Annex T

Report of the Intersessional Correspondence Group 'Satellites to Study Whales'

EXECUTIVE SUMMARY

Very High Resolution (VHR) satellites orbiting Earth offer the prospect of upscaling the monitoring of live and stranded cetaceans around the globe, particularly in remote regions. In recognition of the importance of refining and coordinating the use of optical satellites to study whales, the International Whaling Commission (IWC) Scientific Committee (SC) endorsed the creation of an Intersessional Correspondence Group (ICG) 'Satellites to Study Whales'. The main objectives of the Satellite to Study Whales ICG are:

- coordination of information, data, and code sharing among research groups conducting active research on the use of optical satellite images to monitor whales;
- facilitating the development of automated methods;
- avoiding duplication of effort; and
- negotiating better tasking opportunities with satellite imagery providers.

The ICG held a virtual meeting, convened on the 20-21 March 2023, focusing on three topics: (1) automation; (2) equality in opportunity/partnerships with satellite companies; and (3) information, data, and code sharing.

The proposed recommendations of the ICG aimed at achieving a standardised, equitable and internationally collaborative tool for monitoring live and stranded cetaceans are:

- To coordinate information, data, and code sharing by:
  - publishing a summary table on the IWC webpage, containing links to where annotated datasets of whales in satellite imagery are stored; and
  - storing common code on the IWC github.
- To facilitate the development of automated methods by:
  - adopting a semi-automated human in the loop approach, whereby a human(s) verifies the accuracy of detections made by an algorithm; and
  - developing interdisciplinary collaborations to progress the automated detection of whales.
- Avoid duplication of effort by:
  - developing an open-access working document detailing active research areas being pursued within the ICG; and
  - holding annual or bi-annual meetings for this ICG, virtually or in person at the IWC.
- To negotiate better tasking opportunities with satellite imagery providers by:
  - the Secretariat sending a letter to satellite image providers, requesting support in; reducing the cost of access to satellite imagery; developing licensing agreements to facilitate data sharing; using unique image identifiers to enable multiple groups to access the same image; and detailing collective research questions and a list of candidate areas for speculative tasking, particularly over open ocean areas;
  - developing cross-disciplinary collaborations between government, NGOs and academia, to leverage data accessibility;
  - devising an internationally collaborative consortium/global scale project, endorsed by the IWC, to leverage and negotiate better opportunities;
  - seeking the support of satellite image providers to develop mechanisms to review satellite imagery for environmental conditions, prior to selling imagery to community members;

- using crowd-sourcing as a lower cost mechanism to identify imagery worth investing in;
- welcoming the development of new commercial VHR satellites with access to data in their first collection phases, and of national government funded satellites offering publicly accessible data; and
- establishing nominated direct contacts within the various satellite imaging companies for the Satellites to Study Whales community.

- Holding a best practice workshop (summarised in a published guidance paper made available on the IWC website) to establish:
  - standardised protocols for the data format required for training data;
  - what information to include at publication;
  - standardised definitions of each certainty category;
  - standardised development (annotating whales and environmental conditions in satellite imagery) and sharing of training data;
  - common code to automate the detection of whales in satellite imagery;
  - standardised AI performance terminology, translated for non-AI specialists;
  - the level of accuracy required for AI models compared to a manual observer; and
  - decision matrix to assist the community in determining whether satellites, aerial, or vessel surveys are most appropriate to a research question and region of interest.

The proposed recommendations are targeted at; the Secretariat (S); the Scientific Committee (SC); the SH workplan (via the ICG Satellites to Study Whales); satellite image providers: Airbus, Maxar Technologies and Planet (I); and National Governments (NG).

In conclusion, the ICG agreed to start working towards fulfilling these proposed recommendations through compiling links to datasets and code; taking forward ideas for joint and collaborative work; prioritising candidate areas and writing to satellite image providers for support; and planning workshops to develop best practice.

1. INTRODUCTION

In 2022, the Scientific Committee (SC) of the International Whaling Commission (IWC) encouraged marine mammal research groups using optical satellites to study whales, to coordinate 'data and code sharing among active research groups where possible, to facilitate the development of automated methods, avoid duplication of effort, and negotiate better tasking opportunities with satellite providers' (IWC, 2022). The encouragement follows several made previously by the SC including; 'further refinement and use of Very High-Resolution (VHR) satellites for strandings monitoring (IWC, 2018; IWC, 2021); for 'satellite image providers to develop collaborative partnerships with strandings networks, non-governmental organisations (NGO) and governments, to allow an inclusive way for this platform to prosper' (IWC, 2021); and to 'establish collaborative agreements among marine mammal research groups in regards to coordinated data'. The creation of this 'Satellites to Study Whales' Intersessional Correspondence Group (ICG) was subsequently endorsed by the SC and Clarke was nominated as convenor (IWC, 2022).

The main objectives of the ICG 'Satellite to Study Whales' are:

- The coordination of information, data, and code sharing among research groups conducting active research on the use of optical satellite images to monitor whales.
- To facilitate the development of automated methods.
- To avoid duplication of effort.
- To negotiate better tasking opportunities with satellite imagery providers.

As a first action, a virtual meeting was held to achieve the ICG objectives. The meeting focused on three topics: (1) automation; (2) equality in opportunity/partnerships with satellite companies; and (3) information, data, and code sharing.

The meeting was held between 20-21 March 2023 and included 48 attendees, comprising researchers actively engaged in using optical satellites to study whales, and researchers who were interested in using the tool (see Appendix 1).

The convener Clarke, brought the meeting to order, detailed the tasks of the meeting, and assigned Cubaynes and Fretwell breakout group leaders, and Malette and Cubaynes rapporteurs.

2. BACKGROUND STUDIES

Recent studies using optical satellite images to study whales were presented to provide an overview of the current status of the field.

Cubaynes provided an overview of the history of using VHR satellite imagery for monitoring whales (Cubaynes, 2020a), spanning the first attempts to detect whales in satellite imagery (Abileah, 2002; Fretwell *et al.*, 2014); characterising different species with improved image resolution (Cubaynes *et al.*, 2019); further pilot studies and exploration of density surveys, and species detection (Bamford *et al.*, 2020; Charry *et al.*, 2021; Corrêa *et al.*, 2021; Hodul *et al.*, 2022; Ramos *et al.*, 2022); the recent efforts to automate the detection of whales (Borowicz *et al.*, 2019; Guirado *et al.*, 2019; Houegnigan *et al.*, 2022; Kapoor *et al.*, 2023); and the reviews, guidance and open source datasets, aiming to standardise and advance the field equitably (Höschle *et al.*, 2021; Cubaynes *et al.*, 2022; Rodofili *et al.*, 2022; Cubaynes *et al.*, 2023; Khan *et al.*, 2023).

2.1 Commercial ventures

Höschle presented SPACEWHALE and their use of satellite imagery to survey whales in remote areas, to enhance conservation efforts (Borowicz *et al.*, 2019; Höschle *et al.*, 2022). SPACEWHALE is a semi-automatic process to evaluate satellite images, which combines state-of-the-art artificial intelligence and a large team of marine mammal experts for quality assurance. It can complement data in explored regions and provide baseline data in unexplored or less surveyed regions. SPACEWHALE was used to investigate the detection of Southern Right Whales (*Eubalaena australis*) in Port Ross, Auckland Island, a well-known breeding ground during the austral winter. The effectiveness of SPACEWHALE was demonstrated through an equivalent number of whale detections to those numbers from boat-based surveys, despite the 12-hour difference between the timing of the data collection (Höschle *et al.*, 2022). SPACEWHALE has analysed satellite imagery from three satellites: Maxar Technologies' WorldView-3 satellite (31cm resolution), Airbus' Pléiades Neo satellite (30cm resolution) and Maxar Technologies' WorldView-2 satellite (46cm resolution) in waters off four continents. SPACEWHALE aims to use satellite-based data to inform applied conservation and provide useful guidance to find solutions that balance species conservation with human use of the seas; this tool has the potential to elevate conservation efforts to appropriate spatial scales for wide ranging species.

Charry Tissier showcased efforts by Whale Seeker to scale satellite use for marine mammal detection. Medium sized Arctic cetaceans such as narwhals (*Monodon monoceros*) and belugas (*Delphinapterus leucas*) necessitate the surveillance of large areas in order to monitor their populations. Their study assessed the ability to detect and classify narwhals and beluga whales, using VHR satellite imagery (Charry *et al.*, 2021). The study analysed 12 VHR images acquired in August 2017 and 2019, collected by the WorldView-3 satellite, which has a maximum resolution of 31cm per pixel. The images covered Clearwater Fiord (138.8km^2), an area on eastern Baffin Island, Canada, where belugas spend a large part of the summer, and Tremblay Sound (127.0km^2), a narrow water body located on the north shore of Baffin Island that is used by narwhals during the open water season. A total of 292 beluga whales and 109 narwhals were detected in the images. The ability to detect and classify adequately the targets from the images require expert knowledge of these populations to reduce the misclassification of the targets.

In discussion, the importance of quality labelling of training data for successful automated detection was highlighted. In particular, the power of annotating using polygons and semantic segmentation for detecting individuals, compared to the overlap achieved through bounding box annotations. However, the challenges of using Artificial Intelligence (AI) to identify individuals in densely packed groups was acknowledged, and for studies aiming to count, it was suggested that further experimentation with point annotations be conducted.

2.2 At Sea Distribution and Density of Live Whales

Davenport presented on the feasibility of replacing conventional methods (i.e., aerial surveys) with analysis of satellite imagery to count the number of humpback whales in three core resting and calving areas along the northwest coast of Australia (Thums *et al.*, 2019). The humpback whales (*Megaptera novaeangliae*) that migrate to north Western Australia (Breeding Stock D) for calving and mating in the Austral winter (July-October) are challenging to monitor due to their increasing population size and the broad expanse of appropriate habitat. Satellite images were obtained for three locations of high-density humpback cow-calf pairs: James Price Point (Worldview-2, 46cm resolution); Lalang-Garram/Camden Sound Marine Park (Worldview-3, 31cm resolution); and Exmouth Gulf (Worldview-3). The images were manually analysed for the presence of humpback whales and the detections were used as training data in supervised classification(s), using pixel-based and shape-based algorithms. The results show low confidence of positive humpback whale detections at James Price Point and satellite image counts underestimated their abundance when compared to simultaneous vessel-based surveys. In contrast, Lalang-Garram/Camden Sound Marine Park (Worldview-3 images) yielded high confidence in positive identifications, due to calmer sea conditions and greater pixel resolution.

Automated methods (30 mins) were more time efficient than manual detection (24 hours), however, given that supervised classification requires manually identified whales as input, this increases the processing time required. Overall, the success of satellite imagery analysis was heavily dependent upon sea-state; in the Exmouth Gulf (Worldview-3 image) no whales were identified due to the rough conditions (approx. wind speeds 15 knots, Beaufort 3-4). Whilst using satellite imagery to count humpback whales was determined to be significantly faster than conventional methods, it was severely limited by the financial expense to acquire imagery at the required management scale, and the constraint of requiring a near perfect sea state (approx. wind speeds 0-5 knots, Beaufort 1) to confidently identify humpback whales.

Corrêa presented on the use of satellite imagery to identify southern right whales on a Southwest Atlantic Ocean breeding ground (Corrêa *et al.*, 2021). Brazilian waters are a known breeding ground of southern right whales and the study used satellite images of one preferred concentration area during the winter and spring seasons. The study aimed to test if individual whales could be seen in satellite imagery and then compared to aerial survey data collected in the same area. The results show that the VHR satellite image from Pleiades-1A (50cm resolution), available on Google Earth, displayed the best results, providing views of the shape and whale-like features, when compared to those from Sentinel 2 (10m resolution), Landsat 8 (30m resolution), Rapid Eye (5m resolution), and Planet Scope (3m resolution). No significant differences were observed (Mann-Whitney U test) between the possible whales recorded in the satellite images and the definite whales recorded *in situ* by aerial surveys over five different years (2010, 2013, 2016, 2017 and 2018), while considering either the number of groups (U=11.0, p=0.841, *n*=5), or the total number of animals (U=6.0, p=0.222, *n*=5). Further, when using the VHR image available on Google Earth, the geographical positions of the whales recorded *in situ* had a positive correlation with the positions found in the satellite image (Mantel test: r=0.52, p=.001, *n*=13). This was the first time that satellite imagery has been used to identify southern right whales in the breeding area off Brazil, and comparing detection of large whales in satellite images with data collected by field researchers through aerial surveys. The technique was considered viable to locate whales and can be an important tool for documenting the presence and number of right whales, especially in countries where research funding is scarce.

Watt presented on the work of SWAMM: Space Whales and Arctic Marine Mammals. During the course of a two-year programme funded by Species at Risk, the Government of Canada has been exploring the utility of using VHR satellite imagery to estimate the abundance of Arctic marine mammals. The objectives of the study were to: (1) determine the depth to which whales can be seen in satellite imagery in order to correct surface counts for whales that are too deep to be seen; (2) ground-truth satellite abundance estimates with those obtained from photographic surveys; (3) determine an abundance estimate for the Eastern High Arctic-Baffin Bay beluga whale population; and (4) explore the use of satellite imagery to investigate walrus (*Odobenus rosmarus*) density and bowhead whale (*Balaena mysticetus*) occurrence. SWAMM has tasked the WorldView-3 satellite to collect VHR imagery across the eastern Canadian Arctic from 2020-22. Beluga whale models were submerged to different depths in lakes with different water clarities and a satellite image of the lake was acquired. The results show the whale models were distinguishable only at the surface in turbid water and at a depth of 0-2m in clear water. Based on the proportion of time whales spend at these depths, availability bias correction factors were defined to correct beluga whale surface counts. Synchronous ground-validation surveys were also conducted in the Churchill River estuary and determined that counts of beluga whales were comparable in the satellite and drone imagery when the two methods were spatially and temporally synchronised. In addition, the study assessed the feasibility of using VHR satellite imagery to obtain an abundance estimate for beluga whales in the Eastern High Arctic Baffin Bay beluga whale population, which has not been studied for over 20 years. The study adopted a citizen science crowd counting initiative and developed an auto-detector using object-based image analysis to analyse the satellite imagery. SWAMM are currently exploring the use of satellite imagery to investigate walrus density and bowhead whale occurrence (Ferguson *et al.*, 2022). Overall, the studies highlight the capability of satellite imagery to estimate cetacean abundance and distribution.

The ICG discussed Thums *et al.* (2019) conclusion that satellite imagery surveys have higher costs than aerial and boat surveys in Western Australia. Davenport acknowledged their evaluation may not be an accurate representation of costs, as the boat survey costs were taken from 2007 and compared with satellite imagery surveys from 2018. It was also noted that the cost comparison is also not generalisable, as costs vary by area, particularly for vessel surveys.

Further discussions focused on the value of lower cost or open access high-resolution satellite imagery, like Planetscope (3m resolution), to scope areas worth investing in VHR satellite imagery. However, the ICG felt that in areas with little to no knowledge of local cetacean populations (where satellites will be most valuable), such resolution is too coarse to identify whales with confidence and that it was preferable to invest in VHR satellite imagery instead where possible, for scoping potential areas of interest (AOI). The ICG noted that Google Earth also represents an open-access tool to access satellite imagery. Google Earth's historical imagery tool was considered useful, particularly for image differencing and evaluating and identifying confounding features, such as rocks. However, while Google Earth is considered a useful tool to identify whales in areas of known whale presence and for public engagement and environmental awareness; for systematic long-term monitoring, Google Earth is limited by the regularity of image updates, which is dictated by image availability and biased towards high interest areas.

Finally, the ICG discussed SWAMM and the power of satellites to study migratory routes. While Watt's efforts to study beluga whales around an estuary in Lancaster Sound were unable to confirm the beluga were migrating, they found variability in counts over time. This can offer insights into the timing of migration and variability in estuary use, particularly when comparing satellite data with past satellite telemetry data. The presenter also highlighted to the community that SWAMM's use of Maxar's proprietary 15cmhigh-definition sharpened imagery and object-based image analysis (OBIA) worked well for ideal sea states but less so for windy images.

Fewster provided an overview of a statistical framework for estimating the abundance of whales from satellite data. In any approach to wildlife abundance estimation, it is essential to include an effective way of estimating detectability. Building upon two published approaches for digital aerial surveys (Stevenson, Borchers and Fewster, 2019; Borchers *et al.*, 2022), the statistical framework proposed by Fewster for estimating detectability using data from satellites aims to deliver estimates quickly and with minimal human input. The ultimate goal is to produce a pipeline for automated analysis over large spatial and/or temporal domains. However, estimating detectability imposes certain demands on the equipment and design; in particular, two or more images of each surveyed location are needed, ideally separated by a time gap in the order of minutes. It is important to include statistical input at the stage of designing and developing satellite-based survey methods, to ensure the tool is fit for purpose. The success of this tool would benefit from collaborations between biologists, statisticians and engineers.

In their presentation, Fewster requested guidance on the most feasible satellite deployment options to realise their proposed statistical framework: (1) two satellites at a fixed distance in time; (2) two satellites with variable spacing in time, or (3) one satellite that can collect multiple images; the ICG agreed that one satellite collecting multiple images was most feasible. This would draw upon the capability of optical satellites to collect stereo-pairs, whereby a satellite sensor collects two images of the same location from different angles, which typically collect at 40-70 seconds apart.

2.3 Strandings

Clarke gave an overview of the challenges and opportunities of VHR satellite imagery for the remote monitoring of cetacean mass strandings[1] (Clarke *et al.*, 2021). Whale and dolphin strandings act as early warning systems for the ocean, offering valuable insights into marine ecosystem health and highlighting emerging public health issues. Rising complex human and environmental threats across the globe, as well as whale population recovery from exploitation in some areas, are likely to coincide with an increase in reported strandings. Despite the strong conservation rationale to study strandings, monitoring is geographically biased towards populated coastlines, dependent upon local expertise and resource availability. We need to upscale monitoring across the globe, particularly in remote regions, to better understand local cetacean populations, the threats they face and to evaluate the impact of future change. VHR satellite imagery offers the prospect of upscaling monitoring of mass strandings in minimally populated/unpopulated and inaccessible areas, over broad spatial and temporal scales; to gather baseline data and to retrospectively analyse historical stranding events. While satellites are not currently suitable as an emergency response tool to live mass strandings, due to time delays in image collection, the platform has the potential to highlight stranding patterns and act as an 'early response' tool, complementing existing stranding monitoring methods by supporting and informing intervention on the ground. Significant technical and practical challenges associated with satellites need to be addressed for this platform to become a viable support tool for long term mass stranding monitoring programmes. In addition, the current costing structure of commercial satellite imagery risks facilitating colonial science. Substantial work is required to streamline this process, to more easily and equitably use VHR satellite images for long term monitoring of stranded cetaceans.

Fretwell presented the use of remote sensing to detect whale strandings in remote areas, focusing on the case of the sei whale (*Balaenoptera borealis*) mass mortality event in the Chilean Patagonia (Fretwell *et al.*, 2019). The Golfo de Penas is an extremely remote complex fjord system, and one of the most wave-impacted coastlines in the world, meaning it is near impossible to use traditional methods to survey strandings. For this reason, in 2015 the largest known mass mortality event of baleen whales in the world, 343 primarily sei whales, went undetected for two months. This survey tested the ability of VHR imagery to detect stranded whales using both manual and automated methods. Aerial and boat surveys of the area were conducted two to four months after the mortality event. This study used 46cmresolution WorldView-2 imagery to identify and count strandings from two archival images acquired just after the stranding event and two months before the aerial and ground surveys. The results show that whales are easily detected manually in the images but due to the heterogeneous colouration of decomposing whales, spectral indices were unsuitable for automatic detection. Satellite counts suggest that, at the time the satellite images were taken, more whales were stranded than recorded in the aerial survey, possibly due to the non-comprehensive coverage of the aerial

[1] Further explore the definitions of strandings in the context of satellite imagery with the Strandings Expert Panel (SEP).

survey or movement of the carcasses between survey acquisition. With even higher resolution imagery now available, satellite imagery may be a cost-effective alternative to aerial surveys for future assessment of the extent of mass whale mortality and stranding events, especially in remote and inaccessible areas.

Wilkin summarised the opportunities and challenges of using satellite imagery for cetacean emergency response. Emergencies range from floating carcasses at sea, live or dead animals in oil spills, mass strandings, entanglements, and cetaceans out of habitat or in unusual situations due to extreme events. Satellite imagery could be used for remote detection, tracking, and analyses of potential threats, as well as detection, assessment, and health evaluations of marine mammals, which could potentially be incorporated into operational emergency responses. In the US, the Marine Mammal Health and Stranding Response Program is working with national and international partners to leverage opportunities to evaluate the ability of satellite imagery with spectral analyses to assist with emergency responses. This study piloted tasking satellite image collection in response to reports of strandings, in particular, a floating humpback carcass off the coast of New York in 2023. Collection of a Worldview-2, WorldView-3 and SkySat satellite image was unsuccessful due to cloud cover, time of image collection after the carcass was last seen, and complex environments. This study explored the adoption of a drift model to forecast the deposition of floating strandings. In an initial assessment of the floating humpback carcass, the model predicted the location of the carcass deposition precisely. Such models could be used to forecast stranding deposition in the future and to inform image collection. Due to established stranding response programmes in the US, the rapid removal and collection of carcasses, and necropsy, limits the opportunity for image collection. Other satellite-based work at the Marine Mammal Health and Stranding Response Program exploring, surface oil detection and harmful algal bloom forecasts and nowcasts, could inform stranding events.

In discussion, it was noted that the drift model used by Wilkin is open source, and could be adopted for other efforts to monitor strandings globally. The drift model (GNOME) can be accessed online[2]. The model is designed to model oil spill trajectories but can be customised to model carcass drift[3]. However, the ICG acknowledged that the model can be erroneous, and is dependent upon the quality of local wind and current information. The predictions can be enhanced by combining with local knowledge from oceanographers and placing carcass tags on floating whales to improve the forecasting of models.

2.4 Annotation and Automation of Whales in Satellite Imagery

Cubaynes presented a standardised pipeline to create training datasets for machine learning models, alongside an open-source annotated satellite image training dataset of whales (Cubaynes and Fretwell, 2022, Cubaynes *et al.*, 2023). Surveying large areas using VHR optical satellite imagery requires the development of automated systems to detect targets. Machine learning approaches require large training datasets of annotated images. The standardised workflow presented, to annotate whales in VHR optical satellite imagery using ESRI ArcMap 10.8, and ESRI ArcGIS Pro 2.5., aims to provide guidance to the Satellites to Study Whales community, particularly those new to the field, to achieve AI-ready annotations. The workflow includes a species decision tree and guidance (list of cues such as: (1) individual characteristics, like body colour, body shape and body length; (2) behaviours, like after-breach and bubble net; and (3) other cues, like blows and mud trails) on assigning a level of certainty to an annotation, to assist the community in compiling robust high quality training datasets. The study built a dataset of 633 annotated whale objects, created by surveying 6,300km^2 of satellite imagery captured by various VHR optical satellites (i.e., WorldView-3, WorldView-2, GeoEye-1 and Quickbird-2) in various regions across the globe (e.g., Argentina, New Zealand, South Africa, United States, Mexico). The dataset covers four different species: southern right whale, humpback whale, fin whale (*Balaenoptera physalus*), and gray whale (*Eschrichtius robustus*).

Goetz presented on the Geospatial Artificial Intelligence for Animals (GAIA) initiative to develop an operational system for detecting marine mammals in VHR optical satellite imagery. This study shares lessons learned, challenges faced, and GAIA's vision for how VHR satellite imagery can enhance our understanding of cetacean distribution in the future (Khan *et al.*, 2023). GAIA aims to create an operational platform that leverages the increased resolution of satellite imagery, proof-of-concept research, advances in cloud computing, and machine learning to monitor the world's oceans. GAIA is a collaborative innovation between government agencies, academia, and the private sector. The initiative has compiled 1,600 satellite image scenes, focused on the North Atlantic right whale (*Eubalaena glacialis*) and the Cook Inlet beluga population. To annotate this imagery and create a high-quality training dataset, GAIA are drawing upon; a manual approach using Cubaynes *et al.* (2023); a streamlined process using Microsoft AI for Good 'Human in the Loop' tool (the tool identifies interesting pixels in an image, and serves these interesting points as an image chip for annotators to validate); and crowdsourcing using Maxar's GeoHIVE platform. All annotations will subsequently be used by Microsoft to create a marine mammal detection algorithm, with an active learning approach, where additional annotations will

[2] https://gnome.orr.noaa.gov/.

[3] https://blog.response.restoration.noaa.gov/gray-whale-deaths-rise-how-orr-provides-support-during-unusual-mortality-event.

be used to retrain the model. Once the algorithm has matured, incoming satellites imagery will be processed in the cloud to create operational insights.

Green summarised her recent work on gray whale detection in satellite imagery using deep learning. The combination of VHR satellite remote sensing imagery and deep learning via convolutional neural networks (CNNs) provides opportunities to improve global whale population surveys through increasing efficiency and spatial coverage. Many whale species are recovering from commercial whaling and face multiple anthropogenic threats. Regular, accurate population surveys are therefore of high importance for conservation efforts. In this study, a state-of-the-art object detection model (YOLOv5) was trained to detect gray whales in VHR satellite images, using training data derived from satellite images spanning different sea-states in a key breeding habitat, as well as aerial imagery collected by unoccupied aircraft systems (UAS). Varying combinations of aerial and satellite imagery were incorporated into the training set. Mean average precision ranged from 0.823-0.922 across eight experiments. The results imply that including aerial imagery in the training data did not substantially impact model performance, and therefore expansion of representative satellite datasets should be prioritised. The accuracy of the results on real-world data, along with short training times, indicate the potential of using this method to automate whale detection for population surveys.

Rodofili presented a review of marine mammal automated detection in satellite and UAS imagery (Rodofili *et al.*, 2022), and the development of a workflow using a free platform. Marine mammals face entanglement, collisions, among other threats, which merits frequent and extensive surveys. While satellite and UAS imagery can help, manual counts over them remain time and labour intensive. In review, the study found methods of automation that relied solely on statistical differences in the spectral responses were surpassed by CNNs. In the current state of knowledge, semi-automated approaches with user revision of the output offer the best tradeoff between time and accuracy, while more work is needed to improve accuracy for full automation. The study also identified OBIA as a field in need of further exploration. In consequence, their efforts are currently focused on the development of an OBIA workflow, to detect and count Florida manatees (*Trichechus manatus latirostris*), using a free platform, Google Earth Engine (GEE). Besides free access for researchers, GEE allows for code and imagery (satellite or other) sharing. Initial results of OBIA show varied success, with high false positives (non manatee features, such as mud plumes, identified as manatee), and the processing can be computationally time intensive. A new study now aims to take learnings from initial OBIA exploration, to develop an OBIA workflow to detect migrating gray whales in satellite imagery and extract their swimming direction to study their migration routes.

Kapoor presented a novel deep learning-based automatic whale detection approach (Tiny YOLOv3, modified to include dilated convolutions) using VHR satellite imagery (Kapoor *et al.*, 2023). The study created a training dataset by combining image chips from two different sources: (1) a manually annotated dataset of images from Maxar Technologies (formerly DigitalGlobe) and Google Earth, labelled by three observers as whale or probable whale, producing 1,500 image chips; and (2) augmentation of the data to artificially increase the dataset to 4,500 image chips, using Keras library in Python. The dataset was further enhanced using Cubaynes and Fretwell's (2023) dataset, and applying augmentation to artificially increase the dataset from 633 to 1,500 annotations. This resulted in the largest existing training dataset of whales in satellite imagery, comprising 6,000 image chips (partial dataset available from: https://github.com/SaakshiKapoor/whales). Enhanced Super-Resolution Generative Adversarial Networks (ESRGAN) was applied to all image chips to improve the image quality and maintain the natural texture of the images. The precision achieved by the proposed automated system was 0.95, recall was 0.85, and mean Average Precision (mAP) was 0.74.

In discussion, the ICG encouraged datasets of whales in satellite imagery to be published open source and hosted using platforms that allow for regular updates. Updating a dataset is particularly important in the case of publicly labelled datasets, which have been found to contain mistakes. Cubaynes and Fretwell (2022) published their dataset on the Natural Environment Research Council (NERC) UK Polar Data Centre (PDC) repository, openly accessible (access details in Cubaynes and Fretwell (2022)). The ideal repositories for these datasets allow for data updates, which are directly linked to the doi and original publication, like the PDC. Publishing the datasets on repositories was considered preferable to data published as supplemental work to a scientific research article, which may require an author correction to update a dataset. It was suggested that any research groups wishing to publish datasets, contact the relevant satellite image provider ahead of publication to discuss licensing. Clarke commended the efforts of GAIA to develop operational tools for the community. The ICG were interested to learn GAIA's intentions to make tools they develop open source (for example, their Microsoft AI for Good 'Human in the Loop' tool WHALE (WHale Active Learning Environment)). The ICG commended Green's efforts to automate the detection of whales (the code is freely accessible[4]). Drawing upon Green's findings, the ICG encouraged further refinement of automation methods, to investigate the performance impact of; including more variability in image quality and environmental conditions; using more augmentation tools; and including a new category within training data for mother-calf pairs.

[4] *https://github.com/KMacfarlaneGreen/yolov5.*

2.5 Priority Areas for Satellite Surveys

Tulloch presented an overview of the webinar and workshop 'Detecting and Monitoring Marine Megafauna from Space: Webinar and Workshop' (2nd-3rd November 2022). To explore the potential applications of VHR satellite technology in the Northeast Pacific Ocean, Oceans and Fisheries Canada and the Ocean Decade Collaborative Center for the Northeast Pacific co-hosted an online knowledge-sharing event, setting the stage for future collaborations to detect and monitor megafauna using space-based data and advanced analysis methods. The report details results from the event, with the aim of supporting ongoing, actionable dialogue across sectors and regions working to better understand and manage our ocean's megafauna (Tulloch *et al.*, 2023). The specific objectives of the event were three-fold: (1) to describe the current state of the science, including projects and programmes underway nationally and internationally; (2) to broadly discuss potential research opportunities and applications in the Northeast Pacific Ocean, including any benefits and barriers or obstacles; and (3) to collectively lay out recommended next steps for implementation in the Northeast Pacific region. Specific needs or gaps were identified to help move from idea to action including; the necessity of collaborative work; data and image sharing to help reduce user costs; developing high quality and accessible training datasets for automation; building expert human capacity (particularly for automated systems); enabling data storage and data sharing; improving the provision of satellite technology products; investing in long-term solutions to automation; and identifying priority areas for satellite tasking. A continued and concerted exploration of the potential use of VHR satellite imagery in the Northeast Pacific region was recommended, to encourage the adoption of this novel technology when and where it will effectively supplement traditional surveys, and to support applications looking to efficiently monitor species and promote their survival and recovery.

Collins highlighted three areas where the investment of VHR satellite imagery to study whales could be useful; (1) the Gulf of Aden, Horn of Africa; (2) Lamu Offshore, an Important Marine Mammal Area (IMMA), Kenya; and (3) the Northern Gulf of Guinea (Fig. 1). (1) In the 1960s, the Arabian Sea was subject to Soviet whaling, when ships transiting to Antarctica took advantage of catches along the whole Southern Arabian Coast, from Yemen and Oman to Pakistan. Predictive models built by Redfern *et al.* (2017) and Wilson (2021) suggest these regions are important for blue whales and humpback whales respectively. The Gulf of Aden in particular was the focus of Soviet whaling in the 1960s' with four species targeted (Mikhalev, 2000). It is now one of the busiest shipping lanes in the world and has since been identified as an area of ship strike risk (Wilson, 2021). (2) The Lamu Offshore IMMA is an important aggregation area for blue whales (Barber, Sikora and Nimak-Wood, 2016). However, this area is challenging to monitor, given sightings of blue whales have been made some distance offshore (>100 km), and the region is under resourced to conduct surveys. Satellite imagery could support monitoring of blue whales in this IMMA. (3) In the Northern Gulf of Guinea, in particular Bioko, breeding humpback whale distribution overlaps with areas of cumulative anthropogenic threats (Chou *et al.*, 2020). The region is challenging to study due to political instability and piracy; given the urgency of understanding the anthropogenic impacts to breeding humpbacks in the region, Bioko is an area that would benefit from investigation using VHR satellite imagery.

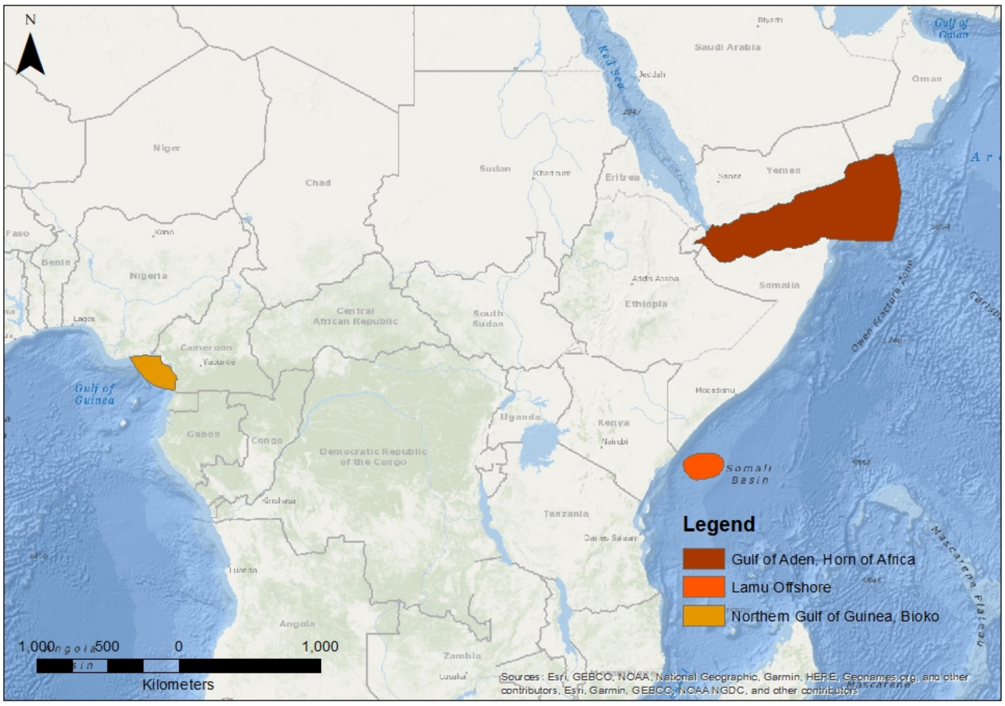

Fig. 1. Map of the three areas proposed by Collins where the investment of VHR satellite imagery to study whales could be useful; (1) the Gulf of Aden, Horn of Africa; (2) Lamu Offshore, an Important Marine Mammal Area (IMMA), Kenya; and (3) the Northern Gulf of Guinea.

Porter gave an overview of how VHR satellite imagery could support whale research in Asia. Southeast Asia is the epicentre of marine biodiversity and supports many resident species of cetaceans as well as providing critical habitat for migrating whale species. The richness of its marine resources, however, contrast sharply with the emergent nature of most of its economies. Despite the lack of consistent and comprehensive funding, Asian marine mammal research has grown tremendously in the last two decades with research teams in every nation and a region-wide stranding network. The use of satellite imagery to map and monitor Asia's whales has not been explored; however, the ability of VHR images to survey the region's most remote areas would likely substantially improve our knowledge. In particular, satellite imagery could help fill knowledge gaps in four areas.

(1) Babuyan Island, Philippines, an IMMA, is the only known wintering ground of humpback whales in the Philippines. Understanding more of this population's annual migratory patterns, would be helpful to conservation and management efforts.

(2) Raja Ampat and Dampier Strait, Papua New Guinea, a candidate IMMA (cIMMA), identified 16 species in 2006, however, no systematic surveys have been conducted since that time. The area is remote and perhaps satellite imagery could assist in identifying species presence and also where it might be appropriate to invest resources in vessel surveys.

(3) West Celebs Sea and Drop-off area, a site that has recorded several species of conservation importance, and a total of 20 species confirmed within the area. There are many security issues within this area, making it challenging to develop a ground-based marine mammal monitoring programme. Satellite imagery would certainly assist in better understanding this cetacean hotspot.

(4) A satellite monitoring programme for the remote Mariana Islands, where there is little to no knowledge of local cetacean populations, would allow us to better understand species assemblages and habitat use.

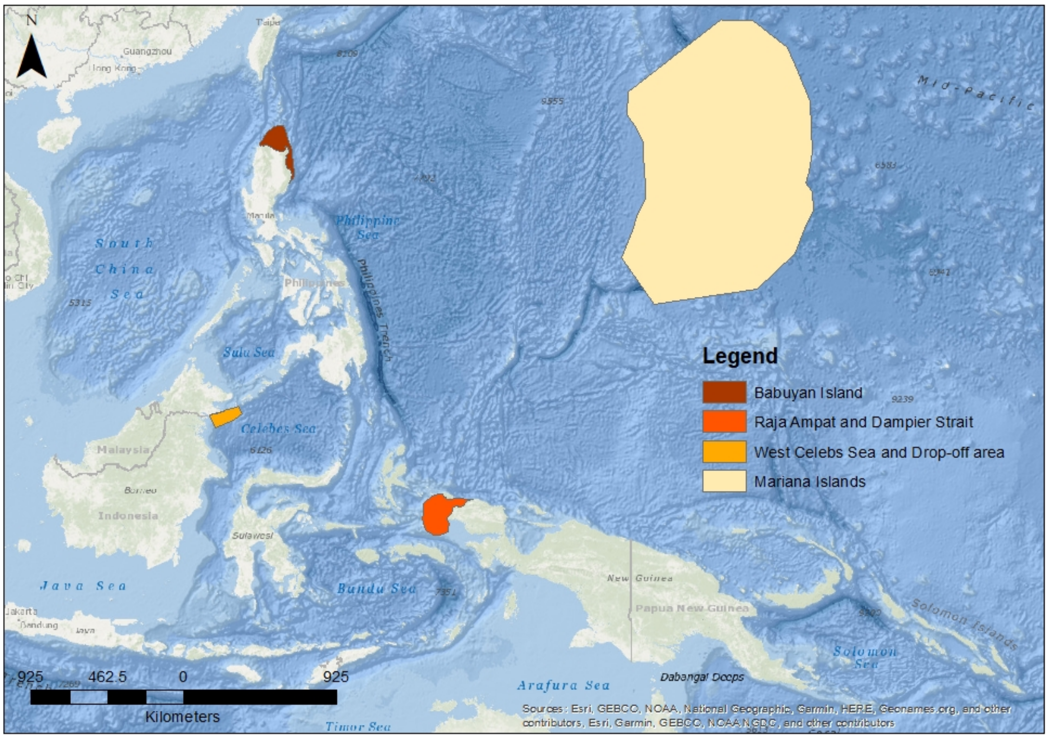

Fig. 2. Map of the four areas proposed by Porter where the investment of VHR satellite imagery to study whales could be useful in South East Asia; (1) Babuyan Island, Philippines, an IMMA; (2) Raja Ampat and Dampier Strait, Papua New Guinea, a candidate IMMA (cIMMA); (3) West Celebs Sea and Drop-off area; and (4) The remote Mariana Islands.

Natoli showcased the potential for satellites to support the study of baleen whales in the Arabian/Persian Gulf (thereafter The Gulf). Based on occasional sightings reported by the public and occasional stranding data collected to date, baleen whales are known to occur in the Gulf. Two species have been confirmed: Bryde's whale (*Balaenoptera edeni*) and humpback whale. Whales in the Gulf are considered rare, at least in the coastal waters, but regular and they have been reported from all the Gulf countries. No dedicated surveys covering offshore waters have been conducted to better assess their frequency. It is assumed that it is unlikely that these species would be resident in the Gulf, but it is probable that the Gulf is part of their distribution range and they seasonally (or periodically) enter it. The Gulf is mainly a shallow basin connected to the Northern Indian Ocean by a single entry point, the Strait of Hormuz (Fig. 3), which at its narrowest point measures about 50km, so all migratory species must pass through this area to enter the Gulf waters.

Can satellites help in detecting the whales' movements in and out of the Gulf, and obtaining an assessment of the occurrence and frequency of these animals in the area?

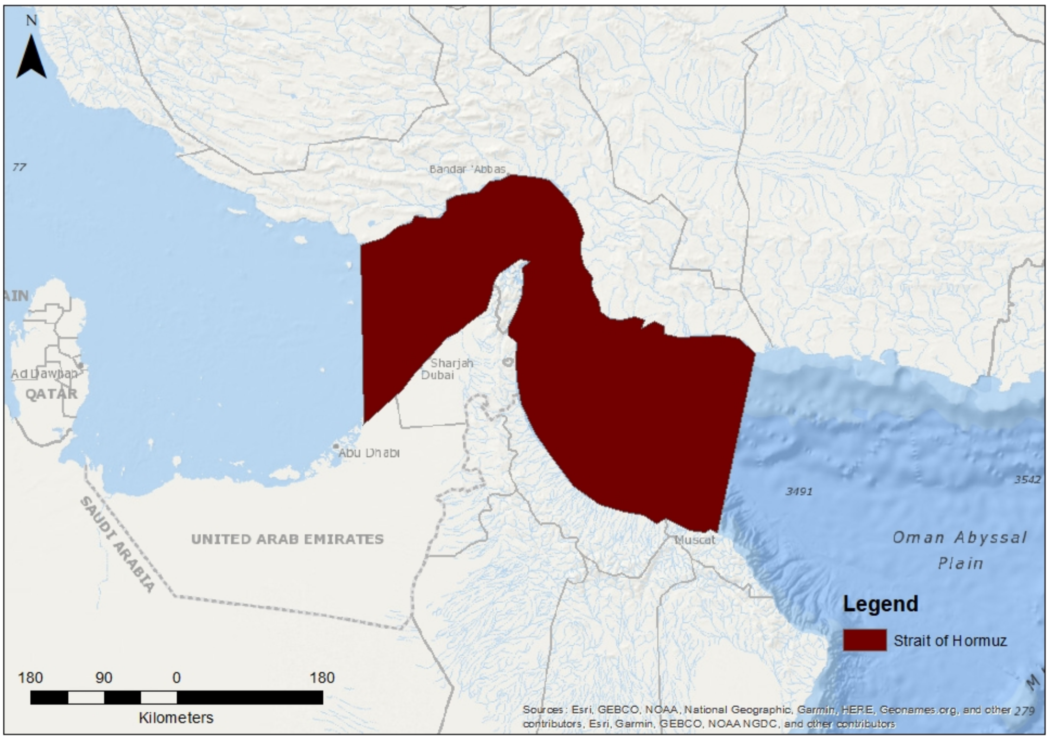

Fig. 3. Map of the area proposed by Natoli in the Arabian/Persian Gulf, the Strait of Hormuz, where the investment of VHR satellite imagery to study whales could be useful.

In discussion, it was noted that priority areas identified by Clarke for the monitoring of strandings using VHR satellite imagery (North West Indian Ocean, Western Indian Ocean - particularly South Africa to Somalia and islands along coast, and South Asia), coincide with the areas presented as worth investing in for live whales, highlighting the importance of these regions for consideration as case studies for investment of VHR satellite imagery. In particular, the oceanographically rich but geopolitically remote Somaliland coast, or more refined area, Socotra Island (pre-monsoon), were considered important case studies for strandings monitoring. Porter emphasised the value of in-person workshops for learning about this approach in Asia; to share knowledge, and to equip Asia with the capacity to formulate research questions using this powerful tool. The request for training and collaborative knowledge sharing was also supported by Natoli in the Arabian/Persian Gulf.

In discussion, Clarke encouraged the ICG to review; the special issue on globalising conservation by confronting parachute science (Schwartz *et al.* 2022); and de Vos' Hack the Planet keynote talk[5]. In particular, the discussion highlighted the risks imposed by the current costing structure of satellite imagery and the nature of remote sensing to access anywhere around the world without investing locally, in facilitating colonial narratives in conservation practice. For the Satellites to Study Whales community to achieve shared conservation goals, we need a global community. From the outset, the Satellites to Study Whales community needs to prioritise equitability and representation, through capacity sharing and developing openly accessible tools and data. Such steps will be crucial to strengthening local long-term monitoring programmes and allowing local researchers, NGOs, government and resource managers to achieve their monitoring and conservation goals.

3. AUTOMATION

Fretwell outlined the ultimate goals of the automation session:

- coordinated efforts to facilitate the development of automated method(s); and
- avoid the duplication of effort.

The ICG was presented with three questions in a series of breakout discussions. The priorities, actions, proposed recommendations and encouragements from the discussions that followed are summarised below.

The ICG was asked to consider:

[5] https://www.youtube.com/watch?v=iS5IT90fLqU.

(1) Which automation methods are worth investing in? In particular, which automation methods worked well or were any less accurate? And to think cross disciplinary and whether other fields are using transferable automation methods?

In discussion, the automation methods considered to work well were; CNN, Faster CNNs like Yolo, and OBIA (Borowicz *et al.*, 2019; Guirado *et al.*, 2019; Rodofili *et al.*, 2022; Kapoor *et al.*, 2023). Pixel based methods, like unsupervised and supervised classification, and thresholding, were considered to have lower accuracy and performance when compared with deep learning approaches (Fretwell *et al.*, 2019; Cubaynes *et al.*, 2020b). To date the development of automation methods has focused on unique datasets and environmental conditions, with few attempts to apply methods across multiple datasets and conditions, making it difficult to confidently draw conclusions on the effectiveness of different machine learning approaches. The ICG acknowledged that a model's performance is only as good as the dataset it is trained with; and emphasised the importance of high-quality annotations made by expert analysts using standardised protocols. By adopting consistent data labelling methods, the community can begin to quantitatively evaluate which algorithms are most effective. The inclusion of variability in environmental conditions in training datasets, like glare and sea state, was considered important for increasing model performance. The ICG encouraged in this developmental phase of automation that a semi-automated human in the loop approach, whereby a human(s) verifies the accuracy of detections made by an algorithm, be adopted (Khan *et al.*, 2023). An iterative process was also considered essential, where outputs from a model are used to retrain the model. To date, no automation model has been capable of summing the total number of features of interest detected, an important feature for abundance estimates; the ICG considered this an area for development. The ICG also discussed future steps to streamline the process of automatically detecting whales in VHR satellite imagery, identifying that automation could be applied beyond detection, for example, pipelines to; automate the collection and selection of imagery (removal of poor-quality imagery); pre-process imagery; and download imagery. The ICG encouraged the Satellites to Study Whales community develop interdisciplinary collaborations to progress the automation of whale detection. The IWC Photo ID working group and experts within this field were identified as valuable collaborators for this community, given their efforts to auto-identify features in imagery.

(2) What data format is required for training data (.shp, .geotiff, etc.), can point shapefiles be shared as a minimum, or are polygons or bounding boxes more useful?

In discussion, no clear consensus was reached on the data format required for training data, and the ICG proposed a best practice workshop or similar, to develop standardised protocols. Points as a universal base data type were considered the easiest way to share identified features. The files are light and easy to share, include geolocation information, allow for pixel analysis, and can be converted to bounding boxes or polygons. However, point placement can vary by observer and it can often be unclear which feature they are associated with. Polygons as a universal base data type were considered a greater investment of an annotator's time, given they can highlight additional information for human annotators and machine learning algorithms alike, such as; the orientation of the whale; the length of a whale, which can inform species identification; and the number of pixels expected for a whale-like feature. Polylines can be considered as a quicker alternative to polygons to inform the orientation of a whale, if important to a research project. Polygons like points can be converted, to provide either points or bounding boxes. Polygons were considered less effective at identifying individuals in tight aggregations, and points may be more suitable for research questions aiming to count individuals. Bounding boxes were agreed to be useful for presence-absence research questions, though mother-calf pairs pose a challenge due to their proximity. It was added that in cases where individuals cannot be separated using a box or polygon, datasets explicitly state the number of animals in the box or polygon. The human in the loop process was considered essential in the developmental phase of automation to identify the limitations of each annotation type and to inform best practice moving forward. The standard data format the community preferred for data sharing was .geotiff, given the location is always linked. However, the community recognised the limitations of sharing .geotiff files due to satellite image provider licensing terms. As an alternative format .shp files were considered valuable, as they preserve information associated with attributes in a layer. The .shp format could be used interchangeably with a .csv format, given the two data formats can easily be converted between types. The .csv file type may offer a more inclusive format for sharing data, particularly for those new to working with geospatial data. Both file types can also be used to create shareable image chips in a .geojson, .png or .jpeg format. Image chips in .png format, like Cubaynes and Fretwell (2022) may be authorised for direct sharing, but require consultation with the relevant satellite image provider for consent.

(3) How do we measure accuracy and what is a measurable way to determine the quality of detections?

To begin to evaluate which automation algorithms are most effective, the ICG needs to agree on a uniform method to evaluate model accuracy and performance. In simple terms, accuracy describes the percentage of predictions the model identified correctly. In discussion, the measure of accuracy was identified as dependent upon the goal of the project, what is a project aiming to achieve? The ICG proposed to establish standardised terminology that address AI performance; and to have this terminology translated for non-AI specialists. The ICG proposed that a best practice workshop be held to agree on terminology and the percentage of accuracy required between the model and an observer, by the Satellites to Study Whales community. It was considered, for reproducibility, publications should ensure that standardised metrics are reported and authors be transparent about the limitations of a model, for example, whether a model is optimised for ideal sea states. The ICG noted that models are trained on human annotations, reiterating earlier discussions that models are only as good as the input training data. As datasets are constantly increasing and improving, the ICG noted that datasets should be updated and with version history detailed for use. In discussion, the ICG considered repeat surveys using models in the same location as an important mechanism for measuring accuracy. Accuracy was also discussed in terms of environmental variables that can impact detection, like glare and swell; and whether thresholding pipelines can be developed and applied to remove poor quality images before applying algorithms.

In discussion the ICG considered methods the community could adopt to reduce the duplication of effort, and agreed to some of the proposed solutions for automating the detection of whales in optical satellite imagery and proposed:

With respect to matters relating to; which automation methods are worth investing in (1, 2); what data format is required for training data and how to measure the accuracy of detections (3); and how to reduce the duplication of effort (4, 5), the ICG:

(1) ***recommends*** *in this developmental phase of automated detection that a semi-automated human in the loop approach, whereby a human(s) verifies the accuracy of detections made by an algorithm, be adopted;*

(2) ***recommends*** *the Satellites to Study Whales community develop interdisciplinary collaborations to progress the automated detection of whales. Drawing upon expertise from other marine mammal experts using machine learning, like acousticians, photo ID experts, and aerial and drone imaging specialists; to beyond the marine mammal community including; physical oceanographers; machine learning experts; engineers; mathematicians; and statisticians, through the Satellites to Study Whales ICG;*

(3) ***recommends*** *a best practice meeting or similar to:*

(a) develop standardised protocols for the data format required for training data

(b) agree on standardised AI performance terminology; and to have this terminology translated for non-AI specialists;

(c) agree on the levels of accuracy required for AI models compared with a manual observer, by the Satellites to Study Whales community;

(d) agree on whether it is necessary to downsample aerial and drone imagery used to supplement training data for automated detection;

(4) ***encourages*** *the development of an open-access working document detailing active research areas being pursued within the ICG, in order to ensure transparency and minimise research duplication;*

(5) ***recommends*** *annual or bi-annual meetings for this ICG, virtually or in person at the IWC, to continue to refine the use of VHR satellite imagery to study whales*.

4. EQUALITY OF OPPORTUNITY/PARTNERSHIPS WITH SATELLITE IMAGE PROVIDERS

The automation session welcomed representatives from the three leading commercial VHR satellite image providers. Simon Delaney, Satellite Imagery and Solutions Sales Manager from Airbus; Paulo Godinho, Sales Manager Europe from Maxar Technologies; and Dr Melania Guerra, Director of Science Strategy from Planet.

Clarke outlined the ultimate goals of the equality of opportunity / partnerships with satellite image providers session:

- build relationships with satellite image providers;
- document existing initiatives and partnerships by satellite image providers supporting research; and
- establish satellite companies understanding of how these initiatives can be more equitable and flexible for researchers.

Delaney presented on Airbus Defense and Space Intelligence and their 37+ years experience in satellite data acquisition, processing, analysis and provision of Earth Observation (EO) products and systems to partners across the globe. Airbus boasts the largest commercial constellation of radar and optical satellites, offering multi-sensor, multi resolution, multi-source data, with daily revisit times. Sensors range from 30cm Pleiades Neo to 22m resolution optical data, and to TerraSAR-X spotlight mode 25cm to wide scan 40m spatial resolution Synthetic Aperture Radar (SAR). Pleiades Neo, commercially launched in 2021, will provide 30cmresolution imagery for the next 10 years, including proprietary sharpening of imagery to 15cm. Airbus archival imagery (10 years) and new tasking requests can be accessed through the 'living library' OneAtlas platform. The platform offers analytical tools from counting and change and object detection, to thematic services like vessel detection. Tasking experts are on hand to advise customers, offering the best chance of accessing imagery on time and within requested parameters. Airbus supports research and development through a number of methods; (1) European Space Agency's (ESA) 3rd Party Mission programme supports high quality and innovative projects with full archival and new tasking imagery; (2) intelligence partnerships: Airbus are always exploring new use cases and applications of EO data; (3) data challenges and initiatives that allow successful applicants access to task and collect archive data; and (4) academic licensing, offering 50% discount on imagery products for education and research purposes.

Godinho presented on Maxar and some of the use cases of their technology. Maxar's satellites are collecting over 3.8 million km^2 of imagery daily. At the core of Maxar's operations is the constellation which they own and operate including; four VHR satellites imaging earth at up to 30cm resolution; and soon to be launching six new 30cm resolution (next generation) satellites in 2023, WorldView Legion. WorldView Legion will include two sun synchronous sensors, imaging the same location at the same time everyday, and four mid-inclination orbits, enabling high revisit (up to 15 revisits a day) in key areas of the globe; particularly across continental Europe, the US and the Polar circle. Maxar offers access to its 22-year archive and new collections added daily, and analytical and exploitation tools, through its Secure Watch platform. Ultimately, Maxar wants to focus on how they can apply this technology to help understand and navigate our changing planet. They achieve this through; purpose partners, supporting organisations that closely align with Maxar company values with benefits in kind; the Open Data Program[6], year-round crisis response, opening up imagery datasets to support organisations and response efforts; and news bureaus, providing trusted media organisations around the world with data to ground truth, to promote transparency and expose injustice.

Guerra presented Planet and its mission to image the whole world every day, making change visible, accessible and actionable. Planet is a public benefit company, where revenue and impact are equally important to their shareholders. Science drives their mission, by making change visible to scientific communities, the changes happening on the earth's surface can lead to policy decisions. Planet's constellation includes; 3m resolution Planetscope; 180 satellites constantly scanning the earth's surface (daily); 50cm resolution SkySat, tasking images at very high resolution; and soon to be launching Pelican, the next generation VHR satellite tasking at 30cm resolution. Alongside RapidEye, a 12 year archive of 5 m resolution imagery from 2008 to 2020; SuperDove, next generation PlanetScope, eight band imagery aligned with Sentinel 2a; and Tanger, a 400 spectral band hyperspectral mission, Planet's constellations are powerful in providing lots of information for the scientific community. An example, the Allen Coral Reef Atlas, saw Planet join forces with universities and National Geographic for digital public good, to map the global coverage of coral reefs and to support intervention either at an environmental or policy level to protect corals. Planet offer data access for science and research through; university affiliation, allowing researchers 5,000km^2 of PlanetScope data every month for free[7]; the Global Education and Research Programme, bespoke partnerships with universities (new packages launched for different areas of the world according to GDP, to truly achieve equitable access of data); and ESA Earthnet Programme, offering access to archival and tasked SkySat imagery[8]. Planet engage the science community through their Planetology newsletter[9]; sponsoring conferences; support universities with Hackathons; hosting webinars and every two years publishing an applications report detailing the most novel science applications.

In discussion, a few of the biggest challenges to studying whales in satellite imagery were outlined including; the costs of purchasing satellite imagery; the limited archival data available over open oceans and for specific events in space and time for strandings; and the lack of training data to achieve machine learning tools. The ICG sought confirmation from the satellite image providers, on whether they would welcome a list of candidate areas (Table 1; agreed areas of prioritisation for satellites to study whales, by the ICG) for speculative tasking (proactively collecting imagery of an area of interest for a future project, ahead of financial exchange). In particular, the ICG was most interested to task in regions where little archival imagery exists, like open ocean and migratory routes, and ensuring equitable distribution of sites across the globe. The satellite image providers agreed to consider the list of candidate areas, but requested that the scope of the request for each area be more focused. In particular, they encouraged the ICG to collectively identify specific research questions for each project which could be addressed with imagery, to ensure parameters can be met for specific projects.

[6] https://www.maxar.com/open-data

[7] https://www.planet.com/markets/education-and-research/

[8] www.planet.com/earthnet

[9] https:/learn.planet.com/Science-newsletter-subscription.html

Table 1

An updated version of a table compiled by Cubaynes and colleagues during IWC SC67a, which originally described candidate areas to carry out proof of concept/pilot studies. Following satellite image providers' welcome of a list of candidate areas, the updated version provided an opportunity to discuss; whether these candidate areas are still important to invest in and continue to test the tool; and/or whether new areas should be added.

Species and IUCN Red List status	Location	Area (km^2)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Animals at sea						
Multispecies						
Multiple species (humpback whale, blue whale, fin whale, Omura's whale, sperm whale) *IUCN: Endangered, Vulnerable, Least Concern, Data Deficient*	Equatorial margin of the Atlantic	TBD	Year round	S: Preliminary vessel surveys between the Brazilian coast and mid Atlantic ridge (visual and acoustic) since 2018, detected multiple odontocete species with a few Omura, blue, fin, sperm and humpback whales detected acoustically - may be an important habitat for multiple species (Project Sentinels of the Blue Amazon (UFRN)). S: Presence of multiple distinct species makes this useful test data for species differentiation algorithms. C: Understudied area due to location, but growing oil and gas industry interest in the area, making monitoring important.	- May be challenging to discriminate species	
Multiple species (including Arabian Sea humpback, blue, Bryde's, sperm whale) *IUCN: Endangered, Vulnerable, Least Concern*	Gulf of Aden, Horn of Africa Bab al-Mandab Strait (passage between the Red Sea and Gulf of Aden)	257,394 (Gulf of Aden) 12,437 (Bab al-Mandab Strait)	Sep.-Dec. (inter-monsoon period)	S: Understudied breeding and feeding area for Arabian Sea baleen whales, which is difficult to access by boat due to cost and security risks. S: Presence of multiple distinct species makes this useful test data for species differentiation algorithms. C: Identified as an AOI by IUCN (not enough contemporary data to support designation as an IMMA at this time). C: Whale distribution coincides with major shipping routes.	+ Relatively calm water +/- Calmer seas during the inter-monsoon period, likely very challenging outside of this period (cloud cover and rough seas) - May be challenging to discriminate species	
Multiple species (bowhead whale, beluga, narwhal) *IUCN: Least Concern*	Hudson Strait	94,782	March	S: Hudson Strait has the greatest density of marine mammals in winter in ice-covered regions of Arctic Canada. C: Baffinland proposal to build Steensby Port in Foxe Basin and ship iron ore via large ore carriers through Hudson Strait. Monitoring before shipping occurs is necessary to determine space use.	+ Bowhead whales are large bodied whales that can be observed from satellites; + Beluga and narwhal are also present and have been detected in satellite imagery	Walrus and seals may be detected on sea ice.
Multiple species (humpback, fin and blue whales) *IUCN: Least Concern, Vulnerable, Endangered*	Mingan Islands, St Lawrence Estuary, Canada	3,578	Jun.-Sep.	S: Regular boat surveys allow for ground-truthing of satellite image detections. S: Presence of multiple distinct species makes this useful test data for species differentiation algorithms.	+ Relatively calm water - May be challenging to discriminate species	Odontocete species are also present.
Multiple species (including Arabian Sea humpback whale, Bryde's whale (possibly coastal form), Blue whale, possible Omuras whale) *IUCN: Endangered, Vulnerable, Least Concern, Data Deficient*	Strait of Hormuz (entrance of the Arabian Persian Gulf)/ Gulf. Occasional whale presence: sightings are rare but regular up to Kuwait.	29,441	Best time not known. See 'Notes'	S: Data deficit; IMMAs identified only in coastal waters because it is difficult to conduct dedicated offshore surveys in the Gulf due to the political situation. S: Some stranding events may be useful to ground-truth satellite detections of strandings. C: Area contains possible calving areas within an area of high shipping traffic (entanglements and ship strikes are documented threats). C: Number of strandings recorded only in UAE (small coastline relative to overall area) raises concern about threats to these populations.	+ Relatively calm water + Generally sunny weather + Relatively small areas that could provide information for a bigger area (the whole Gulf)	Joint effort could be done across countries to review occasional sighting records to try to identify the most likely season.
Mysticetes					+ Body length sufficient for detection on VHR satellite images of 50cm+ resolution	

Species and IUCN Red List status	Location	Area (km²)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Mysticetes cont.						
Blue whale *IUCN: Endangered*	Lamu Offshore IMMA, Kenya-Somalia, Blue whale	61,373	Sep.-Nov.	S: Understudied feeding area for Madagascar pygmy blue whales, which is difficult to access by boat due to cost and logistical complexity of conducting surveys. C: Area identified as an Important Marine Mammal Area by IUCN.	+/- Calmer seas during the inter-monsoon period, likely very challenging outside of this period (cloud cover and rough seas)	
Bowhead whale *IUCN: Least concern*	Bering Strait	40,103	Sep.-Nov.	S: Could assist detection of changing migration times due to environmental change. S: Possibility to ground truth with acoustic data. C: Ice is retreating and new shipping routes are opening within this habitat, which is undergoing rapid change with increased threats to whales.	+ Relatively calm water + Calm behaviour[1] - Other large whale species in area, not sure can differentiate	
Bowhead whale *IUCN: Least concern*	Shantar Islands, Okhotsk Sea	49,280	September	C: Limited surveys of this known feeding ground.	+ Fairly small area +Relatively calm water + Calm behaviour[1]	
Bryde's whale *IUCN: Least concern*	Upper Gulf of Thailand, Thailand	6,441	Sep.-Jan.	S: Visual data from boat surveys complement satellite surveys allowing ground-truthing of the approach. C: Interaction with fishing vessels has been reported. C: Small population (50 individuals) concentrated in small area of 50x50km².	+ Small area of 50x50 km + Relatively calm water + Calm behaviour[1]	
Fin whale *IUCN: Vulnerable*	Strait of Sicily, Italy	45,092	Feb.-Apr.	S: Feeding hotspot in winter; satellites permit monitoring of feeding timing/locations. C: High level of shipping traffic in areas where whales are feeding at the surface, so risk of strike.	+ Relatively calm water + Calm behaviour[1]	
Humpback whale *IUCN: Least Concern*	Abrolhos Bank, Brazil (Marine Protected Area (MPA) focused on humpback whales)	44,539	Aug.-Oct.	S: Large breeding ground with varying group sizes and behaviours, allowing to build satellite training data on a variety of humpback life stages. S: Long-term surveys (land-based, aerial counts, boat surveys) in Abrolhos Bank by Instituto Baleia Jubarte (NGO) can ground-truth counts from satellites.		
Humpback whale *IUCN: Least Concern*	Serra Grande reproductive ground, Brazil	260	Jul.-Oct.	S: Surveys (visual and acoustic) in Serra Grande since 2014 by Projeto Baleias na Serra (UESC). C: Serra Grande ground is on the narrowest part of the Brazilian continental shelf and can be studied from land. Whales are reoccupying this area as the population is growing. Potential for more human impacts here.	+ Relatively calm waters	Odontocete species are also present.
North Atlantic Right whale *IUCN: Critically Endangered*	Cape Cod Bay	1,627	Mar.-Apr.	S: Cape Cod Bay is an important feeding area with significant aggregations. Detections from satellites would support ongoing monitoring for the species and support management measures in the United States. C: Species is critically endangered with only about 340 individuals remaining. They are threatened by vessel strikes and entanglement in fishing gear, which have had significant impacts on the population.	+ Large aggregation in a relatively small, sheltered bay. Has been tasked before with success + Distinct callosities on North Atlantic right whale head allow easy discrimination from other large whales	

Species and IUCN Red List status	Location	Area (km^2)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Mysticetes cont.						
North Atlantic Right whale *IUCN: Critically Endangered*	Florida and Georgia	24,222	Dec.-Feb.	S: Florida and Georgia are the only known calving grounds for the species. Detections from satellites would support ongoing monitoring for the species and support management measures in the United States. C: Species is critically endangered with only about 340 individuals remaining. They are threatened by vessel strikes and entanglement in fishing gear, which have had significant impacts on the population.	+ Calmer, clearer, and/or shallower waters than feeding areas. Potentially better contrast between whale and the ocean, enabling satellite detection + Distinct callosities on North Atlantic right whale head allow easy discrimination from other large whales	
North Atlantic Right whale *IUCN: Critically Endangered*	Southern Gulf of St. Lawrence	45,608	Jul.-Aug.	S: Southern Gulf of St. Lawrence is an important feeding area with significant aggregations. Detections from satellite would support ongoing monitoring for the species and support management measures in Canada. C: Species is critically endangered with only about 340 individuals remaining. They are threatened by vessel strikes and entanglement in fishing gear, which have had significant impacts on the population.	+ Distinct callosities on North Atlantic right whale head allow easy discrimination from other large whales - Turbulent sea conditions may limit satellite survey capacity - Multiple species present in the same area	
North Pacific right whale *IUCN: Endangered*	Northern Gulf of Alaska and Bering Sea	TBD	Jul.-Aug.	S: Little is known about the movement and distribution of the North Pacific right whale, which are located in areas with little survey effort. C: Very few animals in the population.	+ Distinct callosities on head allows for easy discrimination - Multiple species in same area - High cloud cover/high seastate - Very few animals in the population	
Omura's whale *IUCN: Data Deficient*	Nosy Be and Nosy Iranja/Ampasindava Peninsula, Madagascar	4,991	Oct.-Dec.	S: Possibly present all year-round, surveys required to establish this. S: Possibility to ground-truth satellite imagery with acoustic data and visual data from boat surveys. C: Species very poorly known, so establishing local presence and density is of conservation importance.	+ Animals concentrated in a fairly small area + Fairly calm sea, as sheltered area	
Rice's whale *IUCN: Critically Endangered*	Northern Gulf of Mexico	TBD	Year round	S: Will supplement other data to understand the species. C: Species poorly known.	+ Present year round - Relatively large area and few animals	
Sei whale *IUCN: Endangered*	Golfo de Penas, Chile (46°S)	12,467	Jan.Feb.	S: Feeding ground for poorly studied species. S: Inaccessible area, with very few surveys.	+ Relatively calm water; + Calm behaviour[1]; + Several satellite images available for this area	
Southern right whale IUCN: Least Concern	Head of Bight, Australia	277	Jul.-Sep. (peak mid-August)	S: 26 years of land based survey to help ground truth.	+ Distinct callosities on southern right whale head allow easy discrimination from other large whales; + Small area to monitor; + Relatively calm water; + Relatively calm behaviour (nursery ground)[1] + Single species presence (potential killer whale presence who predates on southern right whales)	

Species and IUCN Red List status	Location	Area (km²)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Mysticetes cont.						
Southern right whale *IUCN: Least Concern*	Santa Catarina coast, Brazil (MPA focused on southern right whales)	15,548	Jul.-Oct. (peak September)	S: Long-term abundance surveys, including land-based and aerial counts by Instituto Australis (NGO) can assist ground-truthing of satellite images.	+ Whales stay in small bays for long periods. + Calving bays calmer than offshore	
Odontocetes						
Beluga *IUCN: Least Concern*	Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA) (Darnley Bay)	2,358	Jul.-Aug.	S: Information about spatial distribution and drivers of habitat use is still lacking in this area. C: Eastern Beaufort Sea beluga population is one of Canada's largest beluga populations that supports a subsistence hunt by Inuvialuit that is of significant economic, dietary, and cultural importance. Furthermore, the ANMPA was established in 2016 to preserve critical habitat for the Eastern Beaufort Sea beluga population, and beluga detections from satellite imagery would support ongoing monitoring in the MPA.	+ Belugas have good contrast with the surrounding waters. Waters are exceptionally clear in this area and whales have been clearly seen at the surface in recent drone surveys	
Beluga *IUCN: Least Concern*	Atkinson Point (Tuktoyatktuk Peninsula)	678	Jun.-Aug.	S: Detections from satellite imagery would support ongoing monitoring and can be paired with drone surveys in July 2023. C: The Eastern Beaufort Sea beluga population is one of Canada's largest beluga populations that supports a subsistence hunt by Inuvialuit that is of significant economic, dietary, and cultural importance.	+ Waters are clearer (with periods of increased turbidity) here and whales have good contrast with the surrounding waters	
Beluga *IUCN: Least Concern*	Clearwater Fiord and Kangilo Fiord	1,475 (for both areas)	August	S: They congregate in Clearwater Fiord and to a lesser extent the Kangilo Fiord, which means you can capture the majority of the population in a small area. C: The Cumberland Sound beluga population is listed as threatened by SARA, with less than 1,400 remaining.	+ Good contrast with the surrounding ocean. Have been detected in satellite imagery in the past with success + Satellite imagery is also a good non-invasive option be-cause the com-munity does not like them to be bothered when in their summering areas	
Beluga *IUCN: Least Concern*	Eastern Hudson Bay	53,494	Jul.-Aug.	S: Satellite monitoring would complement ongoing efforts to quantify the abundance, distribution, and habitat use of this population. C: The Eastern Hudson Bay beluga population is listed as threatened by Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and remains at low levels, with around 2,600 mature individuals. Concerns over future impacts to growth and habitat use in response to several threats.	+ Belugas have good contrast with the surrounding ocean and have been detected in satellite imagery previously with success +/- Belugas would be occupying offshore, inshore, river, and estuarine areas that may be muddy	
Beluga *IUCN: Least Concern*	Husky Lakes	4,298	Aug.-Oct.	S: There is a community call to monitor beluga's use of Husky Lakes as this is a site where large entrapments have occurred in the past. C: The Eastern Beaufort Sea beluga population is one of Canada's largest beluga populations that supports a subsistence hunt by Inuvialuit that is of significant economic, dietary, and cultural importance.	+ Waters are clear here and whales have good contrast with the surrounding waters	
Beluga *IUCN: Least Concern*	Southern Ungava Bay	17,090	July-August	S: Very few individuals have been sighted using traditional survey methods and the population may already be extinct. Satellite monitoring may help in determining whether a beluga population still exists in this area.	+ Good contrast with the surrounding ocean. Have been detected in satellite imagery in the past with success	

Species and IUCN Red List status	Location	Area (km²)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Beluga (Southern Ungava Bay cont.) *IUCN: Least Concern*				C: The Ungava Bay beluga population is listed as endangered by COSEWIC, with less than 100 individuals remaining. Supports a subsistence hunt by Nunavimmiut that is of significant dietary and cultural importance.	+/- Belugas would be occupying shallow coastal, river, and estuary areas that may be muddy	
Beluga *IUCN: Least Concern*	St. Lawrence Estuary	12,980	Jul.-Sep.	S: Satellite monitoring would complement ongoing efforts to quantify the abundance and habitat use of this population. C: The St. Lawrence Estuary Beluga population is listed as endangered by SARA, with less than 900 remaining. They are geographically and reproductively isolated from other beluga populations and their recovery is limited by several major threats.	+ Good contrast with the surrounding ocean. Have been detected in satellite imagery in the past with success +/- Multiple species in the same area, but will likely be easy to distinguish from other whales	
Beluga *IUCN: Least Concern*	Tarium Niryutait Marine Protected Area (TNMPA) (Mackenzie River Estuary)	1,800	Jun.-Aug.	S: Information about spatial distribution and drivers of habitat use is still lacking in this area. C: The Eastern Beaufort Sea beluga is one of Canada's largest beluga populations that supports a subsistence hunt by Inuvialuit that is of significant economic, dietary, and cultural importance. Furthermore, the TNMPA was established in 2010 to preserve critical habitat for the Eastern Beaufort Sea beluga whales. Detections from satellite imagery would support ongoing monitoring in the MPA.	+/- Turbid waters prevent whales being seen below the surface, but they have good contrast with the surrounding waters when surfacing; + Large groups gather in the MPA, so on calm days it may be possible to identify aggregation sites	
Beluga *IUCN: Least Concern*	Viscount Melville Sound	60,916	Jul.-Aug.	S: From tagging data it is known that whales frequent this area; however, no visual sightings have been made. C: The Eastern Beaufort Sea beluga population is one of Canada's largest beluga populations that supports a subsistence hunt by Inuvialuit that is of significant economic, dietary, and cultural importance.	- Often heavy sea ice	
Beluga (Cook Inlet subpopulation) *IUCN: Critically endangered*	Cook Inlet, Alaska	12,691	May-Sep.	S: Satellite monitoring would complement ongoing efforts to determine distribution in months when aerial surveys are not conducted. C: The Cook Inlet Beluga population is classified as critically endangered on the US Endangered Species Act, and remains at low levels, with less than 300 animals.	+ Belugas have good contrast with the surrounding environment and have been detected in satellite imagery previously +/- Belugas inhabit an extremely turbid environment and only a portion of their body is available for detection in satellite imagery - Belugas are easily confused with whitecaps, birds, and rocks exposed at low tide	
Narwhal *IUCN: Least Concern*	Admiralty Inlet	3,565	August	S: Narwhals exhibit fidelity to their summering ground. In recent years, Inuit have noticed that narwhals have been moving between summer areas more frequently. C: There is a need to closely monitor narwhal densities in these high density areas and the movement between them.	+ Narwhals have been detected in satellite images (with 30cm resolution)	See Charry *et al.* (2021)

Species and IUCN Red List status	Location	Area (km^2)	Time	Science and conservation rationale (prefix with S for science and C for conservation)	Feasibility of using satellite imagery	Notes and references
Odontocetes cont.						
Narwhal *IUCN: Least Concern*	Eclipse Sound (Milne Inlet and Tremblay Sound)	990	August	S: Narwhals exhibit fidelity to their summering ground. In recent years, Inuit have noticed that narwhals have been moving between summer areas more frequently. C: Shipping has increased in the Eclipse Sounds area due to the Mary River Baffinland mine. There is a need to closely monitor narwhal densities in these high density areas and the movement between them.	+ Narwhals have been detected in satellite images (with 30cmresolution)	See Charry *et al.* (2021)
Sperm whale *IUCN: Vulnerable*	Hellenic Trench IMMA, Greece	56,568	Year round	C: Area identified as an Important Marine Mammal Area by IUCN and as a Cetacean Critical Habitat for sperm whale by the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS).	+ Relatively calm water + Body length sufficient for detection on VHR satellite images of 50 cm+ resolution	
Stranded animals						
Whale strandings	Skeleton Coast Park, Namibia	8,236	June-August	S: Northern and central parts are inaccessible areas for strandings response, so stranding patterns are not monitored. S: Several whale skeletons evidence large numbers of strandings in the past.	+ Sand beach with no trees so can offering a clear view	
Whale strandings	Socotra Island (and associated islands: Abd al Kuri, Samhah, Darsah)	8,429	Intermonsoon months (pre and post monsoon)	S: There is existing evidence of large whale strandings and dolphin mass-strandings. These could be ground truthed through effective collaboration with local stakeholders. C: The island is accessible again after a period of uncertainty during the Yemen conflict. However, the island is generally challenging to get to for research purposes.	+ Has extensive white sandy beaches, sparse vegetation and relatively little traffic - Beached boats are local to a few villages and may be confused for stranded animals	Reviewed as a cIMMA and remains an AOI.
Whale strandings	Somalia, Puntland and Somaliland coasts	1,146	Intermonsoon months	C: Many areas are too hazardous to study, but the coast is extensive and adjacent to very productive seas known for the occurrence of large whales, some threatened.	+ Wide sandy beaches, very little traffic on some, especially in northern areas	Reviewed as a cIMMA and remains an AOI. The whole Somalia coast is huge. Preference should be given to the eastern Somaliland, Puntland, Horn (Ras Gardafui) region, which is very remote but exposed to monsoon upwelling and most adjacent to areas of highest productivity. Overlaps with other priority areas.

[1] 'Calm' whale behaviour is anticipated to assist their ID via satellite image, for example regularly being in horizontal profile in the water column, so more easily detectable as a whale.

In regards to the questions surrounding archival data availability over the open ocean, Maxar confirmed the lack of open ocean archival data was not a storage issue, rather a lack of demand, and that they can speculatively task areas of interest. They highlighted that while collecting more data does not always yield useful data, providers can offer solutions for identifying how much of available data is useful to the user. For example, Maxar can offer crowdsourcing of their archival images, as crowds can be a low cost way of identifying useful data, allowing users to invest in purchasing only those images that are useful. The ICG raised concern over the poor quality of detections often achieved through free crowd campaigns. The ICG encouraged that crowdsourcing use private campaigns, where members of the Satellite to Study Whales community collectively form an expert whale detection crowd. Once algorithms are more advanced, the ICG could focus on applying machine learning algorithms to images in a crowdsourcing platform, instead of a human crowd, to automatically identify useful imagery. Planet confirmed they do have collections over the open ocean, but do not publish data >15km from shore, due to the challenges to orthorectify data without reference points. The ICG considered the high level precision of a whale's location was not necessarily of high importance, though further discussion is required between the ICG and satellite image providers to understand the impacts of absent orthorectification on the study of whales in satellite imagery. The ICG encouraged seeking clarification from all satellite image providers on orthorectification for the study of whales in satellite imagery, to determine whether this level of pre-processing is necessary for data analysis and accuracy. Guerra on behalf of Planet, welcomed the ICG to contact them directly to request use of unpublished open ocean data.

Aside from provider solutions, like crowdsourcing as methods to identify useful imagery, the ICG highlighted the value of providers developing mechanisms to filter data by additional environmental conditions, other than cloud cover, like wind on surface (sea state) and glare. Reviewing or filtering poor quality imagery ahead of purchasing, would help the Satellites to Study Whales community in minimising unnecessary costs to projects. The ICG strongly welcomed the support of satellite image providers to develop mechanisms to review satellite imagery for environmental conditions, like wind on surface (sea state), prior to purchasing imagery. In particular, the ICG considered it important to have a high level discussion with satellite image providers, to agree on thresholds for environmental conditions when tasking a satellite, where customers are under no obligation to purchase imagery above the defined threshold.

The ICG and satellite image providers discussed whether data purchased by companies or used as part of open data programmes (like the data used for the search of aircraft MH370), could be made available after initial use via a philanthropic conservation model, for education and research to answer scientific questions. Planet does offer programmes for NGOs, like Global Fishing Watch; and they are reviewing and reevaluating such programmes, to tailor quotas and needs for applications of data for the ocean. The ICG also enquired whether the community could share image chips as .png or .jpeg format to increase training datasets through international collaboration. Planet's education and research rights enable publication of scientific discoveries made with the data, but not the data itself. In all cases, the community were encouraged to contact the satellite image providers to discuss licensing on a case by case basis. Finally, the ICG agreed it would be useful to establish nominated direct contacts within the various satellite imaging companies for the Satellites to Study Whales community.

Table 1 is an updated version of a table compiled by Cubaynes and colleagues during IWC SC67a, which originally described candidate areas to carry out proof of concept / pilot studies. The updated version provided an opportunity to discuss; whether these candidate areas are still important to invest in and continue to test the tool; and/or whether new areas should be added. The ICG agreed the updated table should be presented to satellite image providers, as a list of candidate areas for speculative tasking, to increase available archival repositories.

Ahead of presenting the list to satellite image providers, the ICG was encouraged to add candidate areas to the table. In discussion, it was raised that any areas proposed should consider the; scientific rationale; conservation concerns; detectability of the species; environmental conditions at the time of year whales are present (like wind and cloud cover); seasonal state (such as breeding, feeding or migratory); and the difficulty of access for survey. The ICG agreed the table should be expanded upon to include; details of publications already conducted in the listed regions; and a rationale for prioritisation based on conservation concerns and scientific merit. To prioritise the candidate areas, the ICG needs to devise a system to rank regions based on the conservation rationale alongside the scientific merit of doing the work in a particular region relative to what has already been done. The ICG considered whether it could be useful to identify key criteria that make a project feasible and define thresholds for those criteria that must be met. Further discussion is required on the prioritisation of these candidate areas, the ICG will agree on an objective rationale for prioritisation.

Once agreed, the prioritised list can be provided to satellite image providers to conduct a feasibility assessment based on their technical knowledge. It is important for the community to confirm with satellite image providers the maximum area of imagery the community can request, and for the community to then devise AOIs in .kmz format or similar that can be shared with providers. In discussion, a key question was posed to the community, whether multispectral imagery adds value to analysis or is an unnecessary expense? In particular, it was noted that multispectral and pansharpened imagery added value for manual annotation but less so for machine learning approaches. The ICG needs to give further consideration to the minimum spectral and spatial resolution, and the spatial and temporal extent of the data the community requires, as this may help satellite image providers to support the communities requests.

The ICG agreed to prepare a letter to satellite image providers and requested the Secretariat send the letter on the ICG's behalf (the ICG to provide the Secretariat a draft, timescale, and directions of where to send). The ICG agreed the letter will request support in; reducing the cost of access to satellite imagery; developing licensing agreements to facilitate data sharing; using unique image identifiers to enable multiple groups to access the same image; as well as detailing the collective research questions and accompanying list of candidate areas for speculative tasking, particularly over open ocean areas.

In discussion the ICG recognised that satellites may not always be the most appropriate tool to study whales, and that aerial or vessel surveys may be more effective. Aside from developing a list of candidate areas, the ICG considered it important to establish mechanisms to evaluate which survey platform (e.g., satellites, plane or vessel) may be most suitable to address a particular research question or to study a particular region, and encouraged developing a decision matrix to assist researchers in selecting the most appropriate platform.

In discussion, the ICG was asked to consider their top recommendations for creating opportunities that are more equitable and building partnerships with satellite image providers. For the proposed recommendations that arose from those discussions, see below.

*The ICG **requests the Secretariat** send a letter to satellite image providers, requesting support in; facilitating access to satellite imagery; developing licensing agreements to facilitate data sharing; using unique image identifiers to enable multiple groups to access the same image; as well as detailing collective research questions and a list of candidate areas for speculative tasking, particularly over open ocean areas.*

*To create more equitable opportunities the ICG **requests the SC Chairs** approach commissioners in countries with active space programmes, like the European Union, the UK and the USA; to consider launching national government funded very high-resolution satellites, with publicly accessible imagery.*

To create opportunities that are more equitable and build partnerships with satellite image providers, the ICG:

(1) ***agrees** the priority research areas table should be finalised and presented to satellite image providers, providing a list of important candidate areas for speculative tasking, to increase available archival repositories;*

(2) ***recommends** cross-disciplinary and cross sector collaborations to partner with governments, NGOs and academia exploring other uses of remotely sensed data, such as IUU (illegal, unreported and unregulated) fishing investigation, to leverage data accessibility;*

(3) ***encourages** further discussions as a group to devise an internationally collaborative consortium/global scale project, endorsed by the IWC, to develop partnerships with satellite image providers, to leverage and negotiate better opportunities;*

(4) ***strongly welcomes** the support of satellite image providers to develop mechanisms to review satellite imagery (through an iterative process drawing upon the expertise of the ICG) for environmental conditions, like sea state, prior to selling imagery to community members;*

(5) ***encourages** the use of crowd-sourcing as a lower cost mechanism to identify imagery worth investing in. Initial campaigns should use a private crowd, drawing on members of this ICG to collectively form an expert panel to review imagery; and then once machine learning algorithms are more advanced, focus on using them as a form of crowd;*

(6) ***strongly welcomes** the development of new satellites with improved spatial resolution and revisit rates; and **encourages** that satellite image providers partner with the Satellites to Study Whales community in their first collection phases, to make the imagery available to the community, and to test and showcase their products;*

(7) ***requests** satellite image providers establish nominated direct contacts (nationally/internationally) for the Satellites to Study Whales community;*

(8) ***recommends** as part of best practice, the Satellites to Study Whales community develop a decision matrix to assist the community in determining whether satellites, aerial, or vessel surveys are most appropriate to a research question and region of interest.*

5. INFORMATION, DATA AND CODE SHARING

Cubaynes outlined the ultimate goals of the information, data and code sharing session:

- to coordinate data and code sharing among active research groups; and
- to establish what is needed to standardise the field.

The ICG was presented with two questions in a series of breakout discussions. The priorities, actions, recommendation and encouragements from the discussions that followed are summarised below:

(1) How and where can we centralise all datasets and code, including those already published and those to come? What steps are needed to make this happen?

Given the large volumes of data required to train most machine learning algorithms, the ICG considered the sharing of datasets important to working collaboratively towards successful detection algorithms. The ICG discussed the potential challenges of locating an increasing number of datasets hosted on many independent repositories. The ICG requested the Secretariat's and General Databases Working Group's (GDR) support for the IWC to publish a summary table; to store and share data for Satellites to Study Whales. This may require IWC server hosting and access to the IWC data hub to store metadata, papers and links[10]. The ICG recognised the costs to host large amounts of data and the complexity surrounding licensing of sharing satellite data, so rather than the IWC hosting physical datasets, the IWC could publish links, directing users to published datasets around the globe. This may require support from IWC personnel to collate links and annotate links for searchability, for example, by species. In addition, the ICG requested the Secretariat's support for the storage of common code, to be formulated as part of best practice guidance by the Satellites to Study Whales ICG, on the IWC github. Emphasis was placed on the need to work collaboratively on code via github to ensure code represents best practice. The ICG recognised the importance of ensuring the centralised database has mechanisms which allow users to know how others are using their data, and also for maintaining an accurate and up to date database. Methods considered for maintaining the database included, living documents which can be updated, and the researcher (while active in the field and host institution) managing their own link and data; and thereafter, with the support of IWC funds, transfer and archive datasets with the IWC when they cannot be hosted locally by researchers. In discussion, the ICG encouraged that prior to centralisation, the ICG needs to prioritise standardisation and best practice in the development and sharing of training data, to ensure data is reproducible and the field develops with internationally collaborative capabilities.

(2) What do datasets need as a minimum for standardisation across the field?

Attendees were asked to consider; what information to attach to annotations; what information to include in publications; how can we standardise the definition of certainty (Definite 90-100%, Probable 60-90%, Possible 10-60%); and what environmental conditions should be recorded?

In discussion, the suggestions made by the ICG for standardising Satellites to Study Whales and the information to include with annotations and publication, were largely concurrent. However, further discussion is required to agree on a standard, and the ICG enouraged development of best practice guidance. The discussion of what information to attach to annotations were supportive of those outlined in Cubaynes *et al.* (2023), like; the location of a feature (latitude and longitude); the certainty of a detection; and the species identified. The ICG considered it important that publications detail; the satellite provider and sensor; the image catalogue ID; the image date and time; the ground sampling distance (GSD); nadir angle; and image quality. The ICG added that publications should, where possible, publish openly accessible datasets (either as image chips, whole geotiffs, point, polygons or boxes - format to be agreed in best practice guidance) including; the image metadata; the doi to the data repository; and the contact details for the author. For standardising certainty, the ICG supported the move from a classification scoring system to observers' judgement. However, the ICG discussed the value of annotating possible whales in imagery given they are typically not used in machine learning. The community agreed that these annotations could be useful in the future, with satellite and computational advancements. The consensus was certainty should be defined within the three categories in Cubaynes *et al.* (2023), 'Definite', 'Probable', and 'Possible', however, the ICG proposed amending the percentages to 'Definite 90-100%', 'Probable 70-90%', and 'Possible 50-70%'; as they considered anything a human would evaluate below 50% certainty, was unlikely to be a whale. The ICG enouraged experimental analysis to understand the level of consensus between human observers for these certainty categories and for the community to agree standard definitions / a rationale for the assignment of each category, in best practice guidance. The ICG also highlighted the value of reviewing other fields' methods of assigning certainty, to understand how they resolved challenges and whether their methods are applicable to use by Satellites to Study Whales. Finally the ICG considered which environmental conditions impact our ability to detect whales and should be recorded; like sea state, cloud cover, glare, and turbidity. In summary, further discussion is needed surrounding best practice including; what variables to record; at what level, whole image or at annotation level; the

[10] *similar to: https://ecosound-web.de/ecosound_web/ .*

feasibility of measuring variables in 2D satellite imagery, like sea state; and what mechanisms can be used to assess conditions, like image based scales.

In discussion, the ICG was asked to consider their top recommendations for standardising the field and coordinating data and code sharing among active research groups. For the proposed recommendations that arose from those discussions, see below.

To establish an internationally collaborative community working towards collective conservation goals, the ICG:

(1) ***requests*** *the Secretariat's and Adhoc Working Group on Databases (GDR) support, for the IWC to publish a summary table on the IWC webpage, containing links to where annotated datasets of whales in satellite imagery are stored;*

(2) ***requests*** *the Secretariat's support for the storage of common code, to be formulated as part of best practice guidance by the Satellites to Study Whales group, on the IWC github.*

To establish what is needed to standardise the field, the ICG:

(1) ***recommends*** *prioritising standardisation and best practice guidance in:*

(a) the development (annotating whales and environmental conditions in satellite imagery) and sharing of training data, ensuring data are reproducible;

(b) what information to include during annotation and publication;

(2) ***recommends*** *experimental analysis to understand the level of consensus between human observers for these certainty categories and for the community to agree standard definitions / a rationale for the assignment of each category, in best practice guidance.*

Throughout the discussions in the report, it is evident the Satellites to Study Whales community and this tool would benefit from establishing best practice guidelines across the whole operation of the tool. This was considered particularly important in the early stages of the tools development, to facilitate internationally collaborative efforts and to strengthen local efforts to use satellites to study whales. The ICG discussed IWC's history of producing best practice guidance for tools and proposed an in-person workshop, to establish best practice guidance. The ICG encouraged that the best practice guidance to standardise Satellites to Study Whales be summarised in a published paper, and that this be made available on the IWC website. As this tool is novel, the best practice guidance should be established with version histories, so as the tool develops and the community evolves, the guidelines can be updated.

In the early stages of the development of optical satellite imagery to study whales, to facilitate internationally collaborative efforts and to strengthen local efforts to use satellites to study whales, the ICG:

(1) ***recommends*** *an in-person meeting is held, with the aim of establishing best practice guidance following the recommendations made in section 3, 4, 5 of this report, along with any other topics that may be identified by the ICG;*

(2) ***recommends*** *that the best practices to standardise Satellites to Study Whales are summarised in a published paper, and that this be made available on the IWC website.*

6. CONCLUSIONS

The meeting covered a wide range of issues related to achieving a standardised, equitable and internationally collaborative tool for monitoring live and stranded cetaceans. The conclusions and recommendations made by the Satellites to Study Whales community can be found highlighted in grey boxes under each agenda item. The key takeaways and recommendations made by Tulloch *et al.* (2023) for the use of satellites to study whales, complement those made in this report.

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Appendix 1

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Appendix 2

AGENDA

1. Introductory items
2. Background studies
    - 2.1 Commercial ventures
    - 2.2 At sea distribution and density of live whales
    - 2.3 Strandings
    - 2.4 Annotation and automation of whales in satellite imagery
    - 2.5 Priority areas for satellite surveys
3. Automation
4. Equality of opportunity/partnerships with satellite image providers
5. Information data and code sharing
6. Conclusions
7. Adoption of the Report

Appendix 3

ACRONYMS AND GLOSSARY

Acronyms

ACCOBAMS: Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area

AI: Artificial Intelligence

ANMPA: Anguniaqvia Niqiqyuam Marine Protected Area

AOI: Area of Interest

cIMMA: candidate Important Marine Mammal Area

CNN: Convolutional Neural Network

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

EO: Earth Observation

ESA: European Space Agency

ESRGAN: Enhanced Super-Resolution Generative Adversarial Networks

GAIA: Geospatial Artificial Intelligence for Animals

GEE: Google Earth Engine

IMMA: Important Marine Mammal Area

ICG: Intersessional Correspondence Group

IUCN: International Union for Conservation of Nature

IWC: International Whaling Commission

mAP: mean Average Precision

MPA: Marine Protected Area

NERC: Natural Environmental Research Council

NGO: Non-Governmental Organisation

NOAA: National Oceanographic and Atmospheric Administration

OBIA: Object-Based Image Analysis

PDC: Polar Data Centre

SC: Scientific Committee

SWAMM: Space Whales and Arctic Marine Mammals

TNMPA: Tarium Niryutait Marine Protected Area

VHR: Very High-Resolution

UAS: Unoccupied Aircraft systems

Glossary

This glossary is a reference of terms relevant to the Satellites to Study Whales community, the terms are drawn from definitions made in a number of publications (Clarke *et al.*, 2021; Cubaynes *et al.*, 2023 and Khan *et al.*, 2023).

Remote Sensing Terms

Annotation - the process of categorising and labelling objects of interest (e.g., whales) within the satellite image either by placing points or bounding boxes along with associated metadata.

Area of Interest (AOI) – the area on the Earth that you want to view.

Catalogue ID - unique identifier for satellite images.

Convolutional Neural Network (CNN) - a type of network architecture for deep learning algorithms specifically used for image recognition.

False positive - When an object is misidentified, for example in the context of strandings, this is when a confounding feature or pixel containing a non-cetacean object is misclassified as a cetacean.

GeoTIFF Format; Georeferenced tagged image file format - GeoTIFF file is a TIFF file that is embedded with geographic data tags.

Image Differencing - also known as change detection, is the identification of changes between a target image and a reference image collected at different times.

Machine Learning - is the use of computational power to apply a diversity of data analysis approaches and algorithms to existing data/information, to learn from, and then accurately predict.

Multispectral imagery - is electromagnetic radiation with emission properties in the visible electromagnetic spectrum that produces colour imagery.

Nadir - the point on the ground vertically beneath the sensor.

Orthorectification - the process of removing image distortions introduced by the collection geometry and variable terrain, and re-sampling the imagery to a specified map projection. It is also referred to as ortho-correction or terrain correction.

Panchromatic imagery - is electromagnetic radiation with emission properties in the visible electromagnetic spectrum that produces greyscale imagery.

Pansharpened - a pansharpened image is created by combining the high spectral resolution (colour) of a multispectral image with the high spatial resolution of a panchromatic image, resulting in an image that is both high resolution and colour.

Projection - the transformation of latitude and longitude coordinates to plane coordinates.

Remote sensing - also known as 'Earth Observation,' is the principle of deriving information about the earth's surface using a remote device, acquired using a number of electromagnetic radiation sensors such as: microwave, radar, thermal, infrared, ultraviolet and multispectral.

Spatial Resolution - also known as ground sampling distance, is the length of ground represented by a single pixel, which in turn determines the level of detail visible.

Spectral Bands - parts of the electromagnetic spectrum of specific wavelengths.

Spectral Resolution - is the number of radiometric sensors aboard a satellite, that are receptive to different ranges of wavelengths (spectral bands) of incoming electromagnetic radiation. These include the panchromatic band, the visible light spectrum, and infrared bands.

Stereo - the collection of two or more images of the same Area of Interest (AOI) from different viewing angles.

Tasking - the ability of a satellite image provider to directly send information to a satellite, requesting when and where imagery be collected, and the satellites return transmission of imagery.

Very High Resolution (VHR) - is the capability of satellite imagery to collect sub-metre spatial resolution images of the earth's surface.

Stranding Terms

Mass Mortality Event (MME) - is when cetaceans strand either deceased or dying, over extended temporal scales (days to weeks).

Mass Stranding Event (MSE) - is when two or more individuals of the same species, not including mother calf pairs, simultaneously strand alive in the same location.

Stranding - is a cetacean that falters ashore, debilitated, or is in an environment incompatible with its natural survival; if the cessation of life has occurred prior to deposition, the cetacean is considered beachcast.

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