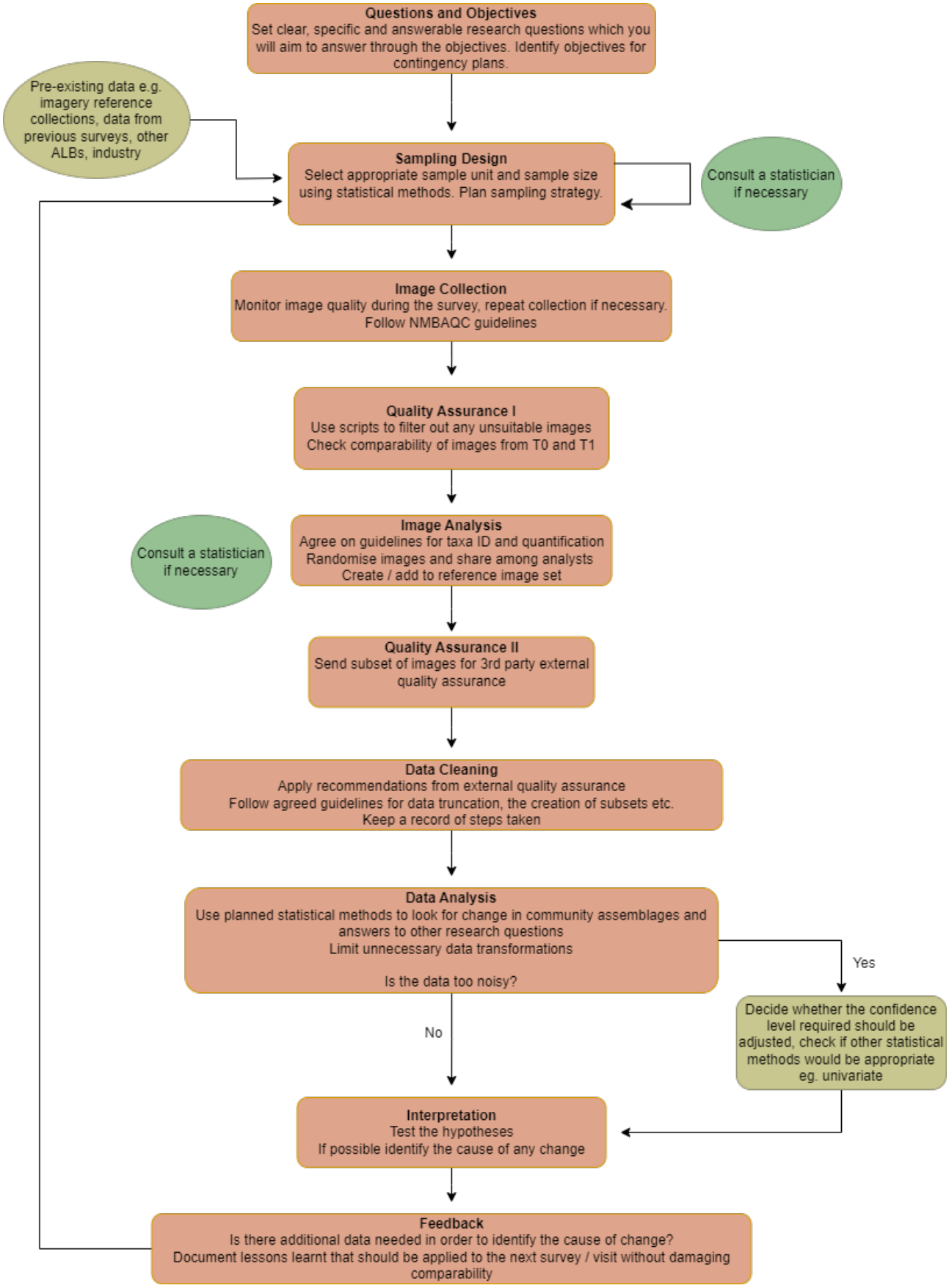

Figure 13. Blended flowchart for the process of marine imagery analysis.

4 Recommendations

Much discussion was had across the two days of the workshop, as described in detail in the report above. The main recommendations output from these discussions for ongoing offshore imagery collection and analysis are summarised below:

- The research questions should be clear, specific, and answerable with the data that is collected during the survey.
- Research questions should be set during the planning stage before data collection begins.
- Statistical analyses should be planned *before* the survey is designed so the volume of imagery required can be calculated. As more data becomes available with each additional site visit, the accuracy of statistical methods for calculating sampling volumes increases. The design should be tailored to the characteristics of the site and recalculated at each point in the time series.
- It may be helpful to consult an external statistician to ensure sampling collection is completed in a statistically robust way. If necessary, this should be done at the beginning of the survey planning process.
- Statistical, ecological and survey-going expertise should be considered during planning, particularly if the survey is likely to be repeated and conclusions drawn about temporal variation.
- A standard set of guidelines should be set up for ALBs to follow during the process of annotation, data extraction and data cleaning once the imagery has been collected. This will allow for better comparison between sites and improve consistency between timepoints.
- The most appropriate enumeration method for each taxon should be decided and used consistently between visits to ensure comparability.
- A reference collection of imagery should be compiled for each site and added to with each visit. This will improve consistency of taxa identification between analysts and along the time series.
- In the case of noisy data, it may be worthwhile to try to carry out additional analyses to attempt to find evidence of change, for instance by looking at a particular species, however the data should not be transformed repeatedly until a pattern is found. It should be accepted that there may not be any detectable change, and epifaunal communities may not fit into clusters.
- Results should be considered in an ecological context. Not all statistically significant change is ecologically significant (e.g. change may be the result of natural temporal variation). Questions may need to be further specified to investigate the cause of any change seen.
- An ‘MPA Imagery Analysis Toolbox’ should be created, drawing together best practice guidelines and tools such as scripts from R or Python. This can be used to maximise efficiency across the ALBs by sharing skills and resources. Guidelines can and should be added to as new lessons are learnt. Existing scripts for image filtering, data extraction, analysis etc. should be shared if possible.

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Appendix 1 - Feedback

Feedback was provided by the attendees at the end of the session via Conceptboard (see Appendix 3). Those who attended online and in-person commented in separate areas so that any differences of experience could be noted. The comments have been summarised in the table below:

Table 1. Feedback on the workshop from in-person and online attendees, illustrating the key successes of the event and suggestions for areas to improve.

Attendees	Event Highlights	Areas for Improvement
In-person	• Discussion during lunch and breaks. • The range of people from different places, prompted discussion and debate. • Understanding how different agencies monitor and analyse their data. • Seeing that other people and agencies are asking the same questions. • Venue and IT worked very well. • The food provided for lunch.	• Increasing discussion time and level of detail for statistics. In-depth workshop on what to do in each situation. • Discussing alternative approaches for when data is too noisy for usual methods. • Providing a summary of minimum statistical knowledge and analytical approaches prior to the meeting to build understanding beforehand. • Having a dummy data set to use and work through the analysis to practise.
Online	• Inclusion of online participants. • Online participants being their own group rather than mixed with in-person attendees. • Use of Conceptboard. • Presentations before the discussions. • Facilitators supporting online.	• Inviting people from different specialisms (e.g. statisticians, contractors). • Preparing descriptions of tasks/activities to ensure clarity and save time. • Having workflows and case studies from each organisation beforehand. • Facilitating discussion online to make sure everyone is heard and on-topic.

Ideas for Future Workshops

- Statistics trainings or workshops on using specific methods and tests.
- Guidance and best practice for imagery annotation.
- A workshop targeted at towed video.