UPDATE ON THE POTENTIAL USE OF UNMANNED VEHICLES FOR CETACEAN MONITORING IN THE ACCOBAMS AREA

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ACCOBAMS Report

"Update on the Potential Use of Unmanned Vehicles for Cetacean Monitoring in the ACCOBAMS Area"

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1. Introduction

The ACCOBAMS Secretariat coordinates the ACCOBAMS Survey Initiative (ASI) to meet the ACCOBAMS strategic objective on improving the understanding of the conservation status of cetaceans at the macro-regional level of the Mediterranean and the black Sea. Carrying out monitoring of marine macrofauna remains an expensive and difficult exercise in terms of implementation, especially on a large scale, and it has become essential to explore the use of new techniques and instruments to facilitate monitoring cetaceans at very different scales, including for example at the level of Marine Protected Areas (MPAs). Autonomous platforms, such as aerial drones (UAVs), surface drones (ALVs Autonomous Laboratory Vehicles) and underwater drones (gliders) have undergone significant development in recent decades for various purposes, in particular for environmental monitoring. They represent a promising approach for the study of cetaceans and marine macrofauna in the near future, as they may require less human effort in the field and prove to be economical in the long term. However, a number of limitations remain, in particular with regard to current technical capacities, data processing and the administrative and legal aspects related to their use. Within the framework of ASI, the ACCOBAMS secretariat supported an activity to explore the possibility of using aerial drones to implement cetacean monitoring. This "Feasibility and experimentation study on the use of drones for the monitoring of cetaceans in the area covered by the ACCOBAMS agreement" was carried out in 2019 and 2020 by the Morris Kahn marine research station of the University of Haifa, in collaboration with Murdoch University. Three reports were prepared as a result of this activity:

- Potential use of Unmanned Aerial Vehicles for megafauna monitoring in the ACCOBAMS Agreement Area: transitioning to the new technology (Hodgson et al., 2020)

- Automated detection of dolphins in imagery from unmanned aerial vehicles and performance optimisation; deep-learning in animal abundance surveys. (Bigal et al., 2020).

- Reduction of species identification errors in wildlife abundance surveys utilising unmanned aerial vehicles (Bigal et al., in review).

In addition, the ACCOBAMS Secretariat has joined the Sphyrna Odyssey project aimed at exploring the potential of autonomous surface laboratory vehicles in monitoring the marine environment. In particular, the ACCOBAMS Secretariat collaborated with Marine Conservation Research (MCR) to develop an experiment to assess the feasibility of using surface drones to apply remote sampling methods to estimate the abundance and distribution of cetacean species. An MCR experience report was prepared as part of the Sphyrna Odyssey project: 'Testing the feasibility of unmanned surface vehicles to estimate the distribution and abundance of cetacean species' (Boisseau et al., 2020).

In this context, and in line with the ACCOBAMS 2020-2022 work program, this document is an updated synthesis on the use of autonomous platforms for the monitoring of cetacean populations, taking into account the results and recommendations of the various experiments supported by the ACCOBAMS Secretariat as well as a bibliographic review of recent scientific articles and projects on the subject treated.

2. Updated bibliographic synthesis

When talking about drones, it should be clear that different types exist, mainly three at sea, and their playgrounds are separated.

2.1 Types of drones to collect data

Unmanned Aerial Vehicle **(UAV)**

Most known vehicles are drones, which are unmanned aircraft. Traditionally, these are used in military surveillance missions. Their use has been growing rapidly since the beginning of the 21st century with an unprecedented development for missions for different types of environments (El Mahrad et al., 2020). UAVs represent an emerging tool to provide possibly a safer, cheaper, and quieter alternative to traditional methods of studying marine megafauna in their natural habitat, and can contribute to research and management when monitoring marine protected areas (Brooke et al., 2015). One of the main advantages of drone-monitoring is the acquisition of high spatial and temporal resolution, and the footage they produce constitutes systemic and permanent data which can later be reviewed by a high number of experts (Linchant et al., 2015 *in* Bigal et al., 2020.*).* Data collected by UAVs realising aerial surveys have been utilized for a wide variety of studies on marine megafauna including monitoring, habitat use, abundance estimates, behaviour, photogrammetry and biological sampling e.g., whale “blow” (Angliss et al., 2018, Durban et al., 2015, Goebel et al., 2015, Hodgson et al., 2013, Nowacek et al., 2016, Oleksyn et al., 2021, Pirotta et al., 2017). UAVs have been proposed as a tool for marine mammal surveys, as they allow researchers to reach remote areas and observe animals from an advantageous perspective (Fiori et al., 2017). The most popular use of UAVs in marine mammal research has mostly been through visual observation of marine species using both fixed-wing and multirotor vehicles (Hodgson et al, 2020, Fiori et al., 2017, Aniceto et al., 2018). These vehicles usually have a camera attached to them, which enables observers to analyse images which are either stored in memory or relayed in real-time (Babatunde et al., 2020).

Unmanned Surface Vehicle **(ASV)**

These are vehicles that operate on the water surface without a crew. They are also called autonomous surface vehicles, unmanned surface vessels, or autonomous surface crafts. Significant progress in the development of USVs occurred from the end of the 20th century into the 21st century (El Mahrad et al., 2020). USVs have been used for many aspects related to marine management, including monitoring of marine fauna (Verfuss et al., 2019).

In 2020, *Sphyrna 70*, an ASV bearing multi-hydrophones aboard, successfully collected acoustic data on the presence of sperm whales off Toulon (France, Mediterranean Sea). In June 2021 the USV “MAS400” has crossed the Atlantic (the Mayflower project), carrying hydrophones and planning to detect cetaceans apart from the ambient noise, among other tests.

Autonomous Underwater Vehicle **(AUV)**

These are robotic devices or vehicles that are unmanned underwater. Most current autonomous platforms operate, sample, and navigate according to a pre-programmed mission and in general are operated with some human ‘supervision.’ Only recently have such vehicles been deployed in fully autonomous mode. It is intended that future advanced autonomous platforms will be capable of adapting their parameters and algorithms, and they may choose actions or behaviours based on prior information or real-time collected data, to achieve a predetermined goal (Whitt et al., 2020). PAM applications in bioacoustics include presence/absence monitoring and density estimation of marine fauna (Marques et al., 2009, 2011). Since PAM does not emit sound, they are easier to deploy in protected areas. These data can be collected *in situ* by AUVs. The collected acoustic data are analyzed onsite or offsite, by manual or automatic methods, to detect sounds of interest. Human interpretation is usually needed to make inferences from the recorded events (Whitt et al., 2020).

Glider is a type of AUV, providing high resolution (~2 h, ~2 km) hydrographic profiles (Testor et al. 2010, Rudnick 2016 in Cauchy et al., 2020), performing long autonomous missions (several months to 1 yr, and several thousand km) unaffected by extreme weather events. They are highly suitable for PAM, gliding quietly, unpropelled, through the water and collecting information on the acoustic properties of the water column. PAM sensors have been successfully deployed on ocean gliders for cetacean monitoring (Moore et al. 2007, Baumgartner & Fratantoni 2008, Klinck et al. 2012, Baumgartner et al. 2013, Cauchy et al., 2020). Cauchy et al., 2020 presented a case of study on the ability to use PAM glider observation as a tool to study sperm whale habitat in the NWMS. Repeated observations of sperm whale distributions along predefined glider transect lines can provide useful information about their habitat use (Verfuss et al. 2019). In addition, intensive PAM glider observations during the winter season could fill observational gaps, such as those identified by Mannocci et al. (2018) in the Mediterranean Sea like the winter period or adverse weather conditions. Use of onboard data-processing systems is now possible on marine autonomous platforms, allowing for real-time transmission of the observations.

2.2 Objectives and capacities of the drones

In order to use drones for monitoring cetaceans in the ACCOBAMS area, it is crucial first to maintain consistency and comparability with existing long-term datasets from traditional methods (Hodgson et al., 2020). However, the applications of UAVs offer new opportunities to collect and analyse data that were not possible from manned aerial, or boat-based, surveys. Therefore, the ultimate aim should not be to simply replicate manned surveys, but continue to improve the data obtained from marine megafauna monitoring, for example under the next ACCOBAMS Survey Initiative (Hodgson et al., 2020).

The following table gives some technical characteristics of different categories of unmanned vehicles (Table 1).

Type of unmanned vehicle	Battery technology	speed	bandwidth (acoustic only)	storage	Example of use
Small multi-rotor UAV	Limited to a time flight usually < 30 minutes (Raoult et al., 2020, Cleguer et al., 2021))	40 km/h (travel speed) up to 54km/h speed and position during the flight depend on the study area size, the animal size to be monitored, and the available time (Barreto et al., 2020) 32.9 km/h (cruise speed) for the Phantom 4 Pro (Cleguer et al., 2021)	*Not concerned*	Data can be downloaded or viewed on real-time or stored on-board SD cards	Quadcopter (VTOL) (Barreto et al., 2020; Detectability of threatened marine megafauna) P4Pro (multirotor aircraft) (Cleguer et al., 2021; density and abundance estimation of dugongs)
Fixed –wing UAV	24hours for the *ScanEagle*	50-60 knots (travel speed) until 80 knots (maximum) for the *ScanEagle*	*Not concerned*	1 TB of storage in the camera. 1 TB of storage translates to roughly 10 h of flight time while collecting	*ScanEagle* (Hodgson et al., 2013; monitor species' habitat use and

				uncompressed raw images (Angliss et al., 2018)	Population of dugongs, Angliss et al., 2018; cetacean distribution and density in the Arctic)
ASV	10 hours for *Sphyrna 70* towing a 50m array of hydrophones *Mass400*: 13 days with gasoil, more when self-powered	The majority operates at speed between 3 and 10 knots (Verfuss et al., 2019) Mass400: 9-10 knts with gasoil, 4-5 knts with self-powered by solar	when using ASV or AUV with a PAM sensor to detect low-frequency baleen whales, only a low bandwidth acoustic system is required, with capacity to store many months of data with modest data storage requirements. To detect high frequency odontocete vocalisations, a higher bandwidth system is needed, with increased power and high data storage requirements, with storage probably lasting for days only (Verfuss et al., 2019)		*Sphyrna 70* (Boisseau et al., 2020; testing the feasibility to estimate distribution and abundance of cetacean species (Sperm whale))
AUV	Up to 200 hours for the Slocum glider (Cauchy et al., 2020)	0.5 – 2m/s current speed and are representative of energetic ocean currents (Whitt et al., 2020) average speed of 0.7 to 1.2 km/h (Burnham et al., 2021)			Slocum glider (Cauchy et al., 2020; Sperm whale presence using PAM from gliders of opportunity) Glider which recorded fin whale calls and allowed the survey of zooplankton (Burnham et al., 2021)

Table 1: Main technical characteristics of some unmanned vehicles of the three types (aerial, surface, underwater)

Suitability of unmanned vehicle system for the different monitoring types

Population monitoring means to estimate population abundance or density, assess spatial and temporal patterns in the distribution of populations and investigate changes in density and distribution as a result of anthropogenic activities (Verfuss et al., 2019). Unmanned vehicles can be used for wildlife surveys for population monitoring, by adhering to transect lines, and are particularly suited to collection of data for transect surveys. UAV are best suited for visual surveys whereas AUV and ASV are best suited for acoustic monitoring. Fig.1 illustrates which platform may be the most suitable for which monitoring type. All classes of AUV/ASV are capable of conducting population monitoring. However, according to Verfuss et al. (2019), powered UAS represent the best candidate for aerial surveys using autonomous vehicles following a transect method with constant speed.

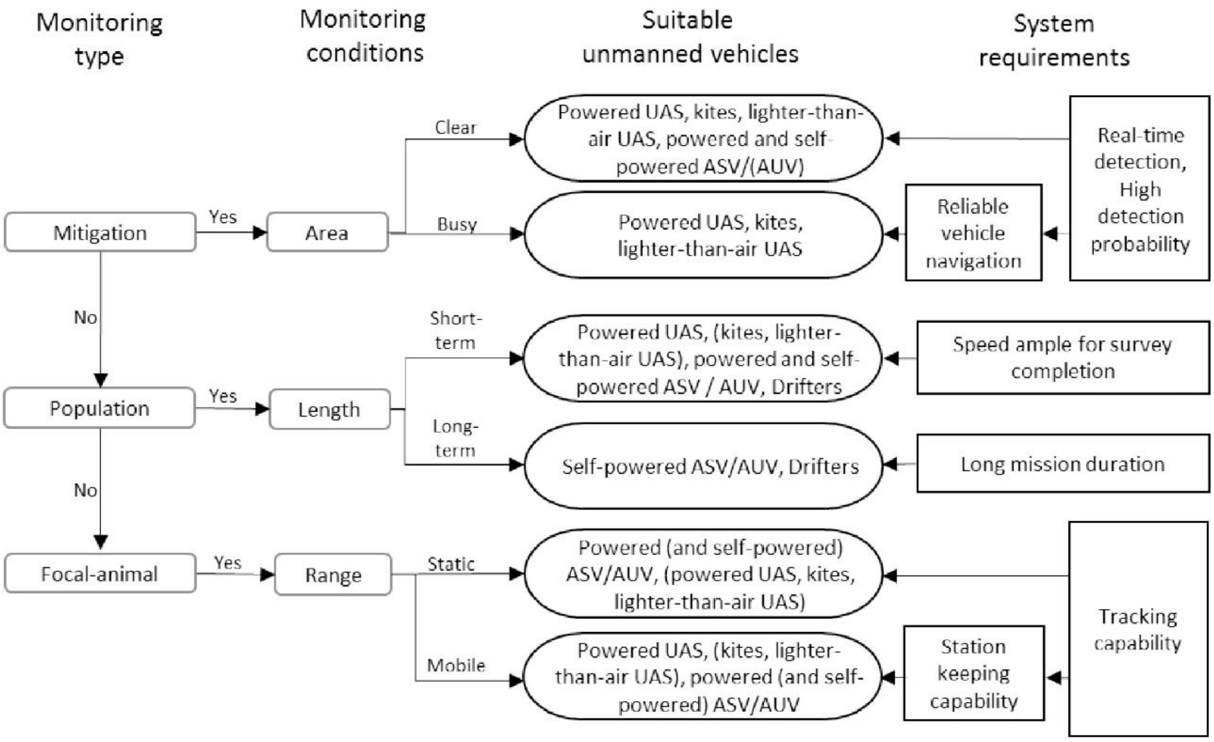

Fig. 1. Decision tree: unmanned platform suitable for monitoring type and condition. Unmanned vehicles in brackets are less suitable (from Verfuss et al., 2019)

The long mission durations of self-powered AUV/ASV are a major benefit for population monitoring, compared to the shorter deployment times (on the order of hours) of most powered AUV/ASV craft.
A limitation of some AUV, and to a lesser extent to ASV is sensitivity to environmental conditions, particularly currents, and the subsequent effect on survey design. The slow movement of self-powered platforms does have consequences for density/abundance estimation; analytical approaches that explicitly deal with animal movement may be required (Marques et al., 2013). However, despite these additional considerations, autonomous vehicles' long deployment durations present a major advantage for marine animal surveys and their ability to move efficiently to other study areas make them a powerful asset.

2.3 Potentialities for ACCOBAMS

Possibilities and advantages of unmanned vehicles:

- Considering technical capacities: in recent years there have been improvements in mission safety and high degree of repeatability, longer survey durations, and reducing costs. Unmanned vehicles also enable long-range operations beyond detection ranges of human observers. The technical capacities of these types of vehicles will improve year after year.

- Considering methodology: the UAV image processing method is able to accurately map the horizontal position of surface available animals detected in images (Cleguer et al., 2021). Whereas in traditional surveys, either vessel-based or aerial, the measurement error in distance sampling (i.e., measuring distances from the trackline). This can be quite pronounced for a range of species (Conn and Alisauskas, 2018 in Cleguer et al., 2021) and potentially impacts precision in fitting detection functions and subsequent density and abundance estimation (Marques, 2004, Borchers et al., 2010, Buckland et al., 2015). With a nadir camera setting and the high accuracy provided by the UAV telemetry, this approach greatly reduces this distance estimation error (Cleguer et al., 2021). Moreover, with the individual-scale observation, the location of groups is more accurate and the method minimizes the error in group size estimation compared to traditional methods.

- Considering work at sea: Collection of aerial imagery also minimizes the effects of animal movement (attraction/avoidance) which is associated with traditional vessel-based survey platforms (Bamford et al., 2020). Also, the presence and noise of a research vessel may affect cetacean behavioural responses and bias observations (Fettermann et al., 2019). Additionally, sighting data collected on traditional in situ observer-based platforms can be impacted by observer fatigue, whereas by generating a permanent record of a sighting, an image-based survey allows the analyst to revisit data (Bamford et al., 2020).

- Considering acoustic : Autonomous Surface Vehicles (ASVs) have a number of advantages as platforms for towed-array acoustic surveys for marine mammals, compared to conventional ships: • Ability to survey areas that may be difficult to access, unsafe to survey using other methods • Potentially reduced number of personnel required • Manoeuvrability – precise control when working in close proximity to animals • Flexibility - ASVs can be transported and launched from any harbour or from a support platform • Quieter - smaller vessels with less powerful propulsion systems create less self-noise; they are less likely to disturb target animals or mask their vocalisations (Pierpoint et al., 2016).

- Considering multi-parameters: the glider (ASV) deployed in the study of Burnham et al. (2021) aimed to record fin whale calls using aural and visual methods via spectrogram analysis, but also recorded environnemental variables such as temperature and salinity. And the glider (with echosounder fitted underside) allowed for the survey of the zooplankton that would be potential prey for fin whales including copepods, small schooling fish and krill.

Limitations of Current Technologies and Challenges

- Considering volume of data: The massive volume of data that sensors collect in the course of the surveys need to be stored, processed and analyzed, causing severe procedural bottlenecks that need to be solved. When using aerial images for wildlife census, the manual counting and identification of individuals represent a considerable investment in time and costs (Jiménez López & Mulero-Pázmány, 2019). Upcoming progress in computer vision and machine learning are intended to automate such routine tasks (Jiménez López & Mulero-Pázmány, 2019).

- Considering cost and availability of data: UAV missions are often carried out by private research teams, private companies, individual institutions, or individuals. The data are not free and can be costly as well (El Mahrad et al., 2020).

- Considering technical characteristics: Researchers currently often balance the need to collect high-resolution data with data management in the field, often resulting in data being recorded at less than optimal resolutions to ensure sufficient storage space is available. These factors will be compounded with increasing camera resolutions and highlight the need for appropriate redundant mobile storage devices in the field. There are also associated issues with long-term data storage from projects that may require specific infrastructure (Raoult et al., 2020). Despite technological advances with rechargeable batteries, a limited flight duration hampers the ability to cover larger areas and time of the mission; thus, reduced autonomy is challenging (El Mahrad et al., 2020). Currently, consumer drones and most multirotors are limited to flight times of <30 min. Battery life limitations can be managed by terminating flights soon after the battery falls below 30% charge, minimising the risk of deterioration over the long term (Raoult et al., 2018). While fixed-wing drones are often limited to <90 min. Improvements in battery energy density and drone efficiency have seen almost 50%

increase in flight times since the last generation of consumer drones (e.g., DJI Phantom 3 pro = 23 min max, Phantom 4 pro = 30 min max), whereas the next generation of drones is expected to have a further 50% improvement (Autel Evo 2 = 40 min).

- Considering human parameter (pilot): over these sorts of flight times, human pilot fatigue is likely to become an issue if flights are conducted manually (Raoult et al., 2020). Inexperienced pilots are likely to be less precise with drone commands and less attentive to hazards, posing a risk to the safety of other aircraft entering the same airspace, and other people sharing this area (Oleksyn et al., 2021).

- Considering accuracy: if using a fully automated approach (i.e. without post-processing validation by a trained observer), there is an increased potential of retaining false positives, where another species or a background feature within the image is incorrectly recorded as a detection of the target species (Hodgson et al., 2020). Also, as false-positive detections due to misidentification may be exacerbated by the presence of visually-similar species (Dunshea et al., 2020 *in* Bigal et al., 2020), small cetaceans such as the striped dolphin (*Stenella coeruleoalba*), short-beaked common dolphin (*Delphinus delphis*) and common bottlenose dolphin (*Tursiops truncatus*) are likely to be more challenging to distinguish and require the highest GSD (Bigal et al., 2020).

- Considering legislation and airspace restrictions: there are many restrictions over the ACCOBAMS area (see Hodgson et al., 2020 for a review)

- Considering weather: drones are weather dependent, and sensitive to high winds (most of the UAVs are not waterproof) or high waves.

2.4 Requirement considerations before implementing large-scale drones' surveys within the current ASI

Based on the key points identified by Hodgson et al. (2020) in their report for ACCOBAMS listed below, with some other key elements for consideration added, updated answers or complements are provided here.

- *Integrating historical methods and data*
  a) How can the ASI adapt this new methodology whilst ensuring previous surveys are comparable?

a) The first step in understanding how to transition to UAVs is to gain an understanding of how detections from traditional manned aerial survey platforms compare to aerial photographs captured from either manned or unmanned platforms. A limited number of studies have made this comparison until nowadays (Hodgson et al., 2020) and none really consequent in the Mediterranean Sea. A study has been carried out in the Alaska Arctic aiming to evaluate the ability of the UAS technology (platforms, payloads, sensors and software) to collect data to detect cetaceans, identify individuals to species, estimate group size, and identify calves with direct comparison to conventional aerial line-transect surveys by human observers and digital photographic surveys conducted from fixed-wing manned aircraft (Ferguson et al., 2018). Poor weather conditions affected aircraft performance and subsequently data collection, resulting in small sample sizes. The authors found that the marine mammal observers sighted more cetaceans than what was detected in either imagery dataset, and resulted in more precise density estimates. Because of the cost of transporting the platform, its ground station and crew to remote locations, and the fact that the UAS surveys a much smaller area per hour of flight, they are finding occupied aircraft to be a more cost-effective sampling platform at this time. Also, the photo processing done manually was very time consuming (more than 332 hours). Ferguson et al. concluded that the UAS long-range cetacean survey is promising, but also experimental, and they expect from the UAS to be more weather resistant and easy to transport, with a reliable auto-detection software for cetaceans.
In Australia, Hodgson *et al.* (2013) have successfully demonstrated that fixed-wing unmanned aerial vehicles could be used for humpback whale and dugong surveys. The authors compared its efficacy to a similar survey using manned fixed-wing aircraft (Holley et al., 2006).

Probably several projects are ongoing all over the world, such as the one in France, comparing sightings made by observers in a plane and a digital camera aboard the plane taking pictures during the flight. Analysis is still ongoing, and first results seem to prove that pictures help in correcting and precising the identification of species made by observers and also in the number of sighting detections, at least in good weather conditions (Thomas et al., 2020).

Support for such studies in comparing the capacities of new technologies in detecting cetaceans, identifying individuals to species, estimating group size, and measuring perpendicular distance with direct comparison to conventional aerial line-transect surveys by human observers need to be strengthened.

One of the last up to date studies led by Mediterranean scientists on that subject, Bigal *et al.* (in review) conclude that species identification accuracy from pictures using drones should benefit from their suggested method to get the best reliable results and more trial experiments may become essential for reducing species identification errors in wildlife abundance surveys.

b) How does detection probability compare between manned and unmanned surveys?

b) Hodgson et al. (2017) demonstrated how UAVs could be used to survey marine fauna and assess detection probability by presenting the results of a series of trial UAV surveys of humpback whales on their migration towards their summer feeding grounds. The authors estimated the UAVs overall detection probability based on a comparison between the sighting rates from the UAV surveys and those from the land-based survey. They found a detection probability (which incorporates both the availability and perception biases) for the *ScanEagle* of 0.33 (CV = 0.25) during their surveys. This rate was within the range of detection probability estimates obtained in a similar manner during previous studies (0.23 – 0.48). The detection probability Hodgson et al. achieved advocates that UAVs are a feasible alternative to manned surveys, providing similar sighting rates.

c) Are the effects of the environmental conditions experienced during a survey different for manned versus unmanned surveys?

c) Hodgson et al. (2013, 2017) found that sea state had no significant effect on sighting rates, suggesting that UAV surveys could be conducted in a wider range of wind conditions than traditional occupied surveys. Indeed, The *ScanEagle* (UAV) demonstrated its capability of flying in high wind speeds and sea states of Beaufort 4-5 had no significant influence on detectability when analyzing still images captured from a digital SLR camera on a fixed-wing UAV. However, Aniceto et al. (2018) conducted some small-scale (within line-of-sight) trial UAV surveys of three species of cetaceans – humpback whales, killer whales and harbour porpoises – in two fjords in northern Norway. They found that 'certainty of detection' (which was used as a proxy for detectability) for humpback and killer whales was negatively affected by increasing sea state. Hodgson et al. (2013, 2017) may not have been large enough sample sizes from the various combinations of conditions to adequately quantify their effects on animal detections in the images, especially for high sea states. More recently Hodgson et al. (in prep) investigated whether environmental conditions affected dugong sighting rates differently by directly comparing detections from observers on a manned aircraft and with UAV detections. They found that sea state did affect dugong counts and group size estimates which decreased as sea state was getting worse (Hodgson et al., 2020).

For another category of drone, the *Sphyrna 70*, the AUV speed was impacted by swell, choppy sea conditions and also by some currents that reduced its speed below the required one (Boisseau et al., 2020).

- *Logistical constraints*

  d) Is it possible to survey the ACCOBAMS Agreement Area with UAVs, whilst capturing the required ground sample distance (resolution), in a cost-effective time-frame?

d) Different studies deal with the question of spatial resolution in order to get accurate species identification for example. The spatial resolution may be inverse to the altitude flight, and also the higher, the more sea surface is encompassed. So, flying high enables to capture a larger surface of the sea with less flight effort but probably with less accuracy. And inversely, flying low helps in rising accuracy but then probably effort to cover a surface has to be raised. The balance is the cost-effective time-frame ensuring accuracy. Bigal et al. (submitted) suggested that if the objective of the UAV survey for the ACCOBAMS Survey Initiative was to identify all cetaceans to species level, then a minimum ground sampling distance (GSD) of 3 cm / pixel is required, or 2 cm / pixel in a sea state below Beaufort 1. As an example, for the UAV models that these authors employed in their study, and their associated imaging parameters, a GSD of less than 2 cm/pixel translated into flight altitudes of up to 75m and a maximal strip width of 91m.

The STORMM project (Thomas et al., 2020) tested its technology at the altitude used during manned aerial survey, 182 m/600 ft for a spatial resolution between 0.9 cm to 2cm with good accuracy for cetaceans (2 to 20 m long) and small seabirds (2 to 0.25 m long). More tests are required as it is planned to survey at 457 m/1500 ft when flying without observers over Marine Renewable Energy wind farm for example.

Decisions on flight parameters will depend on the desired accuracy of species identification, which depends on the objective of the survey, the species targeted and also the proportion of sightings that need to be identified as confident to achieve an understanding of species distribution and/or abundance. It is also interesting to know that, raising the proportion of high-confidence for correct species identification would mean that a large number of images would be collected, processed and then discarded, which may well translate into high financial costs.

More results of this kind and a global analysis are needed to define the best trade-off between coverage and resolution and therefore the cost-effective time-frame options for the ASI.

e) Are the multi-species surveys that are currently conducted under the ASI, realistic for UAVs?

e) The main challenge of multispecies surveys using unmanned aerial vehicles would be to achieve the appropriate ground resolution for all taxa of interest (i.e. including smaller species that require high resolution for species identification), whilst achieving coverage (i.e. effective strip width) that is cost and time-effective over a large spatial scale (Marsh et al., 2019). However, some technological systems can already achieve multi-species surveys (Thomas et al., 2020), meaning detect and identify target species from at least 25 cm (seabirds) up to 20 m (fin whale).

- *Selecting unmanned vehicles and their acquisition of data systems*
  f) What are the considerations in selecting UAVs and imaging systems for the ASI, or AUV/ASV and hydrophones?

f) When selecting a platform, it is important to consider the range of operating altitudes/depths, whether a system can follow a pre-designed track (e.g., using pre-programmed coordinates, and/or manual piloting) (Verfuss et al., 2019). The selection of a specific sensor/platform combination depends critically on the target species and its behaviour. Generally, aerial systems use detection systems relying on electro-optical imaging sensors, while underwater and surface vehicles rely mostly on acoustic methods (Fig. 2).

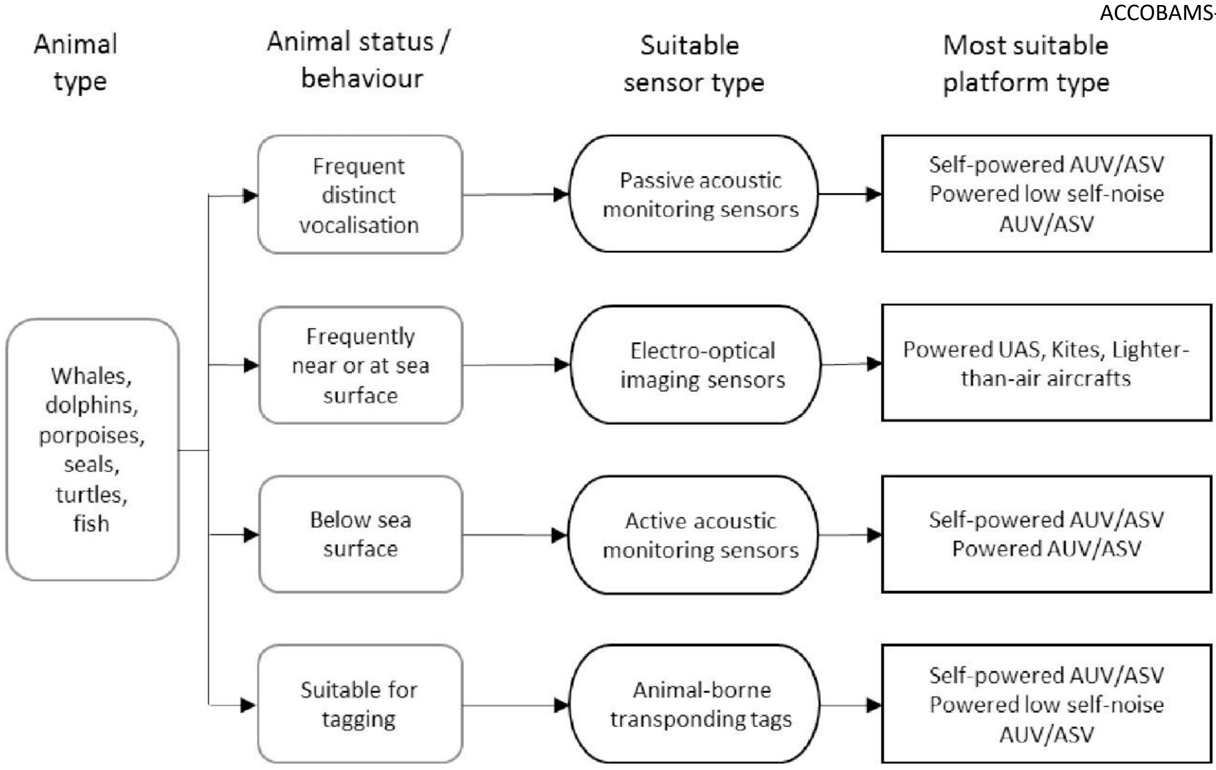

Fig. 2. Decision tree: sensor type suitable for animal type (from Verfuss et al., 2019)

UAVs are now capable of utilising several different **sensors** to collect photographic data, video footage, thermal, multispectral and hyperspectral imagery, as well as light detection and ranging (LIDAR), all of these sensors have shown potential for research but are yet to be fully tested (Butcher et al., 2021).
Considerations should include the time of data analysis needed, i.e., can the images/videos be processed after collection, or does analysis need to be in real-time or some step in between. Critically for main studies which require analysis during the flight, the type and transmission of data collection is a fundamental consideration, the resolution of video telemetry, data bandwidth and meta-data captured (Butcher et al., 2021). The capacity of slight deportation or tilt of the device bearing the sensor in order to avoid the sunglint area depending on sun geometry (Thomas et al., 2020) is an interesting way to limit the number of pictures unusable as the sunglint is the most limiting parameter in aerial detection.

Also, specific consideration should be given to the constraints of the chosen payload. Things to consider include sensor resolution, shutter speed (faster is better but requires more light) and interval, stability and control of sensor payload. In particular, the resolution and focal length of imaging sensors combined with the flight height of the platform will dictate the GSD, a measure of the distance between pixel centres measured on the ground (JNCC, 2019). The constraints of any given platform need to be considered when planning the survey. Factors such as flight speed, flight height, aircraft manoeuvrability and failsafe mechanisms need to be considered. Also, it is important planning to have **sufficient power** to ensure the surveys are completed on time (battery life and replaceability), what environmental limitations may affect a system's ability to remain on a survey path (Verfuss et al., 2019), and to consider potential indirect factors such as disturbance to the target species or other species (JNCC, 2019). Furthermore, drones of increasing weights are divided into different classes. In regard to regulation, this can impact the licenses required to fly which must also be considered. Thus, the interplay of these factors can significantly affect the ultimate drone choice.

When using ASV or AUV with a PAM sensor, it is necessary to define the species targeted, as Mediterranean species produce sounds at different frequencies. To detect low-frequency baleen whales, only a low bandwidth acoustic system is required, with capacity to store many months of data with modest data storage requirements. But the sound of water flowing along the hull of the moving vehicle may interfere with this bandwidth and lower the detection rate. Whereas to detect high frequency odontocete vocalisations, a higher bandwidth system is needed, with increased power and high data storage requirements, with storage probably lasting for days only (Verfuss et al., 2019).

So, it is important that the complete workflow from capturing the data until the results that are required are carefully thought through before starting to acquire a drone and using one (Table 2). This will also help in the traceability of the scientific work and the technical and methodological description in its outcomes (report, article…).

Workflow part	**Factors to consider**
Detection probability	Size of animal, sensor resolution, flying height and speed, possibility to avoid sunglint (tilt capacity of the sensor device), swath along and across track, acquisition frequency of images and overlap
Survey site location	Take-off and landing (TOL) potential sites and accessibility, distance from area to be surveyed or transects to nearest TOL area, flight duration and distance covered by drone. Presence of wind (weather conditions) or obstacles
Regulations	Check local and national regulations
Privacy issues	Will data or objects be collected that need approval?
Social issues	Do people in the vicinity of the flight need to be informed or asked for permission or otherwise engaged with?
Logistics	Will there be electricity to charge batteries for drones, cameras, computers, GPS and other electronics?
Storage	Assure that sufficient storage space is available for all the data that will be collected + backup system
Spare parts	Make sure spare parts of essential items are available in case equipment fails
Analyses	What type of analyses will be conducted, and what software and hardware are needed to achieve those?

Table 2. Workflow considerations for UAV studies (adapted from Serge & Koh L.P., 2018)

This exercise of writing clearly the required specifications for the ASI needs to be launched. It is also worth mentioning that, as stated by industrial meetings, any adaptation of existing material (vehicles, sensors) can be possible, depending on the money available to do it. And resolution and material capacities are improving fast. What is also needed for some choices is the scientific validation and factor of comparability with the previous methods used.

g) Can alternative camera systems (thermal / hyperspectral...) increase detection probability, and how can these technologies be integrated to improve detection?

g) Recently available technological developments, such as component miniaturization, increasing functionality and high-resolution image capture, have made UAVs more versatile and affordable in the civilian market (Colefax et al., 2018). This has effectively increased the utility of drones and subsequently their use in ecology in recent years. The advances in electronic component miniaturisation have allowed alternative sensors, such as thermal infrared, multispectral (such as red edge and near infrared) and hyperspectral systems to be mounted on small drones of less than 25 kg, and some micro-sensors on drones that are less than 2 kg (Johnston et al., 2019). Such alternative sensors are available in different spatial resolutions, just like their RGB (Red Green and Blue) counterparts. However, the spectral accuracy and resolution is also a major consideration and usually scales with costs (Butcher et al., 2021).
The use of **thermal** has enabled increased detection rates compared with RGB when there is sufficient temperature difference between target individuals and their surroundings (Seymour et al., 2017). These sensors generally detect long-wave infrared energy (8–15 µm) emitted by objects in the camera's field of view and can provide detailed images and maps of temperature in the absence of illumination (Johnston, 2019). Thermal infrared has been used in the case of Humpback whales (Horton et al., 2019) investigating temperature differentials as indicators of animal health.
Alternatively, **multispectral sensors** (red edge and near infrared) have been reported in the study of Schoonmaker et al. (2011) to both increase the number of animals detected (reducing uncertainty) and reduce the sensitivity of probability of detection due to environmental conditions when compared to visual techniques in marine mammal surveys. Fretwell et al. (2014) used high resolution satellite imagery, with the WorldView 2 satellite, to count Southern right whales. The image consisted of 8 colour bands and one panchromatic band. The authors found that the coastal bands (corresponding to the far-blue part of the spectrum) allowed them to see deeper in the water and provided best results in whale identification.
Hyperspectral sensors are sensitive to wavelengths not detectable by human eyes (Johnston, 2019). Most studies are limited to multispectral imaging systems, having between six and twelve bands, as opposed to over a hundred in hyperspectral studies. Hyperspectral imagery has been used in coastal monitoring of seagrass/coral reefs, for example in the assessment of the coral reef's health (Parsons et al., 2018). The results showed that airborne UAV-based hyperspectral imagery has the potential to detect coral bleaching, where accurate visual inspection may not be possible. In early stages, this system was applied in other fields, indeed few studies have been conducted for **macroplastic detection** on natural surfaces, either UAV-based in coastal and marine environments (Balsi et al., 2021, Tasseron et al., 2021). Regarding **marine fauna**, Colefax et al. (2021) used drone-based hyperspectral sensor to identify what wavelength selection might enhance detectability rates, and found that a band of wavelengths between 514 and 554 nm provided the greatest contrast between fauna and their surrounding backgrounds, and thus increased accuracy in the detection of submerged fauna.

So, yes, it seems that alternative camera systems increase detection probability. Airplanes can easily bear several different systems that may complement each other, whereas for drones, the larger can bear the most. But considering accuracy and resolution depends on the money that can be put in the material.

- *Data storage, power requirement and data relay system types*

Collecting raw data and storing it as material (pictures) is really interesting as it enables traceability and *a posteriori* process (e.g.: validation). But the amount of data collected needs to be stored, and this needs storage capacity and power, with some consequence on weight and autonomy. The risk of losing data is also present. So, even if data are not required in real time, it can be advantageous to recover data at regular intervals in order to minimize the risk of data loss, reduce the need for on-board storage and to assess at regular intervals if there are any problems with the data collection. However, data relay to transfer information relevant for marine animal monitoring generally demands considerably more bandwidth and may be impractical due to the limitations of power requirement, transmitter size and cost. As a general rule, sending larger amounts of data over longer distances will require more power, larger and heavier equipment and is likely to incur greater costs (Verfuss et al., 2019).

Improved optical links will allow autonomous vehicles to download larger data sets to docking stations or relay nodes that connect with surface and land-based platforms. Docking station standards and best practices are needed to allow heterogeneous platforms to use shared nodes for communications and power (Whitt et al., 2020).
For vehicles operating in remote locations far from a human operator or base station, satellite technologies are often the only practical solution (Verfuss et al., 2019).

A balance is needed between storage method and capacity, power requirements and the possibility to transfer regularly stored data and the cost of the system chosen.

- *Image processing*

  h) What is the current status of image processing methods?

  i) Can the image processing be automated to obtain:

    - *Sighting data (of multiple species)?*
    - *Location of sightings (accounting for UAV rotations)?*
    - *Environmental conditions?*
    - *Sampled area (accounting for UAV rotations)?*
    -

h,i) Many initiatives are launched as attempts to automate the image analysis process to increase the speed of analysis. In recent years, Artificial intelligence (AI), encompassing systems using machine learning (ML), deep learning and computer vision, is revolutionizing ecology research. AI systems are capable of automating aspects of flight and the detection of target species (videos, photographs, passive acoustic data). The majority of recent advances in computer vision and object detection have been made with convolutional neural networks (CNNs) (Gray et al., 2019). Those authors have used the CNN method to demonstrate the potential of a deep-learning-based photogrammetry system applied to automatically identify marine mega vertebrate species. The results correctly predicted whale species with 98% accuracy. Bigal et al. (2020) tests with CNNs on three common dolphin species within the Mediterranean Sea obtain up to 80% accuracy. Cleguer et al. (2021) manually reviewed post flight by trained observers using a customized image review program written in Python software (see the section Image Processing in Cleguer et al. for more details). The time spent on each image can vary, depending on the complexity of the image, which can be affected by glare (sun glitter), the benthic substrate, water depth, and sea conditions. The total estimated time for post-process of the images in Cleguer et al. (2021) was approximately 210 h. The published attempts seem not yet as reliable and time-effective as hoped. A lot of aerial images are needed to feed the process of deep-learning in order to ensure robustness of the model, and are not yet available for all species and all types of conditions (Saqib et al., 2019). Pre-process training is recommended anyway to improve the performance of the process. Improvements in that topic may be fast, so it is interesting to monitor the upcoming scientific literature.

- *Regulations*

  j) Can permission realistically be obtained to fly beyond visual line-of-sight and at appropriate altitudes throughout all of the jurisdictions included in the ACCOBAMS Agreement Area?

j) Drone operations face important social and legal barriers that undermine their potential in the civilian sphere (Jiménez López & Mulero-Pázmány, 2019). Civil aviation regulations often require training, certification, and impose specific usage (recreational vs. commercial use) and other flight restrictions depending on the jurisdiction. Generally, these rules are evolving and are varied from country to country (Butcher et al., 2021). One major consideration is that regardless of drone type, size and payload configuration, generally authorities limit flight distances to 'visual line-of-sight', which restricts operations to localized spatial scales (Butcher et al., 2021). An overly restrictive and indiscriminate regulatory framework arguing privacy and safety issues is currently limiting the applications of drones in the field of conservation. Within the ACCOBAMS area, Hodgson et al. (2020) updated country by country the permission required, and the feasibility of using drones for the ASI seem not won yet at all. Entire areas may not be sampled at all with this kind of vehicle.

This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish between the purpose of leisure, research and management (Jiménez López & Mulero-Pázmány, 2019). A code of best practice and recommendations could be continuously updated based on lessons learned, forming the basis for wildlife certified drone operators (Jiménez López & Mulero-Pázmány, 2019). Improvements are greatly needed in that topic.

k) Are there animal ethics or animal disturbance considerations or regulations?

k) The question about the behavioural impact of drones on dolphins needed to be investigated before such vehicles become more and more used for cetacean's studies. Christiansen, et al. (2016) undertook a detailed investigation of the ability of marine mammals to hear drone-produced noise underwater and concluded that while dolphins near the surface may hear the drone approaching, the propeller noise is likely to be masked by ambient noise. All available evidence suggests that when a small drone is flown at an altitude between 10–30 m above bottlenose dolphins, short-term behavioural responses occur (Fettermann et al., 2019, Castro et al., 2021), such as deep diving, turning toward the drone, side rolling, change in swimming direction and tail slap. These reactions are generally limited to short duration and individual responses (Raoult et al., 2020). The authors suggest the precautionary approach with drones flying below 30 m only if necessary for <2 kg drones, and higher for larger models.

Based on those results, a regulation could be created within ACCOBAMS for AUV, and some tests should be supported considering impact by other unmanned vehicles (surface and underwater).

2.5 Time and costs

Time and cost vary considerably from one study to another. It is often said that drones can obtain the required data in a more cost-effective way than alternative traditional methods. However, the cost of long-range UAS platforms and surveys currently far exceeds that of comparable aerial platforms, both for deployment (Ferguson et al., 2018), and subsequent analysis (Fiori et al., 2017). In this case, a lot of the cost difference is due to the need to transport the drone, its ground station, and personnel to remote locations. It is not yet obvious that medium-sized, fixed-wing UASs are viable alternatives or supplements to occupied aerial aircraft for transect surveying of marine mammals along coasts or over the open ocean (Marine Mammal Commission, 2016). Angliss et al. (2016) reported that post-field processing of the data was roughly 23 times greater for 'camera-surveys' because the images have to be examined individually by a technician, and that it required approximately seven hours for each hour of surveying to examine every third photograph. Most researchers using UASs to capture images of marine mammals for later analysis highlighted the urgent need for sophisticated image-analysis software in order to speed the process. As UASs have become popular with the public, more models with increased capability and reliability, at decreasing prices, are becoming available on the market.

On the other hand, low-cost UAVs have been successfully used in several studies surveying marine megafauna (Barreto et al., 2020, Cleguer et al., 2021) with an efficient method adopting optimized parameters such as the flight height, position, and camera tilt angle.
The development of software that can automate the processing of images from UAVs could reduce the observer bias, and eliminate the error caused by human fatigue. However, whether such an algorithm could overcome the challenges of high sea state and high glare conditions remains untested (Hodgson et al., 2017).

Babatunde et al. (2020) employed UAV (the flying hydrophone) with a system enabled to record harbour porpoise vocalisations. Using relatively low-cost hardware, the authors describe in their study, the potential applications of UAVs in passive acoustic monitoring. While the acoustic recorder has been designed to record sound within a specific frequency band for harbour porpoises, the modular design of the system allows for an extension of the system to record other species vocalisations. The inclusion of a form of real-time spectral analysis also enhances the usability of the system and creates a platform that can be extended to implement real-time species detection on low-cost hardware. The authors showed successfully that relatively low-cost systems can be used in place of heavier, more expensive alternatives.

3. Conclusion, Improvements and future perspectives

Unmanned aerial vehicle focus on marine studies has been increasing as the technology is quickly available at a fraction of the costs of manned aircraft. However, it is clear at this stage that drones will not be used for a survey at the level of the ASI yet, in replacement of the classical methods (observers). A lot has to be achieved before that. As aircraft continue to develop, concerning the availability of new equipment, several features are expected to become more efficient in the future, such as autonomy, distance, and cost–benefit ratio. As drones evolve towards longer flight times and better sensor packages, it will be possible to use them more regularly in surveys. Also, researches are run on rending drones more autonomous in energy (self-powered) and more autonomous in decision (AI) considering routing, avoidance, etc. And the evolution of payloads and camera systems that can accompany this technology will play a key role in detectability improvements (Aniceto et al., 2018).

Moreover, capacities of new technologies versus conventional aerial line-transect surveys by human observers, in order to obtain comparable or corrected factors for detection probability, level of identification of species, estimation of group size, and measures of perpendicular distance are still needed.

Validation of, and estimates of uncertainty around those automated techniques will remain essential. Research into both the magnitude and the effects of mis-detection and mis-classification, and investment into systems that aid human observers in the decision processes is of high importance (Verfuss et al., 2019).

Regarding the safety precautions, further research into 'detect-and-avoid' systems for unmanned vehicles would lead to improvements in the operational safety of unmanned vehicles.

Even if more details are presented in the field of aerial work (UAV, image processing, etc), surface vehicle and acoustic methods and capacities are globally at the same stage than that of the aerial field, with the same questioning and the same kind of limitations in all aspects. But technology developments (autonomy, detection and species identification, etc) are also developing fast.

We sum up here three important factors related to the upcoming improvement of this technology:

- The large amount of data: the need to deal with large quantities of data (storage, power) and also afterwards the need to process this quantity efficiently.
- reliability in information extracted from the data: In automated detection, false-positive sightings still exist and an observer reviewing manually the images is still needed, which as seen previously, can be cost-timing. A reliable automated detection software is a key factor to develop in the future, potentially contributing to a time saving in the post-process imaging and recordings (acoustic) but also a high reliability.
- A third factor is documenting and making available the methods used in observations and analyses across the value chain of data to information in order to support **reproducibility and interoperability.** This encompasses both standards and best practices (Pearlman et al., 2019 in Whitt et al., 2020). They can come in many forms such as "standard operating procedures," manuals or guides. The definition of a best practice for ocean observing is: "a best practice is a methodology that has repeatedly produced superior results relative to other methodologies with the same objective; to be fully elevated to a best practice, a promising method will have been adopted and employed by multiple organizations" (Simpson et al., 2018 in Whitt et al., 2020). Standards have the same objectives as best practices; the difference is that standards may serve as benchmarks for evaluation in addition to being processes. Also, they are generally top-down and may become mandatory legislated standards, such as the European INSPIRE legislation. The International Standards Organization (ISO) defines standards as "documents of requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose." The time for the formation of a standard by a Standards Development Organization (SDO) is 3–5 years or more using formal working groups to write the standard (Whitt et al., 2020). It could be interesting to think about developing standardized protocols applied for the entire area under ASI.

Other perspectives

- Usually with observers, only daylight can be sampled, but with sensors, some nocturnal flight could be interesting to launch as very few is known about nocturnal spatial distribution, group structure, etc.
- Several industrials and drones developers are already talking about the launch of a fleet of drones, even of different types (aerial and surface), which would be autonomous in energy and decision. This fleet could send real-time information to a Headquarter which monitors its deployment.

To conclude, as technological improvements (autonomy, sensors, etc) can be fast, the use of drones can be envisaged first as a complement to the ASI classic methods, for example in local or specific areas, or to target specific species.

4. Recommendations

Based on all reports from ACCOBAMS on the drone topic, it is recommended:

- to update the "Guidelines for the Monitoring of Cetacean Range, Abundance and Demographic Characteristics of Populations" adopted by Resolution 6.13.
- to *s*upport studies comparing the capacities of new technologies versus conventional aerial line-transect surveys by human observers, in order to obtain comparable or corrected factor for detection probability, level of identification of species, estimation of group size, and measures of perpendicular distance in the different weather conditions included in the line transect methodology (<= 3 Beaufort).
- to support an analysis to define the best trade-off between coverage and resolution and therefore the cost-effective time-frame options for the ASI
- To start drawing up guidelines for the use of unmanned aerial vehicles for aerial imagery data collection and for unmanned surface vehicles for acoustic data collection in the frame of the ASI/ LTMP of ACCOBAMS), as **a complementary approach** to conventional aerial surveys in the first instance. Such guidelines would include in particular:
  - standardized protocols for using unmanned vehicles to collect data collection on cetacean Distribution and Abundance.
  - a dedicated segment for 'best practices' or regulated guidance for minimising/avoiding AUV negative impact/disturbance on cetaceans (ex. defining a minimum flying height)
  - to encourage owners of aerial images to exchange their images banks, in order to feed the processes of deep-learning

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